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Increased lactation in females due to the use of probiotic-based feed additives

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Abstract. The transition of females from childbirth to lactation is a physiologically complex period characterised by metabolic, endocrine and immunological changes. In addition, difficult labour drains the female and can lead to hypolactia. The purpose of the study was to determine the effect of probiotics on lactation recovery and metabolic changes in the body of females. Among the methods used are: the determination of lactation level, the physiological method for determining live weight, the biochemical method for blood testing; and the statistical method. The application of *Bacillus subtilis* AX 20, *Bacillus licheniformis* EA 22 contributes to an increase in milk productivity in cows on

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day 7-9 of the study by 12.9%, on day 10-12 – by 15.03%, on day 13-15 – by 13.93%, on day 16-18 – by 13.5% and on day 19-21 – by 21.35% compared to the control. The total protein content in experimental cows increased by 18.92%, globulins – by 37.26 ($p \leqslant 0.05$), compared to the initial indicators. The activity of alanine aminotransferase, urea, and urea nitrogen in animals of the control and experimental groups was within the normal range during the experiment. The application of *Bacillus megaterium* NCH 55 to sows with hypolactation contributes to lactation recovery in sows. In the experimental group, piglets showed a lag in growth of 18.5% on the third day and 11.39% on the tenth day due to hypolactation. Starting from day 15, there was an increase in the live weight of suckling piglets due to the restoration of lactation in sows by 20.56%, on day 20 – by 20.43%, on day 25 – by 30.56%, on day 30 – by 31.91%, compared to the control. In the blood serum of experimental sows, the content of total protein increased by 10%, globulins – by 19.13%, total cholesterol – by 40.11%, urea by 48.0%, compared to the beginning of studies ($p \leqslant 0.05$). The activity of alanine aminotransferase in the experiment increased by 8.95% ($p \leqslant 0.05$), alkaline phosphatase decreased by 27.46% ($p \leqslant 0.05$), compared to the beginning of the study. In the blood of experimental sows, the level of circulating immune complexes increased by 42.85% and a decrease in seromucoids by 30.43%. The practical value of the study lies in the use of probiotics to restore the milk productivity of cows and sows after childbirth

Keywords: milk productivity; hypolactia; live weight gain; protein metabolism; metabolic adaptation

INTRODUCTION

The profitability of a dairy farm directly depends on the milk production of each cow. If for some reason milk yields decrease or the quality of milk worsens, the farm loses money and becomes unprofitable. Therefore, each farmer evaluates the capabilities of his herd and decides on the balance between the cost of keeping animals and making a profit from them. Increased milk production encourages dry matter consumption due to increased energy and nutrient requirements in animals. Studies (Ledda *et al.,* 2023) showed a link between dry matter consumption and productivity. The experiment was conducted on sheep, so it is necessary to clarify this hypothesis on cattle.

The consequence of high milk productivity is the appearance of a negative energy balance, which is manifested in cows by lipolysis, ketogenesis, and endocrine changes. Researchers S. Krnjaić *et al.* (2022) examined the relationship between energy balance, lipolysis, and ketogenesis in cows that were milked two and three times a day. The results showed that cows that were milked three times a day showed more pronounced signs of lipolysis and ketogenesis, and lower energy balance levels. Therefore, an increase in milk productivity affects metabolic disorders in the body of dairy cows. In the study, the question of how reducing the amount of milking will affect the mammary gland remained unresolved. A study by O. Shkromada *et al.* (2022) proved that the use of probiotics helps restore milk productivity and normalise the metabolic processes associated with ketosis. However, the effect of probiotics on lactation recovery remains unclear. Adding probiotics to the main diet improves growth productivity, meat quality, and humoral immunity, reducing the release of pathogenic microbes. Researchers I. Kwoji *et al.* (2021) addressed the possibility of using multicomponent probiotics to improve metabolism in animals.

A paper by J. Babot *et al.* (2018) proves that probiotics effectively protect the intestinal epithelial cells of broilers from food intoxication. In addition, the authors substantiate the effectiveness of the antimicrobial action of probiotics in relation to *Salmonella enterica* in broiler chickens. The question of the mechanism of influence on the metabolism of chickens remains unidentified. M. Tian *et al. (*2023) established that probiotic and prebiotic supplements of the mother during pregnancy have a positive effect on the regulation of the development of the nervous system and fetal immunity. However, detailed studies are needed on microbial metabolites that are involved in regulating fetal organ development.

In the paper by T. Bruun *et al. (*2023), the problem of long-term use of lactating sows and their subsequent productivity for re-breeding was examined. However, the paper does not offer solutions that would help restore lactation and reproductive capacity of the sow. A production study of the effectiveness of using a probiotic based on viable *Bacillus subtilis* C-3102 spores was conducted on the health and productivity of sows and their piglets (Kritas *et al.,* 2015) showed an improvement in the sow's condition during pregnancy. An increase in feed intake, improved health during lactation, and a reduction in the period of weaning a sow before estrus was also noted. The issue of the effect of probiotics on lactation recovery in sows diagnosed with hypolactia remained unresolved.

H. Liu *et al.* (2020) focused on determining the effects of a probiotic based on *Pediococcus acidilactici* ZPA017 on reproductive capacity, restoration of the gut microbiome and metabolism in sows during late pregnancy and lactation. The experiment did not investigate the direct effect of a probiotic on the lactation capacity of sows. Researchers N. Nam *et al.* (2022) determined that the use of probiotics in late pregnancy in sows has a positive effect on reproductive ability. However, the paper did not analyse the effect on piglet growth. Q. Zhu *et al.* (2023) showed that the addition

of 4.0×10^8 CFU/kg of *B. subtilis* PB6 to the feed of sows during late pregnancy and lactation helps to reduce the intervals between the birth of piglets, improves live weight gain in suckling piglets. However, there are no studies on the effect of probiotics on the milk production of sows.

The purpose of the study was a restoration of lactation and the development of metabolic adaptation of cows and sows using probiotics. The objectives of the study were: determination of milk productivity in females, examination of metabolic processes in the body of cows and sows using probiotics.

MATERIALS AND METHODS

The study was conducted in September 2022 at the State Enterprise "Experimental Economy of the Institute of Agriculture of the North-East" of the National Academy of Agrarian Sciences of Ukraine, located in Sad, Sumy district, Sumy region. Sows with hypolactation (5 individuals in the experimental group) were provided with mixed feed supplemented with *Bacillus megaterium* NCH 55(1×10^9 CFU/g) at a dose of 5 g per animal. In the control group (5 heads), regular mixed feed was given for 30 days. Weight gain in suckling piglets from birth to 30 days was examined to determine the level of lactation in sows. The average weight of piglets in each nest (8-10 heads) was determined.

In addition, this farm conducted a similar study with Holstein cows. The study involved a total of 20 animals from the post-calving milking group. The effectiveness of the feed additive was determined based on experimental samples of strains *Bacillus subtilis* AH 20, *Bacillus licheniformis* EA 22 at a concentration of 1×10^9, colony-forming units per gram (CFU/G). The probiotic dosage in the experimental group of post-calving milking was 35 grams per animal. Probiotic strains of microorganisms *Bacillus megaterium* NCH 55, *Bacillus subtilis* AH 20, *Bacillus licheniformis* EA 22 were manufactured and refilled in the company PE "Kronos Agro". All cows received a diet according to the production group. Milk productivity was determined in cows in the morning and evening from 4 to 21 days in the control and experimental groups.

Examination of biochemical parameters of cow blood serum. Biochemical parameters of cow blood were determined in cows and sows at the beginning and end of the study. The content of total protein (SOP-BP-02-2017), urea (SOP-BP-03-2017), albumin (SOP-BP-25-2018), urea nitrogen, CA/R, and globulins was examined by calculation, total cholesterol (SOP-BP-07-2017), aspartate aminotransferase AST (SOP-BP-09-2017), alanine aminotransferase alt (SOP-BP-08-2017), total Ca (SOP-BP-05-2017), inorganic P (SOP-BP-04-2017), magnesium (SOP-BP-06-2017), creatinine levels were determined by Jaffe method, CIC (circulating immune complexes were determined by enzyme immunoassay, Seromucoids were examined spectrophotometrically (SHIMADZU UV-1800, Japan).

Biological ethics. All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they comply with the requirements of DSTU ISO/IEC 17025:2005 (2006), in accordance with directive 2010/63/EU (Hartung, 2010), which were approved by the conclusion of the commission on ethics and bioethics of the Faculty of Veterinary Medicine of Sumy National Agrarian University dated 05.03.2022. The keep of animals and all manipulations were conducted in accordance with the provisions of the procedure for conducting experiments and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (European convention..., 1986).

Statistical analysis. Statistical data were calculated using the Fischer-Student method, considering statistical errors and the probability of comparable similar indicators. Indicators with a level of probability of more than 95% were considered ($p<0.05$).

RESULTS AND DISCUSSION

Results of a study of the productivity and metabolism of cows using a probiotic. Milk productivity of cows was determined from 4 to 21 days of lactation after calving (Fig. 1).

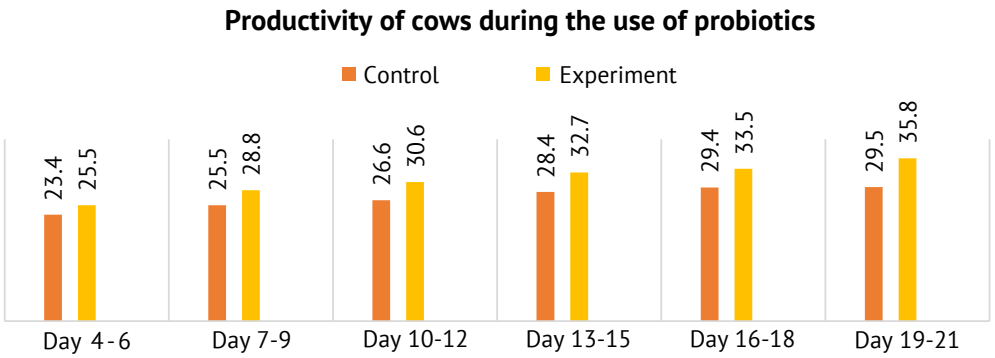

Figure 1. *Productivity of cows during the use of probiotics in the period of 4-21 days of lactation*
Source*: compiled by the authors of this study*

From the results obtained, it follows that at the beginning of the study, 4-6 days in the control and experimental groups of animals the milking levels were almost at the same level. On the 7th-9th day of the experiment, cows of the experimental group showed an increase in milk yield by 12.9% compared to the control group. On the tenth or twelfth day, the use of a probiotic in the experimental group contributed to an increase in milk yield by 15.03%. After two weeks of the study, an increase in milk productivity in the experimental cows was established by 13.93%, compared to the control. In the period of 16-18 days in the study group, milking output increased by 13.5% in the group with the use of probiotics. At the end of the study (19-21 days), a 21.35% increase in milk productivity was recorded in cows that received a probiotic based on experimental samples of *Bacillus subtilis* AH 20, *Bacillus licheniformis* EA 22 strains. The conducted study proves the positive effect of probiotics on the milk productivity of cows in the period of the first 21 days after calving. During the experiment, the effect of a probiotic on the metabolism of lactating cows was determined. Biochemical parameters of blood were examined at the beginning and at the end of the experiment (Table 1-2).

Table 1. *Results of biochemical studies of cow blood serum, M±m, n=5*

No.	Name of the parameters to be defined, units of measurement							
research methods	total protein, g/L	Albumines, g/L	*Globulines, g/L	*Albumines, %	*Globulines, %	*(A/G), units	Urea mmol/L	*Urea nitrogen, mg/dL
	SOP-BP-02-2017	SOP-BP-25-2018	Calculation				SOP-BP-03-2017	Calculation
Control group (start of the study)								
1	75.104 ±4.26	30.63 ±1.25	46.96 ±2.82	39.42 ±1.09	55.99 ± 2.15	0.66 ±0.052	5.46 ±0.42	13.67 ±1.31
Control group (end of the study)								
2	70.48 ±4.92	31.39 ±1.55	37.68 ±2.82	42.34 ±2.09	58.28 ±0.91	0.76 ±0.04	4.38 ±0.42	13.32 ±1.19
Research group (start of the study)								
3	71.95 ±2.94	32.98 ±1.25	41.00 ±3.43	44.24 ±2.57	53.54 ±2.27	0.85 ±0.07	6.47 ±0.46	18.18 ±1.28
Research group (end of the study)								
4	85.57 ±3.44*	28.95 ±1.88	56.28 ±5.39*	34.07 ±3.33*	65.15 ±3.71*	0.50 ±0.07*	5.46 ±0.57	16.83 ±1.36
Reference values for cows	59-85[2] 70-90[3]	27-43[2]	25-45[2] 33-55[3]	38-50[1]	50-62[1]	0.6-1.1	3.30-6.70	8-20[4]

Note: ** – p≤0.05, compared to the start of the study*
Source*: compiled by the authors of this study*

Studies have shown that the total protein content of cows in the experimental group was substantially higher by 18.92% (p≤0.05) at the end of the study, compared to the initial indicators. Notably, the total protein was increased in experimental animals due to an increase in globulins by 37.26 (p≤0.05). The calculation of the percentage of globulins was also substantially higher by 11.61% compared to the beginning of probiotic use. The content of urea and urea nitrogen in cows of the experimental groups during the study period was within the physiological norm and did not substantially decrease at the time of completion of the experiment.

Table 2. *Results of biochemical studies of cow blood serum, M±m, n=5*

No.	Name of the parameters to be defined, units of measurement						
	Total cholesterol, mmol/L	AST, units/L	ALT, units/L	*(AST/ALT), units	Total Ca, mmol/L	Inorganic P, mmol/L	*Ca/P, units
research methods	SOP-BP-07-2017	SOP-BP-09-2017	SOP-BP-08-2017	Calculation	SOP-BP-05-2017	SOP-BP-04-2017	Calculation
Control group (start of the study)							
1	3.34 ±0.59	68.81 ±9.25	17.31 ±0.54	3.97 ±0.23	2.39 ±0.18	1.88 ±0.66	0.51 ±0.03

Table 2, Continued

No.	Name of the parameters to be defined, units of measurement						
	Total cholesterol, mmol/L	AST, units/L	ALT, units/L	*(AST/ALT), units	Total Ca, mmol/L	Inorganic P, mmol/L	*Ca/P, units
Control group (end of the study)							
2	3.63 ±0.60	70.62 ±4.25	18.08 ±0.58	3.56 ±0.2	2.70 ±0.17	2.10 ±0.14	0.90 ±0.03
Research group (start of the study)							
3	2.80 ±0.69	108.51 ±10.44	20.36 ±4.03	4.58 ±0.73	2.35 ±0.19	2.17 ±0.63	1.01 ±0.05
Research group (end of the study)							
4	4.02 ±0.78	77.28 ±3.04*	20.89 ±3.11	3.75 ±0.52	2.36 ±0.15	2.10 ±0.04	1.17 ±0.23
Reference values for cows	2.20-6.60[2]	48-108[2]	17-40[2] 20-45[3]	1.0-3.4	1.98-3.12[1.2] 2.2-2.6[3]	1.50-2.90[1.2] 1.2-2.4[3]	1.1-1.6

Note: ** – p≤0.05, compared to the start of the study*
Source*: compiled by the authors of this study*

The total cholesterol content in cows of the experimental and control groups during the research period did not exceed the physiological norm. However, in cows of the experimental group, the AST enzyme at the beginning of the study was higher than the permissible reference values and substantially decreased by 71.22% at the end of the experiment due to the use of a probiotic (p≤0.05). The level of the alt enzyme in animals of the control and experimental groups was within the control level during the entire study period. The mineral content, namely total Ca and inorganic P, was within the normal range, which indicates a properly balanced diet for cows during lactation. During the study, there were no negative effects on the organism of experimental animals from probiotics based on *Bacillus subtilis* AH 20, *Bacillus licheniformis* EA 22.

Results of the study of the effect of probiotics on the productivity and metabolism of pigs. Sows were prescribed a probiotic *Bacillus megaterium* NCH 55 to improve lactation. Weight gain in piglets from birth to 30 days was determined to establish the therapeutic effect (Fig. 2).

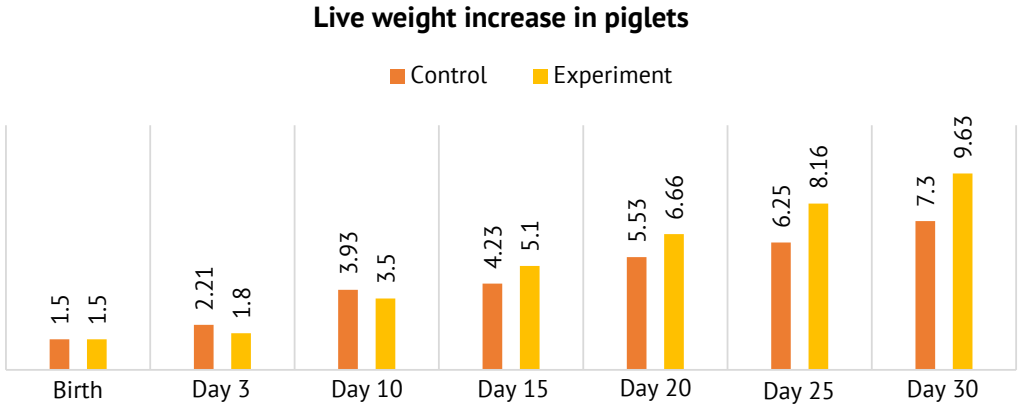

Figure 2*. Live weight gain in piglets when using a probiotic in the period from birth to 30 days*
Source*: compiled by the authors of this study*

At birth, piglets on average in the nest had a weight of 1.5 kg in the control and experimental groups. The number of suckling piglets in the nest ranged from 8 to 10 heads, so the calculation of the average live weight in the nest was considered. On the third day of the study, the piglets of the experimental group lagged behind in weight by 18.5%, compared to the control group due to a lack of milk in sows. On the 10th day of the experiment, the growth lag in suckling piglets of the experimental group decreased to 11.39%. Weighing of piglets on day 15 showed an increase in live weight in the experimental group by 20.56%, compared to the control group. This indicates an increase in lactation in experimental sows treated with the probiotic *Bacillus megaterium* NCH 55. On day 20 of the study, the trend continued and the piglets

had a larger live weight by 20.43% compared to the control group. The difference in the weight of piglets of the experimental and control groups persists for 25 days and amounts to 30.56%. At the end of the experiment, the live weight of piglets in the experimental group was 31.91% higher than in the control group. During the entire trial period of using a probiotic based on *Bacillus megaterium* NCH 55, a positive effect on the milk productivity of sows was determined. The presence of possible metabolic shifts in the body of sows was determined by biochemical parameters in blood serum samples (Table 3-4).

Table 3. *Results of biochemical studies of cow blood serum, M±m, n=5*

No.	total protein, g/L	Albumin g/L	Total globulines, g/L	Glucose mmol/L	Total cholesterol, mmol/L
Control group (start of the study)					
1	80.97±0.56	31.59±1.90	40.33±2.21	4.67±0.36	1.99±0.20
Control group (end of the study)					
2	79.01±1.22	31.72±0.99	40.16±0.88	4.42±0.41	2.13 ±0.19
Research group (start of the study)					
3	72.90±2.30	33.40±0.77	39.32±1.94	4.48±0.30	1.67±0.05
Research group (end of the study)					
4	80.19±0.63*	33.37±1.97	46.84±2.53*	4.94±0.22	2.34±0.05*
Norm*	70-80	28.0-44.0	32.9-52.0	3.33-5.55	1.56-2.86

Note: ** – p⩽0.05, compared to the start of the study*
Source*: compiled by the authors of this study*

The total protein content in pigs of the experimental group was substantially higher by 10% compared to the beginning of the studies (p⩽0.05). The level of total globulins increased by 19.13% (p⩽0.05) and did not exceed the reference level. The total cholesterol content increased by 40.11% compared to the start of the probiotic in sows.

Table 4. *Results of biochemical studies of cow blood serum, M±m, n=5*

No.	ALT, mmol/h L	AST, mmol/h L	Alkaline phosphatase, nmol/Ls	CIC, mg/mL	Seromucoids, mg/mL	Urea wine, mmol/L	Creatinine, μmol/L
Control group (start of the study)							
1	0.65±0.09	0.83±0.07	665.2±33.95	0.14±0.02	0.14±0.01	4.69±0.46	140.78±3.55
Control group (end of the study)							
2	0.63±0.12	0.75±0.05	731.8±23.6	0.15±0.02	0.15±0.01	4.71±0.42	151.32±4.64
Research group (start of the study)							
3	1.06±0.04	0.67±0.02	1595.2±110.9	0.07±0.01	0.23±0.02	4.54±0.15	127.92±5.40
Research group (end of the study)							
4	1.15±0.01	0.73±0.02*	1157.0±104.0*	0.10±0.01*	0.16±0.01*	6.72±0.2*	127.94±1.77
Norm*	0.3-1.2	0.60-2.10	500-2500	0.1-0.3	0.11-0.19	3.3-7.0	100.0-200.0

Note: ** – p⩽0.05, compared to the start of the study*
Source*: compiled by the authors of this study*

The level of alt enzyme in sows of the experimental and control groups was within the normal range, which indicates the absence of intoxication of the body and the integrity of internal organs. The AST enzyme in experimental sows increased by 8.95% (p⩽0.05) compared to the start of the study but within the reference level. The level of alkaline phosphatase in experimental animals substantially decreased by 27.46% (p⩽0.05), compared with the initial data. At the end of the experiment, the number of circulating immune complexes in experimental sows increased by 42.85% and the level of seromucoids decreased by 30.43%. The sows of the experimental group increased their urea levels by 48.0% compared to the beginning of the experiment.

Creatinine levels in the experimental and control groups of animals remained within the physiological norm throughout the experiment. According to the results of the study, it was established that all sows that took part in the experiment after a month of feeding *Bacillus megaterium* NCH 55 with the main diet, an increase in lactation and an improvement in appetite were observed.

Studies have shown an increase in lactation in cows that received the probiotic. Specifically, on days 7-9 of the experiment, there was a 12.9% increase, on days 10-12 – a 15.03% increase, on days 13-15 – a 13.93% increase, on days 16-18 – a 13.5% increase, and on days 19-21 – a 21.35% increase, compared to the control group (Figure 1). Researchers Z. Várhidi *et al.* (2022) proved that the use of probiotic microorganisms contributes to an increase in milk productivity and live weight gain in cattle. This mechanism is explained by the stimulation of active microorganisms in the rumen. C. Ma *et al.* (2020) proved the positive effects of probiotic feed additives on milk consumption, productivity, and intestinal microecology.

When determining the effect of probiotic microorganisms on the metabolism of lactating cows, an increase in the total protein content was established due to an increase in the level of globulins (Table 1). The results obtained indicate an increase in the activity of the immune response in the animal body, which coincides with the data of Y. Zhao *et al.* (2023). The study showed that the content of urea and urea nitrogen in cows of the experimental groups during the study period was within the physiological norm (Table 2). Researchers C. Chang *et al.* (2019) established restoration of normal metabolism, namely urea, ALT, and AST levels in the serum of cows treated with the probiotic. The mineral content, namely total Ca and inorganic P, was within the normal range, which is consistent with the study by T. Larsen & K. Moyes (2015).

Sows were prescribed a probiotic *Bacillus megaterium* NCH 55 to restore lactation. It was established that suckling piglets increased their live weight in the period from 10 to 30 days of probiotic use in sows (Fig. 2). A study by O. Shkromada *et al.* (2022) proved the recovery of milk productivity in cows by using *Bacillus megaterium* as a feed additive. An increase in the content of total protein and globulins in the blood serum of pigs of the experimental group was established by S. Liao & M. Nyachoti (2017). The total cholesterol content increased in the blood of experimental pigs after the use of a probiotic (Table 3), which is confirmed by the study by M. Zommiti *et al.* (2020). Q. Zhu *et al.* (2023) prove that adding probiotics to the diet of sows and piglets promoted feed growth and consumption and improved meat quality.

In experimental sows, the number of circulating immune complexes increased and the level of seromucoids decreased after the use of a probiotic (Table 4). A study by C. Ma *et al.* (2022) confirms the positive effect of probiotics on restoring immunity in pigs. According to the results of the conducted studies, normalisation of the level of AST, ALT, and alkaline phosphatase enzymes in the blood of sows after the use of a probiotic was established. Researchers M. Saladrigas-García *et al.* (2022) established that long-term use of two strains of *Bacillus* in pigs helped to improve their metabolism by restoring the intestinal microbiome. The authors also confirm that feeding probiotics to lactating sows does not cause any changes in their reproductive capacity, metabolic and health status, and in the concentration of immunoglobulins and nutrients in colostrum and milk. Therewith, a high level of cellular immunity and the concentration of haptoglobin in plasma were noted in suckling piglets after weaning.

The general conclusion from the conducted studies is that the use of probiotic microorganisms in feeding cattle and pigs has a positive effect on their productivity, health, and immunity. The researchers confirmed an increase in milk production and weight gain in animals, and a recovery in metabolic parameters after the use of probiotics in the diet. According to the results of studies, probiotics helped to improve the immune response, the state of intestinal microecology, and metabolism. An important factor is the ability of probiotics to normalise the level of enzymes and immune complexes, contributing to the overall health and productivity of animals.

CONCLUSIONS

The research has established that the use of a probiotic supplement based on *Bacillus subtilis* AH 20 and *Bacillus licheniformis* EA 22 leads to an increase in lactation in cows. Specifically, on days 7-9 of the experiment, there was a 12.9% increase, on days 10-12 – a 15.03% increase, on days 13-15 – a 13.93% increase, on days 16-18 – a 13.5% increase, and on days 19-21 – a 21.35% increase, compared to the control group. In cows of the experimental group, the total protein content increased by 18.92%, globulins – by 37.26 ($p \leq 0.05$), compared to the initial indicators. The level of the AST enzyme at the beginning of the study was higher than normal and substantially decreased by 71.22% at the end of the experiment ($p \leq 0.05$). Levels of the enzyme ALT, urea, total Ca, and inorganic P were within the control levels in the control animals during the study.

The use of a probiotic supplement based on *Bacillus megaterium* NCH 55 increases lactation in sows with hypolactia, which is directly related to live weight gain in suckling piglets. At birth, the piglets had the same weight, but due to hypolactia in sows of the experimental group, they lagged behind in growth on the third day from the control group by 18.5%, on the tenth – by 11.39%. Starting from the 15th day of the experiment, there was an increase in the live weight of suckling piglets due to the restoration of lactation in sows of

experimental groups by 20.56%, on the 20th day – by 20.43%, on the 25th day – by 30.56%, on the 30th day – by 31.91%, compared to the control ones.

The effect of probiotics on the body of sows affected an increase in the content of total protein by 10%, globulins – by 19.13%, total cholesterol – by 40.11%, and urea – by 48.0%, compared to the beginning of studies ($p \leq 0.05$). The level of AST in experimental sows increased by 8.95% ($p \leq 0.05$), alkaline phosphatase decreased by 27.46% ($p \leq 0.05$) compared to the beginning of the study. The immune system is activated by increasing the CIC by 42.85% and reducing the level of seromucoids by 30.43% within the physiological norm. The prospect of further research is to determine the dependence of the frequency of hypolactia in cows and sows depending on the number of lactation.

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CONFLICT OF INTEREST

None.

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Збільшення лактації у самок за використання кормових добавок на основі пробіотиків

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Анотація. Перехід самок від пологів до лактації є фізіологічно складним періодом, який характеризується метаболічними, ендокринними та імунологічними змінами. Також важкі пологи виснажують самку і можуть призводити до гіполактії. Метою дослідження було визначення впливу пробіотиків на відновлення лактації та метаболічні зрушення в організмі самок. Використані методи: визначення рівня лактації, фізіологічний метод визначення живої маси, біохімічний метод дослідження крові; статистичний метод. Застосування *Bacillus subtilis* АХ 20, *Bacillus licheniformis* ЕА 22 сприяє збільшенню молочної продуктивності у корів на 7-9 добу дослідження на 12,9 %, на 10-12 добу – на 15,03 %, на 13-15 добу – на 13,93 %, на 16-18 добу – на 13,5 % та на 19-21 добу – на 21,35 %, порівняно з контролем. Вміст загального білка у дослідних корів збільшився на 18,92 %, глобулінів – на 37,26 ($p \leqslant 0,05$), порівняно з початковими показниками. Активність аланінамінотрансферази, сечовини та азоту сечовини у тварин контрольної та дослідної груп був у межах норми протягом експерименту. Застосування свиноматкам з гіполактією *Bacillus megaterium* NCH 55 сприяє відновленню лактаці через гіполактію у свиноматок поросята дослідної групи відставали у прирості на третю добу на 18,5 %, на десяту – на 11,39 %. Починаючи з 15 доби відбувалось збільшення живої маси поросят-сисунів за рахунок відновлення лактації у свиноматок на 20,56 %, на 20 добу – на 20,43 %, на 25 добу – на 30,56 % на 30 добу – на 31,91 %, порівняно з контрольними. В сироватці крові дослідних свиноматок збільшився вмісту загального білка на 10 %, глобулінів – на 19,13 %, загального холестеролу – на 40,11 %, сечовини на 48,0 %, порівняно з початком досліджень ($p \leqslant 0,05$). Активність аланінамінотрансферази у досліді збільшився, на 8,95 % ($p \leqslant 0,05$), лужної фосфатази зменшився на 27,46 % ($p \leqslant 0,05$), порівняно з початком дослідження. В крові дослідних свиноматок збільшився рівень циркулюючих імунних комплексів на 42,85 % та зниження серомукоїдів на 30,43 %. Практична цінність дослідження полягає у застосуванні пробіотиків для відновлення молочної продуктивності корів та свиноматок після пологів

Ключові слова: молочна продуктивність; гіполактія; приріст живої ваги; обмін білка; метаболічна адаптація

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Risk factors associated with stillbirth of piglets in Ukrainian Meat breed sows

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Abstract. Stillbirth often causes significant piglet losses shortly before or during the farrowing process. This issue leads to a high level of stillbirths, causing substantial losses in the swine industry and requiring immediate attention. The purpose of this study is to evaluate farrowing order, the total number of piglets born, the year and season of farrowing, the breed of the boar, and the average piglet weight in the litter at birth as risk factors for stillbirths in sows of the Ukrainian Meat breed. Experimental data obtained from 262 sows of the Ukrainian Meat breed in the main herd of LLC "Tavriyski Svyni" (Skadovsk district, Kherson region, Ukraine) were used for the study. The proportion of litters containing at least one stillborn piglet, the number and proportion of stillborn piglets in the litter were investigated over 11 years. At least one stillborn piglet was observed in 56.9% of litters, with an average number and proportion of stillborn piglets in the litter of 1.2 and 10.5%, respectively. The results indicate a highly significant impact of the farrowing year on the proportion of litters

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containing at least one stillborn piglet, the number, and proportion of stillborn piglets in the litter (in all cases: *P*<0.001). There was a decrease in estimates of stillbirths during 2007-2013, with a gradual increase until 2017. The farrowing season had a certain (*P*<0.05) influence on estimates of stillbirth rates, since the proportion of stillbirth piglets in litters born in summer was 9.5%, and in litters born in autumn – 12.0%. The proportion of stillborn piglets in litters sired by Duroc boars (15.0%) was significantly higher (*P*<0.001) than in litters sired by Ukrainian Meat breed, Large White, or Landrace boars (10.1-10.0%). From the first to the 10th farrowing, stillbirth rates gradually increased (in all cases: *P*<0.001). The number and proportion of stillborn piglets in the litter tended to increase among sows with larger litter sizes at birth (in both cases: *P*<0.001). Binary logistic regression results suggested that the probability of having at least one stillborn piglet in the litter was significantly associated with the average live weight of piglets at birth

Keywords: stillbirths; farrowing order; litter size; year and season of farrowing; boar breed; Ukrainian Meat breed sows

INTRODUCTION

The death of piglets just before or during the farrowing process is a common phenomenon, resulting in high stillbirth rates causing significant losses to the pig industry. Accordingly, the analysis of the risk factors for the occurrence of stillbirths can help optimise the reproductive efficiency of sows by increasing the number of live piglets per sow per year. Stillborns are piglets that are found dead at farrowing but are fully formed and normally developed. There are three classes of stillborn piglets. The first class includes animals that died shortly before farrowing (*prepartum stillbirth*), the second class – animals that died directly during farrowing (*intrapartum stillbirth*) and, finally, the third – animals that died immediately after farrowing (*postpartum stillbirth*), most often, during the first 24 hours of life. Stillborn piglets typically account for 30-40% of all piglet mortality from birth to weaning, as described by S. Menčik *et al.* (2020). The appearance of at least one stillborn piglet in a litter increased the risk of piglet mortality by 1.28 times compared to litters where stillborn piglets were not observed, as noted by L. Rangstrup-Christensen *et al.* (2018).

Non-infectious risk factors for stillbirths have been studied for a long time and are typically classified into several groups, as described by R. Raguvaran *et al.* (2017). First, these are factors related to the characteristics of the sow. This group includes the parity number (age of the sow), the live weight and condition of the sow, the litter size at birth, the duration of pregnancy, the duration of farrowing, and more. Secondly, these are factors related to the characteristics of a newborn piglet. These are the interval between births, the birth order of each piglet, live weight at birth, and the variability in live piglet weights within a litter., etc. Finally, the third group consists of factors related to environmental and management influences, such as the diet of pregnant sows, the year and season of farrowing, induction of farrowing (e.g., the use of oxytocin and other drugs), human intervention during the farrowing process (e.g., palpation), stress (including temperature), and others.

Although the genetic heritability of stillborn piglets is low, with estimates ranging from 0.02 to 0.05, the influence of breed/genetics, both of the sow and the boar, plays a substantial role in shaping this reproductive trait in pigs. Recent studies, such as that conducted by V.L. Sens Junior *et al.* (2023), has expanded the understanding of risk factors for stillborn piglets by including variables such as piglet measurements, ponderal index, the total weight of the litter at birth, the thickness of the sow's backfat before farrowing, haematological parameters of piglet umbilical cord blood at birth, and polymorphism in the *RNF4-SacII* gene, among others. K. Gourley *et al.* (2020) showed that numerous factors of various natures affect the stillbirth of piglets, and these factors are closely related to each other. Accordingly, knowing the relative importance of risk factors may be important for pig specialists when dealing with stillbirth. Identifying specific factors associated with stillborn piglets is key to achieving this ultimate goal (Raguvaran *et al.*, 2017).

The problem of stillbirth of piglets is given little attention by Ukrainian researchers. Often, this aspect is considered as an element when assessing key fertility indicators of sows, primarily focusing on evaluating the total number of piglets born, prolificacy (the number of live piglets in a litter), and the overall number of piglets at weaning. Special emphasis is placed on factorial dependence (genotypic or technological factors) of these traits, without explicitly addressing piglet mortality levels at birth and from birth to weaning. There are a few exceptions where these issues have been covered for widely recognised pig breeds globally, such as the Large White breed (LW) (Kramarenko & Kramarenko, 2021) and their crosses with the Landrace breed (Luhovyi, 2023). However, research specific to local Ukrainian pig breeds, particularly the Ukrainian Meat breed, is currently lacking. Therefore, the purpose of this study is to identify the risk factors associated with stillborn piglets in Ukrainian Meat breed sows.

MATERIALS AND METHODS

The primary materials for analysing the risk factors of piglet stillbirth were obtained from 262 purebred Ukrainian Meat breed sows (UMB) maintained at the LLC "Tavriyski Svyni" farm (Skadovsk district, Kherson region, Ukraine). The average number of farrowings was 4.2±2.5 (*Mean*±*SD*) on a scale from 1 to 10. In total, data from 1533 farrowings were included in the analysis. For each farrowing, the following traits were evaluated: the number of stillborn piglets (NSB) and the stillbirth rate (SBR) in the litter. In addition, the incidence of stillbirths at the sow level (ISSL), defined as litters with at least one stillborn piglet, was determined.

Mean±*SE* estimates were calculated for specific subgroups formed based on relevant risk factor gradations included in the analysis. The distribution of litter characteristics in terms of both the number and proportion of stillborn piglets deviated significantly from normal (Kolmogorov-Smirnov *d*-test: $P<0.01$). Therefore, the non-parametric Kruskal-Wallis test (H_{KW}) was used to test the null hypothesis of no significant differences among specific subgroups. The chi-square goodness-of-fit test was employed for comparisons of qualitative data.

The independent variables used in the analysis included: the year of farrowing with 11 gradations (2007-2017), the season of farrowing with 4 gradations (winter, spring, summer, and autumn), the breed of the boar (UMB, LW, Landrace, Duroc), the farrowing order (parity) with 10 gradations (P1-P10), and the total number of piglets at birth with 15 gradations (3-17 piglets per litter). Furthermore, one quantitative trait, the average live weight of piglets in the litter at birth (AWPB), calculated as the ratio of the litter weight to the total number of piglets at birth, was used.

The likelihood of a linear trend was assessed using the Spearman's rank correlation coefficient (*Rs*). A binary logistic regression algorithm was applied to build a predictive model for the presence of at least one stillborn piglet in the litter:

$$P(SB) = [\exp(a + b \times AWPB]/[1+\exp(a + b \times AWPB)], \quad (1)$$

where $P(SB)$ – probability of having at least one stillborn piglet in the litter; AWPB – average live weight of the piglet in the litter at birth; a and b – regression coefficients. The predictive value of the model (1) was evaluated as the proportion of correct predictions, separately for '1' (presence of at least one stillborn piglet in the litter) and '0' (absence of any stillborn piglets in the litter), and for the overall model (1).

All statistical processing was performed using STATISTICA v. 7 software (Stat Soft Inc.). The maintenance of experimental animals and all manipulations with them were conducted in accordance with the provisions of the "Procedure for conducting scientific research, experiments on animals by scientific institutions" (Law of Ukraine No. 249, 2012) and the "European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes" (European convention..., 1986).

RESULTS AND DISCUSSION

General characteristics of the stillbirth rate. The average number of piglets in the litter at birth over the study period (2007-2017) was 10.9±0.07 (with a range from 3 to 17 piglets). The number of stillborn piglets in the litter ranged from 0 to 13 (with an average of 1.2±0.04), and the proportion of stillborn piglets varied from 0 to 100% (with an average of 10.5±0.3%). Of the 1,533 litters analysed, 872 (56.9%) had at least one stillborn piglet. Of these, one stillborn piglet was observed in 24.7% of farrowings, two – in 16.8% of farrowings, three – in 7.0% of farrowings four – in 4.2%, five or more – in 4.1% of farrowings. In previous studies on Large White pigs and crossbred Large White × Landrace sows, similar estimates were obtained, approximately 63.3% (Kramarenko & Kramarenko, 2021) and 56.8% (Luhovyi, 2023), respectively. Overall, it can be acknowledged that this trait, which characterises the level of stillbirth in pig herds in Ukraine, had high values, which requires further work aimed at improving their reproductive performance.

Estimates of the average number of stillborn piglets in the litter varied significantly when examining different farms. For instance, a study of nine farms with crossbred Landrace × Yorkshire sows (Denmark) allowed the estimation of this trait at 1.1 piglets, with a range of 0.7 to 1.9 piglets for different farms (Rangstrup-Christensen *et al.*, 2018). The average number of stillborn piglets in litters of crossbred Landrace × Yorkshire sows in five herds (Denmark) ranged from 1.0 to 2.3 piglets per litter (Schild *et al.*, 2019). The proportion of stillborn piglets in the litter was most often in the range of 4% to 10% (Roongsitthichai & Olanratmanee, 2021), although cases are known where this estimate reached 19% or more (Langendijk & Plush, 2019). Thus, the obtained estimates of the average number and proportion of stillborn piglets in the litters of UMB sows in the studied herd (1.2 piglets and 10.5%, respectively) fall within the values previously noted for highly productive pig herds from different countries worldwide.

Year of farrowing. The year of farrowing significantly influenced the proportion of litters that had at least one stillborn piglet (Pearson's chi-square goodness-of-fit test: $\chi^2=55.9$; $df=10$; $P<0.001$). In this regard, for farrowings in 2017, this proportion was the lowest (29.4%), while for farrowings in 2013, it reached the maximum value (72.3%). On the other hand, for farrowings in 2012-2014 and 2016, an increase in the proportion of litters with 2-4 stillborn piglets was noted (Fig. 1).

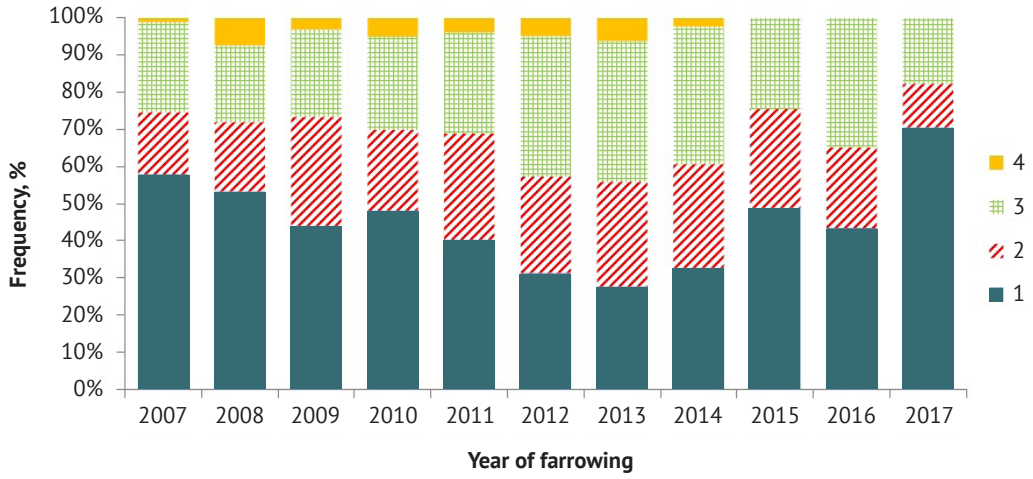

Figure 1. *Distribution by number of stillborn piglets (NSB) per UMB sow litter depending on the year of farrowing*
Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*
Source*: compiled by the authors*

The average number of stillborn piglets in the litter ranged from 0.5 (farrowing 2017) to 1.6 heads (farrowing 2012-2013). The proportion of stillborn piglets in the litter ranged from 4.6% (farrowing 2017) to 14.8% (farrowing 2013). Overall, the year of farrowing significantly affected both the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases, $P<0.001$) (Table 1).

Table 1. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the year of farrowing*

Year of farrowing	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
2007	95	0 – 9	0.9±0.14	0 – 60.0	7.6±1.2
2008	150	0 – 10	1.2±0.16	0 – 76.9	9.4±1.2
2009	200	0 – 9	1.1±0.10	0 – 60.0	9.6±0.8
2010	262	0 – 13	1.2±0.11	0 – 92.9	9.8±0.8
2011	261	0 – 8	1.2±0.09	0 – 57.1	10.3±0.7
2012	185	0 – 9	1.6±0.12	0 – 90.0	13.6±1.0
2013	177	0 – 8	1.6±0.13	0 – 100.0	14.8±1.2
2014	89	0 – 6	1.3±0.14	0 – 42.9	11.2±1.1
2015	45	0 – 4	0.9±0.17	0 – 33.3	7.9±1.4
2016	23	0 – 4	1.2±0.28	0 – 28.6	8.9±2.0
2017	17	0 – 2	0.5±0.19	0 – 28.6	4.6±2.0
$H_{KW}(10; 1503); P$	-	-	54.69; $P<0.001$	-	56.38; $P<0.001$

Note: *H_{KW} – non-parametric Kruskal-Wallis test; P – level of significance*
Source*: compiled by the authors*

Previously, in a study of 91 herds in Spain over the period 2007-2016, a significant ($P<0.01$) linear trend for the temporal variability of the number of stillborn piglets in the litter was also found (Koketsu *et al.*, 2021).

Farrowing season. The farrowing season likely influenced the proportion of litters with at least one stillborn piglet (Pearson's chi-square goodness-of-fit test: $\chi^2=10.19$; $df=3$; $P=0.017$). This difference was primarily due to a significant increase in the proportion of such litters in the autumn months (63.3%) compared to farrowings in other seasons (52.4-57.0%) (Fig. 2).

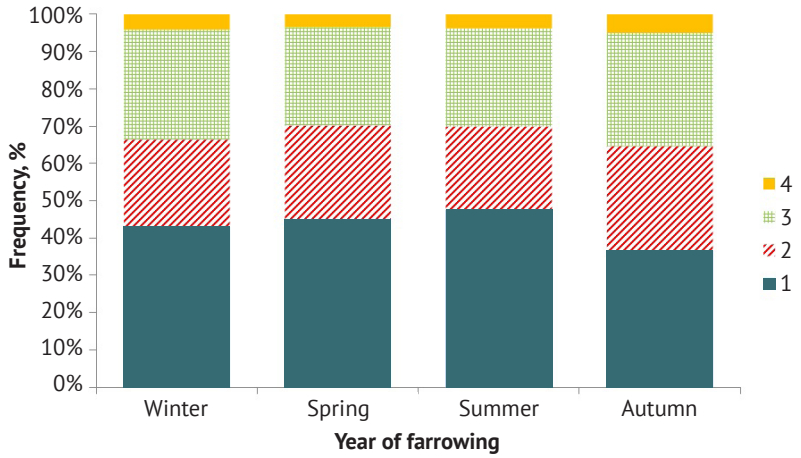

***Figure 2**. The distribution of the number of stillborn piglets (NSB) per litter of UMB sows depending on the farrowing season*

***Note:** 1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*
***Source**: compiled by the authors*

The average number of stillborn piglets in the litter was highest for autumn (1.4 piglets) and winter (1.3 piglets) farrowings. However, for sows farrowing in spring and summer, this number was the lowest, 1.1 piglets. The proportion of stillborn piglets in the litter was highest for spring farrowings (12.0%) and lowest (9.5%) for farrowings that occurred during the summer months.

Overall, the farrowing season considerably influenced both the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases $P<0.05$) (Table 2).

***Table 2.** Variability indicators of the number (NSB) and proportion (SBR) of stillborn piglets in the litter of UMB sows depending on the farrowing season*

Farrowing season	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
Winter	384	0 – 13	1.3±0.08	0 – 92.9	10.4±0.6
Spring	375	0 – 9	1.1±0.08	0 – 90.0	10.1±0.7
Summer	398	0 – 9	1.1±0.08	0 – 80.0	9.5±0.6
Autumn	376	0 – 10	1.4±0.09	0 – 100.0	12.0±0.7
$H_{KW}(3; 1533)$; *P*	-	-	9.00; *P*=0.029	-	10.57; *P*=0.014

***Note:** H_{KW} – non-parametric Kruskal-Wallis test; P – level of significance*
***Source**: compiled by the authors*

Numerical studies analysing the influence of the sow's farrowing season on the number and proportion of stillborn piglets in the litter often yield conflicting results. Most often, an increased stillbirth rate was observed for farrowing in the spring and summer seasons. The authors demonstrated the influence of the farrowing season on the number of stillborn piglets in the litter of crossbred sows (Landrace × Yorkshire, Denmark), with the highest values recorded for sows farrowing during the summer months (May to August). This was explained by the fact that during the summer of 2014, when the study was conducted, the average air temperature was 1.6°C higher than the long-term average (Rangstrup-Christensen *et al.*, 2018).

Some influence of temporal fluctuations on the stillbirth rate was also noted for Landrace sows and crossbred Yorkshire × Landrace sows (Denmark) but without a clear seasonal effect (Chu *et al.*, 2022).

The seasonality in the increased number and proportion of stillborn piglets in the litter may be related to the age of the sows. For Iberian × Duroc crossbred sows in Spain, a significant influence of the farrowing season and the combination of "farrowing order" × "farrowing season" on the number of stillborn and mummified piglets in the litter at birth was established. The lowest values were noted for primiparous sows in the spring months and sows in the 2-4 farrowings category in the summer months. The effect of farrowing number on stillbirth rates was most pronounced for summer farrowing. The curve of monthly estimates of the proportion of stillborn piglets in the litter demonstrated significant seasonal fluctuations, with a maximum (for

multiparous sows in the 2-4 farrowings category) in August-September and a minimum in March-May. In addition, the combined effect of the duration of the photoperiod, especially among sows in the 2-4 farrowings category, was noted (Piñán *et al.*, 2021).

Breed of the boar. A significant influence of the boar breed on the proportion of litters with at least one stillborn piglet was established (Pearson's chi-square goodness-of-fit test: χ^2=13.61; *df*=3; *P*=0.004). The highest proportion of such litters was recorded for UMB sows inseminated with Duroc boar sperm (77.5%). Primarily, this increase was due to the high proportion (46.5%) of litters with 2-4 stillborn piglets (Fig. 3). When using sperm from UMB, LW, and Landrace boars, the proportion of litters with at least one stillborn piglet was the lowest (55.2-58.9%).

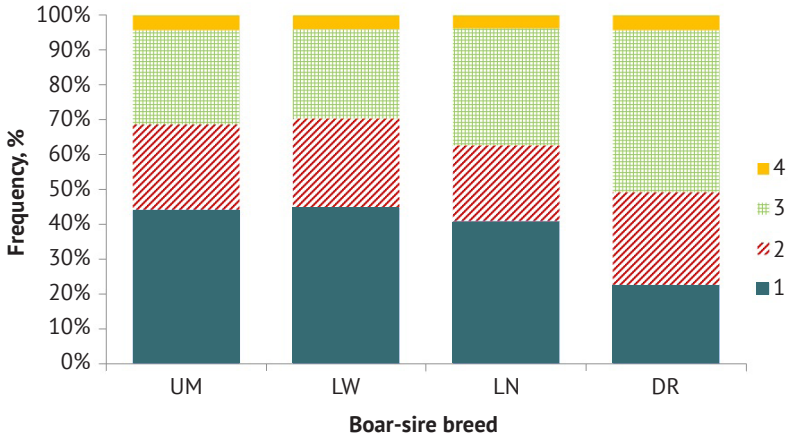

Figure 3. *Distribution by the number of stillborn piglets (NSB) per litter of sows depending on the boar breed*
Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+. UMB - Ukrainian Meat breed; LW – Large White breed; LN – Landrace; DR – Duroc*
Source*: compiled by the authors*

The boar breed also significantly influenced both the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases *P*<0.001). These differences were primarily related to a substantial increase in the number (1.8 piglets) and proportion (15.0%) of stillborn piglets in litters from sows inseminated with Duroc boar sperm (Table 3).

Table 3. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the breed of boar*

Boar breed	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
UWS	611	0 – 13	1.2±0.07	0 – 92.9	10.3±0.5
LW	651	0 – 9	1.1±0.06	0 – 100.0	10.1±0.5
Landrace	185	0 – 10	1.3±0.12	0 – 76.9	10.9±0.9
Duroc	71	0 – 7	1.8±0.19	0 – 100.0	15.0±1.5
H_{KW}(3; 1518); *P*	-	-	18.24; *P*<0.001	-	16.40; *P*<0.001

Note: *H_{KW} – non-parametric Kruskal-Wallis test; P – level of significance*
Source*: compiled by the authors*

The paper by M. Pedersen *et al.* (2019) presents the results of analysing the piglet mortality rate of crossbred sows (Landrace × Yorkshire) inseminated with purebred boars of the Pietrain and Duroc breeds. Piglet mortality at birth and within the first five days after farrowing was significantly lower (*P*<0.0001) among the offspring of Duroc boars compared to Pietrain boars. P. Nevrkla *et al.* (2021) established a significant influence of the breed/crossbreed origin of the terminal boar on the number of stillborn piglets. The lowest average number of such piglets was observed in litters from Duroc × Pietrain boars (1.1 piglets), while the highest was in litters from purebred Pietrain boars (2.8 piglets per litter). In addition, the farrowing order of the sow also had an impact on the stillbirth rate.

Farrowing order. With an increase in the farrowing order (i.e., the age of the sow), the proportion of litters with at least one stillborn piglet linearly increased,

ranging from 34.6% (sows with 2nd farrowing) to 83.3% (sows with 10th farrowing). These likely differences between animals of different ages (Pearson's chi-square goodness-of-fit test: χ^2=123.35; *df*=9; *P*<0.001) are primarily due to an increase with age in the proportion of litters with 2-4 stillborn piglets (Pearson's chi-square goodness-of-fit test: χ^2=73.01; *df*=3; *P*=0.004) and the proportion of litters with 5 or more stillborn piglets in the litter (Pearson's chi-square goodness-of-fit test: χ^2=36.23; *df*=3; *P*=0.004) (Fig. 4).

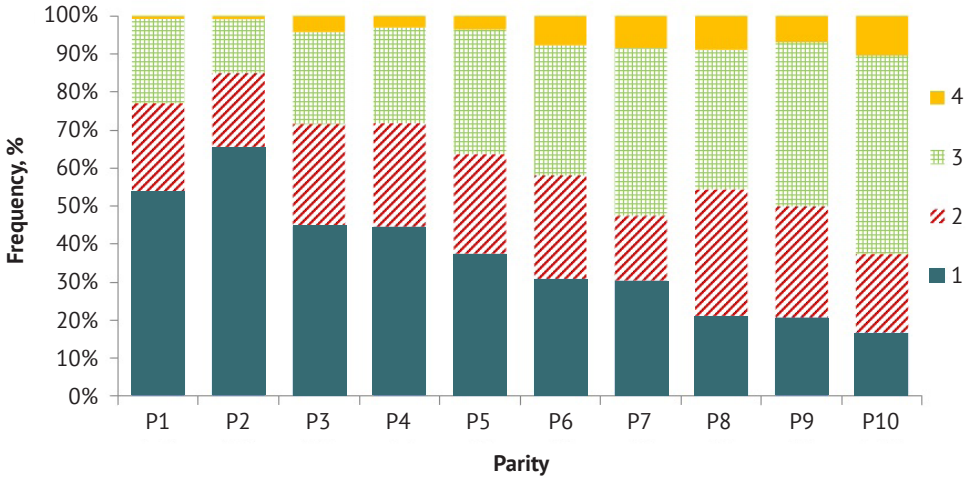

Figure 4. *Distribution by number of stillborn piglets (NSB) per UMB sow litter depending on farrowing order*
Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*
Source*: compiled by the authors*

Similarly, with the age of the sow, the average number and proportion of stillborn piglets in the litter increased (non-parametric Kruskal-Wallis test: in both cases *P*<0.001) (Table 4). The lowest number and proportion of stillborn piglets were observed for sows with 2nd farrowing (0.6 piglets and 5.1%, respectively). In animals with 3-6 farrowing, the number and proportion of stillborn piglets ranged from 1.1 to 1.6 piglets and 9.8% to 12.6%, respectively. In the oldest sows (7th farrowing and above), these figures increased to 1.8-2.3 piglets and 15.1-21.4% of stillborn piglets per litter, respectively. Thus, the observed dependence had a clear linear trend (Spearman's rank correlation coefficient: in both cases *P*<0.001).

Table 4. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the farrowing order*

Farrowing number	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
P1	262	0 – 6	0.8±0.07	0 – 57.1	8.4±0.7
P2	239	0 – 6	0.6±0.06	0 – 42.9	5.1±0.5
P3	212	0 – 10	1.2±0.12	0 – 80.0	9.8±0.9
P4	195	0 – 8	1.1±0.10	0 – 57.1	9.3±0.8
P5	168	0 – 8	1.3±0.12	0 – 50.0	10.6±0.9
P6	143	0 – 10	1.6±0.15	0 – 76.9	12.6±1.1
P7	118	0 – 9	2.0±0.18	0 – 90.0	15.9±1.4
P8	90	0 – 13	1.8±0.21	0 – 92.9	15.1±1.6
P9	58	0 – 8	1.8±0.23	0 – 80.0	16.0±1.9
P10	48	0 – 7	2.3±0.28	0 – 100.0	21.4±3.0
H_{KW} (9; 1533); *P*	-	-	157.41; *P*<0.001	-	135.00; *P*<0.001
Rs (*n* = 1533); *P*	-	-	0.295; *P*<0.001	-	0.260; *P*<0.001

Note: *H_{KW} – non-parametric Kruskal-Wallis test; Rs – Spearman's rank correlation coefficient; P – level of significance*
Source*: compiled by the authors*

Previously, R. Klimas *et al.* (2020) already established that the stillbirth rate increases with the farrowing order (i.e., the age of the sow). In most cases, this relationship is non-linear, with the number (proportion) of stillborn piglets in the litter slightly decreasing in sows with the 2nd farrowing compared to primiparous sows but then almost linearly increasing, which is consistent with the results obtained for UMB sows (Table 4). On the other hand, such an increase may not be proportional among sows of different genetic groups (Kobek-Kjeldager *et al.,* 2023). Overall, both the results of this study and the literature data (Leonard *et al.*, 2020) indicate that older sows have a 2-3 times higher risk of giving birth to a stillborn piglet than younger animals.

Litter size at birth. The total number of piglets at birth significantly influenced (Pearson's chi-square goodness-of-fit test: χ^2=204.75; *df*=14; *P*<0.001) the proportion of litters with at least one stillborn piglet. This was primarily due to the likely increase in the proportion of farrowings with 2-4 (Pearson's chi-square goodness-of-fit test: χ^2=183.16; *df*=14; *P*<0.001) and five or more (Pearson's chi-square goodness-of-fit test: χ^2=125.56; *df*=14; *P*<0.001) stillborn piglets with an increase in the litter size (Fig. 5).

In summary, for litters with 3-8 piglets at birth, the proportion of those that had at least one stillborn piglet varied between 23.7% and 33.0%. However, starting from litters with 9 or more piglets at birth, this proportion increased almost linearly. Finally, in litters with 17 piglets, there was always at least one stillborn piglet present, with most cases (87.2%) having 2 or more stillborn piglets (Fig. 5).

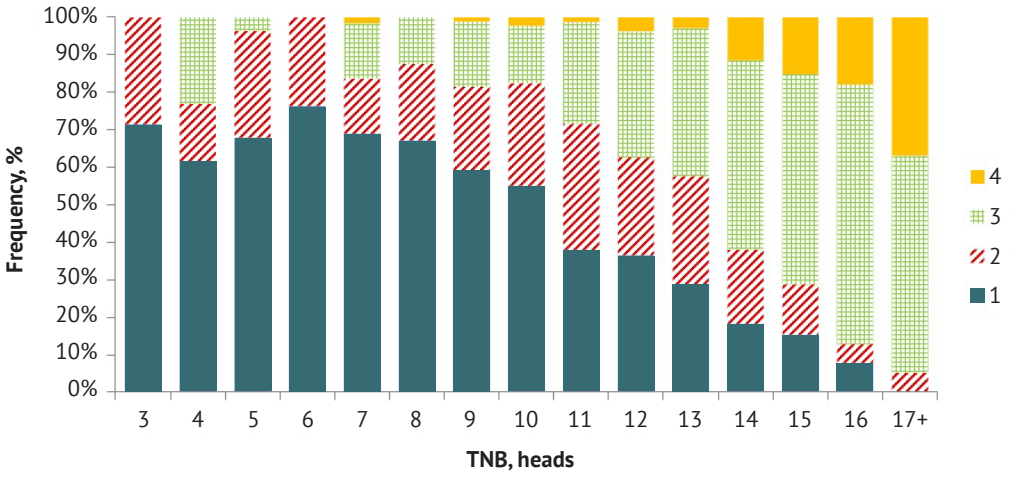

Figure 5. *Distribution by the number of stillborn piglets (NSB) in UMB sow litters based on the total number of piglets at birth (TNB)*

Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*

Source*: compiled by the authors*

The average number and proportion of stillborn piglets in the litter for sows whose litter size ranged from 3-8 piglets at birth varied between 0.2-0.6 piglets and 3.9-15.4%, respectively (Table 5). For litters containing 9-13 piglets at birth, these values ranged from 0.8-1.5 piglets and 7.8-11.2%, respectively. For litters containing 14 or more piglets at birth, these values reached 2.4-4.4 piglets and 17.1-26.0%, respectively. Therefore, litter size significantly influenced the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases *P*<0.001), and this relationship had an almost linear form (Spearman's rank correlation coefficient: in both cases *P*<0.001).

Table 5. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the total number of piglets at birth (TNB)*

TNB, heads	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
3	14	0 – 1	0.3±0.13	0 – 33.3	9.5±4.2
4	13	0 – 2	0.6±0.24	0 – 50.0	15.4±6.0
5	28	0 – 2	0.4±0.11	0 – 40.0	7.1±2.1
6	38	0 – 1	0.2±0.07	0 – 16.7	3.9±1.2
7	61	0 – 7	0.6±0.15	0 – 100.0	8.4±2.2
8	88	0 – 4	0.5±0.09	0 – 50.0	6.1±1.1

Table 5, Continued

TNB, heads	n	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
9	167	0 – 7	0.7±0.08	0 – 77.8	7.8±0.9
10	256	0 – 9	0.8±0.08	0 – 90.0	7.9±0.8
11	222	0 – 6	1.1±0.08	0 – 54.5	10.0±0.7
12	238	0 – 7	1.3±0.09	0 – 58.3	10.5±0.7
13	170	0 – 10	1.5±0.11	0 – 76.9	11.2±0.9
14	121	0 – 13	2.4±0.19	0 – 92.9	17.1±1.4
15	59	0 – 9	2.7±0.25	0 – 60.0	18.0±1.7
16	39	0 – 10	3.2±0.31	0 – 62.5	19.9±2.0
17	19	1 – 9	4.4±0.54	5.9 – 52.9	26.0±3.2
H_{KW}(9; 1533); *P*	-	-	331.80; *P*<0.001	-	176.94; *P*<0.001
Rs (n = 1533); *P*	-	-	0.440; P<0.001	-	0.305; P<0.001

Note: *H_{KW} – non-parametric Kruskal-Wallis test; Rs – Spearman's rank correlation coefficient; P – level of significance*
Source*: compiled by the authors*

The paper by M. Pedersen *et al.* (2019) previously demonstrated that as litter size at birth increased, the mortality of piglets in the first five days after farrowing (including stillborn piglets) also increased. In litters with 14 piglets, the mortality rate was 12-15%, while in litters with 24 piglets at birth, the mortality estimate was almost twice as high (24-27%). M. van den Bosch *et al.* (2022) showed that each additional piglet in the litter led to a reduction in the average birth weight of piglets by 17.6 grams, an increase in farrowing duration by an average of 11 minutes, and, consequently, an increase in the proportion of stillborn piglets in the litter by 0.5%.

The question of the threshold of litter size above which stillbirth rates would increase rapidly is noteworthy. In this study, this threshold separated litters with 13 or fewer piglets from those with 14 or more piglets at birth (Table 5). In the paper by N. Nam & P. Sukon (2021) on crossbred Landrace × Yorkshire (Vietnamese) sows, the proportion of stillborn piglets in litters containing 5-10 and 11-13 piglets at birth did not differ (3.6 and 1.7%, respectively), but these litters had a significantly lower proportion of stillborn piglets compared to litters with 14-21 piglets (6.7%). Thus, the results obtained for UMB sows fully coincide with the earlier findings.

Average live weight of a piglet at birth. The average live weight of a piglet at birth ranged from 0.600 to 2.440 kg (with an average of 1.362±0.008 kg). This characteristic proved to be a significant factor in predicting the presence or absence of at least one stillborn piglet in the litter (logistic binary regression: χ^2=204.75; *df*=1380; *P*<0.001). The resulting model was:

$$P(SB)=[\exp(4.2856 - 2.9087\times AWPB)]/[1+ \exp(4.2856 - 2.9087\times AWPB)], \quad (2)$$

where *P*(SB) – probability that there would be at least one stillborn piglet in the litter;

AWPB – average live weight of the piglet in the litter at birth (Table 6).

Table 6. *Indicators of the binary logistic regression model for the presence of stillborn piglets in UMB sow litters depending on the average live piglet birth weight (AWPB)*

Indicator	Assessment
Intercept (a)	4.2856
AWPB	-2.9087
χ^2; *P*	236.57; *P*<0.001
Forecast accuracy, %:	
absence of a stillborn piglet in the litter	49.0
presence of at least one stillborn piglet in the litter	79.9
total	66.8

Note: *χ^2 – Pearson's chi-square goodness-of-fit test; P – level of significance*
Source*: compiled by the authors*

The average predictive value of this model was 66.8%, and it performed well in predicting the presence of at least one stillborn piglet in the litter (79.9%), but relatively less well in predicting the absence (49.0%). As expected, litters with lower live piglet birth weights (0.5-1.0 kg) had a very high risk (77% or higher) of having at least one stillborn piglet. Conversely, litters with live piglet birth weights of 1.8 kg or higher had a low risk (25% or less) of stillborn piglets (Fig. 6). The 50% probability of giving birth to such a piglet in the litter corresponded to an average live birth weight of 1.5 kg.

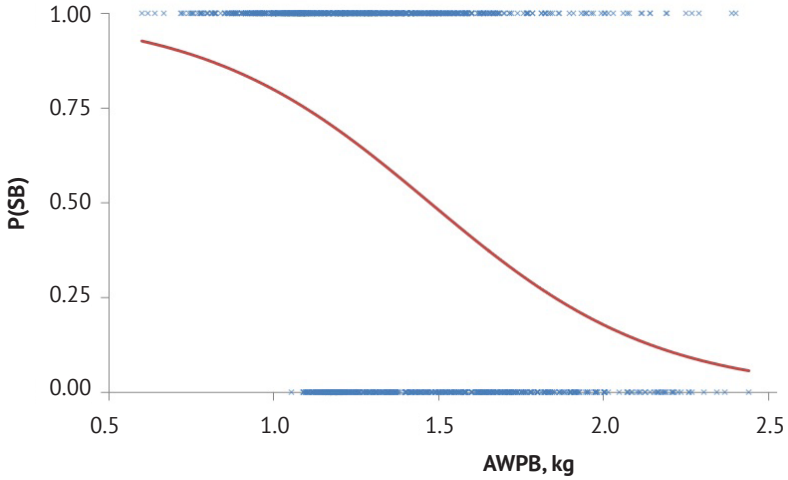

Figure 6. *Logistic regression of the presence/absence of at least one stillborn piglet in the litter based on the average live piglet birth weight (AWPB)*
Note: *for the Y-axis: 0 – no stillborn piglets in the litter; 1 – at least one stillborn piglet in the litter*
Source*: compiled by the authors*

It has been previously shown that the birth weight of piglets is one of the factors associated with the risk of stillbirth. For instance, 43.3% of live-born piglets had a birth weight below 1 kg, while among stillborn piglets, this percentage was 60.9% (Udomchanya *et al.*, 2019). Besides live birth weight, stillborn piglets were found to have significantly lower body mass index and ponderal index, indicating that they were disproportionately long and thin. Therefore, these indices proved to be better indicators of stillbirth risk than live piglet birth weight alone (Lanh & Nam, 2022).

The reasons explaining the link between low piglet body weight and increased stillbirth risk may include the following: lighter fetuses suffer from nutrient deficiency due to improper placental functioning during gestation period, they have a higher chance of broken umbilical cord, and they are more susceptible to hypoxia during farrowing (Udomchanya *et al.,* 2019). On the other hand, very heavy piglets at birth may experience difficulties during farrowing due to their large size relative to the maternal pelvis, leading to prolonged farrowing, hypoxia, and stillbirth. Thus, selection for high uniformity in litter birth weights shows great promise as a method for improving piglet survival at birth.

CONCLUSIONS

The obtained values for the average number and proportion of stillborn piglets in the litters of Ukrainian Meat breed sows (UMB) from the studied herd (1.2 piglets and 10.5%, respectively) correspond to the previously noted estimates for high-productivity pig herds in various countries worldwide. It was statistically demonstrated that the year of farrowing significantly influenced (in all cases: $P<0.001$) the proportion of litters containing at least one stillborn piglet, including the number and proportion of stillborn piglets in the litter. Notably, there was a substantial decrease in stillbirth estimates from 2007 to 2013, followed by a gradual increase until 2017. The season of farrowing also possibly ($P<0.05$) had an impact on stillbirth rates, with litters from sows farrowing in summer having a stillbirth rate of 9.5%, while those farrowing in autumn had a rate of 12.0%.

The proportion of stillborn piglets depended on the breed of boar. The breed of the boar used for breeding also influenced the proportion of stillborn piglets. It was significantly higher ($P<0.001$) in litters sired by Duroc boars (15.0%) compared to litters sired by boars of other breeds (10.1-10.0%). It was found that older sows had a 2-3 times higher risk of giving birth to stillborn piglets compared to younger animals. Among sows with larger litter sizes at birth (more than 14 piglets), both the number and proportion of stillborn piglets in the litter significantly increased ($P<0.001$). The results of binary logistic regression indicated that litters with low piglet weights (0.5-1.0 kg) had a very high risk (77% and higher) of containing at least one stillborn piglet. Future research prospects include analysing the combined influence of identified risk factors for piglet

stillbirth in Ukrainian Meat breed sows (UMB) and other local breeds in Ukraine.

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CONFLICT OF INTEREST

None.

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Фактори ризику мертвонародження поросят у свиноматок української м'ясної породи

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Анотація. Часто відбувається велика загибель поросят безпосередньо перед або під час процесу опоросу. Ця проблема призводить до високого рівня мертвонародження, що наносить серйозні збитки галузі свинарства і потребує негайного вирішення. Головною метою дослідження стало оцінювання номеру опоросу свиноматки, загальної кількості поросят при народженні, року та сезону опоросу, породи кнура-плідника та середньої маси поросяти у гнізді при народженні як факторів ризику мертвонародження поросят у свиноматок української м'ясної породи. Для дослідження було використано експериментальні дані, отримані від 262 свиноматок української м'ясної породи основного стада ТОВ «Таврійські свині» (Скадовський район, Херсонська область, Україна). Частку гнізд, що містили хоча б одне мертвонароджене порося, кількість та частку мертвонароджених поросят у гнізді було досліджено протягом 11 років. Хоча б одне мертвонароджене порося було відмічено в 56,9 % гнізд, середня кількість та частка мертвонароджених поросят у гнізді становила 1,2 гол. та 10,5 %, відповідно. Отримані результати свідчать про високо вірогідний вплив року опоросу на частку гнізд, що містили хоча б одне мертвонароджене порося, кількість та частку мертвонароджених поросят у гнізді (у всіх випадках: $P<0,001$). Відмічено суттєве зниження оцінок рівня мертвонародження протягом 2007-2013 рр. із їх поступовим

зростанням до 2017 р. Сезон опоросу мав певний (P<0,05) вплив на оцінки рівня мертвонародження, оскільки частка мертвонароджених поросят у гніздах, що народилися влітку, становила 9,5 %, а у гніздах, що народилися восени – 12,0 %. Частка мертвонароджених поросят у гніздах, отриманих від свиноматок, яких було запліднено спермою кнурів-плідників породи дюрок (15,0 %) була вірогідно вищою (P<0,001), ніж в гніздах, отриманих від свиноматок, яких було запліднено спермою кнурів-плідників української м'ясної, великої білої або породи ландрас (10,1-10,0 %). Від першого до 10-го опоросу оцінки рівня мертвонародження поступово зростали (у всіх випадках: P<0,001). Кількість та частка мертвонароджених поросят у гнізді мали тенденцію до зростання серед свиноматок із великим розміром гнізда при народженні (в обох випадках: P<0,001). Результати бінарної логістичної регресії свідчили про те, що ймовірність присутності хоча б одного мертвонародженого поросяти у гнізді, була вірогідно пов'язана із середньою живою масою поросяти при народженні

Ключові слова: мертвонародження; номер опоросу; розмір гнізда; рік та сезон опоросу; порода кнура-плідника; свиноматки української м'ясної породи

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Respiratory form of infectious rhinotracheitis: Analysis of immunomorphological reactions

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Abstract. The concentration of cattle in limited areas, nutritional disorders, and imbalance of micro- and macroelements contribute to suppression of natural resistance of the organism, insufficient live weight gain, leading to the growth of infectious diseases of young animals with high rates of forced slaughter and cattle mortality. The source of the causative agent of rhinotracheitis infection – *Bovine alphaherpesvirus 1* hinders the development of the livestock industry, thus, it is necessary to search for possible approaches to prevent and control this infection. The purpose of the research

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is to determine the immunomorphological changes in the lymphoid tissue of the trachea and bronchial system, in the regional lymph nodes of the lungs and in the spleen in calves naturally affected by infectious rhinotracheitis. The experimental studies were based on the research of immunomorphological reactions in lymphoid tissue during infection of young cattle with *Bovine alphaherpesvirus 1*, using polymerase chain reaction, histological and immunohistochemical methods. According to the results, it was established that hyperplasia of trachea-associated lymphoid tissue was observed in the trachea, and hyperplasia of bronchial-associated lymphoid tissue was observed in the lungs; the affected areas of the trachea and lungs were infiltrated with lymphocytes, macrophages and plasma cells. The immunomorphological reactions of regional lymph nodes demonstrate hyperplasia of B- and T-dependent zones, and in the spleen – hyperplasia of T-dependent zones of the white pulp. Thus, immunocompetent cells of lymphoid tissue associated with B- and T-dependent areas of the trachea, bronchial system of the lungs and regional lymph nodes of the lungs, and with T-dependent areas of the spleen, are directly involved in the pathogenesis of infectious rhinotracheitis of respiratory type calves. Antibacterial therapy with antibiotics destroys pathogenic and normal flora in the intestine, but they are not effective enough on viral infection, therefore, production trials of effective means of specific prophylaxis and vaccination are the primary task of veterinary medicine

Keywords: cattle; herpesvirus; polymerase chain reaction; pathology; immunomorphology; associative diseases

INTRODUCTION

Diseases of young animals caused by viruses occupy an important place in the structure of diseases of cattle. The etiological structure of infections of calves is represented by: infectious rhinotracheitis, viral diarrhoea, parainfluenza, respiratory syncytial virus, rotavirus, and coronavirus – the causative agents of all these infections are opportunistic viral flora that activate when natural resistance of the organism is suppressed. As noted by M.J. Counotte *et al.* (2016), the above infections lead to significant economic losses, including treatment costs, ineffective prevention, reduced productivity of sick calves and their death. They account for 34.1-47% of all diseases under conventional livestock production methods, and more than 60% of all diseases in young cattle under industrial methods.

According to C. Iscaro *et al.* (2021), these diseases affect 82-100% of calves under one year of age, some of them recurrent – 9.6-17.2%. The causative agent of rhinotracheitis is the genomic virus BHV-1 (*Bovine Herpesvirus 1*), which is resistant to low temperatures, unstable to the external environment and sensitive to various chemicals: 2% formalin solution, 1-2% hot alkali solution, 10-20% quicklime solution, 0.3% estosteril-1 solution. Exposure to sunlight for 48 hours kills the virus.

Herpesvirus diseases of cattle are widespread, with bovine herpesvirus infection type 1, or Infectious Bovine Rhinotracheitis IBR-1 (IBR-1), being the primary cause. K.J. Mars *et al.* (2019) reported that economic losses from respiratory diseases of young cattle in countries with well-developed commercial livestock production are enormous, with mortality rates of 5-20% and sometimes as high as 60%. As noted in the work of Zh. Atambekova *et al.* (2023), reproduction of herpesviruses in susceptible cells is a complex process involving many virions, cells, virus-inducing and virus-modifying enzymes subdivided into stages of development of herpetic infection: primary infection of the skin and mucous membranes; "colony-formation" and acute ganglion infection; latent infection with the herpes virus. In addition to rhinopharyngitis, associated infectious diseases of cattle are: viral diarrhoea, mucous membrane disease, parainfluenza type 3, respiratory syncytial virus and adenovirus infections, mycoplasmosis, chlamydia, pseudomoniasis, trichomoniasis and trichinellosis.

J.J. Hodnik *et al.* (2021) estimate that clinical syndromes in the feedlot are frequently associated with respiratory infections. Disease in cattle on IBR-1 should be prevented before it occurs and becomes latent in animals that have recovered from primary infection, as any type of stress that increases endogenous cortisol levels, including administration of exogenous corticosteroids, can lead to virus recurrence. K. Kydyshov *et al.* (2022) state that during virus reactivation, infected cattle excrete IBR-1 virus through the eyes, nose and genital secretions. Close contact between large numbers of cattle establishes ideal conditions for the rapid spread of IBR-1 virus. Serum-neutralising antibodies prevent infection but do not eliminate degradation or release of latent BHV-1 virus.

The purpose of this research is to explore the morphological and cellular composition and to determine the immunomorphological changes in lymphoid tissues associated with the trachea and bronchial system of the lung, and in pulmonary lymph nodes and spleen in calves.

THEORETICAL OVERVIEW

IBR-1 infection of cattle is a viral infection occurring predominantly in the respiratory and urogenital systems, characterised by elevated body temperature, scarring and necrotic inflammation of the mucous membranes of the upper respiratory tract, eyes, genitals, central nervous system and abortive lesions. The causative agent of IBR-1 infection in cattle is herpesvirus

BHV-1, family *Herpesviridae*, subfamily *Alphaherpesvirinae*, genus *Varicellovirus*.

World Organisation for Animal Health (WOAH) (2017) classified herpesviruses according to the cell types involved in the infectious process, their persistence in the natural host and their pathogenicity against phylogenetically similar organisms. They classified them into three groups according to differences in virulence to phylogenetically similar organisms. According to the data, the virus is considered to be classified into strains: type 1 IBR, type 2 (subtypes 2a and 2b) and type 3 (subtypes 3a and 3b). BHV-1 is associated with the major clinical syndromes, Infectious Pustular Vulvovaginitis (IPV) and Infectious Pustular Balanoposthitis (IPB).

According to the research data of J. Wang *et al.* (2007), BHV-1 has a size of 150-200 nm and is a cubic symmetric phage containing 162 phages. The sedimentation constant of the mature virus is 1630-1830 S. BHV-1 is viable for 7-9 minutes at 60-70°C, inactivated within 20 minutes at 56°C, 4-10 days at 37°C, 50 days at 22°C. BHV-1 is sensitive to acetone, ether, and chloroform, e.g., a 1:500 formalin solution inactivates the virus in 24 hours, and a 1:4000 formalin solution inactivates the virus in 46 hours. As reported by S. Nandi *et al.* (2009), when infecting cattle, the virus persists in the organism for 6-12 months and poses a threat to healthy animals in the herd, and IBR-1 virus is cultured in calf kidney cells and cattle embryos.

C. Righi *et al.* (2023) reported that the incubation period of BHV-1 is 2-21 days, but the clinical picture depends on the type and course of the disease, manifested by upper respiratory tract lesions, vaginitis, encephalitis, conjunctivitis and arthritis to varying degrees. In addition, cattle of any gender and age are susceptible to BHV-1, but the disease is most severe in young beef cattle. As established by G. Duca *et al.* (2022), genital infections in female heifers and heifers are characterised by purulent vulvovaginitis, ovariitis, orchitis and salivary gland infection, with pustules and vesicles developing on the genitals and penis of affected bulls. According to J.V. Rosete Fernández *et al.* (2023), in lactating cows, BHV-1 viruses can cause intrauterine foetal death, abortion late in pregnancy and death of non-viable calves a few days after birth, and there are known cases of acute mastitis in cows resulting in reduced milk production.

As reported by P. Mottaghian *et al.* (2022), keratoconjunctivitis caused by BHV-1 can be either independent or concomitant with other diseases. In this disease, the mucous membranes of the conjunctiva, cornea and third eyelid become inflamed, resulting in lacrimation, increased sensitivity to light and mucosal oedema. The cornea often loses transparency and becomes cloudy, and a warty cortex appears. According to C.A. Evans *et al.* (2021), typical neurological signs in young animals are acute agitation, aggression and impaired motor coordination. In contrast, severe depression is observed in some animals. The disease is accompanied by muscle tremors, convulsions, salivation and paralyses, ending in death. Cutaneous aetiology of BHV-1 is observed mainly in bulls and is characterised by skin lesions of the anus, spine, perineum, buttocks and scrotum, accompanied by hair loss and eczema-like rash, and lesions are accompanied by genital lesions anal crepitus or orchitis, as noted by A. Martucciello *et al.* (2023).

Assessment of the general pathogenesis is associated with clinical and morphological manifestations of various respiratory lesions of viral aetiology in cattle, and in many cases these diseases are interrelated, complicating accurate diagnosis and the development of therapeutic and preventive methods for the treatment of IBR-1. According to S.R. Compton (2020), pathological autopsies, virological studies, histopathological studies, histopathological studies using polymerase chain reaction (PCR), and immunohistochemical studies are currently being performed to fully diagnose BHV-1 to explore its pathogenesis and immunogenesis. To enhance epidemiological surveillance of infectious diseases, a multidimensional Syndromic Surveillance (SyS) system is gaining popularity, allowing simultaneous evaluation and synthesis of information from different data sources, as planned in the work of C. Faverjon *et al.* (2019).

In a work by E.R. Snyder *et al.* (2019), reported that the presence of infection is only indicated by analysing viral DNA in the nucleus of nerve cells. The BHV-1 viral genome consists of double-stranded DNA with a virion diameter of 120-140 nm, which encodes about 70 proteins, among which 33 structural and more than 15 non-structural proteins were identified. Nine structural proteins have been identified in the viral DNA (VP105, VP90, VP74, VP64, VP54, VP50, VP47, VP40, and VP31), but the proteins VP74 and VP90 involved in A-gene conversion have the greatest immunogenicity.

As reported by T.G. McDaneld *et al.* (2022), molecular diagnostic techniques have the advantage of high throughput of analysis and rapid results, allowing scientists to amplify a very small DNA sample sufficiently for detailed research. The PCR, histological and immunohistochemical data obtained from the liver demonstrate that the liver is a key organ for etiological diagnosis and that viral glycoproteins, which are located in the envelope on the surface of the virion, play an important role.

MATERIALS AND METHODS

The experimental study was based on histological and immunohistochemical methods of analysis of immunomorphological reactions in lymphoid tissues during infection of young cattle with BHV-1 virus. The methods of analysis and synthesis, diagnostics, analogy, and systematisation were used as a methodological foundation. The objects of the research were tissue samples of trachea, bronchi, lung lymph nodes and spleen.

The incidence of IBR-1 has a seasonal character, due to sharply increasing resistance in the winter months. Experimental trials were conducted in the cold period – from October to December 2022, on cattle in farms of Chui oblast, Kyrgyzstan. Histological and immunohistochemical studies were conducted at the Department of Veterinary and Sanitary Expertise, Histology and Pathology, Kyrgyz National Agrarian University named after K.I. Skryabin.

Lymphoid tissue is represented by lymphoid follicles, therefore, to determine the initiation of immune response to airborne pathogens and antigens, it is necessary to perform a morphological evaluation of lymphoid tissue associated with the trachea, bronchi, regional lymph nodes of the lungs and spleen of young cattle killed by IBR-1. Following the method of analogy, two groups, control and experimental, 3 heads in each, aged 4-5 months, were developed and subjected to pathological autopsy. Histological preparations of the trachea, lungs, lung lymph nodes and spleen of the control group were taken from clinically healthy calves. Samples of pathological material of the experimental group from infected animals were taken during the period of maximum manifestation of clinical signs (temperature reaction, oppression, inflammatory processes in the upper respiratory tract, serous discharge from the nasal cavity and eyes). Laboratory tests of blood serum from 10 heads of diseased calves for the presence of antibodies to the BHV-1 virus by PCR method were performed.

Tissue samples were stabilised no later than 2 hours after slaughter. Tissue samples of the trachea, lungs, lymph nodes and spleen were prepared in the laboratory according to the generally accepted methods of the European Food Safety Authority (EFSA) (Istituto Superiore di Sanità, 2021) and fixed in 10% neutral formalin solution for histological and immunohistochemical studies. Paraffin blocks were developed, from which thin histosections 3-5 μm in diameter were prepared. Hematoxylin-eosin and Van-Gizon methods were used for staining tissue samples.

The animals were kept, cared for and fed according to the provisions and diets recommended for this type of animals. The peroxidase-anti peroxidase (PAP) method and anti-PCNA (proliferating cell nuclear antigen) monoclonal antibody, Clone PC10, were used for immunohistochemical studies. Histological preparations were examined using a LEICA ICC 50 HD binocular microscope at magnifications of 50, 100 and 200. Microphotography was performed using the digital camera of this microscope. All experimental studies were carried out in accordance with modern methodological approaches and in compliance with relevant requirements and standards, in particular, the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (1986).

RESULTS

The assessment of tissue damage from IBR-1 disease is based on pathological and anatomical changes and clinical examination. This work describes the morphofunctional state of immunogenic peripheral organs – lymphoid tissue associated with the trachea, lungs, regional lymph nodes and spleen. Autopsy of young cattle with severe IBR-1 acute respiratory inflammation usually demonstrates serous conjunctivitis, catarrhal pyogenic rhinitis, laryngitis, tracheitis and mucosal lesions of the appendicular cavities.

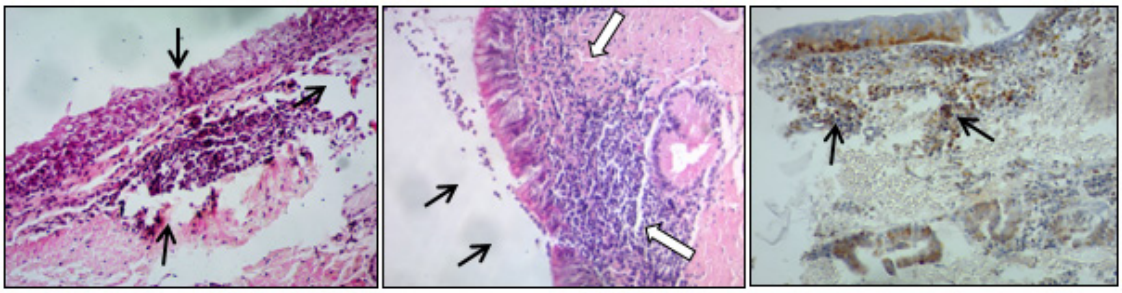
The clinical picture of the condition of experimental animals was marked by swelling, hyperaemic mucosa of the nasal cavity covered with mucopurulent plaque, erosive lesions of various shapes and sizes, purulent exudates accumulating in the nasal cavity and appendicular cavities, on the mucous membranes of the larynx and trachea. Severe forms of IBR-1 rhinotracheitis contribute to pathohistological changes in regional bronchial and mediastinal lymph nodes and the spleen. Therefore, acute serous or serous-necrotising lymphadenitis and follicular hyperplasia are noted in calves. In the acute form of IBR-1 in calves, the tracheal mucosa is locally necrotised, and the lumen of alveoli and bronchioles in the affected area is filled with serous exudate, the interstitial tissue is markedly oedematous, there is hyperaemia and haemorrhages on the skin of the nasolabial mirror. When the eyes are affected, the conjunctiva becomes hyperaemic with oedema spreading to the conjunctiva of the eyeball, which may be covered with plaques established by papillary nodules, small erosions and ulcers up to 2 mm in size. Usually, on days 3-5, a dry cough appears, which later changes to a moist cough with serous purulent discharge from the eyes and nasal passages. Breathing becomes more frequent, heavy, predominantly abdominal type, accompanied by wheezing. Sick animals are lethargic, inactive and mostly lying down. Feed refusal and cachexia are noted.

The lymph nodes of calves with respiratory IBR-1 demonstrate serous or serous-necrotising lymphadenitis, follicular hyperplasia and, as the disease progresses, lymph node atrophy, a decrease in the number of lymphoid follicles and thinning of the paracortical zone. EFSA AHAW Panel *et al.* (2017a) identified that IBR-1 in the spleen of severely affected calves demonstrated necrotic lymphocytes and small cell foci with infiltration, with 12 cases presenting 52.2% necrosis and devastation of lymphoid tissue. The asymptomatic form of viral herpetic infection of cattle is due to the prolonged persistence of BHV-1 virus in the animal and manifests itself in three main forms: latent, chronic, and slow viral infection. J.H. Hernandez-Medrano *et al.* (2021) reported that when the body is infected with the virus, specific humoral and cellular immunity factors including antibodies, macrophages, lymphocytes, and leukocytes exert a protective effect. The latent nature of BHV-1

in individual animals depends on the Immunofluorescence Assay (IFA) antibody assay, but the PCR test determines the presence of the virus even at an early stage of the disease with high sensitivity.

IBR-1 infection can be presumed based on clinical, pathological and epidemiological findings, but laboratory serological or virological investigations are required to confirm the diagnosis. Comprehensive laboratory diagnostic procedures are designed to identify the causative virus or the viral component of the specific antibodies it induces. Laboratory costs for measuring antibody titres in serum are low compared with those for histopathology, virus isolation and molecular testing. However, estimates of antibody titres in individual serum samples are limited and sometimes very unreliable, thus, serum must be collected from several animals in the acute and convalescent phases to properly assess the association between seroconversion and disease, but the total cost of such diagnostic tests can be very high. The assessment of immunity during BHV-1 diagnosis is made by the indication of specific receptor molecules – immunoglobulins IgA, IgM and IgG (Immunoglobulin A, M, G), which are consistently synthesised in recurrent herpes virus, becoming crucial for protection against infection. In the presence of complement, antibodies neutralise the extracellular virus, but complement deficiency increases the susceptibility of the animal to infection. When the BHV-1 virus is not confirmed by antibodies, it can be an intracellular virus, in which case virus multiplication is inhibited by cellular factors such as T-lymphocytes, macrophages, and polymorphonuclear leukocytes. On the one hand, cellular immune factors cause lysis of infected cells, promoting the escape of intracellular virus and its subsequent neutralisation by antibodies, and on the other hand, cellular immune factors affect neighbouring normal cells, preventing them from becoming infected. Antibody development and the cellular immune response are the result of the interaction between the virus, the cells responsible for immunity, namely the different subpopulations, lymphocytes without marker T cells or B cells, monocyte-macrophages and granulocytes, and their products.

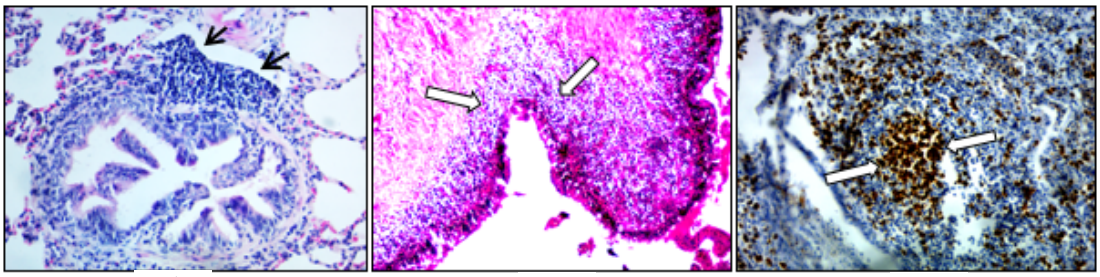
If the pathogen is identified in laboratory tests, the presence of histological tests for immunomorphological reactions provides confidence that the pathogen is indeed causing disease in the animal. Calves that presented clinical signs of infectious rhinotracheitis were tested with PCR tests for the BHV-1 virus. Tracheal histosections from a clinically healthy calf of 4 months of age are presented in Figure 1 (a). The control group represents histosections from healthy animals that were PCR-negative and had unchanged tracheal mucosa. The tracheal tissue of calves infected with IBR-1 at the age of 4 months is presented in Figure 1 (b). Changes in the tracheal mucosa and its lamina were identified; the glands were infiltrated with lymphocytes, plasmocytes, histiocytes and neutrophils. In histosections of trachea samples from IBR-1-infected calves aged 4 months, active mitosis of lymphoblasts, which were detected in the centre of the lymphoid tissue associated with the tracheal mucosa (Fig. 1 (c)), was observed when staining with the PAP method using the monoclonal antibody Anti-PCNA.



a) b) c)

Figure 1. *Tissue samples of the trachea of a four-month-old calf: a) Control group; b) In IBR. Haematoxylin-eosin staining; c) In IBR. PAP method, Anti-PCNA monoclonal antibody, Clone PC10. Microscope magnification* ×200
Source: *compiled by the authors*

Immunomorphological analyses of the bronchial system of clinically healthy animals and calves with IBR-1. Figure 2 (a) Histosection specimens from a clinically healthy calf aged 4 months present bronchial mucosa without any changes. The lymphoid tissue associated with the bronchial system is in a state of relative quiescence, as delineated by the arrows. Figure 2 (b) demonstrates hyperplasia of bronchus-associated lymphoid tissue, disintegration of bronchioles walls with their replacement by connective tissue, lung parenchyma along bronchiolar system infiltrated with plasmocytes, lymphocytes, macrophages and neutrophils. Figure 2 (c) using the PAP method and the monoclonal antibody Anti-PCNA, labelled histosection specimens of trachea from IBR-1 infected calves aged 4 months. Hyperplasia of broncho-associated lymphoid tissue and active proliferation of lymphoblasts were established, which is emphasised by white arrows.

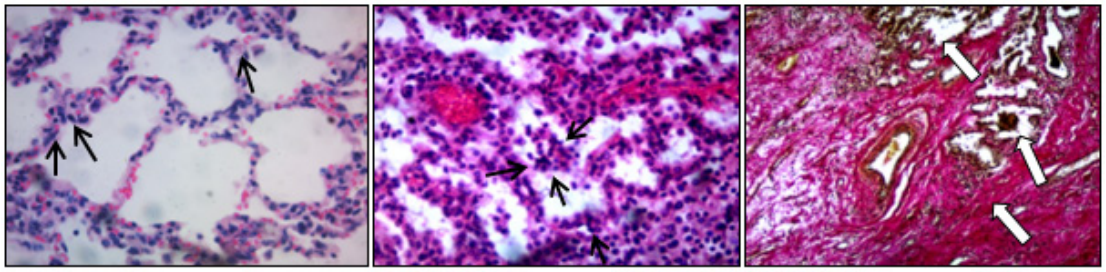


a) b) c)

Figure 2. *Tissue samples of the bronchial system of a four-month-old calf: a) Control group; b) In IBR. Haematoxylin-eosin staining; c) In IBR. PAP method. Anti-PCNA monoclonal antibody, Clone PC10. Microscope magnification* ×200

Source: *compiled by the authors*

Immunomorphological analysis of lung parenchyma from clinically healthy calves and IBR-1-infected calves is demonstrated in Figure 3. The control group, marked in Figure 3 (a), was characterised by free alveolar cavities with isolated macrophages, as indicated by the black arrows. In addition, macrophages and small lymphocytes were located in the walls of the alveoli. Figure 3 (b) presents lung tissue samples from IBR-1 infected calves at 4 months of age. Numerous cubic alveolocytes are identified and the lumen of the alveoli contains sloughed alveolocytes, macrophages and necrotic mass as indicated by the black arrows. Figure 3 (c), the Van Gieson method demonstrates fibrosis of lung parenchyma and disintegration of alveoli in IBR, which is marked by white arrows.

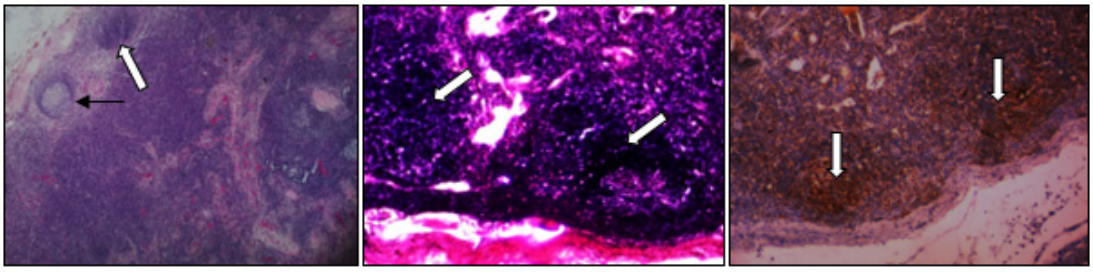


a) b) c)

Figure 3. *Tissue samples of lung alveoli of a four-month-old calf: a) Control group; b) In IBR. Haematoxylin-eosin staining; c) In IBR. Van Gieson's staining method. Microscope magnification* ×400

Source: *compiled by the authors*

Immunomorphological analysis of regional lymph nodes of lungs of clinically healthy calves and IBR-1 infection is presented in Figure 4. Figure 4 (a) in the control group calves lymph nodes demonstrate lymphoid follicles with light centres marked with black arrows and lymphoid follicles without light centres marked with white arrows. Figure 4 (b) in IBR demonstrates hyperplasia of the B-dependent zone of lymph nodes, where the number and size of lymph follicles with light centres are increased, and active mitosis of lymphoblasts in the light centre of lymph follicles is observed. In addition, hyperplasia of the T-dependent zone of lymph nodes is noted. In Figure 4 (c) using the PAP method with monoclonal antibody Anti-PCNA, active proliferation of lymphoblasts in the luminal centre of lymphoid follicles and hyperplasia of B-dependent zone of lymph nodes, which are indicated by white arrows, were identified in IBR.



a) b) c)

Figure 4. *Tissue samples of regional lymph nodes of lungs of a four-month-old calf: a) Control group; b) Serous purulent lymphadenitis in IBR. Haematoxylin-eosin staining; c) In IBR. PAP method. Anti-PCNA monoclonal antibody, Clone PC10. Microscope magnification* ×100

Source: *compiled by the authors*

Analysis of the obtained data in Figure 4 demonstrates that B- and T-dependent zones of regional lymph nodes are actively functioning, indicating the development of humoral and cellular immune response to IBR-1. Figure 5 presents an immunomorphological analysis of the spleen of clinically healthy animals and young cattle infected with IBR-1. Figure 5 (a) presents a red circle – T-dependent periarterial zone and a green circle – B-dependent zone of spleen white pulp in calves of the control group. Figure 5 (b) demonstrates hyperplasia of the white pulp of the spleen in IBR, where the T-dependent zone demonstrates clusters of lymphocytes around vessels, and the B-dependent zone has no distinct lymphoid follicles. In the red pulp, the presence of erythrocytes, lymphocytes, macrophages, plasma cells, neutrophils and blast cells can be seen. As noted in Figure 5 (c), IBR demonstrates active proliferation of lymphoblasts in the T-dependent zone, while in the B-dependent zone, there are only isolated lymphoid follicles with weak proliferation of lymphoblasts.

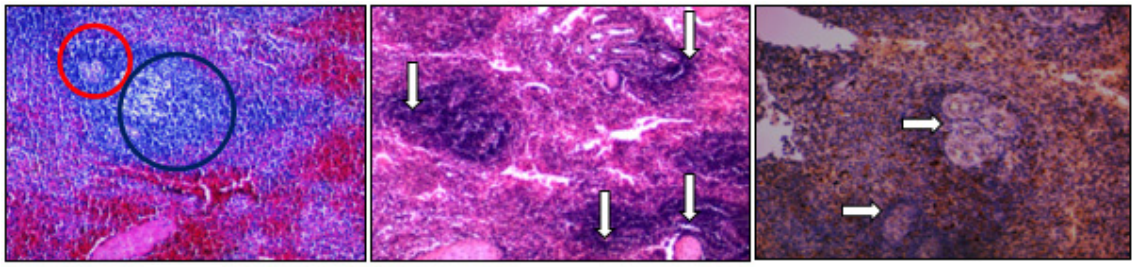


Figure 5. *Spleen tissue samples of a four-month-old calf: a) Control group. Red circle indicates T-dependent periarterial zone, blue circle B-dependent zone in the form of lymphoid follicles; b) In IBR. Haematoxylin-eosin staining; c) In IBR. PAP method. Anti-PCNA monoclonal antibody, Clone PC10. Microscope magnification* ×100

Source: *compiled by the authors*

The results of the spleen examination indicate that T-dependent sites are more active and are responsible for the development of the body's cellular immune response. It appeared that trachea-associated lymphoid tissue is closely related to the presence of herpesvirus BHV-1 pathogen. IBR-1 is morphologically manifested by hyperplasia of lymphoid tissue, an increase in the number of lymphocytes, plasma cells and immunoblasts in the centre of the lymphoid tissue, and its distribution over the entire area of contact with the mucous membrane, infiltration of the trachea and tracheal glands with lymphocytes, plasma cells and macrophages. In addition, the research confirmed that with the active participation of herpesvirus BHV-1, there is a change in broncho-associated lymphoid tissue, which is morphologically accompanied by its hyperplasia and infiltration of the bronchial system and alveolar walls with lymphocytes, plasma cells and macrophages. It was established that infection of four-month-old calves with IBR-1 virus leads to follicular hyperplasia of regional lymph nodes with subsequent atrophy as the disease progresses. Histopathologically, it is expressed by a decrease in the number of lymphoid follicles, and thinning of the paracortical zone, i.e. atrophy of B- and T-dependent zones of lymph nodes.

DISCUSSION

The various causes of respiratory diseases of cattle coincide in their clinical manifestation, but when making a definitive diagnosis, require mandatory pathological autopsy and pathohistological studies. The respiratory form of IBR-1 requires careful examination of the bronchi and bronchioles of the lungs, which are represented by inflammation of the mucous membrane of the upper respiratory tract, emphysema, frothy fluid in the bronchioles and bronchopneumonia. The results of this research corroborate the findings reported by D. Aniţă *et al.* (2010), where immune cells of the trachea, pulmonary-bronchial system, regional lymph nodes and white pulp of the spleen are directly involved in the pathogenesis of the respiratory form of IBR-1 in calves. The research established that infectious bovine rhinotracheitis is IBR-1, a febrile disease caused by a primary viral infection, which is usually accompanied by respiratory distress, tracheal vesiculation, tracheal mucosal lesions covered with exudate of mucus, pus and fibrin. Based on the experimental data of R. Mandelik *et al.* (2021), it was found that in IBR-1, extrudates are easily removed from the tracheal mucosa, exposing a smooth and intact membrane, whereas in bronchopneumonia, multifocal pale areas and mucosal necrosis are observed. Massive keratoconjunctivitis and sometimes encephalitis may occur in young animals. Some IBR-1 strains cause acute gastroenteritis, which is difficult to distinguish from dyspepsia and enterotoxemia.

The results of the histological analysis confirmed the data obtained at autopsy and demonstrated the presence of changes not detectable at macroscopic examination. Assessing immunomorphological reactions in the lungs of 4-month-old calves infected with IBR-1, it was noted that there were numerous cube-shaped alveolar cells near the alveolar wall, and in the lumen of the alveoli they were exfoliated; the presence of macrophages and necrotic masses on fibrotic parts of the

lung parenchyma was noticeable. In the pathological anatomical research of S. Comakli *et al.* (2019), lobular, serous and serous haemorrhagic pneumonia were observed in calves infected with the respiratory form of IBR-1. The lungs presented with white thick bronchial secretions and cavities of various sizes that were filled with white contents. In most cases, these changes were found in the cephalic and middle lobes of the lungs. In severe cases, pulmonary gangrene with putrefactive pleurisy, dilated haemorrhages and intra-alveolar oedema were observed. EFSA AHAW Panel *et al.* (2017b) indicated that in the respiratory form of IBR-1, necrosis, desquamation and atrophy of lymphoid tissue, hyperplasia of the T-dependent zone of the white pulp of the spleen was observed in the spleen of calves. Notably, these areas are more active and responsible for the development of the cellular immune response of the organism.

IBR-1 is initiated by multiple viruses and is, therefore, a multipathogenic respiratory disease of cattle that causes bacterial pneumonia; when infected sexually in adults, infectious pustular vulvovaginitis; and the keratoconjunctival form in calves. It is believed that IBR-1 is a disease in which the viral genome fuses with the genome of the host cell, causes immune dysfunction, and the organism is completely neutralised from viral infection, but the stress factor increases the incidence of the disease and on the background of reduces resistance. The results of these observations confirm the data of N. Beristain-Covarrubias *et al.* (2019), IBR-1 causes acute morbidity of about 75% and more than 50% mortality of cattle in farms due to secondary infections. The natural gateway for entry of BHV-1 is the mucosa of the upper respiratory tract. Inflammatory processes in infectious rhinotracheitis led to hemostasis disorders, changes in blood properties, increased platelet aggregation, and developing microvascular thrombosis in various organs and tissues, such processes were observed in the trachea and lungs.

At agricultural cattle breeding and rearing enterprises in Kyrgyzstan, live vaccines "TRIVAK", "BOVILIS" and "HYPRABOVIS-4" are used for the prevention of IBR-1 in cattle, but the possibility of residual vaccine viruses in immunised animals should be considered. According to A.E. Erdem and B. Sareyyüpoğlu (2022), adherence to a four-year vaccination schedule reduces the incidence of disease in the herd and minimises the number of virus carriers. Successful eradication of IBR-1 has been achieved in Denmark, Finland, Norway, Sweden, Austria, Switzerland and parts of Italy by adopting a strategy of separating infected animals and Differentiating Infected Vaccinated Animals (DIVA). Vaccines usually prevent the development of clinical signs and significantly reduce virus spread after infection, but do not completely prevent infection. L.F. Garcia *et al.* (2020) inform that in moderate epidemics of the BHV-1 virus, it is reasonable to use a labelled vaccine lacking specific glycoprotein gE (Glycoprotein E) antibodies to vaccinate up to 5% of positive animals in a herd, followed by culling. Parenteral administration of a mutant viral vaccine with deleted gE in BHV-1, used in combination with diagnostic testing and targeted culling according to a strategy of testing and slaughter of seropositive animals infected with field strains, has led to the eradication of the disease in some European countries.

Vaccination of cattle against BHV-1 herpesvirus is a priority in meat production in Kyrgyzstan. Most vaccines are administered intramuscularly or intranasally from 20 days of age, depending on the type of antigen, and the timing of vaccination is determined by the calendar of preventive measures on the farm. As the research of J. Baruch *et al.* (2019) demonstrates, the following rules must be observed to maximise vaccine efficacy: only vaccinate healthy animals; vaccinate before herd selection, considering that the immune response develops on day 14; plan revaccination of calves during the weaning period, as immunisation with colostrum affects the effectiveness of prophylaxis; heifer cows should be vaccinated 2-4 weeks before calving. As reported in research by B.W. Newcomer (2021), economic losses in infectious rhinotracheitis: under-fertilisation due to abortions and stillbirths is in the range of 5-30%; birth of non-viable calves about 10%; decrease in milk yield during the disease in the range of 50-60%; mortality of young animals from serous pneumonia is about 20%; under-receipt of live weight gain in young animals – 50-70%; increase in the number of cows with multiple unfertilised inseminations up to 30%; reduction of calf yield per 100 cows by 5-10%.

The study demonstrated that IBR-1 causes significant economic losses to livestock production and is associated with multi-organ infections leading to severe morbidity and mortality, therefore, it is important to find inexpensive and practical methods that allow selective detection of the BHV-1 antigen. In addition, it is advisable to establish an IBR-1-free breeding herd by gradually removing herpes-positive animals from regular breeding lots and replacing them with healthy calves. In farms in Kyrgyzstan that have experienced an outbreak of herpesvirus BHV-1, the purchase and sale of cattle, regrouping of animals, and export of forage, care items and milk products from sick animals without prior disinfection are prohibited. Sick animals shall be assigned to separate service personnel. Carcasses of slaughtered animals are sold without restrictions if there are no anatomical changes. It is forbidden to buy and sell livestock, rearrange livestock, move feed, care for sick animals and export dairy products on farms where herpesvirus BHV-1 has occurred without prior disinfection. Sick animals should be segregated in a separate attendant. Carcasses of slaughtered animals can be sold without restrictions if there are no anatomical changes. Milk from clinically sick IBR-1 cows is pasteurised at 70°C for 30 minutes, while milk from

clinically healthy animals is used without restrictions. Farm restrictions are lifted after the animals have recovered and veterinary and sanitary measures have been completed, but not earlier than 30 days after the last vaccination.

CONCLUSIONS

As a result of the conducted research, it was established that since IBR-1 is the most widespread viral disease of cattle, its pathomorphological signs need more detailed investigation. IBR-1 of cattle causes significant economic damage to production and it is necessary to make a timely diagnosis and conduct effective therapeutic and prophylactic measures. Clinical examination of calves identified typical signs of the respiratory form of infectious rhinotracheitis in cattle: increased body temperature by 1.5-2°C, hyperemic nasolabial triangle, serous conjunctivitis, serous catarrhal rhinitis, dry cough, eventually changing to wet cough, rapid breathing, predominantly abdominal type with rales. To qualitatively diagnose infectious rhinotracheitis in cattle, PCR assays for the presence of infectious disease in agricultural farms were analysed. Calves with clinical signs of infectious rhinotracheitis were tested by PCR tests for the BHV-1 virus, which was positive in 100% of cases.

Histological examination of the lungs in the majority of calves indicated serous-neutrophilic pneumonia with pyogenic bronchiolitis. The respiratory form of IBR-1 in calves included hyperplasia of lymphoid tissue in the bronchi of the trachea and lungs, hyperplasia of B- and T-linked areas of regional lymph nodes in the lungs and hyperplasia of T-linked areas of white pulp in the spleen. In addition, IBR-1 in calves demonstrates dense infiltration of lymphocytes, macrophages and plasma cells in the affected organs of the trachea and lungs. There is hyperplasia of lymphoid tissue in the trachea, bronchial system of the lungs, regional lymph nodes of the lungs and corresponding areas of the spleen. In some calves, the respiratory form of IBR-1 resulted in fibrosis of pulmonary foci, with complications in the form of serous pyogenic inflammation of the trachea and lungs. The data on histopathological changes in lymph nodes of the lungs and spleen of calves in the acute form of IBR-1 were clarified and supplemented.

The main means of controlling BHV-1 is routine vaccination, which prevents clinical manifestations of the disease in the vaccinated person, and protection of the foetus from infection and careful analysis of the epizootic situation in the farm. For qualitative diagnosis of infectious rhinotracheitis in cattle, it is necessary to comprehensively analyse the IBR-1 situation in farms, distinguish clinical signs of infectious diseases in animals, and conduct a thorough evaluation of the results of serological, pathological, and histological studies. From the standpoint of relevance and usefulness of the investigation described in this research, further investigation of IBR-1 herpesvirus and its new strains as frequently occurring diseases of cattle on modern farms seems promising.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Респіраторна форма інфекційного ринотрахеїту: аналіз імуноморфологічних реакцій

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Анотація. Концентрація худоби на обмежених територіях, порушення режиму харчування, дисбаланс мікро- та макроелементів сприяють пригніченню природної резистентності організму, недостатньому набору живої маси тварини, що призводить до зростання інфекційних захворювань молодняка з високими показниками вимушеного забою та падежу худоби. Джерело збудника інфекції ринотрахеїту – герпевірус великої рогатої худоби *Bovine alphaherpesvirus 1* – перешкоджає розвитку тваринницької галузі, тому необхідно шукати можливі підходи щодо профілактики та контролю даної інфекції. Метою дослідження є визначення імуноморфологічних змін у лімфоїдній тканині трахеї та бронхіальної системи, у регіонарних лімфатичних вузлах легень і в селезінці

в телят, які природно хворі на інфекційний ринотрахеїт. В основу експериментальних досліджень покладено вивчення імуноморфологічних реакцій у лімфоїдній тканині під час інфікування молодняка великої рогатої худоби вірусом *Bovine alphaherpesvirus 1*, із застосуванням полімеразної ланцюгової реакції, гістологічних та імуногістохімічних методів. За результатами досліджень встановлено, що в трахеї спостерігалася гіперплазія трахеє-асоційованої лімфоїдної тканини, а в легенях – гіперплазія бронхіально-асоційованої лімфоїдної тканини, при цьому уражені ділянки трахеї та легень були інфільтровані лімфоцитами, макрофагами та плазматичними клітинами. В імуноморфологічних реакціях реґіонарних лімфатичних вузлів відзначають гіперплазію В- і Т-залежних зон, а в селезінці – гіперплазію Т-залежних зон білої пульпи. Таким чином, імунокомпетентні клітини лімфоїдної тканини, асоційовані з В- і Т-залежними ділянками трахеї, бронхіальної системи легень і реґіонарних лімфатичних вузлів легень, а також з Т-залежними ділянками селезінки, беруть безпосередню участь у патогенезі інфекційного ринотрахеїту телят респіраторного типу. Антибактеріальна терапія антибіотиками знищує патогенну та нормальну флору в кишечнику, але недостатньо ефективно діють на вірусну інфекцію, тому виробничі випробування ефективних засобів специфічної профілактики та вакцинації є першочерговим завданням ветеринарії

Ключові слова: велика рогата худоба; герпевірус; полімеразна ланцюгова реакція; патологія; імуноморфологія; асоціативні хвороби

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Pathological changes in aborted fetuses and placental tissue in cows with neosporosis

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Abstract. The failure to obtain offspring due to abortion causes considerable damage to the dairy industry worldwide, costing millions of USD. *Neospora caninum*, a protozoan parasite of the *Apicomplexa* class, is the causative agent of neosporosis, a disease that leads to abortions or the birth of weak offspring in cows. Therefore, addressing this issue is crucial. The purpose of this study is to describe the pathological changes in aborted fetuses and placental tissue in cows with neosporosis. Macroscopic examination of fetal and placental parts was performed through pathological dissection. The gestation age (days) was determined using the formula: 68+2.25×CRL (cm) and/or from historical data. DNA of *N. caninum* was detected by polymerase chain reaction in all fetuses and/or fetal parts of placentas described in the study. It was found that the majority of abortions occurred at 4-5 months of gestation. External examination revealed isolated instances of skin hyperemia and haemorrhages throughout the body. Some fetuses were mummified. Autolysis of the fetus and placental parts was observed in most cases. Placentitis and oedema of the placental tissue were also noted in some cases. Internal examination of fetuses revealed changes in the brain, skeletal muscles, heart, lungs, liver, spleen, and kidneys, in addition to characteristic autolysis. These changes, including grey foci in the brain with a light grey centre, white foci, and multiple white streaks in skeletal muscles and the tongue, can be attributed to typical pathological changes in aborted fetuses with neosporosis. These changes are rare but can impact the determination of the cause of abortion, narrowing down the factors responsible

Keywords: cattle; *Neospora caninum*; abortion; macroscopic changes; pathological dissection

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INTRODUCTION

Abortion remains one of the main challenges in the dairy industry, as reproductive efficiency is crucial, and the failure to obtain offspring can result in significant losses. In many studies, abortion rates range from 5 to 12%, representing a substantial loss of calves and future economic losses (Moore *et al.,* 2021). Infections continue to be the most important cause of abortion in cattle. The infectious agents causing abortions can vary depending on the country in which they occur, with *Neospora caninum* often being referred to as the most common pathogen on an international level (Mee, 2020).

Neosporosis is a disease caused by an obligate intracellular protozoan parasite called *Neospora caninum* (*Apicomplexa*, *Sarcocystidae*), which is known to cause abortions and stillbirths in cattle, as described by M. Reichel *et al.* (2020) and D. Lindsay & J. Dubey (2020). Authors like C. Klein *et al.* (2019) established that dogs, coyotes, wolves, and dingoes are definitive hosts of *N. caninum*, becoming infected by ingesting bradyzoites present in tissues of intermediate hosts such as cattle, deer, sheep, buffalo, bison, rodents, birds, and horses, which acquire infection by ingesting oocysts of the parasite through contaminated food or water.

In the study by J. Perotta *et al.* (2021), it is described that *N. caninum* infection in cattle can occur through various routes: horizontal (ingestion of oocysts), exogenous transplacental (ingestion of oocysts by pregnant cows), and endogenous transplacental (reactivation of latent infection in the fetus within the pregnant cow). Transplacental transmission of *N. caninum* is the most efficient method and leads to endemic infections. The endogenous infection cycle in the host population is continuous since infected cows give birth to infected calves, which, in turn, enter the breeding herd and continue to spread the infection.

If a cow becomes infected within the first 100 days of pregnancy when lymphoid tissues are developing, the survival of the fetus is unlikely because infectious agents directly kill fetal cells, leading to resorption or fetal mummification (Donahoe *et al.,* 2015). The paper by M. Reichel *et al.* (2018) noted that during the second and third trimesters, the fetus develops an increasing ability to mount an immune response (IgG antibody production). However, in many cases, this response is inadequate, as abortion is the most common outcome of infection during mid-pregnancy. Infections occurring in the third trimester, after the fetal immune system is nearly fully developed, are more likely to result in the birth of infected but clinically healthy calves. Nevertheless, the birth of uninfected calves can occur very rarely, and fetal death is also a possible outcome.

P. Melendez *et al.* (2020) reported that neosporosis-related abortions in cattle typically occur between the 3rd and 9th months of gestation, with the majority of cases happening during the 4th to 6th months of pregnancy. Aborted fetuses are often found in an autolytic state with the accumulation of serosanguinous fluid in body cavities, but they may also be fresh or mummified, with no specific pathological changes typically observed. S. Donahoe *et al.* (2015) noted that, in some cases, pathological dissection of the fetus can reveal hydrocephaly, hypoplasia of the cerebellum and brainstem, as well as scattered white or dark foci in the brain, spinal cord, heart, and skeletal muscles. K. Uesaka *et al.* (2018) described that placentitis and changes in the placental cotyledons are most commonly observed in the placental tissue. The pathological-anatomical changes were more pronounced in fetuses during the first and second trimesters of intrauterine development than in the last trimester. This means that the gestational age at the time of abortion affects the degree of damage to the fetus and placental tissues. Infected calves may exhibit symptoms such as hypotrophy, ataxia, hind limb paresis, exophthalmia, scoliosis, hydrocephalus, and spinal cord atrophy.

Neosporosis causes significant economic losses. For example, the financial expenses related to *N. caninum* infection were estimated at 710 USD (438-1043) per dairy cow, and annual economic costs were estimated at 40.5 million USD (24.6-60.3) for Turkey. These losses comprise 67.3% due to abortion, 16.8% due to extended calving intervals, 4.6% due to milk loss, 3.5% due to additional artificial insemination, and 7.7% due to veterinary and diagnostic expenses, as described in the study (Demir *et al.,* 2020). In Brazilian dairy herds, approximately 20% of abortions are linked to neosporosis, resulting in annual losses of approximately 51.3 million USD (Perotta *et al.*, 2021). In Argentina, economic losses are estimated at 33 million USD per year for dairy cattle and 12 million USD for beef cattle (Campero *et al.,* 2023).

Since reproduction is a key element in agricultural production, detecting pathological changes in this context can contribute to the development of effective strategies for neosporosis control and prevention. This, in turn, will preserve herd health and have a positive impact on the economic indicators of the farming industry. The purpose of this study is to describe the pathological-anatomical changes in aborted fetuses and placental parts with detected *N. caninum* DNA in Ukraine.

MATERIALS AND METHODS

Between 2019 and 2022, 126 cases of abortion were investigated. Of these, 43 cases were attributed to *N. caninum*. A case was defined as an aborted fetus and/or placental part from a cow, resulting in the examination of 36 fetuses and 34 placental parts. Fetuses and placentas were submitted to the laboratory by veterinary practitioners from dairy and dairy-meat cattle farms in various regions of the country.

The dissections and pathological-anatomical examinations of fetuses and placental parts were conducted in the dissection room of "Centre Veterinary Diagnostics" LLC (Kyiv), following the methodology described by J.F. Mee (2016). This methodology encompasses both external and internal examinations, involving the investigation of all organs and organ systems at the

macroscopic level, for both fetuses and placental parts. The gestational age at which the abortions occurred was determined based on data provided by the owners of the aborted animals, in the absence of information, using the formula (1):

$$\text{duration (days)} = 68 + 2.25 \times CRL \text{ (cm)}, \quad (1)$$

where *CRL* represents the length from the crown to the tail root of the fetus (Mee, 2020).

DNA from *N. caninum* was detected in all cases from fetal organs (including the brain, cerebellum, thymus, heart, lungs, liver, spleen, kidneys, adrenal glands, abomasum, skeletal muscles) and placental parts using the polymerase chain reaction (PCR) method. Amplification reactions were carried out using a commercial test kit from a European manufacturer on the QuantStudio 5 Real Time PCR System (Thermo Fisher Scientific, USA), following the manufacturer's recommendations. Thus, *N. caninum* was determined as the cause of abortion in each of the cases.

Sample collection for genetic-molecular research (PCR method) was performed directly in the dissection room of "Centre Veterinary Diagnostics" LLC during the pathological-anatomical examination. All manipulations with aborted fetuses and placental parts were performed in accordance with the provisions of the Order for scientific institutions conducting research and experiments on animals (Law of Ukraine No. 249, 2012) and the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (European convention..., 1986).

RESULTS AND DISCUSSION

Based on the medical history and calculations using the formula for gestational age, it was determined that abortions caused by *N. caninum* occurred at the following gestational months: at 4 months in twenty cases, at 5 months in thirteen cases, at 6 months in six cases, at 7 months in two cases, and at 8 months in two cases. Upon external examination of the fetuses, it was found that out of thirty-six fetuses, twenty-nine showed signs of autolysis (Fig. 1), while two were fresh.

Figure 1. *Autolysis of the fetus and fetal part of the placenta in a cow*
Source: *photographed by the authors*

Five fetuses with fetal membranes were mummified (Fig. 2). Moreover, individual findings included skin hyperemia and focal haemorrhages on the skin throughout the body, accumulation of red-coloured fluid under the skin throughout the body in twelve fetuses, and accumulation of gelatinous-like masses under the skin and in skeletal muscles throughout the body in nine fetuses. Corneal opacification was observed in twenty-nine fetuses.

Figure 2. *Mummified fetus in a cow*
Source: *photographed by the authors*

During internal examination of the fetuses, watery consistency of the brain was observed in ten cases, and hyperemia in seven cases. Individual findings in the brain included multiple grey-coloured foci with a light grey centre, ranging in diameter from 1 to 4 mm, and hyperemia of the brain's soft meninges. Dark-red fluid was observed in the thoracic and abdominal cavities in twenty-six fetuses. Generalised tissue reddening was noted in eleven fetuses. Heart hyperemia was found in three fetuses. Atelectasis of the lungs was observed in thirty-one fetuses. Interstitial oedema of the lungs – in two fetuses. Hyperemia of the lungs was noted in one fetus. The liver showed flaccid consistency in eleven cases, oedema in two cases, uneven colouration in three cases, and uneven colouration of the liver along with grey-coloured foci with diameters ranging from 2 to 8 mm in three fetuses. Individual findings included icterus of the liver, hepatomegaly, congestive hyperemia, and firm consistency of the liver (Fig. 3).

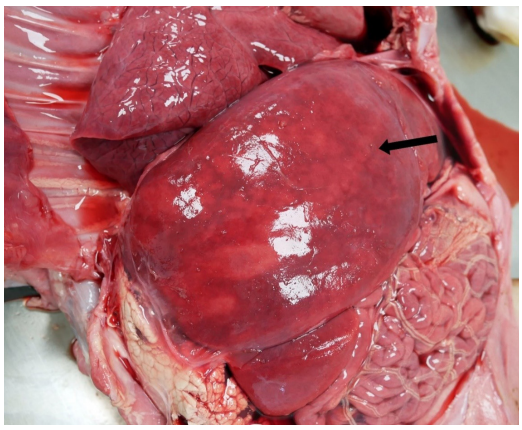

Figure 3. *Unevenly coloured liver in a cow fetus (arrow)*
Source: *photographed by the authors*

Flaccid consistency of the spleen, a smeared pattern, and the presence of dirty-red fluid oozing from the spleen's cut surface were found in eleven fetuses, while oedema was found in four fetuses. Red colouration of the renal capsule and perirenal fat, softening of the renal cortical layer, were identified in eleven fetuses, hyperemia of the kidneys in five, and multiple grey-coloured foci with diameters ranging from 1 to 4 mm in the renal cortex in one fetus. Multiple white-coloured streaks with diameters ranging from 1 to 4 mm in skeletal muscles were observed in two fetuses (Fig. 4), multiple white-coloured streaks ranging from 2 to 6 mm in length in skeletal muscles in three fetuses, and in two fetuses, white-coloured streaks were observed in the tongue (Fig. 5).

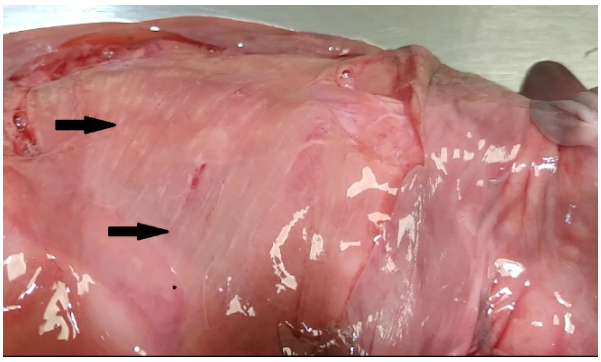

Figure 4. *Multiple white streaks in skeletal muscles of the fetus (arrows)*
Source: *photographed by the authors*

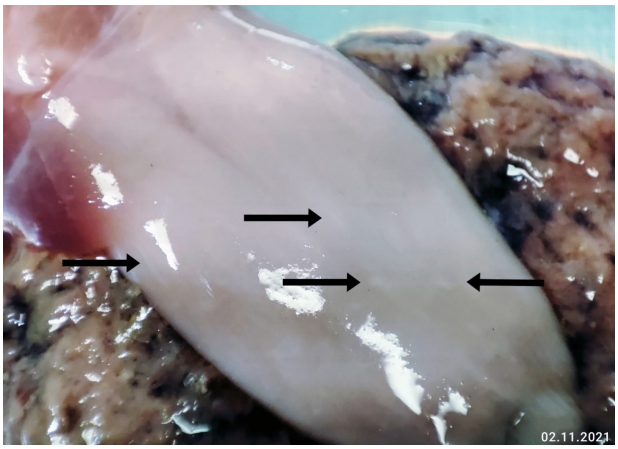

Figure 5. *Multiple white streaks in the tongue of the fetus (arrows)*
Source: *photographed by the authors*

Autolysis of the placenta was found in nineteen samples, oedema of the placenta (Fig. 6) – in three, fibrinous placentitis – in three (Fig. 7), serous placentitis – in two, foci of chorionic necrosis – in one. Placenta without visible changes was observed in one case.

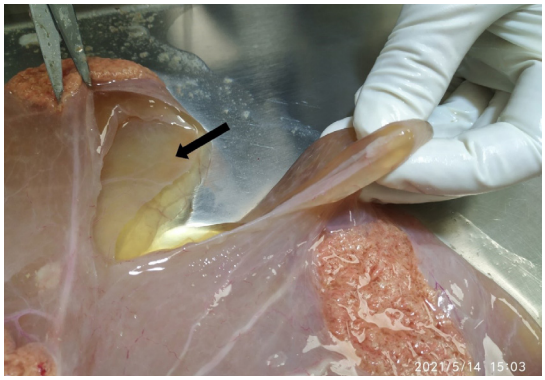

Figure 6. *Oedema of the fetal part of the placenta (arrow)*
Source: *photographed by the authors*

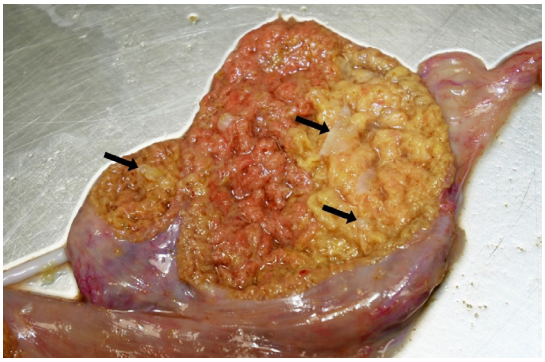

Figure 7. *Fibrinous placentitis. Fibrin on and between chorion fronds (arrows)*
Source: *photographed by the authors*

Thus, in this study, autolysis was present in twenty-nine out of thirty-six fetuses (Fig. 8) and manifested as corneal opacification; accumulation of gelatinous-like masses under the skin and in skeletal muscles or red-coloured fluid under the skin throughout the body; accumulation of dark-red fluid in the thoracic and abdominal cavities; generalised tissue reddening; flaccid liver consistency; flaccid consistency, smeared pattern, and dirty-red fluid oozing from the spleen's cut surface; red colouration of the renal capsule and perirenal fat, softening of the renal cortical layer.

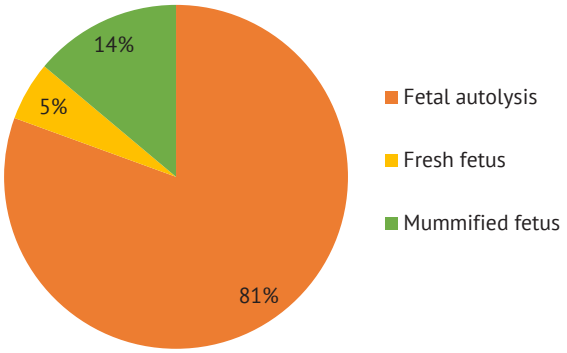

Figure 8. *Condition of the studied fetuses*
Source: *photographed by the authors*

Autolysis can obscure or distort pathological-anatomical changes and, as a result, negatively affect the determination of the direct cause of abortion. Furthermore, the results of the conducted study indicate a weak manifestation and infrequent occurrence of changes, except for signs of autolysis, in the fetuses and fetal parts of the placenta due to neosporosis. For example, a study of 655 cases of bovine abortions in California found that approximately 20% of examined fetuses showed no specific pathological anatomical changes (Clothier & Anderson, 2016), and any other changes present could have been concealed by autolysis. According to the authors who have investigated this issue, specific changes in fetuses and placentas for neosporosis were also not found (Costa *et al.,* 2021; Nayeri *et al.,* 2022).

Various data indicate that aborted fetuses from cows infected with *N. caninum*, both experimentally (Jiménez-Pelayo *et al*., 2019) and naturally (Dubey *et al*., 2017), were predominantly in a state of autolysis of varying severity. However, cases of mummification also occur. Fetal mummification is not a characteristic feature of neosporosis because it occurs far from always and can be a consequence of other factors: viral bovine diarrhoea, leptospirosis, fungal diseases, mechanical factors such as umbilical cord compression and/or torsion, uterine torsion, placental insufficiency, genetic anomalies, abnormal hormonal backgrounds, and chromosomal anomalies (Lefebvre, 2015).

Some sources J. Dubey *et al.* (2017) report cases of hydrocephalus, cerebellar hypoplasia, and hypoplasia of brain tissue. There were no such changes in this study. The pathological-anatomical examination of the fetuses showed that most commonly, the brain had a watery consistency, typically a result of the presence of a large amount of fluid (Njaa, 2012). Hyperemia of the brain was also often detected. Only in isolated cases were multiple grey-coloured foci with a light grey centre, ranging in diameter from 1 to 4 mm, and hyperemia of the brain's soft meninges found. These changes in the brain are histologically consistent with foci of necrosis (Donahoe *et al.,* 2015).

In all cases, atelectasis of the lungs was noted, indicating that the fetus did not breathe, which is normal for aborted fetuses (Ancker & Agerholm, 2010). In some cases, hyperemia and oedema of the interstitial connective tissue of the lungs were found, which are non-specific changes that can result from various factors. Multiple white-coloured foci with diameters ranging from 1 to 4 mm and multiple white-coloured streaks in skeletal muscles and the tongue, ranging from 2 to 6 mm in length, were observed in some fetuses, which are indicative of necrosis. These changes are similar to those described earlier and are very rare (Dubey *et al.,* 2017).

Uneven colouration of the liver, as mostly observed in this study, can be a sign of dystrophic changes. In addition, grey-coloured foci with diameters ranging from 2 to 8 mm, which can sometimes also be observed in abortions caused by *Listeria monocytogenes*, *Salmonella spp.*, and bovine herpesvirus-1 (BHV-1), were found (Njaa, 2012). Individual findings included oedema, congestive hyperemia, icterus, and hepatomegaly, which can be the result of various factors as they are not commonly mentioned in the context of neosporosis. In most cases, no visible changes were found in the spleen, while in some, oedema was observed. Apart from autolysis, the kidneys showed hyperemia and, in isolated cases, multiple grey-coloured foci in the renal cortex with diameters ranging from 1 to 4 mm, indicating necrosis or inflammation.

It is worth noting that abortion can be entirely triggered by an infection localized exclusively in the placenta and is often the focus of pathological changes rather than the fetus itself. Virtually all infectious agents causing abortion are transported to the pregnant uterus through the bloodstream and therefore initially localise in the placenta, possibly later spreading to the fetus (Ancker & Agerholm, 2010). In the current study, autolysis of the placenta was predominantly observed, making it difficult to evaluate changes in many cases. There were also cases of oedema, serous placentitis, and focal chorion necrosis. Similar changes in the fetal part of the placenta are described in abortions caused by bovine herpesvirus-1 (BHV-1), *Campylobacter fetus*, and *Tritrichomonas foetus* (Njaa, 2012).

In summary, most of the pathological anatomical changes identified in this study can manifest due to the involvement of other infectious agents in fetuses and placentas. Therefore, attention should be paid to this when establishing a preliminary diagnosis, and additional methods of investigation, such as histological and genetic-molecular analysis (PCR method), should be used to establish a final diagnosis. However, among all the findings, the changes in the brain, skeletal muscles, and tongue, which are rarely reported for other causes of abortion, are valuable for establishing a preliminary diagnosis.

CONCLUSIONS

Any information related to *N. caninum* is important for the development and implementation of measures to combat bovine neosporosis in Ukraine. Considering its impact on the reproduction of cattle worldwide, examining the prevalence of *N. caninum* in the country is crucial. This study established that abortions due to neosporosis occurred between 4-8 months of pregnancy, but most of them were between 4-5 months. When evaluating the condition of fetuses and the fetal part of the placenta, autolysis was observed in most cases. In addition to changes characteristic of autolysis, some fetuses exhibited pathological changes in skeletal muscles, the brain, liver, kidneys, and the fetal part of the placenta, which, based on other sources and our

research, are common in aborted fetuses due to neosporosis and are considered nonspecific. Changes such as grey-coloured lesions with a light grey centre in the brain, white-coloured lesions, and multiple white stripes in skeletal muscles and the tongue can be attributed to typical pathological changes seen in aborted fetuses due to neosporosis. While these changes are rare, they can still serve as diagnostic markers for identifying the cause of abortion.

The association of some pathological changes identified in this study with neosporosis requires further clarification through additional research. Therefore, pathological examinations should be conducted whenever possible. In the future, research can delve deeper into the pathological changes associated with neosporosis in cows and their impact on aborted fetuses and the placenta. Understanding the mechanisms underlying these changes will help better comprehend the nature of the disease and develop more effective strategies for prevention and treatment.

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CONFLICT OF INTEREST

None.

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Патологоанатомічні зміни у абортованих плодів та плодової частини плацент корів за неоспорозу

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Анотація. Недоотримання приплоду через аборт завдає великої шкоди молочній промисловості у всьому світі і складає десятки мільйонів доларів США. *Neospora caninum* – найпростійший паразит типу *Apicomplexa*, збудник неоспорозу – хвороби, яка у корів проявляється абортами або народженням слабкого потомства, тому варто приділити увагу цій проблемі. Мета даного дослідження – описати патологоанатомічні зміни у абортованих плодів та плодовій частині плацент корів за неоспорозу. Макроскопічне дослідження плодів та плодової частини плацент корів виконувалося шляхом патологоанатомічного розтину. Термін тільності (дні) визначали за формулою – 68 + 2,25×CRL (см) і/або з даних анамнезу. У всіх, описаних у дослідженні, плодах і/або плодових частинах плацент виявлено ДНК *N. caninum* методом полімеразної ланцюгової реакції. Встановлено, що більшість абортів відбувались на 4-5 місяці тільності. За зовнішнього огляду виявлено, поодиноко, гіперемію шкіри та крововиливи на шкірі по всьому тілу. Також деякі плоди були муміфіковані. У більшості випадків відмічали автоліз плоду та плодової частини плаценти. Також в деяких випадках відмічали плацентит та набряк плодової частини плаценти. За внутрішнього дослідження плодів, окрім змін характерних автолізу, у деяких виявляли зміни в головному мозку, скелетних м'язах, серці, легенях, печінці, селезінці, нирках. Такі зміни як осередки сірого кольору з світло-сірим центром в головному мозку, осередки білого кольору і множинні смужки білого кольору в скелетних м'язах та язиці можна віднести до характерних патологоанатомічних змін для абортованих плодів за неоспорозу. Ці зміни рідко трапляються, але можуть вплинути на встановлення причини аборту, звузивши коло чинників, які його викликають

Ключові слова: велика рогата худоба; *Neospora caninum*; аборт; макроскопічні зміни; патологоанатомічний розтин

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Indicators of reproduction when using complex use of drugs for spontaneous manifestation of heat in cows for mycotoxicosis

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Abstract. Alimentary infertility is becoming increasingly important due to the toxic effects of mycotoxins, especially zearalenone and deoxynivalenol, which leads to a decrease in the efficiency of the cattle breeding industry, so it is necessary to examine this problem. The purpose of the study was to identify the effect of the complex use of sorbents, acidifiers, and aromatase inhibitors on the reproductive capacity of cows in mycotoxicosis. During the study, clinical methods (general examination) and biochemical methods (serum content of calcium, magnesium, urea, total and direct bilirubin, malonic

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dialaldehyde, aminotransferase activity) were used. Cows were divided into two groups: the first group was a control group, where no treatment was used, and cows of the second group received a comprehensive treatment method. A decrease in the level of calcium to 1.68±0.53 mmol/L, phosphorus – 0.98±0.16, selenium – 0.64±0.1 mmol/L, an increase in the level of magnesium to 1.15±0.17 mmol/L, an increase in aspartate aminotransferase to 121.33±3.91 units, alataminotransferase to 79.31±6.53 units, and total bilirubin to 10.21±0.55 mmol/l, malone aldehyde up to 8.27±0.41 mmol/L, and ceruloplasmin up to mmol/L 2.14±0.39 in chronic mycotoxicosis caused by zearalenone and deoxynivalenol. When using a complex treatment regimen for animals, a substantial change and approximation to the reference levels of selenium, creatinine, AST, ALT, malonic aldehyde, and ceruloplasmin were established. The use of the proposed treatment regimen increases the fertilising capacity of cows after the 1st calving by 18.15%, cows aged 3-4 years – 30.12%, and cows of the older age group – by 40.47%. A complex method of treatment of cows for mycotoxicosis caused by zearalenone is proposed using an acidifier based on organic acids, a sorbent based on celeolite and an aromatase inhibitor, which can be used in livestock farms for the production of milk and meat of various forms of ownership to restore and normalise the reproductive ability of cows

Keywords: mycotoxins; reproduction; aromatase inhibitor; antioxidant protection

INTRODUCTION

One of the widespread problems in cattle breeding is the use of concentrated and coarse feed affected by mycotoxins, in particular, the *Fusarium* genus. The low reproductive capacity of cows causes substantial economic damage to livestock farms due to overspending of feed on infertile animals, premature culling, early abortions, and germ resorption, which leads to an increase in the cost of products created, and a decrease in the competitiveness of enterprises. Therefore, improving the methods of reproduction of cows remains the main task of veterinary specialists in farms. Due to the use of animals and sperm imported from abroad, the quality of feed and the requirements for keeping breeding stock are becoming increasingly important.

Therewith, some studies report the development of destructive changes in the ovaries, uterus (Bailey *et al.,* 2019), kidneys, liver (Yang *et al.,* 2020). Authors S. Fedorenko *et al.* (2017) and L. Silva *et al.* (2021) argue that the use of feed with a high content of zearalenone leads to an increase in the level of estrogen-like substances, the main of which are β-searalenol, α-searalenol in a ratio of 1:11, but the author provides data at laboratory-created levels of zearalenone, but the study remains relevant in production conditions when the level of individual mycotoxins is due to accumulation during harvesting, storage, and preparation of feed for consumption. Researchers E. Lee *et al.* (2021) report that as a result of chronic poisoning caused by β-searalenol, follicular cysts occur in the ovaries of cows due to a violation of the synthesis of follicle-stimulating and luteinising hormones due to inhibition of the formation of the α-isomer of releasing hormone, with luteinising hormone-sensitive receptors playing a leading role, and this study is aimed at restoring the balance of follicle-stimulating and luteinising hormones. In the paper by G. Zhang *et al.* (2018), it is reported that in chronic mycotoxicosis, the formation of sex hormones is suppressed due to destructive changes in the ovaries, which manifest themselves in the form of optosis of cells of the ovarian cortical layer.

Similar results were obtained by other researchers, M. Abdel-Kareem *et al.* (2019), indicating a negative effect of mycotoxins on the reproductive capacity of cows and heifers of mating age. The authors propose a large number of means to reduce the negative impact of mycotoxins on the body of cows, namely preservatives in the collection and storage of feed, sorbents in the preparation of feed and hepatoprotectors in the treatment of cows with mycotoxicosis. However, as noted by L. Silva *et al.* (2021), long-term use of feed containing zearalenone leads to ovarian dysfunction due to apoptosis of cortical layer cells and organisation of brain and mezentorial layer cells. H Kadokawa (2020) provides data confirming the violation of cyclical changes in the types of endometrium of the uterus during the sexual cycle, and therefore there is an imbalance of hormones: sex – estradiol, progesterone and those that are formed in the hypothalamus – releasing factor (α-and β-isomers), and pituitary-follicle – stimulating and luteinising, as indicated by another researcher.

The purpose of the study was to investigate the effectiveness of using a comprehensive treatment regimen for cows with mycotoxicosis using certain types of celeolites, organic acids, and lipid oxidation inhibitors.

MATERIALS AND METHODS

The study was conducted in milk production farms Agrofirm "Lan", Agrofirm "Mriya", and Limited Liability Company Agrofirm "Vladana", Sumy region during 2019-2021. In each farm, the number of cows was examined and a diagnosis of mycotoxicosis was established. Then the cows were divided into two groups (in each farm). In the first experimental group of cows, a complex application of biological agents was used to reduce the effect of zearalenone on the reproductive ability of cows (an acidifier based on organic acids, a sorbent based on celeolite, and an aromatase inhibitor). The acidifier was added to drinking water, creating a concentration of 0.1%, which was given to the cows for 5 days. Celeolite-based sorbent was used at the rate of 2.5 kg per

1 ton of feed for 14 days. An aromatase inhibitor (letrozole) was used at a dose of 30 mg once, orally, when the dominant follicle reached a diameter of 18 mm. In the second group (control), no funds were used.

Therewith, the types of ovarian and uterine pathology were considered (they were established by transstrect examination using a sensor with a Convex matrix of 6-9 MHz (Ultrasonix RP). The dynamics of some biochemical parameters in all experimental groups is established. Therewith, generally accepted methods were used to determine calcium by reaction with Arsenazo III, magnesium – by reaction with xylidyl blue, activity of ataminotransferases (AST, ALT) – kinetic method (in vitro), activity of aspartate aminotransferase (AST) – kinetic method (in vitro), urea – urease method; total and direct bilirubin (according to the Endrashik method); activity of γ-lutamyltransferase – with the substrate L-γ-glutamyl – p-nitroaniline, malone dialaldehyde (MDA) was performed spectrophotometrically. The next step was to determine the effectiveness of the use of biologically active agents on reproductive ability. Therewith, fertilisation indicators, insemination index, and hidden abortions were established.

All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). The keep of animals and all manipulations were conducted in accordance with the provisions of the procedure for conducting experiments and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (1986).

RESULTS AND DISCUSSION

Biochemical parameters are markers of pathological changes both in the body as a whole and in individual organs and systems. Some biochemical parameters of the blood were examined, indicating both metabolic disorders (calcium, phosphorus and magnesium), toxic effects of mycotoxins (AST, ALT, total bilirubin), and violations of antioxidant protection in violation of lipid oxidation under the influence of zearalenone (selenium, malonic aldehyde Te ceruloplasmin) to diagnose and predict the occurrence of gynecological pathology. The results of studies of changes in individual biochemical parameters of cow blood for mycotoxicosis are presented in Table 1.

Table 1. *Comparison of biochemical parameters of blood in cows for mycotoxicosis*

Indicator	Control group (n=12)	Cows after applying acidifier (n=12)	reference indicators	P
Calcium, mmol/L	1.68±0.53	2.23±0.31	2.4-2.6	0.38
Phosphorus, mmol/L	0.98±0.16	1.2±0.34	1.45-2.1	0.556
Magnesium, mmol/L	1.15±0.17	0.89±0.13	0.8-1.15	0.246
Selenium, mmol/L	0.64±0.1	1.1±0.15*	0.8-1.9	0.018
Creatinine, nmol/d	107.3±4.59	82.6±3.5**	80.0-130.0	0.001
AST	121.33±3.91	67.25±7.61**	10.0-50.0	0.001
ALT	79.31±6.53	37.28±4.12**	10.0-30.0	0.001
De Ritis Indicator	1.53	1.8	1-1.5	
Bilirubin, μmol/L	10.21±0.5	7.65±1.13	0.3-7.0	0.061
Malonic aldehyde, mmol/L	8.27±0.41	5.27±0.69*	4.5-6.0	0.002
Ceruloplasmin, μmol/L	2.14±0.39	1.69±0.47	1.6±2.0	0.393

Note: ** – p<0.05, ** – p<0.001*
Source: *compiled by the authors*

Therewith, a positive increase in the use of a complex treatment regimen for cows with mycotoxicosis is shown. When using an acidifier based on organic acids together with a sorbent based on celeolite and an aromatase inhibitor, a result was obtained indicating the restoration of calcium levels, while in the control group (cows in whose diet the amount of zearalenone exceeded 400 mg/kg) it remained at the level of 1.68±0.53 mmol/L. In addition, when exposed to mycotoxins, in particular, deoxynivalenol, magnesium levels were recorded at the upper limit of the reference limit, which also contributed to a decrease in calcium levels and an imbalance of calcium, phosphorus, and selenium. There is evidence indicating a correlation between selenium levels and the fertilisation capacity of cows.

The use of the proposed treatment regimen for cows under the influence of zearalenone and deoxynivalenol contributed to a decrease in malone aldehyde

by 1.57 times and ceruloplasmin – by 1.27 times. Notably, these indicators have restored their level to the same level in healthy animals. In addition, the proposed scheme helped to reduce toxic effect on the body of cows. This is indicated by a decrease in AST by 1.8 times and alt by 2.13 times, which is confirmed by studies by other authors (Kinoshita *et al.,* 2018). Reducing the toxic effect and restoring the antioxidant protection of the cow's body led to an increase in reproductive capacity (Table 2).

Table 2. *Indicators of reproduction when using a complex treatment regimen for cows with mycotoxicosis*

Indicators	Without treatment			Using a comprehensive treatment regimen		
	Cows, 1st calving	Cows aged 3-4 years	Cows aged 5-7 years	Cows, 1st calving	Cows aged 3-4 years	Cows aged 5-7 years
Number of animals	102	114	112	98	124	107
Duration of the postpartum period	40.1±0.22	45.3±1.21	52.9±2.67	32.8±2.39*	37.4±3.68	39.1±3.67*
Duration of the service period	70.2±1.18	73.61±1.97	73.39±2.63	52.39±2.61 *	55.97±2.67*	59.67±2.32*
Number of calves per 100 cows	82.64	79.42	72.39	93.41	90.37	85.94
Insemination index	3.28±0.18	3.41±0.22	3.68±0.31	2.1±0.21	2.4±0.18	2.84±0.19
Rejected for various reasons	14	32	38	10	14	16

Note: ** – p<0.001*
Source: *compiled by the authors*

A substantial decrease in the duration of the postpartum period was identified in cows after the first calving compared to animals of the same age group with mycotoxicosis. The tendency to reduce the postpartum period was also observed in older age groups, but it was statistically unreliable. This is due to deeper destructive changes in the organs of the reproductive system in cows, in particular, the uterus (thickening of the uterine mucosa and organisation processes) with chronic exposure to zearalenone and apoptosis processes in the ovarian tissue, which in turn inhibited the processes of involution of the genitals of cows after childbirth.

In general, zearalenone contributed to a constant increase in the level of estrogen-like substances in the blood of cows, which led to the development of destructive changes in the endometrium of the uterus. The use of a complex treatment regimen using an acidifier, sorbent, and aromatase inhibitor helped to reduce the toxic effect of zearalenone on the endometrium, ovaries and increase the antioxidant capacity of cows. Positive dynamics were established in all age groups of such indicators as the number of offspring received and the insemination index. The main indicator of restoration of reproductive ability is fertilisation. The analysis of cow fertilisation in a comparative aspect is conducted (Table 3).

Table 3. *Fertilisation by day 120*

Indicators	Without treatment						Using a comprehensive treatment regimen					
	Cows, 1st calving		Cows aged 3-4 years		Cows aged 5-7 years		Cows, 1st calving		Cows aged 3-4 years		Cows aged 5-7 years	
	number	%	number	%	number	%	number	%	number	%	number	%
Number of animals	102		114		112		98		124		107	
Total fertilised	71	69.61	53	46.49	29	25.89	86	87.76	95	76.61	71	66.36
Not fertilised	31	30.39	61	53.51	83	74.11	12	12.24	29	23.39	36	33.64

Note: ** – p<0.05, ** – p<0.001*
Source: *compiled by the authors*

Therewith, the fertilisation rate of cows after the 1st calving after applying a comprehensive treatment regimen increased 1.26 times (18.15%), among cows aged 3-4 years – 1.65 times (30.12%). Cows of the older age group after using the proposed scheme had fertilisation by 2.56 times more often (40.47%). This difference is explained by the development of hypogonadism in older cows, characterised by a large number of atretic follicles and the absence of dominant follicles due to the chronic effect of zearalenone on the ovaries of cows. This is confirmed by the study by J. Gong *et al.* (2020). The use of an aromatase inhibitor reduces the level of lipid peroxidation and the release of estrogen-like substances, which in turn can reduce the amount of

follicle-stimulating and luteinising hormones, which leads to defective sexual cycles, in particular, anovulatory ones. In chronic poisoning with mycotoxins, in particular, zearalenone and deoxynivalenol, a huge number of both compensatory and destructive mechanisms occur in the body. Certain biochemical parameters are markers of such changes, so their interpretation is fundamental in the diagnosis and development of methods for the prevention and treatment of cows exposed to mycotoxins in general and zearalenone in particular.

A decrease in the level of calcium in cows under the influence of mycotoxins occurs firstly, as a consequence of the use by the cow's body of a large amount of this macronutrient in a cascade of redox reactions under oxidative stress of the body, and secondly-poor absorption of calcium due to destructive changes in the intestinal wall. This statement is supported by authors I. Alassane-Kpembi *et al.* (2019), indicating a decrease in the viability of intestinal cells and the concentration of short-chain fatty acids, and as a result, the death of saprophytic bacteria that counteract oxidative stress and impair effective digestion and absorption of substances. Selenium is known to play a role in preventing oxidative stress in the body and apoptosis of ovarian cells and stimulating the formation of blastocysts in the embryo (Gonzalez Andueza *et al.,* 2022). Most authors tend to believe that a decrease in selenium levels under the action of mycotoxins leads to a decrease in the overall antioxidant capacity, while the level of malonic aldehyde and ceruloplasmin increases (Gong & Xiao, 2018).

After applying a complex treatment regimen for cows with chronic mycotoxicosis, the amount of selenium increased, which is associated with the restoration of redox reactions in the body due to the blocking of aromatase and slowing down the formation of estrogen-like substances, including from adipose tissue. A similar trend has been identified by A. Iorga *et al.* (2017), indicating a positive effect of aromatase in the development of oxidative stress. Another diagnostic criterion for the development of oxidative stress, and therefore a violation of the synthesis of both gonadotropic hormones and sex hormones, is the level of malone aldehyde. Thus, a decrease in the level of malone aldehyde in the blood serum to the reference values was observed after the use of the proposed treatment of cows. It is known that in infectious diseases and toxicoses caused by mycotoxins and bacteria, the amount of malone aldehyde increases (Ayemele *et al.,* 2021). Therefore, it is possible to start the idea of a positive result of using the proposed treatment for oxy-reducing reactions in chronic mycotoxin poisoning.

There was a reduction in the duration of the postpartum period after the use of a complex treatment regimen with a sorbent based on celeolite, an oxidant based on organic acids and an aromatase inhibitor, which is associated with the restoration of the synthesis of follicle-stimulating hormone and prostaglandin F_{2A} uterine tissues, which stimulated the contraction of the uterus, and then the processes of involution of the organs of the reproductive system. Therewith, the yellow body of pregnancy melts, the amount of progesterone decreases sharply and the local protective reaction of the endometrium increases. Other authors agree with these statements, in particular, M. Adnane & A. Chapwanya (2022) indicate an increase in the number of lactic acid bacteria on the vaginal mucosa, which in the process of vital activity produce lactic acid, which acts bactericidal on conditionally pathogenic microflora that entered the organs of the reproductive system during childbirth.

Special attention should be paid to the duration of the service period because it directly affects the effectiveness of insemination at the first manifestation of the stage of sexual heat arousal in cows. At this time, it is important to establish the condition of the organs of the reproductive system of cows before insemination. This is due to the fact that according to foreign authors (Wagener *et al.,* 2017; Ballas *et al.*, 2022; Pascottini *et al.,* 2023), during this period subclinical inflammatory processes are diagnosed, namely endometritis, salpingitis, or ovariitis. After applying the prescribed treatment, the duration of the service period decreased by an average of 25%. This is due to a faster involution of the organs of the reproductive system, after which dominant follicles are formed in the ovary, and therefore the first ovulation after childbirth. This standpoint is supported by Y. Lin *et al.* (2021). The presented data indicate substantial changes in the biochemical parameters of cow blood due to the negative effect of mycotoxins, which negatively affect the reproductive capacity. A characteristic complex change in the main biochemical parameters is both a diagnostic and prognostic test for the occurrence of infertility due to exposure to zearalenone and deoxynivalenol. The proposed treatment regimen for sick cows can be used to treat cows with mycotoxicosis to restore and stimulate the reproductive ability of cows and heifers.

CONCLUSIONS

Long-term feeding of feed containing zearalenone leads to a decrease in the reproductive capacity of cows after the 1st calving by 30%, cows of the middle age group (3-4 years) – by 53.5%, and cows of the older age group – by 74.11%. The presence of zearalenone in the diet of more than 400 mg/kg contributes to the accumulation of estrogen-like substances and a decrease in the level of calcium, phosphorus, and the antioxidant capacity of the cow's body. The use of complex treatment of cows using an acidifier based on organic acids, a sorbent based on celeolite, and an aromatase inhibitor helps to normalise the level of individual micro- and macronutrients and restore the antioxidant protection of the cow's body.

The use of the proposed treatment regimen increases the fertilising capacity of cows of the song

of the 1st calving by 18.15%, cows aged 3-4 years – by 30.12%, and cows of the older age group – by 40.47%, respectively. Further research on this subject should be aimed at a deeper understanding of the relationship between mycotoxicosis and the reproductive function of cows, in particular, with regard to molecular and hormonal mechanisms of influence. It is important to examine the effect of different types of mycotoxins on different stages of the reproductive cycle and explore the possibilities of optimising complex drugs to improve heat.

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CONFLICT OF INTEREST

None.

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Показники відтворення при використанні комплексного застосування препаратів за спонтанного прояву охоти у корів за мікотоксикозу

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Анотація. Все більшого значення набуває аліментарна неплідність зумовлена токсичним впливом мікотоксинів, особливо зеараленоном та деоксиніваленолом, що призводить до зниження ефективності діяльності галузі скотарства, тому необхідним є вивчення даної проблеми. Метою роботи було виявити вплив комплексного застосування сорбентів, підкислювачів та інгібіторів ароматази на відтворну здатність корів за мікотоксикозу. При проведенні досліджень було використано клінічні методи (загальне обстеження) біохімічні (вміст в сироватці крові кальцію, магнію, сечовини, загального та прямого білірубіну, малонового діальдегіду, активність амінотрансфераз. Корів було поділено на дві групи: перша група була контрольною, де лікування

не застосовували, коровам другої групи застосовували комплексний метод лікування. Встановлено зниження рівня кальцію до 1,68±0,53 ммоль/л, фосфору – 0,98±0,16, селену – 0,64±0,1 ммоль/л, підвищення рівня магнію до 1,15±0,17 ммоль/л, підвищення аспартат амінотрансферази до 121,33±3,91 Од, алатамінотрансферази до 79,31±6,53 Од, загального білірубіну до 10,21±0,55 мкмоль/л, малонового альдегіду до 8,27±0,41 мкмоль/л та Церулоплазміну до мкмоль/л 2,14±0,39 при хронічному мікотоксикозі, зумовленого зеараленоном та деоксиніваленолом. При застосуванні комплексної схеми лікування тварин встановлено достовірну зміну та наближення до референтивних рівнів показників селену, креатиніні, АСТ, АЛТ, малонового альдегіду та церулоплазміну. Застосування запропонованої схеми лікування підвищує запліднюючу здатність корів пісня 1-го отелу на 18,15 %, корів віком 3-4 роки – 30,12 % та корів старшої вікової групи на 40,47 %. Запропоновано комплексний метод лікування корів за мікотоксикозу, зумовленого зеараленоном з використанням підкислювача на основі органічних кислот, сорбенту на основі целеоліту та інгібітору ароматази, яка може бути використана в тваринницьких господарствах з виробництва молока та м'яса різної форми власності для відновлення та нормалізації відтворювальної здатності корів

Ключові слова: мікотоксини; відтворення; інгібітор ароматази; антиоксидантний захист

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Efficiency of growth regulators in corn crops of the Northern Steppe of Ukraine

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Abstract. The continuous increase in prices for mineral fertilisers for corn limits the use of fertilisers, which leads to the search for unconventional sources of food elements, and in particular, the use of biological natural and synthetic growth stimulators that are not harmful to the environment and allow wider use of the entire genetic potential of corn. The purpose of the study was to examine the influence of various plant growth regulators on the intensity of photosynthesis, development, growth and productivity of corn of various ripeness groups in the steppe of Ukraine. The field scientific study was conducted according to generally accepted methods of research, followed by the use of mathematical processing of experimental data using variance analysis. An increase in the chlorophyll content was identified when Avangard Grow Amino and Avangard Grow Humate preparations were applied compared to Vympel 2 and Alpha Nano Grow by 11.3-23.7%. The increase in grain from the use of growth stimulators on corn was in the early-maturing hybrid DN Pivikha – 0.13-0.37 t/ha (2.7-7.7%), medium-early DN Khortytsia – 0.85-1.08 t/ha (16.6-18.5%), medium-maturing DN Julia – 0.20-0.22 t/ha (3.20-3.4%), medium-late DN Olena – 0.05-0.53 t/ha (0.65-7.6%). Among the preparations used, Avangard Grow Amino and Avangard Grow Humate should be highlighted, which provided a tendency to increase the crude protein content to 6.42-8.4%, or by 0.12-0.48 percentage points more compared to the control (3.53-4.71%), and the crude fat content to 3.73-5.52%, or by 0.20-0.81 percentage points. The use of

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growth stimulators in the conditions of the Northern Steppe of Ukraine on corn, especially Avangard Grow Amino and Avangard Grow Humate on early-maturing and medium-early corn hybrids, allows increasing the gross yield of high-quality grain by 7.6-18.4%

Keywords: corn hybrids; growth stimulators; biometrics; SPAD units; grain yield; crude protein; crude fat; economic efficiency

INTRODUCTION

The increase in manifestations of extreme weather conditions (droughts, high temperatures, dry winds, frosts, etc.) is due to climate changes towards its warming, man-made loads, reduction in the use of mineral and organic fertilisers, which makes it necessary to improve the technology of growing corn to increase its yield, gross grain collections, and quality indicators.

According to T. Marchenko (2019) and Ya. Byelov (2018), corn in all phases of growth and development requires favourable conditions for plant development (nutrition, moisture, heat, etc.), but in extreme conditions there is often a need to increase the stress resistance of corn plants, especially in the Steppe zone of Ukraine, to obtain high grain yields. It is necessary to create favourable conditions for plant growth and protect them from the effects of environmental stress factors, in particular, the use of growth stimulants, microfertilisers, etc. A study conducted by A. Abdo *et al.* (2022) determined that all examined biometrics, crop structure elements, and overall yield were maximal when using 75% NPK + biofertiliser in combination with amino acids or a mixture of humic acids with amino acids, proving the importance of growth stimulants in enhancing the strategy of reducing chemical NPK by 25%. M. Szcsepanek (2018), proved that the Kelpak biostimulator together with Nano Active microfertiliser increased the yield of corn grain by up to 10% compared to the control. Experiments conducted by M. Pashchak *et al.* (2021) show that foliar top dressing with multi-complex microfertiliser Orakul in the BBCH 13-15 phase (3-5 leaves) increased the yield increase by 0.82 t/ha, due to the provision of plants with nutrients during this period.

T. Marchenko *et al.* (2019) proved that the use of growth regulators in the phase of 5-7 maise leaves contributed to the growth and development of plants, increasing grain yield. The increase in the yield of cobs from the introduction of Megafon was 9%, Delfan Plus – 8%, Folik Aminovigor – 6%. Seed treatment with growth stimulants is also highly effective, in particular, according to T. Bortnik *et al.* (2019), Alga 600 growth stimulator, when used in the early stages of plant development, ensures high plant biometrics and grain yield. Through growth stimulators, it is possible to solve an important drought problem for plants by using 5-aminolevulinic acid (5-ALA), zearalenone (ZEN), triacontanol (TRIA), and silicon (Si), which improve the water balance of maise and its photosynthetic activity in soil drought conditions (Ostrowska *et al.,* 2021). Similar results were obtained by V. Palamarchuk *et al.* (2018), where the use of organic balance improved the growth, development of photosynthetic potential and yield of seeds of maise lines, the parent components of promising hybrids, which are usually less resistant to negative environmental factors. In thius case, under irrigation conditions, the maximum grain yield of the parent FAO 420 line was obtained – 7.08 t/ha.

Considering the experience of Ukrainian and foreign researchers, research in this area was continued, which led to the purpose of the study – to examine the effect of growth-regulating preparations on photosynthesis activity, growth processes, development, and productivity of corn hybrids in the northern steppe of Ukraine.

MATERIALS AND METHODS

The study was conducted at the research field of the Scientific and Educational Centre for Practical Training of the Dnipro State Agrarian and Economic University (hereinafter – DSAEU) in 2020-2022. The soil of the research sites is ordinary low-humus dusty-medium loamy loess chornozem. Chornozem has a high potential and effective fertility (humus content in the 0-30 cm layer – 3.9%, total nitrogen – 0.22%, phosphorus – 0.13%, potassium – 2.2%.

Corn was grown according to the generally accepted technology characteristic of the Steppe zone of Ukraine. The predecessor of corn was winter wheat in grain-fallow-row crop rotation (clean fallow – winter wheat – corn – barley – sunflower). After mowing the predecessor of corn (winter wheat), general background stubble peeling was performed with heavy disc harrows PALLADA 2400 (Ukraine) to a depth of 10.0-12.0 cm. The next processing was ploughing, which was performed with a PLN-3-35 plough (Ukraine) to a depth of 23-25 cm. In spring, pre-sowing cultivation of KSO–4N to a depth of 6-8 cm was conducted, under which the soil herbicide Aspect Pro – 2.2 L/ha was applied, and in the phase of 3-5 leaves, the herbicide Elumis was used at a rate of 1.5 L/ha. Soil fertilisation was conducted in the spring under the cultivation of N15P15K15. The preparations were applied with a small-sized rod sprayer OM-4 (Ukraine) in the phase of 5-7 and 10-12 maise leaves. Before sowing, the corn seed material was etched with a mixture of Maxim XL 035 FS – 1.0 L/T + Vibrance 500 FS – 1.5 L/T + Force Zea 280 FS – 6.0 L/T.

Hybrids of different ripeness groups were used: DN Olena 440 MV FAO 440 of medium-late maturation,

DN Julia 340 MV FAO 340 medium-late, DN Khortytsia FAO 240 medium-early, and DN Pivikha FAO 180 of early maturation. In the phase of 3-5 leaves and 10-12 leaves, preparations based on growth stimulators and microfertilisers were used: Avangard Grow Humate – 1.0 L/ha, Avangard Grow Amino – 1.5 L/ha, Alpha Nano Grow – 50 ml/ha, Vympel 2 – 0.5 L/ha. There was also a control without the use of growth stimulants on corn. Scientific studies were conducted according to generally accepted research methods, the results of which were subjected to mathematical processing using variance analysis (Dospehov, 2013). Among the features of the method, the determination of the chlorophyll content in corn leaves in SPAD units on the SPAD-502 Plus device (Ukraine) is notable.

Experimental plant analysis (both cultivated and wild species), including plant material collection, adhered to institutional, national, or international ethical principles. 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 AND DISCUSSION

The height of corn increased in ascending order from the early-maturing DN Pivikha up to the medium-late DN Olena – 215.0-225.0 cm, that is, it had a dependence on the group of plant maturation. The height of corn did not substantially depend on the introduced growth stimulants, the growth was only 3-8 cm, or 1.4-3.7% compared to the control (without the introduction of preparations). The maximum height of corn was noted for processing with Avangard Grow Humate – 223-225 cm. Images of corn habitus in the BBCH 31-32 phase (11-12 leaves) are presented to visually confirm the increase in biometric indicators of corn (plant height, number of leaves, leaf area). From the size of corn plants, the growth of vegetative mass is visible precisely on the options for using growth stimulants (Fig. 1).

Figure 1. *Corn plant habitus under the influence of plant growth stimulators in 2020*

There was a tendency to increase the number of leaves with the introduction of growth stimulants in comparison with the control without the use of stimulants by 3.5-5.6%, regardless of the corn maturation group. Notably, the number of leaves of corn plants is substantially associated with the biological characteristics of plants, namely, with a gradual increase in the number of leaves from the early-maturing DN Pivikha – 10.70-11.30 pcs./plant and up to the medium-late DN Olena – 13.40-14.40 pcs./plant. The same patterns are inherent in the area of leaves on one plant. That is, their minimum area is typical for the control version of 329.80-538.80 cm^2. The use of stimulants contributed to the trend of increasing the area of leaf blades by 5.30-28.30% without substantial differences between the preparations used since the difference between them was within the smallest substantial difference.

All growth stimulators had a substantial effect on chlorophyll levels in maise leaf blades. An increase in the quantitative indicators of chlorophyll in SPAD units compared to the control was observed in hybrids DN Pivikha by 8.10-9.10 units (17.90-19.60%), DN Khortytsia by 9.21-12.81 units (18.21-23.71%), DN Julia by 2.31-6.62 units (4.7-12.3%), DN Olena by 1.5-6 units (3.2-11.4%). The tendency to increase the content of chlorophyll after the introduction of Avangard Grow Amino and Avangard Grow Humate preparations compared to Vympel 2 and Alpha Nano Grow is notable (Fig. 2).

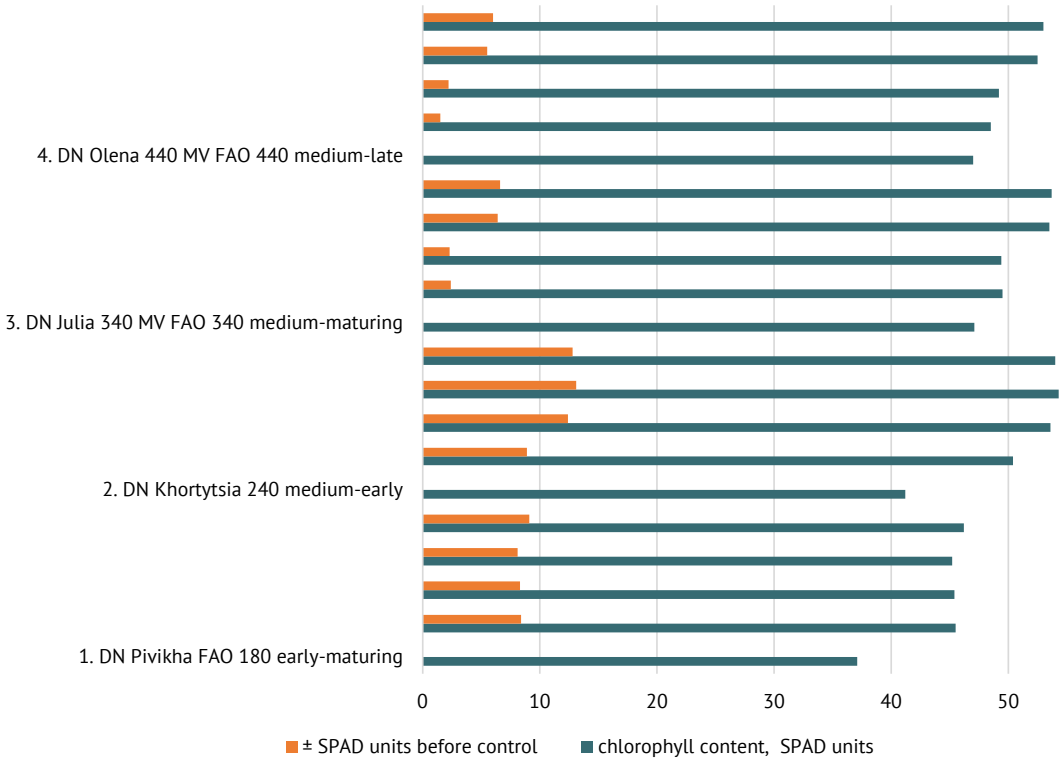

Figure 2. *Dynamics of chlorophyll content under the action of growth stimulators for 2020-2022, (SPAD units)*
Source: *compiled by the authors*

The effectiveness of stimulants on corn in terms of chlorophyll content decreased over time after their use, especially this can be noted on medium-ripening DN Julia and medium-late DN Olena, which have a slightly longer growing season compared to early-ripening and medium-early hybrids, which gives grounds for repeated (additional) use of stimulants in later phases of corn growth and development for further prolongation of the action of preparations, and ultimately to an increase in chlorophyll content and grain yield. The results of this study are also confirmed by other researchers (Szulc *et al.,* 2021; Zabolotna *et al.,* 2022). The examined elements of the crop structure (the length of cobs, the number of rows of grains, the number of grains from the cob, the mass of grains from the cobs, and the mass of a thousand grains) tended to increase and, depending on the maturation group of corn, these indicators increased from early-maturing to medium-late. Elements of the crop structure generally depended on growth stimulators, which is also confirmed by many researchers (Sukhomud *et al.,* 2019).

In the control version, all hybrids had minimal values of the length of cobs, the use of stimulants allowed to slightly increase this indicator by 0.50-1.70 cm (2.60-8.60%). Directly proportional to the length of the cobs, there was also an increase in the number of grains per cob, depending on the action of growth stimulators in the early-maturing hybrid DN Pivikha by 31.2-56.4 pcs. (6.6-11.3%), medium-early DN Khortytsia – 47.8-71.9 pcs. (11.4-16.1%), medium-maturing DN Julia – 102.7-102.9 pcs. (18.9-18.8%), and in medium-ripening DN Olena – 43.3-104.6 pcs. (8.5-18.4%). The same patterns were identified when determining the mass of grain from one cob and the mass of a thousand grains. The mass of grains from the cob grew under the influence of growth stimulants in corn by an average of 5.610-30.10 g (7.820-31.420%), and the mass of a thousand grains by 5.410-50.20 g (2.6-18.9%). Notably, the plant growth stimulators Avangard Avangard Grow Humate and Grow Amino tended to maximise the growth of these elements of the crop structure.

The content of chlorophyll in maise leaf blades substantially correlated with grain yield, this pattern is also confirmed by various researchers (Gong *et al.,* 2021). With an increase in the content of chlorophyll, grain yield increased. The increase from the use of stimulants was in the early-maturing hybrid DN Pivikha – 0.13-0.35 t/ha (2.7-7.7%), medium-early DN Khortytsia – 0.85-1.08 t/ha (16.6-18.5%), medium-maturing DN Julia – 0.18-0.20 t/ha (3.18-3.4%), medium-late DN Olena – 0.05-0.53 t/ha (0.65-7.6%).

The use of growth stimulators on corn allowed improving the grain quality of hybrids of different ripeness groups (Table 1). The use of almost all plant growth stimulators examined allowed improving the quality of corn grains of different ripeness. The obtained experimental data directly correlated with biometric indicators, elements of the crop structure and grain yield. Thus, the use of growth stimulators increased the content of crude protein in DN Pivikha

by 0.03-0.65 percentage points, DN Khortytsia – 0.58-1.04 percentage points, DN Julia – 0.1-0.74 percentage points, DN Olena – 0.15-0.68 percentage points, the maximum increase in crude protein was observed in the medium-early hybrid DN Khortytsia. Among the preparations used, Avangard Grow Amino and Avangard Grow Humate should be highlighted, which tended to increase the crude protein content to 6.42-8.4%, or 0.12-0.48 percentage points more. As for hybrids, the maximum values of crude protein content were noted in the early-maturing hybrid DN Pivikha – 7.75-8.4%. There is also a tendency to reduce the content of crude protein with the lengthening of the growing season from early-maturing hybrid to medium-late, which is likely due to a gradual slowdown in the action of preparations over time and requires additional research using additional (third) application of preparations on later hybrids.

Table 1. *Grain quality of different corn hybrids under the influence of growth stimulators for 2020-2022*

Hybrids	Preparations	Seed yield, t/ha	Crude protein, %	Raw fat, %	Grain moisture content, %
DN Pivikha early-maturing	Control (no stimulators)	4.37	7.75	4.02	14.08
	Vympel 2	4.49	7.78	4.68	13.91
	Alpha Nano Grow	4.64	7.92	4.76	13.82
	Avangard Grow Amino	4.73	8.21	4.82	14.03
	Avangard Grow Humate	4.73	8.40	4.81	13.83
DN Khortytsia medium-early	Control (no stimulators)	4.72	6.08	3.55	14.02
	Vympel 2	5.08	6.66	5.06	13.06
	Alpha Nano Grow	5.56	7.12	4.33	14.14
	Avangard Grow Amino	5.74	6.86	4.48	14.01
	Avangard Grow Humate	5.79	7.10	4.45	13.93
DN Julia 340 medium-ripening	Control (no stimulators)	5.77	6.32	3.53	14.34
	Vympel 2	5.96	6.55	3.73	14.04
	Alpha Nano Grow	5.97	6.43	4.43	14.12
	Avangard Grow Amino	5.95	6.42	4.11	14.32
	Avangard Grow Humate	5.94	7.06	4.10	14.18
DN Olena 440 medium-late	Control (no stimulators)	6.18	6.05	4.71	14.50
	Vympel 2	6.68	6.20	4.77	14.53
	Alpha Nano Grow	6.41	6.62	5.38	13.80
	Avangard Grow Amino	6.22	6.73	5.52	14.44
	Avangard Grow Humate	6.29	6.60	5.17	14.45
	$HI_{P0.5\ t/ha/\%}$	0.19	0.18	0.13	-

Source*: compiled by the authors*

The content of crude fat had an inverse correlation with the content of crude protein, that is, there was an increase in its content on the medium-late hybrid compared to early-maturing ones. In the medium-late hybrid DN Olena, the maximum fat content of 4.71-5.38% was obtained, while the remaining hybrids were slightly inferior by 0.32-1.18 percentage points. Growth stimulants increased the content of crude fat compared to the control (3.53-4.71%) to 3.73-5.52%, or by 0.21-0.81 percentage points, the most positive trend here was the preparations Avangard Grow Humate, Avangard Grow Amino, and Vympel 2. Corn hybrids of different maturation periods against the background of different preparations containing growth stimulators and microfertilisers were marked by different grain yields, which depended on the biological properties of hybrids, the use of growth stimulators and microfertilisers, which ultimately determined the amount of production costs that are necessary for conducting technological cycles of work in the technology of growing corn hybrids with different maturation periods (Table 2).

Table 2. *Economic performance indicators of corn cultivation under the influence of growth stimulants on average for 2020-2022*

Hybrids	preparation options	Seed yield, t/ha	Grain sales price UAH/t	preparation costs, UAH/ha	Production costs total, UAH/ha	Cost of gross output, UAH/ha	Net profit, UAH/ha	Profitability level, %	Percentage point surcharge
DN Pivikha early-maturing	Control (no stimulators)	4.37	7900	-	19900	34523	14623	73.4	-
	Vympel 2	4.49	7900	200.0	20100	35471	15371	76.4	3.0
	Alpha Nano Grow	4.64	7900	275.0	20175	36656	16481	81.6	8.2
	Avangard Grow Amino	4.73	7900	282.0	20182	37367	17185	85.1	11.7
	Avangard Grow Humate	4.73	7900	133.0	20033	37367	17334	86.5	13.1
DN Khortytsia medium-early	Control (no stimulators)	4.72	7900	-	19900	37288	17388	87.3	-
	Vympel 2	5.08	7900	200.0	20100	40132	20032	99.6	12.3
	Alpha Nano Grow	5.56	7900	275.0	20175	43924	23749	117.7	30.4
	Avangard Grow Amino	5.74	7900	282.0	20182	45346	25164	124.6	37.3
	Avangard Grow Humate	5.79	7900	133.0	20033	45741	25708	128.3	41.0
DN Julia 340 medium-ripening	Control (no stimulators)	5.77	7900	-	19900	45583	25683	129.0	-
	Vympel 2	5.96	7900	200.0	20100	47084	26984	134.2	5.2
	Alpha Nano Grow	5.97	7900	275.0	20175	47163	26988	133.7	4.7
	Avangard Grow Amino	5.95	7900	282.0	20182	47005	26823	133.8	4.8
	Avangard Grow Humate	5.94	7900	133.0	20033	46926	26893	134.2	5.2
DN Olena 440 srednepizny	Control (no stimulators)	6.18	7900	-	19900	48822	28922	145.3	-
	Vympel 2	6.68	7900	200.0	20100	52772	32672	162.5	17.0
	Alpha Nano Grow	6.41	7900	275.0	20175	50639	30464	150.9	5.6
	Avangard Grow Amino	6.22	7900	282.0	20182	49138	29001	143.4	-1.9
	Avangard Grow Humate	6.29	7900	133.0	20033	49691	29658	148.0	2.7

Source*: compiled by the authors*

Thus, the total costs in the technological cycle of corn cultivation in the experimental field of the Scientific and Educational Centre for Practical Training of DSAEU amounted to 19900 UAH/ha (material costs, labour remuneration, depreciation charges). The cost of the preparations used in the experiment, as of the 2022 marketing year, was: Vympel 2 – 400 UAH/L, Alfa Nano grow – 550 UAH/0.1 L, Avangard Grow amino – 188 UAH/l, Avangard Grow Humate – 133.0 UAH/l. As can be seen from Table 2, the maximum total production costs were for the use of Avangard Grow amino – 282 UAH/ha (in total – 20182 UAH/ha) and Alfa Nano grow – 275.0 UAH (in total – 20175 UAH/ha) due to the slightly higher cost of these preparations.

With the same production costs of 19900-20182 UAH/ha, different-maturing hybrids did not form the same grain yield (an increase in yield from early-maturing to medium-late hybrid), and economic indicators changed accordingly. The maximum yield, and accordingly the profitability of grain production, was provided by the medium-late hybrid DN Olena – 145.3-148.0%. Slightly inferior to the medium-early DN Khortytsia and medium-maturing DN Julia, and with minimal yield indicators (4.37-4.73 t/ha), the minimum profitability of grain production was provided by the early-maturing hybrid DN Pivikha – 73.4-86.5%. Economic indicators are obtained from the effect of stimulants on corn plants. The maximum increase in percentage points (p.p.) of profitability from the use of preparations in relation to control was obtained on early-maturing DN Pivikha (3.0-13.1 percentage points) and medium-early Dn Khortytsia (12.3-41.0 percentage points) hybrids. Avangard Grow Humate (1.0 L/ha) had the best economic indicators here with the best increase in p.p. in relation to the control (+13.1-41.0 VP).

Medium-ripening DN Julia and medium-late DN Olena hybrids had a minimal increase in profitability from the preparations used, only 4.7-5.2 and 2.7-

17.0 p.p., respectively, due to small grain increases from the use of preparations. On these corn hybrids, the best results were provided by Vympel 2, which provided an increase in the level of profitability by 5.2-17.0 percentage points. The best effectiveness of preparations on early-maturing and medium-early hybrids can be explained by the better effect of preparations at the beginning of the growing season of the plant and its gradual attenuation over time. Medium-ripening and medium-late hybrids, to the extent of their biological characteristics, have a longer growing season, and accordingly require a more extended prolongation of the action of preparations, that is, it is necessary to additionally apply preparations in later phases of growth and development to obtain the greatest increase in grain and increase the level of profitability of grain production.

Growth stimulators and microfertilisers that were examined in the experiment (Avangard Grow Amino, Avangard Grow Humate) are relatively new preparations and are practically not examined in the conditions of Ukraine and the world, so there is little data on their effectiveness, except for the declared characteristics of the originator, in addition, they are contradictory due to the specific features of climatic conditions and elements of corn cultivation technology. A number of Ukrainian and foreign researchers note that plant growth stimulators in combination with microfertilisers are highly effective preparations that increase the stress resistance of corn plants and increase its yield, which is also confirmed by the data of this study (Marchenko *et al*., 2019; Gong *et al.,* 2021). The increase in corn grain from the use of growth-stimulating preparations in the early-maturing hybrid DN Pivikha was 0.13 – 0.37 t/ha (2.7-7.8%), medium-early DN Khortytsia – 0.85-1.08 t/ha (16.6-18.5%), medium-maturing DN Julia – 0.18-0.22 t/ha (3.18-3.4%), medium-late DN Olena – 0.05-0.51 t/ha (0.65-7.6%). Foreign researchers have similar results regarding the use of growth stimulants and microfertilisers. Thus, in particular, according to the authors J. Xue *et al.* (2020), the growth regulator Megamix N10 provided a grain increase of 30-32.5%, and the growth regulator Aminocate 30% provided a grain increase of 23.7-24.7% in relation to the control without preparation treatment.

Experiments conducted by O. Laszlo & R. Olepir (2022) show an increase in the yield of corn grains from the plant growth regulator Vympel and Oracle at the level of 8% or more. In the control variants without the use of stimulants, the corn yield was 3.79 t/ha. Seed treatment with Vympel-K + Orakul tank mixture at a rate of 1.0 l/t increased the yield by 0.250 t/ha, respectively, while plant treatment in phases 3-5 and 7-8 leaves increased the grain yield by 0.290 and 0.330 t/ha. The preparations showed an increased growth-stimulating effect in the early stages of plant growth and development. Experiments by H. Ebrahimi *et al.* (2020) proved that the use of plant growth stimulators has improved the use of fertilisers by plants, because they increase the efficiency of nutrient availability and perception by maise plants. Experiments on growth stimulators with corn in China have shown that the growth stimulator EDAH+DA-6 suppresses stem elongation, promotes stem thickening, and increases mechanical strength and the number of vascular bundles (Gong *et al*., 2021). Corn lodging under EDAH+DA-6 treatment decreased by 6.95% compared to control plants, and grain yield increased by 15.51%. In addition, Edah+DA-6 introduction substantially improved the quality of corn. Similar results regarding the thickening of the corn stem and increasing its strength are confirmed by other Chinese researchers (Seknon *et al*., 2020).

According to the results of these studies, it is possible to increase the stress resistance of plants to environmental conditions and level the problems by optimising the technological elements of corn cultivation, introducing new modern biological growth stimulators of corn that have been poorly examined or not examined at all (Avangard Grow Humate, Avangard Grow Amino, Vympel 2), which contribute to accelerated growth, increased resistance to extreme temperatures, improved leaf development, increased chlorophyll content, increased crude protein and fat content in corn grain, and ultimately, an increase in grain yield and quality.

CONCLUSIONS

The use of growth stimulants did not substantially increase the height of maise plants, only by 3.0-8.0 cm (1.5-3%) compared to the control. The maximum height of plants is typical for areas treated with Avangard Grow Humate – 223.0-225.0 cm. There is a tendency to increase the number of leaves when applying growth stimulants by 3.50-5.60%, regardless of the corn ripening group. There were also trends of increasing the area of leaf blades by 5.30-28.30% without substantial differences between the preparations.

The maximum increase in chlorophyll content was provided by Avangard Grow Amino and Avangard Grow Humate compared to Vympel 2 and Alpha Nano grow. In particular, the hybrids DN Pivikha by 8.2-9.2 units of SPAD (17.8-19.7%), DN Khortytsia – by 9.3-12.9 units of SPAD (18.3-23.8%), DN Julia – by 2.4-6.7 units of SPAD (4.7-12.3%), DN Olena – by 1.5-6 units of SPAD (3.1-11.3%). The additional volume of corn grain from the use of growth stimulators in various hybrids showed the following results: in the early-maturing hybrid DN Pivikha, this increase ranged from 0.13 to 0.37 tonnes per hectare (which is 2.7 – 7.8%); in the medium-early DN Khortytsia – from 0.85 to 1.08 tonnes per hectare (16.6-18.5%); in the medium – maturing DN Julia-from 0.18 to 0.22 tonnes per hectare hectares (3.18-3.4%); and in the medium-late DN Olena – from 0.05 to 0.51 tonnes per hectare (0.65-7.6%).

The content of crude protein under the influence of stimulants tended to increase, in particular, in DN Piv-

ikha by 0.03-0.65 p.p. (percentage points), DN Khortytsia 0.58-1.04 p.p., DN Julia – 0.1-0.74 p.p., DN Olena – 0.15-0.68 p.p., preparations Avangard Grow Amino and Avangard Grow Humate provided the greatest increase in the content of crude protein up to 6.42-8.4%, or 0.13-0.48 percentage points more. The use of a medium-late hybrid of corn DN Olena provides maximum indicators of crude fat content of 4.71-5.38%, the rest of the hybrids are slightly inferior by 0.32-1.18 percentage points. Growth stimulants (Avangard Grow Humate, Avangard Grow amino, Vympel 2) contribute to an increase in the content of crude fat compared to the control (3.53-4.71%) to 3.73-5.52%, or by 0.3-0.81 p.p. The medium-late hybrid DN Olena reaches the highest level of profitability in corn grain production, which is 145.3-148.0%. Slightly lower indicators in the medium-early DN Khortytsia and medium-maturing DN Julia. Growth stimulators, and especially Avangard Grow Humate, have a maximum increase in percentage points (VP) of profitability on the early-maturing hybrid DN Pivikha (3.0-13.1 VP) and medium-early DN Khortytsia (12.3-41.0 VP).

Changing climatic conditions and constant updating of the composition of different-maturing hybrids and preparations based on growth stimulants cause the continuation of research in this area to identify the most optimal variants of preparations to increase the level of yield and its quality.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Ефективність регуляторів росту в посівах кукурудзи Північного Степу України

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Анотація. Безперервне зростання цін на мінеральні добрива під кукурудзу обмежує використання добрив, що веде до пошуку нетрадиційних джерел внесення елементів живлення, а зокрема використання біологічних природних та синтетичних стимуляторів росту, які не шкідливі для довкілля і дозволяють ширше використовувати весь генетичний потенціал кукурудзи. Мета роботи полягала у вивченні впливу різних регуляторів росту рослин на інтенсивність фотосинтезу, розвиток, ріст і продуктивність кукурудзи різних груп стиглості в Степу України. Проводили польові наукові дослідження за загально прийнятими методиками дослідної справи із наступним використанням математичної обробки експериментальних даних за допомогою дисперсійного аналізу. Виявлено збільшення умісту хлорофілу при внесенні препаратів Авангард Гроу Аміно і Авангард Гроу Гумат у порівнянні з Вимпел 2 і Альфа Нано Гроу на 11,3-23,7 %. Прибавка зерна від використання стимуляторів росту на кукурудзі становила у ранньостиглого гібриду ДН Пивиха – 0,13-0,37 т/га (2,7-7,7 %), середньораннього ДН Хортиця – 0,85-1,08 т/га (16,6-18,5 %), середньостиглого ДН Джулія – 0,20-0,22 т/га (3,20-3,4 %), середньопізнього ДН Олена – 0,05-0,53 т/га (0,65-7,6 %). Серед використаних препаратів слід виділити Авангард Гроу Аміно та Авангард Гроу Гумат які забезпечували тенденцію до підвищення умісту сирого протеїну до 6,42-8,4 %, або на 0,12-0,48 в.п. (відсоткові пункти) більше та умісту сирого жиру порівняно з контролем (3,53-4,71 %) до 3,73-5,52 %, або на 0,20-0,81 в.п. Використання стимуляторів росту в умовах Північного Степу України на кукурудзі, особливо Авангард Гроу Аміно і Авангард Гроу Гумат на ранньостиглих та середньоранніх гібридах кукурудзи дозволяє збільшити валові збори зерна високої якості на 7,6-18,4 %

Ключові слова: гібриди кукурудзи; стимулятори росту; біометричні показники; одиниці SPAD; врожайність зерна; сирий протеїн; сирий жир; економічна ефективність

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Effect of additives with chelated forms of trace minerals on growth performance of broiler chickens, feed nutrient digestibility, and carcass characteristics

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Abstract. Demand for chicken meat has been growing in recent years, requiring prominent production levels and efficient feed conversion. The purpose of this study was to determine the productivity, preservation, and slaughter performance of broiler chickens, feed conversion on the background of feeding with additives with chelated forms of trace minerals. Poultry growth intensity was determined according to zootechnical methods, slaughter indicators – according to morphological methods, and statistical analysis of the results was used. By the end of the rearing period, the

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live weight of broiler chickens in the groups where the dietary supplement with chelated trace minerals (second group) and copper chelate complex (third group) was significantly higher than in the control group – by 6.9 and 13.8%, and the relative increase was 4.5 percentage points and 8.5 percentage points, respectively. The growth rate of broilers in terms of average daily weight gain is higher in these groups by 6.8% and 14.2%, respectively. The safety of poultry in the experimental groups is 4% better than in the control group. The feed conversion of a diet with chelated trace element additives is higher. Feed consumption in the experimental groups was reduced by 2.8% when feeding the selected additive and by 9.7% when feeding the copper chelate complex. The results of balance studies revealed an increase in the digestibility of nutrients in the diet of broiler chickens. Additives with micronutrient chelates are effective in increasing slaughter yield, meatiness of the thighs and shins, and pectoral muscles by 5.3-6.2 percentage points. The broilers of the experimental groups had a higher meatiness of the thighs and shins. The highest growth rate was found in broilers fed a copper chelate complex in their diet. The lower feed conversion in the control group is due to the lower body weight of these chickens. Based on the research data obtained, the possibility of effective introduction of additives with chelated microminerals into the diet of broiler chickens was established, which helped to increase the growth rate and meat yield. The results can be used in farm poultry farms to produce more products and reduce the cost of chicken production

Keywords: growth intensity; poultry; meat productivity; slaughter performance; feed conversion; feed consumption; live weight gain

INTRODUCTION

To ensure high growth and development of broiler chickens, it is important to provide trace elements that play an essential role in poultry metabolism, health, and bone mineralisation. During periods of intensive growth, a low supply of essential micronutrients leads to the development of micronutrient deficiencies. The bioavailability and assimilation of trace elements by the poultry body is important, depending on the feed composition, chemical form of the element, age, and physiological state of the bird. In poultry farming, trace elements are used to supplement the composition of feed, which allows poultry to reach their genetic growth potential and prevents various diseases.

The genetic base of broilers is constantly changing in the poultry industry, and poultry farmers are working to develop new diets to provide micronutrients to birds that grow intensively and are highly productive for meat. S. Zamany *et al.* (2023) confirm that broilers fed with micronutrient supplements have a higher average daily live weight gain and a lower feed conversion rate.

Most often, trace elements are added to poultry diets in the form of inorganic salts, which have low availability, although Z. Zhu *et al.* (2019) found that supplemental feeding of inorganic micronutrients ensures that poultry diets have sufficient amounts of each mineral to support normal growth, health, and reproduction. M. Kwiecień *et al.* (2017) argue that poor poultry housing conditions combined with high levels of mineral additives and low bioavailability of inorganic trace elements lead to an excess of them in poultry manure, and eventually they accumulate in the soil, which leads to environmental pollution. R. Vieira *et al.* (2020) recommend that to reduce the excretion of trace elements in the manure, it is necessary, first of all, to make them more accessible to the poultry body. Better availability of micronutrients can be achieved by feeding poultry and animals minerals in chelated form so that they can be fed in smaller doses. J. Chen *et al.* (2023) note that coccidiosis reduces poultry growth rate, and the addition of chelated trace elements can overcome this problem.

Trace elements based on organic acids have a higher bioavailability, which has been confirmed in studies using trace elements (manganese, zinc, selenium, iron, and copper). A study by J. Kong *et al.* (2022) investigated the feasibility of reducing the addition of copper, iron, zinc, and manganese in the form of glycine metal chelate hydrate or amino acid, which does not have a negative impact on poultry growth. A mineral chelate supplement based on organic acid that improves not only broiler performance but also bone structure and blood parameters. F. Faghih-Mohammadi *et al.* (2022), using copper, iron, zinc, manganese, and selenium chelates in the feeding of broiler chickens, found that blood chemistry did not change, but cholesterol and triglyceride levels decreased, as well as the bird's immune system increased and egg quality improved. Due to the antioxidant effect of copper, zinc, iron, and feeding these trace elements in a chelated, easily digestible form, the antioxidant status of broiler thigh meat changes.

The addition of methionine chelates, yeast protein forms of copper, iron, manganese, and zinc to broilers increases poultry growth, feed conversion, and reduces the release of trace elements into the environment. A. Winiarska-Mieczan *et al.* (2021) recommend that to increase the antioxidant resistance of chicken meat, glycine chelated copper should be added to the diet in an amount of 25% of the requirement for this element. Copper is widely used in poultry farming as a growth stimulant, antimicrobial agent and to support the immune system. A. Forouzandeh *et al.* (2021) argue that the addition of copper oxide and sulphate to the diet

results in changes in the gut microbiota by regulating the bacterial population in the ileum, which had a positive effect on the growth rate of broilers. Copper plays an important role in the antioxidant system and lipid peroxidation.

Thus, the realisation of the genetic growth potential is possible through the provision of trace elements to broiler chickens, especially chelated amino acids, which will improve metabolic processes in the body and increase live weight gain and slaughter yield. That is why the purpose of this study was to find out the impact of chelated micronutrient supplements on the growth rate of broiler chickens, feed conversion, and meat productivity of poultry.

MATERIALS AND METHODS

The study was conducted in the vivarium of Vinnytsia National Agrarian University (Ukraine) during 2023 on broiler chickens of the Cobb-500 cross. The study used day-old chickens that were evenly distributed between the groups. For this purpose, three groups of poultry were formed using the analogue group method, with 25 birds in each group. The studies followed the requirements for the care and maintenance of poultry. Broiler chickens were kept in three-tiered cages. Each cage had a water drinker and a hanging feeder. Water was supplied to each cage through a nipple drinker system. The vivarium room where the birds were kept was preheated to 27°C 2 days before the study. The room temperature at the beginning of the experiment was 32°C, and during the experiment it was lowered by 2°C every week. The temperature was lowered to 26°C on day 14, to 24°C on day 21 and to 21°C on day 24, and then maintained at 21°C until the end of the fattening period. Throughout the research period, the authors of this study also monitored compliance with the light regime in the vivarium. During the first week, the broilers were provided with lighting for 23 hours. From day 8 to day 39, the light period was gradually reduced to 20 hours, and from day 40 to the end of the experiment it was increased again to 23 hours per day.

During the rearing of broiler chickens, a three-phase feeding programme was used, depending on the age of the birds: the initial phase lasted from day 1 to 15, the growth phase began from day 16 and lasted until day 35, and the final phase from day 36 to 42. During the scientific, economic and physiological experiments, the broiler chickens were fed with dry, nutrient-balanced feed. The feed used for poultry feeding was based on the age of the broiler chickens, and therefore the appropriate feed was used for each phase. At the beginning of the experiment, up to 15 days of age, the starter feed "Starter PK5-1" was fed, from 16 days to 35 days – growth feed "Grover", from 36 to 42 days – finishing feed "Finisher". The feeds met the current age-specific nutrient requirements for growing broilers and were free of antibiotics and growth stimulants.

According to the task of this study, broiler chickens in the control group were fed the basic diet without mineral additives, the second experimental group was fed an additional supplement "Kronocid-L" at the rate of 2.5 ml per 10 litres of water, and the third experimental group was fed a copper-glycine chelate complex at the rate of 3.0 ml per 10 litres of water. Copper chelate complex contains 5% copper and 20% glycine. The Kronocid-L additive contains chelates of copper, iron, zinc, manganese, and 19% acids. The test additives were administered to the poultry diet by watering with water. Throughout the experiment, broiler chickens had free access to feed and water.

To analyse the effect of the copper chelate complex and the additive under study on the growth rate of broiler chickens, the birds were weighed every 7 days, from 3-day-old age until the end of the experimental period (42 days). Broilers were paid for feed gain by the amount of feed consumed, which was recorded during the periods from days 1 to 15, 16 to 35, 36 to 42, by the periods of feeding the respective feed. Daily live weight gain and daily feed intake per bird were calculated for each week, for the periods: days 1-7, 8-14, 15-21, 22-28, 29-35, 3-42. The average daily weight gain and average daily feed intake were calculated at the end of each phase and on a weekly basis. Chicken mortality was also recorded to determine the percentage of poultry survival. Poultry mortality was checked twice a day, and the weight of dead chickens was used to adjust the feed conversion rate. Each bird was weighed separately on an electronic scale.

On day 42, 5 birds from each group were selected close to the average weight of the group for slaughter to take tissue samples and investigate the effect of additives on meat performance. Control slaughter of broiler chickens was conducted following the DSTU 3136-2017 (2019). Based on the results of poultry slaughter, the live weight of uneviscerated, eviscerated, half-eviscerated poultry, the weight of breast, thigh, and leg muscles, the weight of internal organs were determined, and the percentage of carcass yield, percentage of breast, thigh and leg muscles were calculated. After the chickens were slaughtered, their organs and tissues were examined, and samples were taken for further research. All experimental studies were conducted per the modern methodological approaches and corresponding requirements and standards that follow DSTU ISO/IEC 17025:2005 (2006). Animal husbandry and all manipulations were performed according to the provisions of the Procedure for conducting tests and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012) of the European convention for the protection of vertebrates used for experimental and other scientific purposes (1986).

Statistical analyses of the results were performed using Statistica software package. The arithmetic mean and standard deviation were calculated. Results are

expressed as mean ± SD (standard deviation). One-way ANOVA was used to calculate statistically significant (P<0.05) differences between the mean values for the respective groups of broilers. For comparisons, statistically significant differences between the mean values for the respective groups of broiler chickens were calculated. The results were statistically significant at (p<0.05), (p<0.01), (p<0.001).

RESULTS AND DISCUSSION

Growth parameters are usually used to assess the growth rate of poultry. The study found differences in the growth of broiler chickens treated with mineral supplements (copper chelate complex and Kronocid-L). The effect of the additives under study on the performance characteristics (live weight, absolute and relative weight gain, and survival) of chickens is presented in Table 1.

Table 1. *Growth intensity of broiler chickens after introduction of additives with chelated microminerals to the diet, x±SD, n=25*

Poultry age	Group		
	control (MD)	experimental (SK)	experimental (CC)
Live weight at the beginning of the experiment, day 3, g	72.0±1.0	72.3±1.1	71.7±0.8
Live weight on day 8, feeding of starter feed, g	230.2±3.9	235.3±4.3	239.5±3.2
Live weight at day 15, feeding of starter feed, g	508.2±5.9	557.5±6.3***	561.5±7.9***
Absolute live weight gain during the period of feeding starter feed (days 3-15), g	434.2±5.9	485.2±15.1**	489.7±7.8***
Relative live weight gain during the period of feeding starter feed (days 3-15), %	149.1±0.7	154.0±0.8***	154.6±0.6***
Live weight at day 22, feeding with Grover feed, g	987.2±26.6	1,076.5±25.5**	1,091.1±27.3**
Live weight at day 29, feeding with Grover feed, g	1,558.6±30.2	1,712.8±18.9***	1,772.3±28.7***
Live weight at day 36, feeding with Grover feed, g	2,046.8±29.0	2,147.5±22.2**	2,195.2±45.5**
Absolute live weight gain during the period of feeding "Grover" feed (days 15-36), g	1538±30.5	1590±22.3	1633±46.9
Relative gain over the period of feeding Grover feed (days 15-36), %	120.3±1.2	117.5±0.9	118.2±1.7
Live weight at day 42, feeding Finisher feed, g	2,580.1±51.9	2,752.5±25.2**	2,937.5±34.0***
Absolute live weight gain during the period of feeding starter feed (days 36-42), g	533.3±33.7	605.0±35.2*	742.3±43.4***
Relative growth during the period of feeding Finisher feed (days 36-42), %	22.9±2.6	24.7±1.4	29.1±1.8**
Absolute live weight gain during the period of feeding starter feed (days 3-42), g	2,506.2±51.4	2,680.2±25.3**	2,865.8±34.2***
Relative growth during the growing period (3-42 days), %	188.8±0.2	189.7±0.2**	190.4±0.2***
Poultry safety, %	92	96	96

Note*: * – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, SK – supplement Kronocid-L, CC – copper chelate*
Source: *compiled by the authors of this study*

The live weight of broiler chickens on day 8 in all three groups was almost the same at 230.2-239.5 g. Over the next week, after the introduction of the additives under study into the diet, the poultry began to grow more intensively and in the second group the live weight of chickens was 97% higher (at p<0.001), in the third group – by 10.5%. The absolute increase in live weight during the period of feeding the starter feed (days 3-15) was 11.7% higher in the second group (p<0.01), and 12.7% higher in the third group (p<0.001) compared to the data in the control group. The relative increase in live weight, which characterises the growth rate, during this period of poultry rearing with the introduction of the additive "Kronocid-L" to the diet is 3.3 p.p. higher (p<0.001), under the influence of copper chelate complex – by 3.7 p.p. (p<0.01). In the next period, the broilers of the experimental groups maintained their growth rate. At the end of the third week of rearing, live weight in chickens of the second group increased by 9.0% (p<0.01), and in the third group – by 10.5% (p<0.01). In the following period (days 29-36), both supplements showed a higher increase in live weight than in the group without supplementation. The difference was 9.9 and 13.7% (p<0.001), respectively, compared to the data of the control group. On day 36, broilers of the second group showed a trend of more intensive growth

(p<0.01) and outperformed the control group by 4.9%, and the third group by 7.3%.

At the end of the second growing period, the absolute increase in live weight was 3.4% higher when feeding Grover feed and the introduction of the additive Kronocid-L into the diet, and the increase in copper chelate complex was 6.1%. In the final period of rearing, broiler chickens (36-42 days) fed Finisher continued to grow intensively. However, during the last phase of poultry rearing, with the introduction of the additive "Kronocid-L", the live weight of chickens was 6.9% higher (p<0.01) and the copper chelate complex – 13.8% (p<0.001), the relative increase – 7.9 and 27.0 p.p. (p<0.001), respectively. The absolute increase in live weight over the entire period of poultry rearing in the second group was 6.9% higher (p<0.01), and when the chelated copper-glycine complex was introduced into the diet, it was 14.3% higher (p<0.001) compared to the control group. The relative growth during this period in broilers fed with mineral supplements was 4.5 (p<0.01) and 8.5 p.p. (p<0.001) higher, respectively. The introduction of the additives under study into the poultry diet had a positive effect on health, which accordingly affected the safety of the livestock. In the experimental groups, this figure is the same and 4% higher than in the control group. Average daily live weight gain is the main indicator of poultry growth intensity. As Table 2 suggests, the average daily weight gain at different age periods in all groups of broiler chickens differed. The best live weight gains were obtained in broilers when mineral supplements were used in the diet starting from the day 8 of rearing.

Table 2. *Average daily live weight gain of broiler chickens during the period of feeding supplements with chelated microminerals, g*

Rearing period	Group		
	control (MD)	experimental (SK)	experimental (CC)
3-8	25.5±0.7	27.2±0.8	28.0±0.6
8-15	40.2±1.1	46.0±1.1***	46.0±1.1***
15-22	68.4±1.4	74.1±1.6	75.7±1.7
22-29	81.6±1.5	90.9±1.3***	97.3±1.4***
29-36	62.7±2.8	62.1±2.3	67.4±2.6
36-42	83.2±2.1	86.4±1.4	98.9±2.2***
Average for the period of the experiment	62.7±1.3	67.0±0.6**	71.6±0.9***
Feed consumption per weight gain, g	2,197	2,136	1,983

Note*: * – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, SK – supplement Kronocid-L, CC – copper chelate*
Source: *compiled by the authors of this study*

The advantage in average daily weight gain in poultry of the second and third groups during days 8-15 was the same and amounted to 14.4% (p<0.001). In the subsequent periods of rearing, the greatest advantage in this indicator was found in chickens that were supplemented with a copper chelate complex. The increase in the average daily live weight gain was 10.7% during days 15-22, 19.2% (p<0.001) during days 22-29, 7.5% (p<0.01) during days 29-36, and 18.8% (p<0.001) in the final period of rearing. The supplementation of the diet also resulted in lower scores than in the third group, but still higher than in the first control group. The advantage in these periods, starting from day 15 of rearing, for two weeks was 8.3 (p<0.01) and 1.4%, for days 29-36, chickens of the second group were slightly behind in daily live weight gain (by 0.9%). In the next period (days 36-42), broilers retained their growth advantage over control birds and the difference between the groups was 3.8% (p<0.01). On average, over the entire period of the experiment, the highest average daily live weight gain was found in the third group of chickens fed a copper chelate complex. The birds of this group outperformed the control group by 14.2% (p<0.001). In addition, the broiler chickens of the second group, which were fed the supplement, had better average daily live weight gain compared to the control group, with a difference of 6.8% (p<0.01). However, they were 6.4% lower than the third group.

The study demonstrates the benefits of mineral supplements in the poultry diet to pay for feed gain in broilers. Less feed was consumed per unit of live weight gain in chickens fed a copper chelate complex. The birds of the control group were 9.7% lower in this indicator, and those of the second group were 7.2% lower. However, the broilers fed the supplement consumed 2.8% less feed per unit of live weight gain compared to the control. The results of the balance studies revealed an improvement in feed conversion, i.e., an increase in the digestibility of nutrients in the diet of broiler chickens.

The introduction of a copper chelate complex into the broiler diet increased the digestibility of dry matter by 20 p.p. (p<0.01), organic matter – by 3.7 p.p. (p<0.001), protein – by 4.1 p.p. (p<0.001), fat – by 3.1 p.p. (p<0.001), fibre – by 11.7 p.p. (p<0.001) and roentgen equivalent man (REM) – by 2.3 p.p. (p<0.001). In the second group of poultry, a similar trend is observed to increase the digestibility of nutrient components of the feed. Thus, an increase in the conversion of dry matter by 1.0 pp, organic matter – by 3.1 p.p. (p<0.001), protein – by 2.7 p.p. (p<0.001), fat – by 1.4 p.p. (p<0.01), fibre – by 7.0 p.p. (p<0.01), and REM – by 1.3 p.p. (p<0.01) (Table 3).

Table 3. *Digestibility of feed nutrients by broiler chickens with the introduction of additives with chelated microminerals into the diet, %*

Indicator	Group		
	control (MD)	experimental (SK)	experimental (CC)
Dry matter	80.5±0.3	81.3±0.2*	82.1±0.2**
Organic matter	81.2±0.3	83.7±0.4***	84.2±0.6***
Protein	83.1±0.4	85.3±0.3***	86.5±0.7***
Fat	78.3±0.3	79.4±0.2**	80.7±0.2***
Fibre	12.8±0.08	13.7±0.11***	14.3±0.09***
REM	82.7±0.2	83.8±0.3**	84.6±0.3***

Note*: * – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, SK – supplement Kronocid-L, CC – copper chelate*
Source: *compiled by the authors of this study*

Supplementation of the broiler chickens' diet also had a positive impact on slaughter rates, carcass, meat, and internal organ yields. The carcass yield of broilers fed the copper chelate complex and the additive under study was higher than that of the control group. Comparing the pectoral muscle yield in the third group with the control group, it is 6.2 percentage points higher (p<0.01). The second group of chickens also obtained more (p<0.05) pectoral muscles (by 5.3 p.p.) than chickens that were not fed mineral supplements. Birds of the second and third groups had higher thigh meatiness. In these groups, the number of thigh muscles was slightly higher, but the number of lower leg muscles was lower (by 2.1 and 2.7 p.p., respectively) (Table 4).

Table 4. *Indicators of slaughter of broiler chickens under the influence of additives with chelated trace minerals*

Poultry age	Group		
	control (MD)	experimental (SK)	experimental (CC)
Pre-slaughter weight, g	2,690.0±37.8	2,893±18***	2,911± 34***
Weight of half-eviscerated carcass, g	2,193.0±43.7	2,390±31***	2,513±39***
Weight of eviscerated carcass, g	2,009.7±34.5	2,146±19***	2,189±28***
Slaughter yield, %	74.6±0.2	75.0±0.4	75.2±0.2*
Weight of pectoral muscles, g	610.3±32.9	695.0±19.1*	708.0±20.0*
in % of eviscerated carcass	30.4±0.4	32.0±0.3*	32.3±0.5**
Weight of thigh muscles, g	237.7±5.0	257.3±4.9*	262.3±4.9**
in % of eviscerated carcass	11.83±0.07	11.87±0.03	11.98±0.09
Lower leg muscle mass, g	192±3.4	202.6±4.4	203.3±4.3*
in % of eviscerated carcass	9.55±0.07	9.35±0.2	9.29±0.08
Weight, g: liver	57.3±3.3	68.4±3.0*	68.2±2.2*
hearts	14.7±0.1	13.8±0.2**	14.2±0.2
muscular stomach	18.6±0.2	18.3±0.2	17.8±0.1**

Note*: * – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, SK – supplement Kronocid-L, CC – copper chelate*
Source: *compiled by the authors of this study*

There were changes in the weight of internal organs after the introduction of mineral additives into the poultry diet. In the second group of broiler chickens, 19.4 and 19.0% more liver weight was obtained ($p<0.05$). The heart weight of the second group was 6.1% lower ($p<0.01$). There was no significant effect of the mineral supplements on stomach muscle mass. The studies confirmed that the use of feed additives containing chelated trace elements for broiler chickens had a positive effect on economic traits, which contributed to an increase in live weight, slaughter yield, and conversion of feed nutrients.

According to researchers who have investigated this subject, mineral additives are among the products that reduce feed costs for production, improve feed conversion, and increase live weight (Fotina *et al.*, 2021). Recently, chelated micronutrient additives have been increasingly used in livestock production as growth stimulants that improve the general condition of animals and poultry, increase productivity, which helps livestock, including poultry, to develop economically (Bhagwat *et al.*, 2021). S. Villagómez-Estrada *et al.* (2020) managed to increase the productivity and mineral status of pigs by adding copper to their diet at the permissible levels of the European Union. Mineral copper supplementation can be effective for more intensive growth if poultry are fed above the minimum requirements. O. Olukosi *et al.* (2018) found an increase in the growth performance of broiler chickens and meat yield under the influence of zinc and copper hydroxychloride. M. Hamdi *et al.* (2018) confirmed the increase in live weight of poultry with the introduction of chelated copper supplements into the diet.

Copper is often used in combination with amino acids, particularly glycine. V. Sakara & A. Melnyk (2019) also confirm the higher efficiency of the use of vitamin-amino acid chelates of zinc and manganese in poultry feeding, which contributed to an increase in live weight and improved blood counts. The conclusions of the study on the impact of the effectiveness of the use of additives with chelated forms of trace minerals in the feeding of broiler chickens coincided with the previous results of scientists. The effect of the introduction of chelated trace element additives with free access to feed into the poultry diet affected live weight, absolute and average daily weight gain. Studies have revealed differences in the growth of broiler chickens fed supplements containing chelated trace elements. The diet containing additives containing chelated trace elements (chelated copper complex with glycine and Kronocid-L) improved the live weight and growth rate of chickens compared to the diet without additives.

Chelated forms of trace elements improve the overall health of broilers, which subsequently has a positive impact on poultry safety. Higher mineral digestibility, a positive effect on growth rate, bone mineralisation, slaughter performance, and organoleptic properties of meat were obtained by using chelated forms of trace elements in poultry feeding, as described by H. Ghasemi *et al.* (2020). Comparable results were obtained in the current study on broiler chickens. By the end of rearing, the introduction of chelated micronutrients increased the safety of poultry in these groups. The evaluation of the economic and useful properties of broiler chickens under the influence of additives with chelated microminerals (copper chelate complex, the additive under study) in the free access was assessed by the results of a control slaughter carried out at the age of 42 days. Slaughter rates can reflect the meat productivity of animals and poultry, which is a key indicator that affects the economic performance of livestock farming. Adjustment of animal diets with mineral premixes improves not only slaughter yield, but also increases the yield of quality meat (Yaremchuk *et al.*, 2022; Farionik *et al.*, 2023). The studies by S. Van Kuijk *et al.* (2021) and T. Santos *et al.* (2021) confirm the current results on the positive impact of mineral supplements on slaughter performance and carcass characteristics.

Raising broilers on feed with chelated trace elements reduces feed costs per unit of growth (Fotina *et al.*, 2021). The feed consumption of poultry in the three groups was almost the same, but there was a difference in feed consumption for live weight gain. Feed costs per unit of weight gain in broilers fed a copper chelate complex and a supplement with free-access chelated trace minerals were significantly lower. In livestock and poultry farming, the nutrient balance method is used to determine the nutrient absorption potential of the diet. The inclusion of additives with chelated trace elements in the diet of broiler chickens had a positive effect on the absorption of feed nutrients. In the studies conducted, the chickens' diets were formed according to the three-phase feeding system and contained all the necessary components for successful development. When copper chelate complex and additives are introduced into the chicken diet, the digestibility of nutrient components of feed increases. The digestibility coefficients of feed nutrients in these groups of poultry were significantly higher than in the control group. The data obtained from studies on broiler chickens are consistent with the findings of R. Tymoshenko *et al.* (2018), who confirmed that chelated forms of trace elements have a greater ability to be absorbed by the body, which contributes to an increase in poultry productivity. Based on the data from the study, it can be concluded that additives with chelated forms of micronutrients are effective in increasing growth performance, improving feed nutrient absorption and increasing meat yield.

CONCLUSIONS

It was found that the live weight of broiler chickens consuming a diet with additives containing chelated forms of trace minerals) at the age of 7, 14, 21, 28, 35, and 42 days was higher than that of broilers without additives. Live weight was 13.8% higher at 42 days of

age with the introduction of copper chelate complex and 6.9% higher with the supplementation, while the growth rate of broilers in terms of relative live weight gain at the end of the experiment in these groups was 8.5 and 4.5 percentage points higher, respectively.

Chickens grew more intensively when supplemented with chelated micronutrients, which increased the average daily live weight gain in the group where copper chelate complex was introduced into the diet by 14.2% and the supplement by 6.8%. Better availability of trace elements of the additives under study had a positive effect on poultry performance.

The survival rate of young animals where chelated micronutrients were used in feeding was 4% higher. The introduction of additives with chelated trace elements to the broiler diet increased the digestibility of organic matter by 3.1-3.7 p.p., protein by – 2.7-4.1 p.p., fat – by 1.4-3.1 p.p., and fibre – by 7.0-11.7 p.p., which led to a reduction in feed costs in these groups. Feed costs per unit of weight gain were lower in the broiler group with the addition of Kronocid-L to the diet by 2.8% and copper chelate complex by 9.7%, which will help reduce the total cost of raising poultry and increase profitability in the poultry industry.

Growing broiler chickens on feed with chelated forms of microminerals increases the slaughter yield by 1.6 p.p. and significantly increases the yield of breast muscles by 5.3-6.2%. The yield of thigh muscles in the group of poultry administered copper chelate complex was 10.3% higher.

The findings of this study strongly suggest that the use of copper chelate complex and additives as part of an intensive broiler rearing strategy contributes to better availability of micronutrients, which increases growth intensity and slaughter yield while reducing costs per unit of growth and, as a result, reduces overall production costs. Future research may include studying a wider range of micronutrients, determining optimal doses and ratios of micronutrients in the diet to maximise performance, and investigating different forms of chelates to maximise bioavailability.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Вплив добавок з хелатними формами мікромінералів на продуктивність росту курчат-бройлерів, перетравність поживних речовин корму та характеристики туші

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Анотація. Попит на куряче м'ясо останніми роками зростає, що вимагає високого рівня виробництва та ефективної конверсії кормів. Метою даного дослідження було визначення продуктивності, збереженості та забійних показників курчат-бройлерів, конверсії корму на фоні годівлі добавками з хелатними формами мікромінералів. Визначення інтенсивності росту птиці проводили за зоотехнічними методами, показників забою – за морфологічними, при цьому використовували статистичний аналіз результатів. До кінця періоду вирощування жива маса курчат-бройлерів у групах, де вводили до раціону та досліджувана добавка з хелатними мікромінералами (друга група) та хелатний комплекс міді (третя група), достовірно вища за дані контрольної групи – на 6,9 % і 13,8 % та відносний приріст – на 4,5 п.п. і 8,5 п.п. відповідно. Швидкість росту бройлерів за середньодобовим приростом вища у зазначених групах відповідно на 6,8 % і 14,2 %. Збереженість поголів'я птиці у дослідних групах краща на 4 % щодо контролю. Конверсія корму раціону з хелатними мікроелементними добавками вища. Витрата кормів у дослідних групах знижувалась за згодовування обраної добавки на 2,8 % і з хелатним комплексом міді – на 9,7 %. За результатами балансових досліджень виявлено підвищення перетравності поживних речовин раціону курчат-бройлерів. Добавки з хелатами мікромінералів ефективні у підвищенні забійного виходу, м'ясистості стегон та гомілки, грудних м'язів – на 5,3-6,2 п.п. Бройлери дослідних груп мали вищу м'ясистість стегон та гомілки. Найвищий темп росту виявлено у бройлерів, яким у раціоні вводився хелатний комплекс міді. Нижча конверсія корму у контрольній групі пов'язано з нижчою масою тіла цих курчат. На підставі отриманих даних досліджень встановлено можливість ефективного введення до раціону курчат-бройлерів добавок з хелатними мікромінералами, що дозволило підвищити інтенсивність росту та вихід м'яса. Результати можуть бути використані у фермерських птахівничих господарствах для отримання більшої кількості продукції та здешевити виробництво курятини

Ключові слова: інтенсивність росту; птиця; м'ясна продуктивність; показники забою; конверсія корму; витрати корму; прирости живої маси

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Morpho-physiological characteristics of plants and biochemical parameters of rowan berries, common rowan, and domestic rowan grown in the conditions of the Northern Forest-Steppe of Ukraine

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Abstract. The relevance of this subject lies in the comparative evaluation of different species of rowan to increase their significance and use in the system of ornamental and fruit horticulture, in the technologies of processing plant raw materials, and in the production of products for healthy nutrition. The purpose of the study is to examine the morpho-physiological characteristics of plants and the biochemical parameters of the fruits of different species (varieties, forms) of the genus Sorbus. Based on the results of

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practical research, original data on the morphology and economic characteristics of representatives (varieties and forms) of *Sorbus intermedia* Pers., *Sorbus aucuparia* L., *Sorbus domestica* L. are presented. Biological properties of the plants and biochemical parameters of the fruits are highlighted. It is established that all studied representatives of the genus *Sorbus* have high winter hardiness (1.5 points according to S.Ya. Sokolova), in addition, Scandinavian rowan plants have high drought resistance (4.5 points according to S.S. Pyatnitsky) compared to common rowan plants. Phenological observations of plants of different rowan species allowed for the conditions of the Forest-Steppe of Ukraine to determine the time of onset of ontogenesis phases: development of vegetative buds, appearance of leaves, shoot growth, budding, and flowering, formation and development of ovaries, ripening and fruiting, changes in leaf colour, and leaf fall. Subphases that more accurately characterise the time of onset, peak, and end of a certain phase of development have also been identified, which is a scientific achievement for strategies in the system of ornamental and fruit horticulture. The growth intensity of varieties and forms of representatives of the *Sorbus* genus in height was studied, and the general condition of plants for viability is evaluated. Preparatory work on the preparation of rootstocks, the selection of scions, and grafting allowed the formation of model plants in the collection nursery and additional assessment of their growth strength, the onset and passage of individual phases of development, assessment of drought and winter hardiness, age of fruiting, and more. Biometrics and descriptions of stem, branches, vegetative and generative buds, leaves, inflorescences, and fruits are also conducted. The taste characteristics of the fruits are described in the materials of the paper. Biochemical analysis of the fruits allowed establishing their suitability for processing and the production of products for healthy nutrition

Keywords: *Sorbus intermedia* Pers.; *Sorbus aucuparia* L.; *Sorbus domestica* L.; morphological features; physiological features of plants; biochemical properties of fruits

INTRODUCTION

The world needs effective plant species in the system of ornamental and fruit horticulture and safe resources of their raw materials. Preference is often given to niche fruit crops, including species belonging to the genus *Sorbus* L., 1753 (*Rosaceae*, Juss., 1789). Since rowan species are valuable for ornamental, medicinal, and fruit-bearing purposes, and eight of them grow in Ukraine, with the majority of their harvest being important for processing and the production of healthy food products, further research into the morpho-physiological characteristics of plants and biochemical studies of plant raw materials of varieties (forms) of fruit representatives of the genus *Sorbus*: common rowan, domestic rowan, and Swedish rowan, is highly relevant for expanding the database of information for the improvement of directions in plant biology, breeding, and biochemistry for the industries of processing and producing environmentally safe and high-quality food products (jellies, jams, blended juices, beverages, wines, etc.).

The examination of the patterns of the emergence and development of external characteristics of plants and their organs in the genus *Sorbus* has been the subject of several works, such as those by Z. Qiu *et al.* (2023), which allow tracking changes that occurred in the plant forms during ontogeny (individual development) and phylogeny (historical development) and changes induced by the environment. These practical data have been used to enrich fundamental research in botany, plant morphology and physiology, fruit-bearing, breeding, genetics, biochemistry, fruit processing, pharmacology, pharmaceuticals, and more.

According to botanical research by J. Levin *et al.* (2019), new species have been discovered and described in the Baltic Sea basin, specifically in Gotland and the Åland Islands. These are intermediate species between *Sorbus* aucuparia and *S. hybrida*. A. Hajrudinovi´c-Boguni´c *et al.* (2023) note that this diversity results from the interaction of polyploidisation, hybridisation, and apomixis, leading to exceptional diversity in the *Sorbus* genus (*Rosaceae* family), which generates various new genetic and morphological forms requiring further investigation.

Systematised data on the morphology of *Sorbus* representatives are necessary as they allow specialists to choose suitable components for orchard design in the system of ornamental and fruit horticulture. As V. Sarv *et al.* (2020) argue, many species of the *Sorbus* genus are widely used in food production and traditional medicine, necessitating further study of the organic compounds in rowan berries. Therefore, as indicated by M. Räty *et al.* (2016), Sorbus species, varieties (forms) are important in the system of ornamental and fruit horticulture, serving as vital components of forest stands in parks, squares, and gardens. However, there is a challenge – climate change is pushing their localisation to higher altitudes and further north. In the future, it is expected that they will lose their presence in southern, central, and eastern Europe.

Given the above, it can be said that the study of representatives of the *Sorbus* genus is important in the context of current climate fluctuations worldwide. The selection of the best genotypes with high bio-potential and their targeted introduction could expand the range of valuable species for ornamental and, for the most part, fruit-bearing purposes. This is particularly relevant as practically all rowan species are relatively disease-resistant, cold-resistant, and some, such as *Sorbus*

aria (Silver Whitebeam), *Sorbus hybrida* (Swedish Whitebeam), and *Sorbus intermedia*, are highly drought-resistant, which is essential not only for agroforestry and horticulture but also for the food industry due to the high fruit quality.

As noted by M. Sarv *et al*. (2020), there is also an issue regarding the insufficient use of plant raw materials from representatives of the *Sorbus* genus, including fruits, for preparing food products, nutraceuticals, and as sources of polyphenolic compounds and high antioxidant potential. This, according to J. Rand (2018), is possibly linked to the reduction in rowan orchards worldwide. Therefore, there is a need for a comprehensive approach in further research and dissemination of information about representatives of the *Sorbus* genus in a systematic manner to improve the knowledge base in the fields of biology, breeding, fruit-bearing, processing, and the development of technologies for producing medicinal phytopreparations for disease prevention and healthy food products (Lytovchenko *et al.*, 2021).

Thus, the analysis of literature sources indicates the inadequacy of research on the morphology, physiology, and ecology of plants of the species *Sorbus intermedia* Pers., *Sorbus aucuparia* L., *Sorbus domestica* L., and their significance in ornamental and fruit horticulture, including the utilisation of their fruits in processing and producing healthy food products. This highlights the relevance of further research in these areas. The purpose of the study is to evaluate various species (varieties, forms) of representatives of the genus *Sorbus* according to the morpho-physiological characteristics of plants and biochemical parameters of fruits.

MATERIALS AND METHODS

The analysis of the morpho-physiological characteristics was conducted in research plots at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (NAAS) and its research network (Chernihiv and Lviv regions) during 2017-2021. The main methods used for morphological analysis of rowan plants included observation and description, serving as a fundamental comparative method for studying their development, both individual (ontogenetic) and historical (phylogenetic). By measuring the height of rowan plants, the height of the crown's beginning, the height of the largest diameter of the crown, and the lower limit of dead branches' presence, essential parameters for subsequent biometric assessments were determined. Throughout the vegetation period of the rowan plants, dates of phenophase onset were recorded based on phenological observations, which were conducted from a week before the beginning of vegetation to the end of the vegetation period (2017-2021). The assessment included the flowering and fruiting intensity, field winter hardiness, drought resistance following S.I. Melnyk's (2016) criteria

The beginning of the development phase was considered the date when a specific phase occurred in 10% of the observed plants, and the end of the phase when it finished in 90% of the plants. Average start and end dates for the development phase were used. Additionally, plant height was measured annually after the vegetation period using a special ruler with markings to assess the growth intensity. Three categories were used, considering the average height and stem diameter: low-productive (which grew worse than the average indicators by more than 15-20%), medium-productive (growth height did not exceed average indicators), and high-productive (growth exceeded average indicators by up to 10%).

In parallel with growth assessment, the overall health of the plants was considered, reflecting vitality. This was assessed based on resistance to phytopathogens, growth patterns, leafiness, and was expressed on a scale from poor (1 point) to excellent (9 points), where poor condition indicated partial or complete withering of branches or tree death, unsatisfactory condition showed below-average growth with signs of wilting and leaf disease, satisfactory condition indicated average growth with moderate leafiness and slight signs of disease, good condition meant high growth, healthy dark green or green leaf colour, moderate leafiness, and the absence of damage from adverse environmental factors.

Biochemical analysis of the rowan fruit was conducted in the laboratory specialising in post-harvest quality of fruit and berry products, and the experts performed the analysis. The weight and quality of the samples met the requirements of the Methodology for Assessing the Quality of Fruit and Berry Products (Kondratenko *et al.*, 2008) and DSTU ISO 874-2002 (2003). The content of dry matter was determined by drying method, soluble solids were determined according to DSTU 2173:2007 (2009), sugars according to DSTU 4954:2008 (2009), organic acids according to DSTU 4957:2008 (2009), polyphenolic compounds according to DSTU 4373:2005 (2006), pectin substances according to DSTU 8069:2015 (2017), vitamin C according to DSTU ISO 6557-2:2014 (2015), anthocyanins and chalcones by V. I. Krivenkov's method, and oxidation-reduction potential and pH of the juice were determined using a pH meter/ORP meter from HANNA. The study was conducted with threefold replication and statistically processed in Excel. During the research, the requirements of the Convention on Biological Diversity (1992) were followed.

RESULTS

Only after the establishment of a collection nursery and the conduct of expeditionary work to determine model plants of the *Sorbus* genus, data from morphological analysis and physiological research were accumulated, processed, and systematised. This allowed for the formulation of objective descriptive conclusions about each investigated form of rowanberry plants. In general, the results of phenological observations on representatives of the *Sorbus* genus identified the main phases

and subphases of plant development, starting from the moment when the average daily temperature reaches +5°C. Regarding the main phases of development, the focus was on the phase of vegetative bud development and its subphases: swelling and the beginning of budburst (on average, occurring from the end of the third decade of March to the first decade of April); leaf appearance and subphases of the beginning and full leaf unfolding, and full leaf coverage (from the end of the first to the middle of the second decade of April); shoot growth, beginning (beginning of the second decade of April), and end (first decade of August); flowering phase, which includes the subphases of budding (third decade of April), beginning (end of the first to the beginning of the second decade of April), full (middle and end of the second decade of May), and the end of flowering (beginning of the third decade of May); phase of fruit formation and development (first decade of June); the phase of fruit ripening, beginning (third decade of August), and end (end of September); fruit drop (for domestic and Scandinavian rowanberry plants) and subphases of the beginning (end of the third decade of August to the first decade of September), mass (second decade of September), and final (third decade of September), leaf colour change – yellow (second decade of September) and crimson (third decade of September to the first decade of October), and the final phase – leaf drop, subphases of the beginning (second decade of October), mass (third decade of October), and final (first decade of November).

Phenological studies allowed for understanding that the period between the start and completion of the vegetative bud phase lasts 6-9 days, after which bud unfolding and leaf growth begin. The budding and flowering phase lasts approximately 14 days, but this can vary depending on weather conditions. It was also noted that temperature and air humidity significantly affect the duration of the fruit ripening phase, with dry and hot weather causing it to shorten by 36 days, with most fruits falling prematurely. Low air temperatures during the completion of fruit development subphases also influence fruit drop rates, particularly for Scandinavian and domestic rowanberry plants. It is worth mentioning that fluctuations in the weather-climate regime during the vegetation period determine the dates of the onset and duration of rowanberry plant development phases and may vary from year to year. In parallel with phenological observations, morphological and physiological research was conducted. Height measurements of plants after the completion of vegetation each year allowed for determining the intensity of rowanberry plant growth (Table 1).

Table 1. *Growth rate by height of Rowanberry plants (end of growing season)*

Variety/form	Growth intensity category
Domestic Rowanberry Form F. 1	highly productive
Domestic Rowanberry Form F. 2	highly productive
Common Rowanberry Form F. 3	moderately productive
Common Rowanberry (seedling of unknown origin)	moderately productive
Common Rowanberry, Burka variety	moderately productive
Common Rowanberry, Businka variety	moderately productive
Scandinavian Rowanberry, Brouwers variety	highly productive

Source: *compiled by the authors*

Subsequently, the overall condition of rowanberry plants was considered, evaluating them for resistance to phytopathogens, growth characteristics, foliage density, and expressing it in scores (Table 2).

Table 2. *Overall condition of Rowanberry plants by vitality*

Variety/form	Overall condition	
	score	manifestation
Domestic Rowanberry Form F. 1	9	excellent
Domestic Rowanberry Form F. 2	9	excellent
Domestic Rowanberry Form F. 3	5	satisfactory
Common Rowanberry (seedling of unknown origin)	5	satisfactory
Common Rowanberry, Burka variety	7	good
Common Rowanberry, Businka variety	7	good
Scandinavian Rowanberry, Brouwers	9	excellent

Source: *compiled by the authors*

Thus, based on growth intensity, highly productive rowanberry plants were Domestic Rowanberry Form F. 1 and F. 2, and Scandinavian Rowanberry Brouwers variety, which also exhibited excellent overall condition (9 points). It was found that by the growth intensity category, the plants of Domestic Rowanberry Form F. 3, Common Rowanberry (seedling of unknown origin), and Common Rowanberry varieties Burka and Businka were moderately productive, with a good overall condition (7 points). Plants of Common Rowanberry Form F. 3 and Common Rowanberry (seedling of unknown origin) had a satisfactory overall condition (5 points) as they exhibited moderate foliage density and signs of mild disease damage, which locally caused necrosis.

Based on the analysis of long-term data, it was determined that the variety of rowanberry, which is intermediate or Swedish rowanberry (*Sorbus intermedia* (Ehrh.) Pers., 1806, or *Sorbus scandica* (L.) Fr.) Brouwers since 1956, listed in the State Register of Plant Varieties of the Netherlands, is a tree in terms of its life form, with a growth strength of approximately 0.4 metres. The tree studied had an average height of 4 metres. Although the mother plants from which scions were taken for grafting in the park of the Institute of Horticulture of the National Academy of Agricultural Sciences of Ukraine reach heights of over 10 metres. On the tree, the number of skeletal branches is average (⩽10), their orientation is semi-vertical, and branching is strong. Regarding their position relative to the trunk and the angle of placement, they diverge from the trunk at a height of 1.5 metres at an angle >65° from various points. The crown shape of the tree is round-pyramidal, with density being high, and its habit is conical.

One-year-old shoots, with a thickness of 8.6 mm during their period of intensive growth, exhibit a weak anthocyanin colouring at their tips. The colour of the bark of the one-year-old shoot is olive-grey-light-brown, and the size of the base of the bud on it is large (8 mm). The vegetative bud is slightly inclined or inclined relative to the shoot and is of medium size (>8 mm). It is dark brown in colour and has moderate stickiness of the outer scales. The tip of the vegetative bud is wide-conical-elongated, while for the generative bud, the tip is pointed. The time of the onset of development of vegetative buds is average (end of the third decade of March to the beginning of the first decade of April). The time of bud burst (appearance of leaves) is also average (second decade of April). The density of leaf arrangement at the end of the shoot is significant, with 8 leaves present. The leaves are simple, entire, broadly elliptical or elongated-egg-shaped, doubly serrate, weakly pinnately lobed. The leaf tip type is obtuse, the base shape is round, the margin is biserrate, and the venation type is palmate-pinnate. The number of leaflets or ovate leaflets along the length of 3.7 cm is 9-13, and the petiole is short (2.7 cm) in length. The leaf size is medium (11.6×7.8 cm), the cross-sectional profile is straight, and the intensity of green colouration is intensive. The anthocyanin colouration intensity is absent or weak. The leaves have a moderate to high glossiness, with slight pubescence on the upper side and moderate to strong pubescence on the lower side. The onset of yellow leaf colouration is average (beginning of the third decade of September), while the onset of red leaf colouration is average (end of the third decade of September). Leaf fall occurs in the mid-early period (second decade of October).

The inflorescence type is a corymb with a diameter of 15 cm, and the number of flowers on it is average (52 flowers). The flower diameter is smaller than average (d=1.2 cm). There are 5 petals on each flower, their position is horizontal, and their arrangement is non-touching. There are 20 stamens per flower, and their shape is elliptical. The flower stalk is long (⩽2 mm) and characterised by strong pubescence. The time of flowering onset is late (third decade of May to the first decade of June). The degree of flowering (signs) is 4 (good, 60-80%). Self-fertility is very high (90%). The primary colour of the fruit pulp is light brown or light orange, while the skin is brick-red. The skin has moderate glossiness. The fruit is semi-spherical in shape, with a height that is low or medium (7 or 1.2 mm) and a width that is small (1-1.2 mm). The average number of fruits on a corymb is 20. The weight of 1000 fruits is 0.811 kg. The number of seeds in a fruit is low (2 seeds), and the weight of 1000 seeds is low (16.2 g). The onset of fruit ripening is moderately late (second to third decade of September). The ripening group is late.

The taste of the fruits is weakly acidic, weakly sweet, without bitterness. The fruits are rich in nutrients, including a vitamin C content of 69.3 mg/100 g, a total sugar content of 18.9% on a fresh weight basis, dry matter content of 43.5%, soluble dry matter content of 34.4%, titrated organic acid content of 0.7%, pectin content of 1.96% on a fresh weight basis, polyphenolic compounds content of 1056 mg/100 g of fresh weight, flavonoids content of 217.5 mg, anthocyanins content of 3.3 mg, chalcones content of 13.8 mg/100 g of fresh weight. The sugar-acid index is 27.1, and the sensory evaluation on a 9-point scale is 2.7 (average).

It is worth noting that the Brouwers variety plants are highly and moderately resistant to pear mites (*Eriophyes piri* Pagenst.) – 8 points, and rowan aphids (*Dentatus sorbi* Ralt.) – 7 points. They are also highly winter-hardy – 1.5 points (according to S.Ya. Sokolova) and drought-resistant – 4.5 points (according to S.S. Pyatnitsky). The fruiting cycle of Scandinavian rowan plants is annual, the abundance of fruiting is moderate (3.5 points), and the time (age) of maximum fruiting from seedlings is late (8-11 years), while the time (age) of maximum fruiting on a graft is early (2-3 years). The variety "Nevyazhynska Yellow Common Rowan" (Sorbus aucuparia L., 1753) is a deciduous tree in terms of life form. The researched plants were up to 3 metres tall

with an elongated-round crown shape. The maternal plants used for grafting reached 8 metres in height. The crown density is average, and the habit is slightly sprawling. The number of skeletal branches on the tree is low (≤5). The bark of one-year-old flexible branches is greyish-brown, while that of two-year-old and skeletal branches is grey or dark grey.

The leaves are alternate, odd-pinnate, medium-sized, up to 18.7 cm long, and composed of 7-15 broadly lanceolate serrated leaflets. The upper side of the leaf blade is dark green, and the lower side is pale green with pubescence. The flowers are arranged in complex corymbose inflorescences with a diameter of about 12 cm. The flowers are small, about 1.3 cm in diameter, and have five petals with a cream-white colour. During mass flowering, the flowers emit a strong, unpleasant odour. The peak of flowering occurs in the third decade of May. These plants are self-unfruitful. It was found that for the Nevyazhynska Yellow variety, the best pollinator is the Businka variety.

The fruit is apple-shaped, somewhat elongated-round with distinct angular ribs, about 1.4 cm in diameter. The number of fruits on a cluster ranges from 79 to 126. The fruit's weight is 0.6 g, and the weight of 100 fruits is about 57.6 g. The skin of the fruit is dark yellow to yellow-orange. The pulp is pale yellow, sweet-sour in taste. The seeds are small and dark brown. The fruits have moderate keeping quality. The intended use of the fruits is versatile. The juice content of the Nevyazhynska Yellow variety is 34%, which is higher than for the Brouwers variety but lower than for the Burka and Businka varieties, which exceed 45%.

The Businka variety of common rowan (*Sorbus aucuparia* L., 1753) is a moderately tall tree, reaching up to 3 metres in height. The number of skeletal branches on the tree is low (≤5). These plants are self-fruitful. It was found that these plants tolerate partial shade, although they prefer full sun. The average fruit weight is 1.2 g (maximum – 1.85-2.06 g). The skin colour is red or bright red. The pulp is pale yellow to cream-coloured, with a sweet-sour taste that is refreshing and pleasant, without bitterness. Fruiting begins at 3-5 years of age, and fruit ripening occurs in the first decade of September. The intended use of the fruits is versatile. The transportability of the fruits is high (9 points). This variety is characterised by high drought, winter, and frost resistance (9 points). The fruiting cycle of the Businka variety plants is annual, and the abundance of fruiting is high (5 points).

The Burka variety of common rowan (*Sorbus aucuparia* L., 1753) is a slow-growing tree, reaching a height of up to 2-2.3 metres, forming a compact crown with a round or spherical shape. The leaves are pinnately lobed and dark green in colour. The flowers are fragrant, small, five-petaled, arranged in a shield-like inflorescence. The petals of the flower are white, and the anthers of the stamens have a pinkish tint. The generative buds are light greyish-brown and pubescent, formed on two-year-old shoots. The flowering phase begins in the third decade of May. These plants are self-fruitful. The fruits are round and slightly flattened. The fruit skin is thin and dark brown or dark pink in colour. The flesh is juicy, with a sweet-sour taste and hints of bitterness. Fruit ripening occurs in the first decade of September. The fruiting cycle is annual, starting from the 3rd or 4th year, with maximum fruiting occurring in the 5th year.

It is noted that the fruits become sweeter in taste after autumn frosts or artificial freezing in freezer chambers. These plants are characterised by high drought resistance (4.5 points), winter resistance (1.5 points), and frost resistance (1.5 points). However, they negatively respond to prolonged soil waterlogging. The seedling of common rowan (*Sorbus aucuparia* L., 1753) of unknown origin is a small tree, not exceeding 3.5 metres in height during the research period. The bark of the trunk and skeletal branches is grey. The bark of one-year-old branches is grey-brown. The crown is dense and oval in shape. The leaves are 15.7 cm long, alternate, odd-pinnate, and generally consist of 13 lanceolate, pointed leaflets with serrated edges. The flowers are small, arranged in a complex shield-like inflorescence with pubescence. The average diameter of the inflorescence is 11.5 cm. The flower stalk is characterised by weak or strong pubescence. The flower calyx consists of five sepals. The number of petals in the flower is five, and they are white in colour. The corolla has a diameter of 1.5 cm, with one pistil, three stamens, and a lower style. The number of stamens is numerous. The fruit is apple-shaped, with an orange or dark orange skin. These plants are characterised by high drought, winter, and frost resistance (9 points). The fruiting cycle is fixed at 7 years. For the description of common rowan plants based on morphological characteristics, Form F.3 was selected. The Form F.3 of common rowan (*Sorbus domestica* L., 1753) is a moderately tall tree, approximately 1.45 metres in height during the study. The approximate height of the maternal tree does not exceed 12 metres. The crown shape is inversely egg-shaped, and the growth rate is moderate. The number of skeletal branches is low (4 branches).

The bark of young plants is rough with numerous lentils, and it is grey in colour. One-year-old shoots are grey, shiny, almost without pubescence, and the buds on them are sticky and not pubescent. Vegetative buds are large, elongated, or round, while generative buds are mixed and form a rosette with 3-4 leaves during budding. The leaves are complex, 18 cm long, alternate, odd-pinnate, with an average of 13 lanceolate, pointed leaflets with serrated edges. The leaflets are arranged alternately and are 3.5 cm long and 1.2 cm wide. The upper side of the leaves is green and smooth, while the lower side is pale green. The leaflet petioles are pubescent with fine hairs. The plant's inflorescence is a wide pyramidal shield, up to 9 cm in diameter. The flowers

are small, up to 1.5 cm in diameter, with a distinct bitter almond aroma. The petals of the flower are white and roughly oval in shape. There are 20-30 stamens in each flower, and up to 68 flowers can be found in a single shield. The small branches of the shield have dense pubescence. The flowering phase occurs at the end of the third decade of April or the beginning of the first decade of May.

The fruit is apple-shaped, weighs 10.21 grams, and has slightly elongated pear-like characteristics with dimensions of 2.5×2.7 cm. It is yellow-green with a blush, has firm, sweet, and aromatic mealy flesh with a moderate amount of stony cells. Each cluster can contain 5-16 fruits. The seeds are brown or dark brown, with a seed weight of 0.02 grams. It is highly drought-resistant (4.5 out of 5 points) and moderately winter-hardy (2.5 out of 5 points).

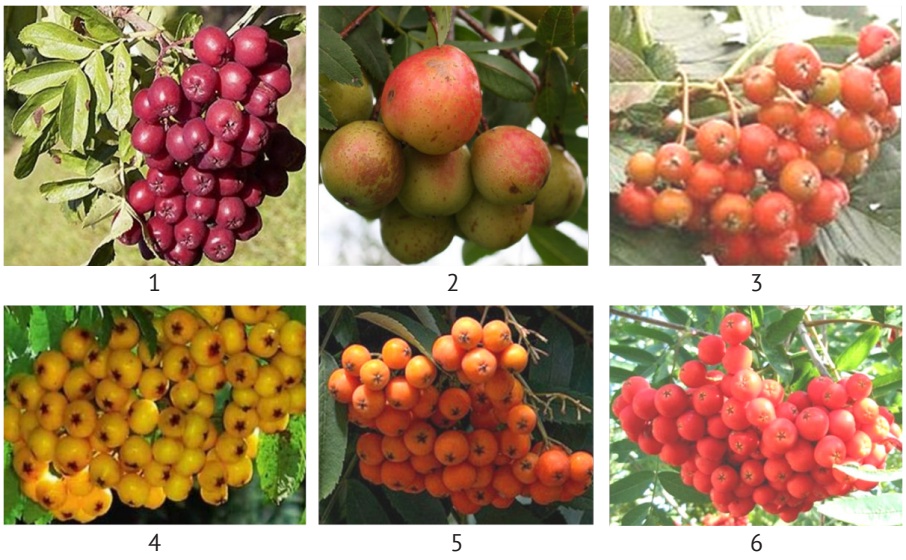

Figure 1. *Rowanberry species: 1 – Common Rowan (Variety: Burka); 2 – Domestic Rowan; 3 – Scandinavian Rowan (Variety: Brouwers); 4 – Common Rowan (Variety: Yellow Nevyezhenska); 5 – Common Rowan (Seedling of Unknown Origin); 6 – Common Rowan (Variety: Businka)*
Source: *photographed by the authors*

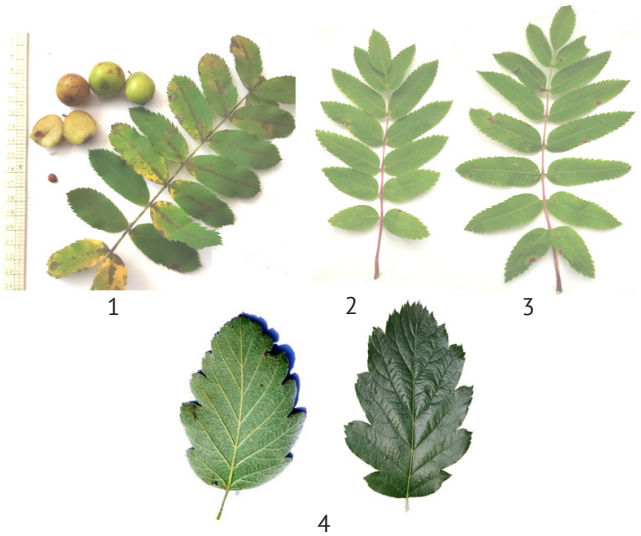

Figure 2. *Rowanberry leaves: 1 – Domestic Rowanberry; 2 – Common Rowanberry (seedling of unknown origin); 3 – Common Rowanberry Variety Yellow Nevezhenska; 4 – Scandinavian Rowanberry Variety Brouwers*
Source: *photographed by the authors*

After completing morpho-physiological studies, it was planned to conduct a biochemical analysis of the rowanberry fruits, the results of which demonstrated their suitability for various types of processing. For all six samples of rowanberries, analyses were conducted to determine the content of organic and biologically active substances. It was found that the highest dry matter content was in the fruits of Scandinavian Rowan

(Variety: Brouwers) (43.5±0.3%) and common rowanberries (from an unknown source) (36.6±0.3%). Below the average value (33.9±0.1) for the group of studied rowanberry species, the dry matter content was observed in rowanberries of domestic Form 3 (27.0±0.3%) and domestic Form 2 (29.2±0.3) (Fig. 3).

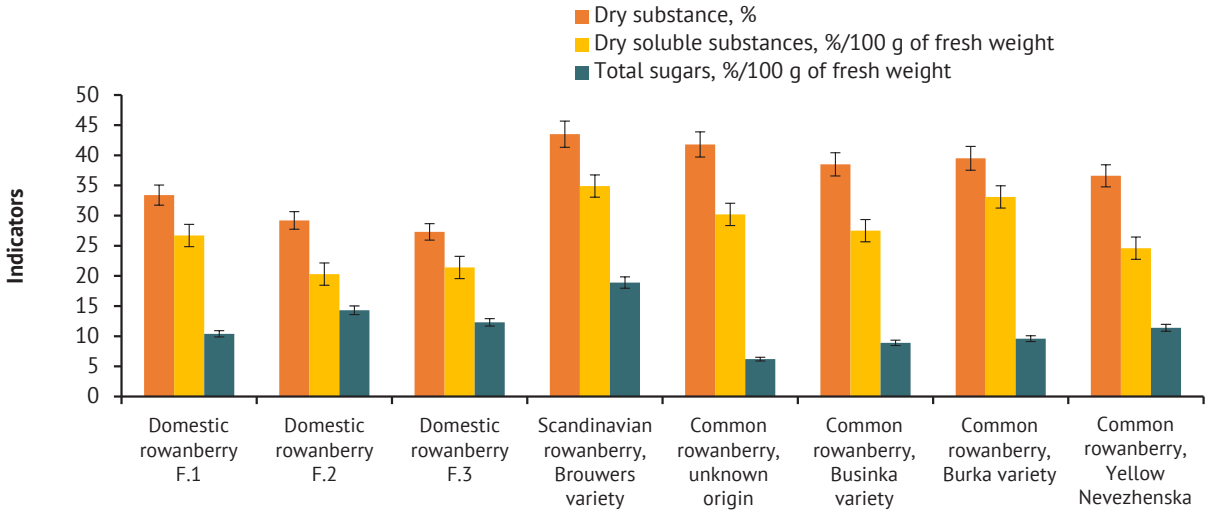

Figure 3. *Content of dry substances, dry soluble substances, and total sugars in rowanberry fruits*

Soluble dry substances in rowanberry fruits of the studied species varied within the range of the highest content of 33.4 (Scandinavian Rowanberry Variety Brouwers) and the lowest of 21.4±0.7% (Domestic Rowanberry Form 3). The average inter-species content was 25.89±0.38%. Rowanberry fruits of the Businka variety (22.6±0.3) and Domestic Rowanberry Form 1 (25.7±0.4%) accumulated less dry soluble substances than the average. Rowanberry of the common variety accumulated the driest soluble substances in its fruits. The overall content of dry soluble substances in rowanberry fruits was adequate for most of the studied species. The highest amount of sugars was accumulated in the fruits of Scandinavian Rowanberry (18.9±0.4% of fresh weight) and Domestic Rowanberry Form 2 (14.3±0.21%). Rowanberry Form 3 (12.0±0.3), Domestic Rowanberry Form 1 (10.4±0.37%), and Common Rowanberry (6.2-11.5%) had lower sugar content on average. Among the common rowanberry varieties, the highest sugar content was observed in the fruits of the Yellow Nevezhenska variety (>11%).

Titrated acids, expressed as malic acid equivalents, in the fruits of the studied rowanberry species varied from 2.78±0.13% (Common Rowanberry, seedling from open pollination) to 0.65±0.02% (Domestic Rowanberry Form 3) (Table 3).

Table 3. *Content of organic substances in rowanberry fruits*

Variety/hybrid	Titrated acids	Pectin substances	SAR
	%/100 g of fresh weight		
Domestic Rowanberry Form 1	1.15±0.03	1.99±0.18	9.1
Domestic Rowanberry Form 2	0.99±0.05	1.07±0.04	14.5
Domestic Rowanberry Form 3	0.65± 0.02	1.68±0.19	18.5
*Common Rowanberry (seedling of unknown origin)	2.78±0.13	0.68±0.18	2.2
Common Rowanberry Variety Burka	1.12±0.17	0.63±0.09	4.8
Common Rowanberry Variety Businka	1.43±0.07	0.79±0.11	3.5
Scandinavian Rowanberry Variety Brouwers	0.70±0.10	1.96±0.21	27.1

Note: ** the content of titrated acids and pectin substances is similar to their content in the fruits of the Yellow Nevezhenska variety. SAR – Sugar-to-Acid Ratio*
Source: *compiled by the authors*

The fruits of common rowanberry varieties Burka and Businka are characterised by titrated acid content close to the average, at 1.12 and 1.43% per 100 g of fresh weight, respectively. In the rest of the studied species (varieties/forms), their quantity was lower than the average content of 1.25±0.02%, with values of 0.70±0.10 (Scandinavian Rowanberry Variety Brouwers), 0.99±0.05 (Domestic Rowanberry Form 2), and

1.15±0.03% (Domestic Rowanberry Form 1). The highest sugar-to-acid ratio (SAR) was found in the fruits of Scandinavian Rowanberry Variety Brouwers (27.1) due to their high sugar content (18.97±0.4%) and low titrated acid content (0.7±0.1%). High SAR values were also observed in Domestic Rowanberry Form 2 (14.5) and Domestic Rowanberry Form 3 (18.5). Common Rowanberry (2.2-4.8) and Domestic Rowanberry Form 1 (9.1) had moderate SAR values. Fruits of Scandinavian Rowanberry Variety Brouwers and Domestic Rowanberry Form 1 had a higher content of pectin substances, amounting to 1.99±0.18% and 1.96±0.21% of fresh weight, respectively. Domestic Rowanberry Form 3 had the highest content of pectin substances (1.68±0.19%) among all studied species. Other species had lower pectin content, with Domestic Rowanberry Form 2 (1.07±0.04%) and Common Rowanberry (0.63-0.79%) having the least.

The content of ascorbic acid in the fruits of the studied rowanberry species varied widely, ranging from 33.41-42.04 mg/100 g in Common Rowanberry to 3.49±0.22 mg/100 g in Domestic Rowanberry Form 3. The content of ascorbic acid was lower than average in the fruits of other species and ranged from 4.9±0.23 (Domestic Rowanberry Form 2) to 9.53±0.32 mg/100 g (Scandinavian Rowanberry). Polyphenols, a group of biologically active substances, were found in varying amounts in the fruits of different rowanberry species. The highest levels of polyphenolic compounds were found in Domestic Rowanberry Forms 1 and 2, with values of 3793±52 and 3729±72 mg/100 g of fresh weight, respectively. Domestic Rowanberry Form 3 had a slightly lower content of polyphenols (3031±57 mg/100 g). Other species had lower polyphenol content, with Common Rowanberry varieties Businka, Yellow Nevezhenska, and Burka having values of 1064, 1242, and 1443 mg/100 g, respectively. Scandinavian Rowanberry and Common Rowanberry had polyphenol content of 1056±30 and 818±16 mg/100 g of fresh weight, respectively (Fig. 4).

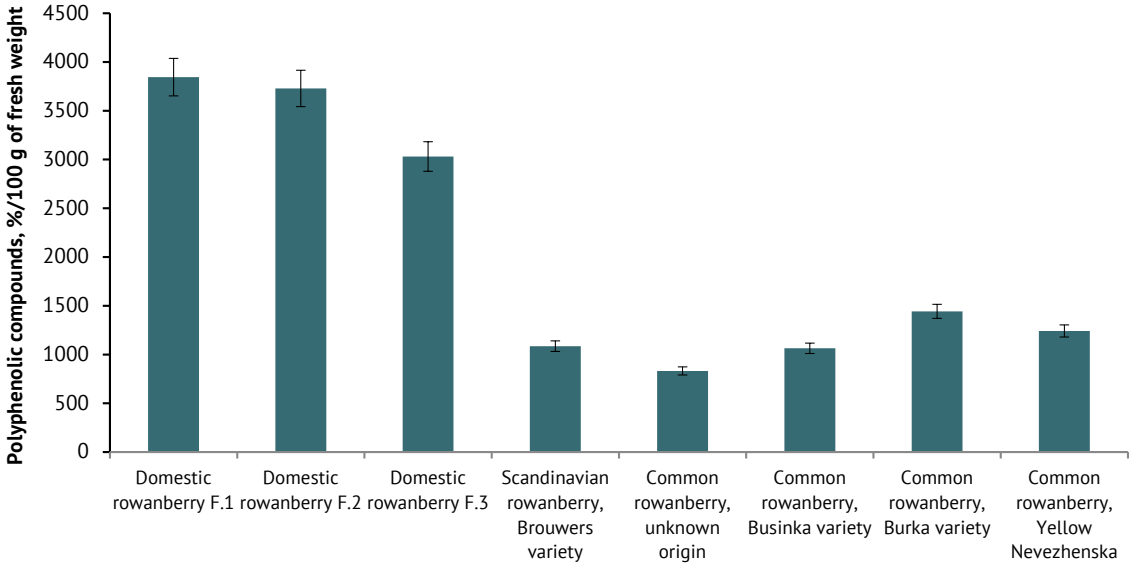

Figure 4. *The content of polyphenolic compounds in the fruits of various rowanberry species*
Source: *compiled by the authors*

Flavonoids, which are biologically active compounds with antioxidant properties, were present in small amounts in the fruits of the studied rowanberry species. The flavonoid content ranged from 217.5±2.0 mg/100 g in Scandinavian Rowanberry to 257.5-303.5 mg/100 g in Common Rowanberry. Domestic Rowanberry Forms 1 and 2 had higher levels of flavonoids (250.0±8.2 and 251.0±0.6 mg/100 g of fresh weight, respectively).

The content of anthocyanin pigments in the fruits of different rowanberry species was relatively low, with a maximum of 6.03±0.3 mg/100 g in Common Rowanberry and a minimum of 1.5±0.2 mg/100 g in Domestic Rowanberry Form 1. Other rowanberry varieties had anthocyanin content slightly above or below the average, with values of 2.63±0.26 mg/100 g in Domestic Rowanberry Form 2, 3.3±0.2 mg/100 g in Domestic Rowanberry Form 3, and 3.3±0.15 mg/100 g in Scandinavian Rowanberry.

In contrast, the content of chalcones in the rowanberry fruits was somewhat higher, with an average value of 13.5±0.14 mg/100 g. Common Rowanberry had the highest chalcone content, ranging from 20.4-24.6 mg/100 g. Other rowanberry varieties had chalcone content below the average, with values of 12.3±0.3 (Common Rowanberry Form 3), 10.8±0.5 (Domestic Rowanberry Form 2), 10.5±0.3 (Domestic Rowanberry Form 1), and 13.80±0.44 mg/100 g (Scandinavian Rowanberry) (Fig. 5).

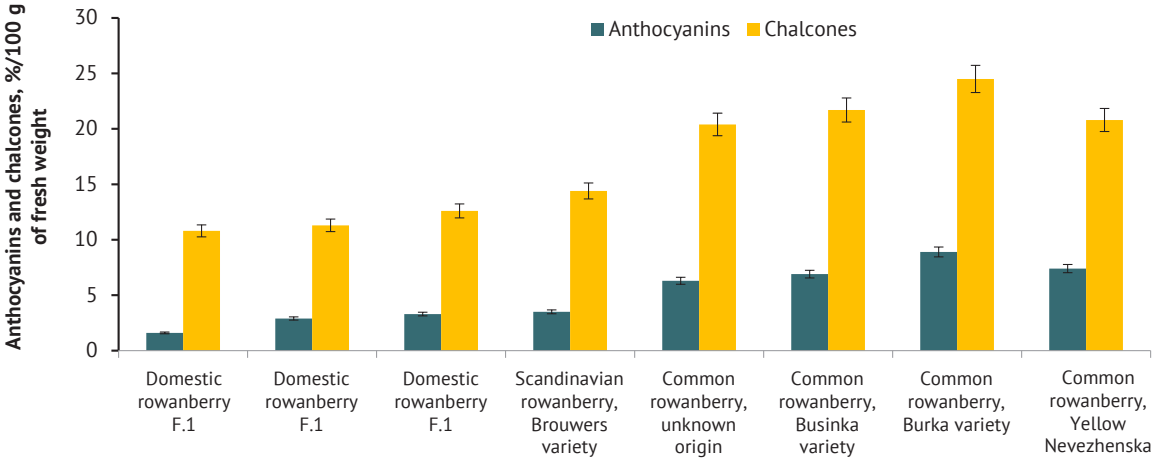

Figure 5. *The content of anthocyanins and chalcones in rowanberry fruits*
Source: *compiled by the authors*

Considering the pH levels of the juice in fruits of other studied crops, which varied within relatively narrow limits, the pH of the juice in the studied rowanberry species showed significant differences. Scandinavian Rowanberry had the highest pH (4.4±0.3), slightly lower in the fruits of Domestic Rowanberry Form 2 (4.1±0.1). Values below the average for this group were observed in Common Rowanberry (3.5±0.3), Common Rowanberry Form 3 (3.8±0.2), and Domestic Rowanberry Form 1 (3.9±0.2). The rowanberry species studied exhibited significant variation in their oxidative-reductive potential (ORP), with Scandinavian Rowanberry having the highest ORP at 243 mV. Fruits of Common Rowanberry Form 3 had an ORP of 251.1±4.3 mV (Table 4).

Table 4. *Average juice pH and redox potential values of fruits from different varieties of rowanberry*

Variety/hybrid	juice pH	redox potential, MV
Common Rowanberry Form 1	3.9±0.2	243.8±12.1
Common Rowanberry Form 2	4.1±0.1	230.3±10.9
Common Rowanberry Form 3	3.8±0.2	251.1±4.3
Common Rowanberry (Unknown Origin)	3.5±0.3	241.7±9.8
Scandinavian Rowanberry (Brouwers Cultivar)	4.4±0.3	230.7±9.9

Source: *compiled by the authors*

Due to the high dry matter content in the fruits of Scandinavian rowanberry (43.55±0.29%) and common rowanberry (36.6-41.3%), they can be used for producing reconstituted juices or fruit powders. The high content of dry soluble substances in the fruits of all studied rowanberry species makes them suitable for the production of therapeutic and preventive beverages, infusions, and compotes. Specifically, the polyphenolic content of over 3000 mg/100 g of fresh weight in common rowanberry Forms 1-3 characterises their high antioxidant properties, which is a distinctive feature of these *Sorbus* species. The indicator of sweetness and suitability for fresh consumption, and for making pastilles, is the high sugar content and pH level. Fruits of Scandinavian rowanberry, as well as common rowanberry Forms 3 and 2, possess these characteristics, making them suitable for desserts and direct consumption. The presence of over 1% pectin in the fruits of common rowanberry Forms 1 and 2, along with titratable acidity levels within ±1.0%, provides a basis for considering them as excellent raw materials for making jelly products. Therefore, valuable source material has been prepared for further breeding to create new varieties with a complex of valuable agricultural traits.

DISCUSSION

Representatives of the genus *Sorbus* are deciduous trees and shrubs belonging to the Tracheophyta clade, comprising about a hundred species (hybrids, forms) with an area covering regions with a temperate climate in the Northern Hemisphere (Rand, 2018). The diversification of European rowanberries was driven by the hybridisation of four common diploid species, namely *Sorbus aria* L. Crantz, *Sorbus aucuparia* L., *Sorbus chamaemespilus* L. Crantz, and *Sorbus torminalis* L. Crantz, and subsequent backcrossing with their parent species, resulting in the formation of several aloploid species, mostly triploids and tetraploids, reproducing via apomixis and restricted to various-sized geographical

regions. As noted by N. Meyer & L. Meierott (2021), many species of the *Sorbus* genus have been individually studied and described.

A. Hajrudinovi´c-Boguni´c *et al.* (2023) report that the clonal structure within and among populations of these rowanberry species is maintained through apomixis. Hybridisation, polyploidisation, and apomixis are the primary drivers of *Sorbus* diversification in Europe. Notably, dominant rowan forests (*Sorbus aucuparia*) are found in the Central and Southern Alps (Graubünden and Ticino, Switzerland – Verbania-Cusio-Ossola province, Northern Italy, etc.). Domestic rowanberry (*Sorbus domestica* L.; synonym *Cormus domestica* L. Spach, 1834) has a significant range as well. As described by V. Moskalets *et al.* (2022), its territory includes Ukraine, particularly Crimea and Transcarpathia, and is somewhat localised in the Forest-Steppe region, and other countries, including the United Kingdom, France, Switzerland, Italy, Montenegro, Serbia, the Czech Republic, Algeria, Tunisia, and countries in the Eastern Mediterranean, the western part of Asia Minor. However, in some regions, this species is endangered, such as Austria, Germany, and Spain. Plants of domestic rowanberry are significant because, as D. Drvodelić *et al.* (2018) indicate, their fruits vary in morphophysiological properties and are consumed both fresh and processed into healthy food products, including marmalade, pastille, jam, preserves, liqueurs, kvass, cider, etc. In a dried and ground form, they are added to flour for making confectionery, tea blends, and sourdough. It has been proven that extracts and jams from domestic rowanberry fruits exhibit antioxidant properties. As noted by M. Rutkowska *et al.* (2019), the plant material of domestic rowanberry, especially its leaves, has increased bioactivity, with extracts made from them showing high antioxidant activity.

However, to produce high-quality products, forms that produce fruits with high quality are needed, which requires additional research. In particular, G. Sebek (2020) notes that in France and Germany, phenological observations of domestic rowanberry plants and the study of their fruit morphology have allowed for the selection of valuable forms. These fruits can be valuable raw materials in processing and food industries.

According to W. Pusz *et al.* (2019), the intermediate or Scandinavian rowanberry (*Sorbus intermedia* (Ehrh.) Pers.) also holds significant importance. Although this species has a very limited natural range, found only in southern Scandinavia and along the Baltic Sea coast, except for the Gulf of Finland, it is now introduced in horticultural and agroforestry practices in many regions, including Ukraine. Z. Mrkonjić *et al.* (2019) showed that extracts from both *S. domestica* and *S. intermedia* exhibit antioxidant properties that inhibit the growth of certain clinically significant bacterial strains, which is a medical breakthrough. As mentioned by A. Ritala *et al.* (2022), the nutritional value of the fruits of common rowanberry (*Sorbus aucuparia* L.) has also been confirmed in practice, particularly in terms of protein content and dietary fibres. Equally significant is the pharmacological property of *Sorbus* L. fruits, as stated by K. Zymone *et al.* (2018), which is attributed to their unique composition of bioactive compounds. For instance, fruits of the "Burka" variety of common rowanberry, distinguished by their exclusive phytochemical composition, are used to produce powders with high antioxidant properties. Furthermore, according to Y. Lykholat *et al.* (2021), the skin of *Sorbus* genus representatives' fruits contains more antioxidant compounds than the flesh, along with elevated levels of polyphenolic compounds.

Researchers, such as M. Bozhuyuk *et al.* (2020), conduct extensive studies involving morphological descriptions of plants, fruit biochemistry of new forms of various *Sorbus* species to form a knowledge base for future use in science, particularly in breeding and nursery practices. It has also been established that the diversity of biotypes of rowanberry (*Sorbus aucuparia* L.) obtained from seeds is characterised by varying organic content in the fruits. This is crucial when choosing the species or variety of *Sorbus* for fruit harvesting and processing, as mentioned by M. Ognyanov *et al.* (2022). For example, in the fruits of common rowanberry, soluble sugars (fructose and glucose) constitute the majority of total carbohydrates, pectin makes up a significant portion of polysaccharides, and malic acid is one of the dominant organic acids. Among the studied common rowanberry varieties, the highest content of total anthocyanins is found in the fruits of the "Burka" (871 mg/kg dry weight) and "Businka" (856 mg/kg dry weight) varieties (Mikulic-Petkovsek *et al.*, 2017).

The nutritional value of rowanberry fruits is undeniable, and as asserted by R. Bobinaitė *et al.* (2020), the antioxidant, antimicrobial, and antiproliferative activity of extracts from these fruits is relevant in various sectors. Consequently, there is a prospect of expanding the use of rowanberry plant material in natural remedies, cosmetics, and as innovative food ingredients, as indicated by V. Sarv *et al.* (2020). These ingredients are expected to have broad applications in the production of food products and in ethnopharmacology for the natural treatment of bacterial, viral, inflammatory diseases, including tumors, and in the prevention and treatment of neurological and cardiovascular disorders.

It is worth noting the effectiveness of rowanberry preparations in inducing apoptosis, a process necessary for the physiological regulation of the body's cell count. Apoptosis is vital for eliminating old cells, generating lymphocytes that are not reactive to their antigens (autoantigens), shedding leaves from plants in autumn, the cytotoxic action of killer T lymphocytes, embryonic development, and more (Kobylinska *et al.*, 2021; Zyablitsev *et al.*, 2022). For instance, S. Moon *et al.* (2021) demonstrated that a water extract from rowanberry fruits induces apoptotic cell death through the active oxygen species (ROS-dependent) pathway.

The bioactive potential of *Sorbus norvegica* fruit extracts in the treatment of type 2 diabetes has been investigated (Broholm *et al.*, 2019). There are also prospects for using the extract to alleviate colitis (Akkol *et al.*, 2020). Information is available on the impact of rowanberry fruits on protein glycation, a process in which sugar molecules react with proteins, causing them to form cross-links and lose functionality, leading to what is known as glycation or "sweet ageing" (Boiarska, 2019). Therefore, as noted by M. Rutkowska *et al.* (2019), organic compounds in *Sorbus aucuparia* L. fruits in the form of fractionated extracts inhibit glycation or the protein glycation process and oxidative/nitrative damage to human plasma components.

In summary, the increased attention of agrarians to representatives of the *Sorbus* genus, along with the search and selection of valuable species (forms, varieties) based on morphological, physiological, valuable, and biochemical research, can lead to the production of valuable consumption products for the domestic market. Even in small quantities, these products can meet the human body's essential nutrient requirements, preventing diet-related diseases, slowing down the ageing process, and boosting immunity. Moreover, they can address vitamin and antioxidant deficiencies and provide essential micronutrients, promising further development in this field.

CONCLUSIONS

Based on the results of phenological observations, it was determined that during dry and hot weather, the duration of the fruit ripening phase is shortened, leading to a significant portion of the fruits falling prematurely and unripe. Fruit drop was also observed during low air temperatures at the end of the developmental phase, particularly for Scandinavian and domestic rowanberry plants. It was found that fluctuations in the weather-climate regime during the vegetation period of rowanberry plants determine the dates and duration of developmental phases, which often differ from year to year. It was established that, in terms of growth intensity by plant height, Scandinavian rowanberry (Brouwers variety) and domestic rowanberry (Forms 1 and 2) are highly productive, while domestic rowanberry (Form 3) and common rowanberry (hybrid seedling and varieties Businka and Burka) are moderately productive.

Scandinavian rowanberry (Brouwers variety) and domestic rowanberry (Forms 1 and 2) plants exhibit distinct overall conditions in terms of disease resistance, growth pattern, and foliage, whereas domestic rowanberry (Form 3) and common rowanberry (seedling of unknown origin) have satisfactory conditions. It was found that the vegetative buds of Scandinavian rowanberry plants have a broadly conical elongated shape, while the generative buds have a pointed tip, with the average start of their development in the conditions of the Northern Forest-Steppe occurring in the late third decade of March to early April. Vegetative buds of domestic rowanberry plants and common rowanberry plants have a conical shape, while generative buds are rounder and larger in size.

It was noted that for the studied common rowanberry plants, flowering begins in the third decade of May, Scandinavian rowanberry blooms from the third decade of April to the first decade of May, and domestic rowanberry blooms at the end of the second decade of May. The aroma of the flowers of each rowanberry species was determined, with domestic rowanberry having a distinct bitter almond-like aroma, common rowanberry having a specific unpleasant scent. It was determined that common rowanberry plants of the Nevyazhynska yellow variety are self-sterile, while for common rowanberry of the Burka variety, domestic rowanberry, and Scandinavian rowanberry (Brouwers variety), self-fertility exceeds 90%.

It was shown that the fruits of different rowanberry species vary in skin colour, with the skin of Scandinavian rowanberry (Brouwers variety) being brick-red, domestic rowanberry Form 1 – yellow-green, Form 2 and Form 3 – green-yellow, common rowanberry of the Nevyazhynska yellow variety – yellow-orange, Burka variety – dark pink or dark burgundy, Seedling – dark orange, Businka variety – bright red, respectively. For all examined rowanberry species (varieties), the fruit-bearing cycle is annual. Considering the high dry matter content in the fruits of Scandinavian rowanberry (43.5±0.3%) and common rowanberry (36.6±0.3%), they can be used to produce reconstituted juices or fruit powders. The high content of soluble solids in the fruits of all examined rowanberry species makes their fruits suitable for the production of medicinal and preventive beverages, tinctures, and compotes. For domestic rowanberry Form 1-Form 3, the content of polyphenolic compounds, exceeding 3000 mg/100 g of fresh weight, indicates their high antioxidant capacity.

It was established that the fruits of Scandinavian rowanberry and domestic rowanberry Form 2 and Form 3 are characterised by dessert qualities and are suitable for consumption in both fresh form and for making pastilles due to their high sugar content and juice pH, indicating their nutritional value. It was also investigated that the fruits of domestic rowanberry Form 1 and Form 2, with a pectin and titratable acid content of over 1.0%, are considered quality raw materials for making jelly products. The studied varieties and forms of Scandinavian rowanberry, common rowanberry, and domestic rowanberry are recommended for use in the decorative and fruit gardening system.

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CONFLICT OF INTEREST

None.

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Морфо-фізіологічні особливості рослин та біохімічні параметри плодів горобини скандинавської, горобини звичайної і горобини домашньої, вирощених в умовах Північного Лісостепу України

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Анотація. Актуальність даної теми полягає в порівняльному оцінюванні різних видів горобини для підвищення їх значимості та більшого використання системі декоративного і плодового садівництва, в технологіях переробки рослинної сировини і виготовлення продукції для здорового харчування. Головною метою дослідження було вивчити морфо-фізіологічні характеристики рослин і біохімічні параметри плодів різних видів (сортів, форм) роду Sorbus. За результатами практичних досліджень представлено оригінальні дані про морфологію й господарську характеристику представників (сортів і форм) видів *Sorbus intermedia* Pers., *Sorbus aucuparia* L., *Sorbus domestica* L., висвітлено біологічні властивості рослин, біохімічні параметри плодів. З'ясовано, що всі вивчені представники роду *Sorbus* володіють високою зимостійкістю (1,5 бали за С.Я. Соколовою), крім цього рослини горобини скандинавської мають високу посухостійкість (4,5 балів за С.С. П'ятницьким), порівняно з рослинами горобини звичайної. Проведені фенологічні спостереження за рослинами різних видів горобини дозволили для умов Лісостепу України з'ясувати час настання фаз онтогенезу: розвитку вегетативних бруньок, появи листків, росту пагонів, бутонізації і цвітіння, утворення і розвитку зав'язей, достигання і плодів, зміни забарвлення і опадання листків, а також підфаз, які більш точніше характеризують час настання, пік і кінець певної фази розвитку, що є науковим доробком для стратегій в системі декоративного і плодового садівництва. Досліджено інтенсивність росту сортів і форм представників роду *Sorbus* за висотою рослин горобини, а також проведено оцінювання загального їх стану за життєздатністю. Підготовчі роботи з підготовки підщеп, добору живців і проведення щеплення дозволили сформувати в колекційному розсаднику модельні рослини та додатково оцінити їх за силою росту, настанням і проходженням окремих фаз розвитку, оцінити їх за посухо- і зимостійкістю, віком настання плодоношення та ін. Також проведено біометрію і опис стовбура, гілок, вегетативних і генеративних бруньок, листків, суцвіття і плодів. Охарактеризовано плоди за смаком, про що зазначено в матеріалах статті. Біохімічний аналіз плодів дозволив встановити їх придатність до переробки і виготовлення продуктів здорового харчування

Ключові слова: *Sorbus intermedia* Pers.; *Sorbus aucuparia* L.; *Sorbus domestica* L.; морфологічні ознаки; фізіологічні особливості рослин; біохімічні властивості плодів

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Sensory evaluation of sweet cherries for sustainable fruit production in the European market

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Abstract. The competitiveness of fresh fruit in the modern market substantially depends on sensory quality indicators. Sweet cherries are a top fruit that is highly valued by consumers due to their taste and visual attractiveness. For the growing demand for fruits on the European market, it is important to examine the sensory properties of cherry fruits in combination with their weight and diameter. The purpose of the study was to substantiate sensory indicators for examining the quality of cherry fruits of different maturation periods and selecting the most competitive varieties for the

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sustainable provision of fresh fruit in accordance with the requirements of the modern market. In the course of the study, the following methods were used: field, laboratory, and comparative. Determination of the mass, diameter, and sensory assessment of fruits was conducted on 33 varieties of sweet cherries. Experts conducted rating tests on a 9-point scale on ten fruit samples of the examined varieties. Fruits were evaluated by their appearance, aroma, taste, and texture. At the final stage of the assessment, experts calculated the average value of sensory indicators. A sensory profile was set for the fruits of each cherry variety and assigned a score based on the following descriptors: colour intensity, taste, pulp hardness and juiciness, and skin density. The standard methodology for evaluating the sensory properties of fresh fruits has been improved. The average weight (8.41 g) and diameter (22.63 mm) of sweet cherry fruits for three ripening groups were determined. Varieties (Kazka, Dilema, and Udivitielna) with the largest mass and diameter of fruits are identified. According to the complex of sensory indicators, the varieties Kazka, Vynka, and Krupnoplidna were distinguished. According to the external attractiveness, consistency, and taste qualities of fruits, a sensory profile has been formed for varieties of different maturation periods. Sensory evaluation of sweet cherry fruits will allow distributing fruit products and selecting raw materials for further use in fresh form, long-term storage, freezing and production of processed products by thermal sterilisation

Keywords: weight; diameter; varieties; expertise; external attractiveness; consistency; taste

INTRODUCTION

Sustainable development of horticulture is essential in ensuring food security and competitiveness of the country since fruit is an indispensable component of a healthy human diet. The development of this industry also guarantees a high economic effect and stable sales of high-quality fruit products not only in Ukraine but also in the European market. The level of quality of horticultural products is a serious issue for all stakeholders. Growing sweet cherries allows for diversifying the diet and extends the time of consumption of fresh fruit due to the early ripening of fruits. The formation of a sensory profile of fruits of different varieties of sweet cherries will allow selecting of the best products at the visual level for the consumer and choosing the most optimal method of processing them, considering the specific features of raw material parameters. Conducting a sensory assessment of fruits of varieties of different maturation periods becomes relevant due to the need of consumers for high-quality dessert products and raw materials for the processing industry.

T. Narandžić & M. Ljubojević (2023) describe sweet cherries as an important and valuable fruit crop of temperate climate, which is very much appreciated by consumers in the market. Now there is an increase in the volume of global production of sweet cherries. The market season for fresh sweet cherries is short. The fruits deteriorate quickly and have a short shelf life. P. Wu *et al.* (2018) believe that consumers expect producers to provide quality sweet cherries for a longer period of time. In addition, there is a tendency to consume cherry varieties with different taste and organoleptic properties. In this regard, there is an urgent need to grow various varieties of sweet cherries with early and late maturation periods with high quality parameters of their fruits.

The studies by researchers U. Ates & B. Ozturk (2022) established the dependence of the quality of fruit raw materials on the weather and climatic conditions of the growing year and varietal characteristics. The production of fruit products does not fully meet the demand of the food market due to the negative impact of stressful weather factors. Global warming and climate change are the basis for deepening research on the response of sweet cherries to abiotic factors. H. Demirsoy *et al.* (2022) determined that fluctuations in air temperature pose a threat to fruit trees. Spring frosts are particularly dangerous for early-blooming sweet cherries. This affects the sustainable development of horticulture in most regions and requires the improvement of fruit quality management methods to minimise economic risks in the activities of fruit producers.

Sweet cherries are recognised as the leader of fruit crops in many countries of the world. Melitopolska sweet cherry has become a geographical brand and is a priority business card of gastronomy in the southern region of Ukraine in accordance with Decision No. 587 of the state enterprise "Ukrainian Institute of Intellectual Property" dated September 8, 2020 (Trusova *et al.,* 2020). The demand for cherry consumption leads to an increase in fruit production and the analysis of sensory parameters of fruit varieties of different maturation periods. This motivates researchers to examine fruit raw materials on the global market to determine the sensory profile of fruits. L. López *et al.* (2023) proved that the organoleptic quality parameters of sweet cherries are determined by the preferences of consumers who are willing to pay high prices for fruits with the desired characteristics. Expert study was aimed at identifying the most important external parameters and taste qualities of fruits to meet the needs of the consumer.

Identification of the most competitive varieties of sweet cherries for consumers is conducted by interviewing them with an assessment of the most important visual and sensory quality indicators. As a result of the survey in the study by G. Paunović *et al.* (2022), it was determined that the attitude of respondents to the

size and hardness of fruits and the presence of a peduncle depended on their place of residence. Consumers have identified the most attractive indicators of cherry fruits: the size and shape of the fruit, the presence of damage on the fruit, and the length of the peduncle.

According to F. Antognoni *et al.* (2020), the commercial value of sweet cherries is determined by the weight and size of the fruit. This is due to the fact that consumers are attracted to larger cherry fruits. That is why the main area of modern breeding research is the creation of cherry varieties with the specified quality indicators. Greek researchers E. Karagiannis *et al.* (2021) analysed 22 samples of cherry fruits of different varieties in terms of quality parameters such as colour, texture, and sensory properties (taste intensity and general perception). Among the examined samples, two varieties Tsolakeika and Bakirtzeika received high consumer recognition. E. Szpadzik *et al.* (2022) highlight the results of evaluating the dessert quality of seven cherry varieties of Czech selection (Horka, Jacinta, Helga, Tamara, Kasandra, Fabiola, Kordia) to determine the most valuable variety in central Poland. Among the examined varieties, Horka, Jacinta, Fabiola, and Tamara had the largest fruits, while Kordia and Fabiola had the highest hardness.

The growth of consumer demand for fruits with excellent quality parameters is a prerequisite for conducting a sensory assessment of the fruits of sweet cherry varieties of early, medium, and late ripening. Studies of fruit quality indicators of cherry varieties are important since those grown in the south of Ukraine may differ slightly from the same varieties in other countries. Therefore, the purpose of the study was to substantiate the sensory parameters of sweet cherry fruits for a comprehensive assessment of their quality, followed by identifying the best varieties of different maturation periods and ensuring sustainable fruit production in the European market.

The following tasks were planned to achieve the goal: to identify the best varieties of sweet cherries of different maturation periods by their weight and fruit diameter; describe the methods that were used for sensory testing of cherry fruit quality indicators in accordance with the requirements of the European market; assess the feasibility of effectively distinguishing the fruits of cherry varieties of different maturation periods by sensory indicators; understand the relationship between sensory parameters and signs of the quality of cherry fruits of three maturation periods to satisfy the preferences of all interested parties and promote food security.

MATERIALS AND METHODS

The study was conducted during 2008-2019 in the laboratories of the Research Institute of Agrotechnology and Ecology of the Dmytro Motornyi Tavria State Agrotechnological University. Cherry fruits of common and promising varieties in Ukraine of three maturation periods were selected to assess quality indicators: 1st (early) – Sweat Earlise, Merchant, Bigaro Burlat, Rubinova rannia, Valerii Chkalov, Kazka, Zabuta; 2nd (medium) – Kordia, Octaviia, Vynka, Pervistok, Temp, Liubymytsia Turovtseva, Talisman, Dilema, Melitopolska chorna, Orion, Chervneva rannia, Dachnytsia, Prostir; 3rd (late) – Karina, Regina, Mirazh, Krupnoplidna, Udivitielna, Zodiac, Siurpryz, Kolkhoznitsia, Kosmichna, Prazdnichna, Anons, Temporion, Meotyda. For the study, fruits were selected from typical trees for each pomological variety of the same age with an average fruiting intensity. Tasting evaluation of sweet cherry fruits was conducted during the period of economic ripeness.

During this period, the fruit pulp was still quite dense, the taste and colour were characteristic of the pomological variety under study. A sample was taken from 100 fruits (in each repetition) from 3-5 typical trees during the period of economic ripeness to determine the weight of one cherry fruit. The repetition of the experiment is threefold (Serdyuk *et al.,* 2020). Fruits should be selected in such a way that the sample taken is characteristic in quality for the harvest of this season. Fruits from trees of the examined varieties were completely removed. With uneven ripening of fruits, they were removed partially – in proportion to the placement of the crop on the tree. Fruit quality assessment was performed in the sorting room. All selected fruits were calibrated by diameter, and then the diameter of one fruit was determined by dividing the total mass by their number (100 pcs). Normally developed, typical-sized fruits without defects in the economic ripeness phase were taken to assess sensory properties. The mass of the sample was 1.0-1.5 kg. A sensory assessment of the quality of cherry fruits was conducted on a 9-point scale (Table 1).

Table 1. *Scale of sensory evaluation of cherry fruits*

Indicator	Compliance parameters on a 9-point scale, score				
	1	3	5	7	9
Fruit size	very small fruits	small fruits	medium fruits	large fruits	very large fruits
Visual attractiveness*	very unattractive fruits (very small, irregular in shape, poorly coloured)	unattractive fruits (small, unattractive in colour and shape)	mediocre fruits (not large enough, less attractive in colour and shape)	attractive, but not large	very attractive, large, pretty in shape and colour

Table 1, Continued

Indicator	Compliance parameters on a 9-point scale, score				
	1	3	5	7	9
Taste	fruits are completely inedible in fresh form	fruits that had an unpleasant taste and are almost unsuitable for consumption	mediocre with a tolerable taste	fruits with a good table taste	fruits with excellent taste with a harmonious ratio of sourness and sweetness
Overall fruit quality assessment**	fruits are unsuitable for fresh consumption	fruits of poor quality	fruits of mediocre quality	fruits of good quality	fruits of high quality
Average value of sensory indicators***	It was determined as the average value of the size, attractiveness, taste, and overall perception of the cherry variety on a 9-point scale				

***Note**: *The external attractiveness of fruits was evaluated by indicators: size, shape, and colour; **the overall assessment of fruit quality was conducted separately as a general impression of the quality of the variety on a 9-point scale; ***the average value of sensory indicators was calculated additionally for a comprehensive assessment of cherry varieties*
***Source:** compiled by the authors*

The tasters' point scores were supplemented with indicators: external attractiveness of fruits (size, shape, colour); consistency of fruits (consistency of pulp, juiciness of fruits, and the nature of the skin); taste qualities of fruits (nature of taste, individual shades of taste). Taste qualities depend mainly on the ratio of sugars and sourness in fruits (berries), the presence of tannins. The sensory profile of the taste qualities of sweet cherries was established according to seven criteria (Table 2).

***Table 2.** Criteria for the sensory profile of sweet cherry fruit taste qualities*

Sweet	Sour-sweet	Sour and sweet	Sweet-sour	Sweet and sour	Sour	Wine-sweet
there is no sour taste	the sweet taste prevails, but the presence of sourness is felt	the presence of sourness and sugar is felt, but the taste of sugar prevails	sour taste prevails, but a little sugar is felt	the sugar and sourness can be felt with the advantage of the latter	there is no sweet taste	it resembles the taste of dessert semi-sweet wine

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

Sensory evaluation of the fruits of the examined cherry varieties was conducted by 10 trained experts. The fruits of each variety had a code. Experts entered their ratings in the tasting lists. Tasters additionally recorded various individual shades of taste, the presence of tartness, bitterness, and various tastes. Next, the average value of sensory indicators of the quality of cherry fruits was calculated. This indicator was introduced to select the best varieties of sweet cherries for all maturation periods.

Such methods of mathematical statistics as correlation-regression and variance (ANOVA) analyses were used to ensure the objectivity, reliability, and reproducibility of the results of the experiment. The data array was previously tested for normality using the Shapiro-Wilk criterion and uniformity of variance using the Leuven criterion (Zhang *et al.,* 2018). Confidence intervals and levels of variation were determined for all data series. The calculation of the main statistical values of the experiment was performed using the Statistica (version 10.0) and MS Excel. The substantiality level was set to $p<0.05$.

RESULTS

The competitiveness of fruits in the modern market depends on important external and sensory properties of fruits. Among the most important parameters of the quality of cherry fruits are the size, diameter, colour, hardness, texture, taste and aroma of fruits. The average weight and diameter of sweet cherries of early ripening varieties is 7.61 g and 19.43 mm, respectively, which is 10.51 and 14.1% lower compared to the average values (Table 3).

***Table 3.** Weight and diameter of fruits of early ripening varieties (2008-2019), $\bar{x} \pm s\bar{x}$, n=5*

Variety	Fruit weight				Fruit diameter			
	average, g	min, g	max, g	Vp, %	average, mm	min, mm	max, mm	Vp, %
Merchant	6.25±0.40	4.46	8.34	22.5	16.13±1.76	14.20	18.05	10.90

Table 3, Continued

Variety	Fruit weight				Fruit diameter			
	average, g	min, g	max, g	Vp, %	average, mm	min, mm	max, mm	Vp, %
Sweet Erlise	7.73±0.23	6.51	9.03	10.6	18.21±1.2	16.51	19.70	6.60
Bigarro Burlat	6.79±0.29	5.38	8.25	14.9	16.42±2.21	13.79	18.91	13.45
Valerii Chkalov	8.35±0.29	6.46	9.43	12.2	22.49±1.63	20.34	24.64	7.24
Zabuta	7.73±0.33	6.38	9.60	15.1	18.93±2.14	16.36	21.44	11.33
Kazka	9.10±0.36	7.17	11.56	14.0	25.72±1.6	23.94	27.54	6.20
Rubinova rannia	7.33±0.41	5.05	9.07	19.4	18.13±1	16.85	19.36	5.53
Average value	7.61±0.33	5.91	9.32	15.5	19.43±1.55	17.48	21.37	7.95
LSD_{05}		0.649				0.57		

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

The minimum weight of sweet cherries (4.46 g) of early ripening was determined in the Merchant variety of the 2018 harvest, which is 41.39% less than the average varietal value of the group. Kazka fruits in 2016 had a maximum fruit weight of 11.56 g, which is 52.03% more than the average varietal value in the early ripening group. The difference in fruit mass values is substantial since it substantially exceeded the LSD_{05} – 0.649. In 2018, the minimum fruit diameter was determined in fruits of the Bigaro Bulat (13.79 mm) and Merchant (14.20 mm) varieties. Fruit diameter indicators in these varieties were 26.72-29.03% lower than the average varietal value in the early ripening group. In 2011, the maximum fruit diameter of the Kazka variety was recorded at 27.54 mm, which is 41.73% more than the average varietal value of the group. The obtained deviations are statistically substantial (HIP_{05} – 0.57). A strong direct positive correlation was determined between the weight and diameter of the fruit in the group of early ripening varieties (r=0.805). The average weight and diameter of the cherry fruit of varieties with an average maturation period are 8.40 g and 22.39 mm, respectively, which is 0.11 and 1.06% lower than the average value (Table 4).

***Table 4.** Weight and diameter of fruits of medium-maturing varieties (2008-2019), $\bar{x} \pm s\bar{x}$, n=5*

Variety	Fruit weight				Fruit diameter			
	average, g	min, g	max, g	Vp, %	average, mm	min, mm	max, mm	Vp, %
Vynka	7.46±0.25	6.34	8.89	11.8	17.99±1.56	15.45	19.97	8.68
Dachnytsia	8.09±0.40	5.71	9.98	17.2	20.35±1.25	18.63	22.05	6.14
Dilema	9.91±0.43	7.92	12.01	15.0	31.35±1.63	28.78	33.48	5.21
Kordia	8.54±0.65	5.51	11.75	26.6	23.13±1.21	21.21	25.00	5.24
Lyubimitsa Turovtseva	7.47±0.48	5.11	10.09	22.5	17.99±1.57	15.74	20.11	8.71
Melitopolska chorna	9.37±0.38	7.63	11.81	14.2	25.72±1.93	22.85	27.94	7.50
Octavia	8.69±0.45	6.01	10.77	18.2	24.28±1.4	21.78	26.01	5.77
Orion	6.85±0.40	4.61	8.77	20.7	16.12±0.63	15.00	16.71	3.91
Pervystok	8.13±0.37	6.69	10.98	15.9	20.66±1.39	18.71	22.59	6.74
Prostir	9.34±0.35	7.78	11.67	13.2	25.19±1.43	23.08	27.02	5.68
Talisman	8.93±0.51	6.80	11.81	19.8	25.41±2.13	22.28	28.20	8.39
Temp	8.90±0.27	7.65	10.55	10.8	25.35±1.17	23.65	26.93	4.62
Chervneva rannia	7.48±0.27	5.90	8.68	12.8	17.52±1.78	15.10	19.91	10.14
Average value	8.39±0.40	6.43	10.59	16.8	22.39±1.38	20.35	24.29	6.18
LSD_{05}		0.520				0.74		

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

The minimum weight of cherry fruits (4.61 g) of the average maturation period was determined in the Orion variety of the 2012 harvest, which is 45.05% less than the average varietal value of the group. Fruits of the Dilema variety in 2010 had a maximum fruit weight of 12.01 g, which is 43.14% more than the average

varietal value in the group of the average maturation period. The difference in fruit mass values is substantial since it substantially exceeded the LSD_{05} – 0.52. In 2008, the minimum fruit diameter was determined in the Orion variety (15.0 mm), which is 33% less than the average varietal value for the group.

The maximum fruit diameter was recorded in the Dilema variety of 27.54 mm of the 2010 harvest, which is 49.53% more than the average varietal value in the group of average maturation period. The data obtained are statistically reliable (HIP_{05} – 0.74). An average direct positive correlation was determined between the indicators of fruit weight and diameter in the group of varieties with an average maturation period (r=0.691). The average weight and diameter of the sweet cherry fruit of late-ripening varieties are 9.24 g and 26.08 mm, respectively, which is 9.86 and 15.24% lower than the average varietal value (Table 5).

Table 5. *Weight and diameter of fruits of late ripening varieties (2008-2019), $\bar{x} \pm s\bar{x}$, n=5*

Variety	Fruit weight				Fruit diameter			
	average, g	min, g	max, g	Vp, %	average, mm	min, mm	max, mm	Vp, %
Anons	9.84±0.37	7.96	11.77	13.2	31.22±1.15	29.73	32.71	3.69
Zodiak	8.95±0.29	7.23	10.05	11.2	25.36±1.26	23.73	27.00	4.98
Karina	9.57±0.37	7.55	11.94	13.5	26.79±1.48	24.93	28.64	5.52
Kolkhoznitsia	8.14±0.37	5.67	9.93	16.0	20.81±2.54	17.72	23.90	12.21
Kosmichna	9.91±0.41	8.05	12.21	14.6	32.19±1.08	30.85	33.81	3.36
Krupnoplidna	11.67±0.47	8.73	13.72	14.0	33.11±1.84	29.85	35.11	5.55
Meotida	9.78±0.39	7.21	11.72	14.1	30.53±1.92	28.01	33.04	6.29
Mirazh	7.73±0.24	6.30	8.81	11.1	20.16±1.47	18.29	22.01	7.27
Festive	7.27±0.27	5.71	8.76	13.2	16.92±1.61	14.87	18.94	9.52
Regina	7.99±0.23	6.71	9.00	10.1	20.45±1.52	18.44	22.47	7.42
Siurpryz	7.37±0.28	6.00	9.40	13.2	18.26±0.82	17.19	19.34	4.47
Temporion	9.68±0.43	7.44	12.01	15.4	29.14±1.21	27.47	30.79	4.16
Udivitielna	12.18±0.51	10.01	14.60	14.7	34.09±1.49	32.07	36.11	4.36
Average value	9.23±0.35	7.27	11.07	13.4	26.08±1.45	24.19	27.99	5.56

Source*: compiled by the authors*

The minimum weight of sweet cherries (5.67 g) of late ripening was determined in the Kolkhoznitsia variety of the 2008 harvest, which is 38.57% less than the average varietal value of the group. Fruits of the Udivitielna variety in 2011 had a maximum fruit weight of 14.60 g, which is 58.0% more than the average varietal value in the late-ripening group. The difference in fruit mass values is substantial since it substantially exceeded the LSD_{05} – 0.538. The minimum fruit diameter was determined for fruits of the Prazdnichnaya variety (14.87 mm) of the 2008 harvest, which is 43% less than the average varietal value of the late-ripening group. In 2010, the maximum fruit diameter of the Udivitielna variety was recorded (36.11 mm), which is 38.45% more than the average varietal value of the group. The data obtained are statistically reliable (HIP_{05} – 0.68). A strong direct positive correlation was determined between the indicators of fruit weight and diameter for late-maturing varieties (r=0.815).

In the results of twelve-year studies, it was established that the average total fruit weight in cherry varieties of three maturation periods is 8.41 g, and the fruit diameter is 22.63 mm. Among the three groups of varieties examined, the optimal fruit weight (9.24 g) and diameter (26.08 mm) was characteristic of late-maturing cherry fruits. From a consumer standpoint, fruits of varieties that are characterised by a stable maximum weight and diameter are of particular value. The coefficient of variation Vp was used to assess the stability of the variety by weight and diameter of the fruit of the different years' harvest. The variability of the sample of the examined indicator for Vp<10% is low or insubstantial, for Vp=10-20% – average, for Vp>20% – strong or substantial. In the group of early ripening varieties, the average and high variability (Vp=10.64-22.54%) of fruit weight was determined (Table 2). The greatest variability in fruit mass was established in the Merchant variety, and the smallest – Sweet Erlise. Low and medium variability (Vp=5.53-13.45%.) in the fruit diameter is established for varieties of early maturation period. The smallest variability in fruit diameter was established in the Rubinova rannia variety, and the largest – Bigaro Burlat. For varieties of the average maturation period, the variability of fruit weight ranged from Vp=10.81-26.69% (Table 3).

The minimum variability in fruit weight was determined in the Temp variety, and the maximum – in

the Kordia variety. For varieties with an average maturation period, the variability of fruit diameter ranged between Vp=3.91-10.14%. The minimum variability in fruit diameter was determined in the Orion variety and the maximum – in the Chervneva rannia variety. In the group of late-maturing varieties, the average variability (Vp=10.20-16.03%) of fruit weight was determined (Table 4). The lowest variability in fruit mass was established in the Regina variety, and the greatest – Kolkhoznitsia. For late-maturing varieties, low and medium variability (Vp=3.36-12.21%) of fruit diameter variability was established. The smallest variability in the diameter of fruits was established in the Kosmichna variety, and the largest – Kolkhoznitsia. It was established that for the formation of fruit mass in three groups of ripeness varieties, the dominant influence was exerted by the weather conditions of years of research – factor A (Table 6).

Table 6. *Results of two-factor analysis of variance in the formation of the mass of cherry fruits*

Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Impact, %
early ripening cherry varieties						
Factor A (year)	215.7	11	19.61	123.2	1.8	39.7
Factor B (variety)	194.1	6	32.35	203.3	2.2	35.7
AB interaction	106.7	66	1.61	10.1	1.4	19.6
medium ripening cherry varieties						
Factor A (year)	671.9	11	61.08	598.7	1.8	51.5
Factor B (variety)	356.5	12	29.71	291.2	1.8	27.3
AB interaction	236.9	132	1.795	17.5	1.3	18.1
late ripening cherry varieties						
Factor A (year)	463.7	11	42.16	384.7	1.8	26.1
Factor B (variety)	1024.4	12	85.37	778.9	1.8	57.8
AB interaction	248.9	132	1.88	17.2	1.3	14.0

Source*: compiled by the authors*

The share of influence of factor A for varieties of early maturation period is 39.7%, average maturation period – 51.5% and late maturation period – 26.1%. The influence of varietal characteristics (factor B) was less substantial. The share of influence of factor B on the formation of fruit mass for varieties of early, medium, and late maturation periods was 35.7, 27.3 and 1.8%, respectively. It was established that varietal characteristics – factor B dominated the formation of fruit diameter in three groups of ripeness varieties (Table 7).

Table 7. *Results of two-factor analysis of variance in the formation of the diameter of cherry fruits*

Source of variation	Sum of squares	Degree of freedom	Variance	F_{fact}	$F_{tab.095}$	Impact, %
early ripening cherry varieties						
Factor A (year)	551.8	11	50.2	401.85	1.85	16.75
Factor B (variety)	2605.9	6	434.3	3478.94	2.15	79.09
AB interaction	115.0	66	1.7	13.96	1.38	3.49
medium ripening cherry varieties						
Factor A (year)	820.4	11	74.6	349.59	1.82	8.79
Factor B (variety)	8282.4	12	690.2	3235.17	1.78	88.70
AB interaction	160.6	132	1.2	5.70	1.27	1.72
late ripening cherry varieties						
Factor A (year)	901.3	11	81.9	450.03	1.82	5.25
Factor B (variety)	16087.9	12	1340.7	7363.00	1.78	93.67
AB interaction	128.1	132	1.0	5.33	1.27	0.75

Source*: compiled by the authors*

The share of influence of factor B for varieties of early maturation period is 79.09%, medium maturation period – 88.70%, and late maturation period – 93.67%. The impact of years of the study (factor A) was less substantial. The share of influence of factor A on the formation of fruit diameter for early, medium, and late varieties was 16.7, 8.79 and 5.25%, respectively. The results of the sensory evaluation of fruits by size, appearance, taste, and general perception of each early-ripening cherry variety by experts are shown in Table 8.

Table 8. *Sensory assessment of fresh fruits of early ripening cherry varieties (average for 2007-2019)*

Variety	Sensory indicators, score					
	size	appearance	consistency	taste qualities	general perception	average value
Merchant	5.8	8.0	7.9	9.0	7.9	7.7
Sweet Erlise	7.5	8.9	8.1	8.2	8.2	8.2
Bigarro Burlat	7.4	7.8	7.8	7.9	7.9	7.8
Valerii Chkalov	8.9	8.8	8.8	8.8	8.8	8.9
Zabuta	7.7	7.9	7.8	8.2	7.8	7.9
Kazka	9.0	9.0	8.9	9.0	9.0	9.0
Rubinova rannia	7.6	7.4	7.6	8.1	7.7	7.7

Source*: compiled by the authors*

The maximum size score was awarded to Kazka cherry fruits (9.0 points) and Valery Chkalov (8.9 points). The fruits of sweet cherries of the early ripening varieties Bigaro Burlat and Sweet Erlise were characterised by a minimum size, so they received tasting points of 7.4 and 7.5 points. The appearance of cherry fruits was evaluated in points comprehensively by such sensory indicators as size, shape, and colour. According to the appearance of the fruit, the varieties Kazka (9.0 points) and Sweet Erlise (8.9 points) were distinguished. The fruits of the Kazka variety were very large, elongated and rounded in shape, and had an intense dark red almost black colour. In the sweet Erlise variety, the fruits were large in size, broad heart-shaped, dark red in colour with a glossy sheen. The minimum score in appearance was awarded to fruits of the Rubinova rannia variety (7.4 points). The assessment of the consistency of fruits included a sensory characteristic of the degree of hardness and juiciness of the pulp, the nature of the skin. In terms of consistency, the highest scores were awarded to Valery Chkalov (8.8 points) and Kazka (8.9 points) varieties.

The fruits of the Valery Chkalov variety were characterised by a semi-grassy, dark red with white veins juicy pulp and dense skin. In the Kazka variety, the flesh of the fruit was juicy, dense, slightly crispy, and the skin was thin. The minimum score in terms of pulp consistency was awarded to fruits of the Rubinova rannia variety (7.6 points). The taste qualities of cherry fruits were evaluated in points comprehensively by nature (the ratio of sourness and sugar) and individual shades of taste (the presence or absence of taste, clearly defined taste or absence). The maximum score (9.0) in terms of taste was awarded to cherry fruits of the Kazka and Merchant varieties. The fruits of these varieties were distinguished by a fragrant sweet and sour taste. The minimum score in terms of taste was awarded to the Bigaro Burlat variety (7.9 points). According to the overall perception of fruit quality, the Kazka cherry variety received the highest score (9.0 points), and the lowest – Rubinova rannia (7.7). As a result of a comprehensive assessment of cherry fruits by average value, the Kazka variety received the maximum score (9.0), and the minimum (7.7) – Rubinova rannia and Merchant varieties. The results of the sensory evaluation of fruits by size, appearance, taste, and general perception of each cherry variety of average maturation period by experts are shown in Table 9.

Table 9. *Sensory assessment of fresh fruits of cherry varieties of average maturation period (average for 2007-2019)*

Variety	Sensory indicators, score					
	size	appearance	consistency	taste qualities	general perception	average value
Vynka	8.9	9.0	8.9	9.0	9.0	9.0
Dachnytsia	8.7	8.8	8.7	8.9	8.8	8.8
Dilema	9.0	8.5	8.4	8.5	8.2	8.5
Kordia	8.0	8.5	8.3	8.8	8.2	8.4
Lyubimitsa Turovtseva	7.4	8.2	8.2	8.4	8.3	8.0

Table 9, Continued

Variety	Sensory indicators, score					
	size	appearance	consistency	taste qualities	general perception	average value
Melitopolska chorna	9.0	8.5	8.4	8.5	8.2	8.5
Octavia	8.5	8.9	8.6	8.6	8.7	8.7
Orion	7.9	8.8	8.5	9.0	8.6	8.6
Pervystok	8.1	8.4	8.4	8.3	8.5	8.3
Prostir	9.0	8.4	8.5	8.6	8.6	8.6
Talisman	9.0	9.0	8.7	8.8	8.8	8.9
Temp	8.4	8.4	8.5	8.3	8.6	8.4
Chervneva rannia	7.5	7.9	7.6	8.0	7.7	7.7

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

The maximum score (9.0) in size was awarded to the fruits of sweet cherries of the Talisman, Dilema, Melitopolska chorna, and Prostir varieties. Cherry fruits of the medium-maturing varieties Lyubimitsa Turovtseva (7.4 points) and Chervneva rannia (7.5 points) were characterised by a minimum size. According to the appearance of the fruit, the Vynka and Talisman varieties were highlighted (9.0 points). The fruits of the Vynka variety are very large, rounded heart-shaped, with a dark red colour. In the talisman variety, the fruits are large in size, wide-rounded in shape, and dark red in colour. The minimum score in appearance was awarded to fruits of the Chervneva rannia variety (7.9 points). The fruit was red in colour and was more vulnerable to mechanical damage. In terms of consistency, the highest score was received by the Vynka variety – 8.9 points. The fruits of the Vynka variety were characterised by juicy tender flesh and dense thin skin. The minimum score in terms of pulp consistency was received by fruits of the Chervneva rannia variety – 7.6 points. The maximum score (9.0) in terms of taste was awarded to cherry fruits of the Vynka and Orion varieties.

The fruits of the Vynka variety were distinguished by a refreshing, wine-sweet taste. The harmonious sweet and sour taste was characteristic of Orion fruits. The minimum taste score was awarded to the Chervneva rannia variety (8.0 points). According to the overall perception of fruit quality, the highest score was received by the Vynka variety (9.0 points), and the lowest – by Chervneva rannia (7.7). As a result of a comprehensive assessment of cherry fruits of the average ripening period by the average value, the maximum score (9.0) was received by the Vynka variety, and the minimum (7.7) – by the Chervneva rannia variety. The results of the sensory evaluation of fruits by size, appearance, taste and general perception of each late-ripening cherry variety by experts are shown in Table 10.

***Table 10.** Sensory assessment of fresh fruits of late-maturing sweet cherry varieties (average for 2007-2019)*

Variety	Sensory indicators, score					
	size	appearance	consistency	taste qualities	general perception	average value
Anons	8.5	8.5	8.4	8.4	8.5	8.5
Zodiak	8.6	8.7	8.6	8.7	8.6	8.7
Karina	8.5	8.4	8.3	8.3	8.4	8.4
Kolkhoznitsia	8.0	8.1	7.9	8.2	8.0	8.0
Kosmichna	9.0	8.7	8.7	8.6	8.7	8.8
Krupnoplidna	9	9.0	8.9	9.0	9.0	9.0
Meotida	8.8	8.8	8.7	8.8	8.8	8.8
Mirazh	8.4	8.6	8.6	8.9	8.8	8.7
Festive	8.2	8.2	8.3	8.6	8.5	8.4
Regina	7.8	8.2	8.0	8.2	8.2	8.1
Siurpryz	8.5	8.8	8.6	8.8	8.7	8.7
Temporion	8.6	8.6	8.4	8.4	8.5	8.5
Udivitielna	9	8.9	8.8	8.9	8.9	8.9

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

The maximum score (9.0) in size was awarded to the fruits of sweet cherries of the Kosmichna, Krupnoplidna, and Udivitielna varieties. The fruits of sweet cherries of the Kolkhoznitsia (8.0) variety of late ripening were characterised by a minimum size. The highest score in all sensory indicators was received by fruits of the Krupnoplidna variety. The fruits of the Krupnoplidna cherry variety were very large, wide-rounded in shape, and had a dark red colour. The fruits of this variety were characterised by a very juicy, cartilaginous pulp and a thin, dense skin. Experts noted the harmonious, sweet and sour taste of Krupnoplidna fruits. The lowest scores on all sensory indicators were awarded to fruits of the Kolkhoznitsia variety (7.9-8.2 points). The fruits of this variety had a red colour and were more vulnerable to mechanical damage.

DISCUSSION

Researchers in many countries are investigating the key challenges of increasing the production of fresh, high-quality fruit products to meet consumer preferences and ways to solve them (Pinto *et al.,* 2018). There has always been a demand for sweet cherries, due to their organoleptic properties, colour, nutritional value (Gonçalves *et al.,* 2019; Faienza *et al.,* 2020). Research by the scientific community is focused on determining the most important external and sensory parameters of sweet cherries, considering the preferences of all interested parties (Palacios-Peralta *et al.,* 2022). In the study by V. Silva *et al.* (2021), the parameters and methodology for assessing the quality of sweet cherries meet the needs of consumers in the market are highlighted. Researchers say that standardisation of cherry fruit quality parameters will help preserve and extend their shelf life, and valorise the entire supply chain. M. Fodor (2022) developed the FT-NIR method for a comprehensive assessment of the ripeness of sweet cherries, which will facilitate rapid sorting of fruits by quality.

The requirements of international markets for the quality of sweet cherries, especially the size of fruits, have increased substantially. Fruit size is a crucial parameter in evaluating fruit quality, which affects consumer perception. According to researchers, the main qualitative characteristics of sweet cherries that affect the perception of consumers are the diameter and size of the fruit, the colour of the peel and hardness (Di Matteo *et al*., 2017). It is recognised that the weight and size, hardness of the peel of sweet cherries primarily depends on the genotype, climatic conditions, and garden management strategy (Lanauskas *et al*., 2023).

According to a result of the study conducted by M. Corneanu (2020), the largest fruit sizes were formed by cherry varieties Bucium, Andreiaş, Paulică, Ştefan, Van, Stella, and Golia. The smallest diameter of sweet cherries over the years of research was determined in the George variety (22.4 mm), and the largest in the Paulică variety (25.8 mm). As a result of evaluating 45 varieties of sweet cherries by Iranian researchers, it was established that the diameter of the fruit varied from 18.88 to 28.45 mm (Khadivi *et al.,* 2019). According to the study by E. Iurea (2019), the largest fruit diameter was established in the Cetăţuia variety (21.8), and the largest in the Cătălina variety (24.0 mm). According to E. Szpadzik *et al.* (2022), the main characteristic that determines the commercial value of sweet cherries is the size of the fruit. Consumers claim that the most attractive fruits are large in size and dark in colour. In the conducted studies, a larger mass of cherry fruits was noted compared to the results of other researchers. In the conditions of Iran, researchers determined that the average weight of sweet cherries was 2.04 g (Khadivi *et al.,* 2019). The results of the study confirm the conclusions of other researchers regarding the dependence of fruit weight and size on varietal characteristics (Šebek, 2019; Ivanova *et al.,* 2022).

Consumer preferences regarding the quality parameters of sweet cherries differ substantially in different regions of the world. According to G. Bujdosó *et al.* (2020), in some countries, a high percentage of consumers prefer medium (diameter from 21.4 to 25.4 mm) and large (diameter up to 29.8 mm) fruits. Therewith, other countries tend to prefer very large fruits. This confirms the data obtained regarding the target area of using fruits of different sizes. Consumer perception is also undoubtedly influenced by the colour of the fruit. In the study by A. Magri *et al.* (2023), the substantial variability of the four cherry varieties examined in the colour of the peel and pulp of sweet cherries from yellow-red (Limoncella variety) to dark red (Montenero) was highlighted. Darker coloured cherry fruits are considered to be more sweet. In addition to the size and colour of the fruit, consumers evaluate the cherry fruit by such an important sensory indicator as hardness. Consumers prefer high-hardness sweet cherries (Aglar *et al.,* 2019).

The sweetness of the fruit is one of the most attractive parameters of sweet cherries, for which consumers are willing to pay a high price. The standard indicator for determining the sweetness of fruit is the content of dry solutes (Scalisi & O'connell, 2021). However, the unique taste of sweet cherries is explained not only by the sugar content, but also by the combination of the ratio of sugars and sourness (Ivanova *et al.,* 2023). The content of soluble solids and titrated sourness in cherry fruits are quite important quality parameters since taste and consumer choice are mainly related to the balance between sugar and sourness content (Szpadzik *et al.,* 2022). A high ratio of dry solutes to titrated acids is desirable (Aglar *et al.,* 2019).

The colour of fruits and their size substantially depend on the genetic characteristics of the variety, the climatic conditions, and the ripeness of the fruit. The experimental data obtained are consistent with the justifications of other researchers regarding the difference in skin colour, texture, and taste of fruits depending

on the variety (Papapetros *et al.,* 2019). According to researchers, the Lapins variety had the darkest fruit skin, and the Germersdorfer variety had the lightest. Canada Giant and Germersdorfer varieties were the most susceptible in structure. The results of the studies by researchers confirm the data obtained regarding the influence of varietal characteristics and weather conditions of growing years on a substantial variation in the quality parameters of sweet cherry fruits (Proietti *et al.,* 2019). Producers must determine the optimal time for harvesting sweet cherries to obtain fruits with high quality indicators. The implementation of new adaptive varieties in production contributes to the supply of fruits with a better sensory profile of fruits to the market (Malchev & Vasileva, 2023).

The results obtained represent a valuable resource for breeding work on creating cherry varieties with high quality indicators. It is advisable to develop strategies for growing different varieties of sweet cherries, which will help improve the quality attributes of the fruit to meet the requirements of consumers

CONCLUSIONS

In the conditions of the southern region of Ukraine, the average weight of cherry fruits is 8.41 g, and the average diameter of fruits is 22.63 mm. It was established that the maximum mass and diameter of fruits were fruits of late-maturing cherry varieties. The highest average weight and diameter of fruits is established in the varieties Kazka (early-maturing), Dilema (medium-maturing), and Udivitielna (late-maturing). A strong (r=0.805-0.815) correlation was established between the indicators of fruit weight and diameter for early and late ripening varieties, and an average direct positive correlation was established for medium-ripening varieties (r=0.691).

The lowest variability in fruit weight was established in the early-maturing sweet Erlise variety (Vp=10.6%), the medium-maturing Temp variety (Vp=10.8%), and the late-maturing Regina variety (Vp=10.1%). The lowest variability in fruit diameter was established in the early-maturing Rubinova rannia variety (Vp=5.53%), the medium-maturing Orion variety (Vp=3.91%), and the late-maturing Anons variety (Vp=3.36%). The determining factor for the formation of fruit mass is the years of research (26.1-21.5%) and for the diameter-varietal characteristics (79.09-93.67%). The maximum score (9.0) on the complex of sensory indicators was obtained by the following cherry varieties: Kazka (early-maturing), Vynka (medium-maturing) and Krupnoplidna (late-maturing).

Experts noted samples of the Kazka early-maturing variety with the following sensory parameters: the fruits are very large, elongated-rounded shape, intense dark red almost black colour with juicy dense slightly crisp flesh and thin skin, characterised by a harmonious, pleasant, aromatic sweet and sour taste. Among the varieties of medium maturation, experts singled out the fruits of the Vynka variety for the following sensory indicators: very large rounded heart-shaped, dark red colour, juicy tender flesh, dense thin skin, refreshing, wine-sweet taste. From late-maturing varieties, experts highlighted the Krupnoplidna variety, which is characterised by the following sensory indicators: very juicy, large, wide-rounded, dark red fruits, with cartilaginous pulp and a thin dense skin, a harmonious sweet and sour taste.

The prospect of further research is the examination of commercial properties of fruits of sweet cherry varieties of early, medium, and late ripening. In combination with sensory parameters, this will allow forming a waste-free chain of using fruit products of various commercial classes in fresh form and choosing the optimal storage and processing of fruits.

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CONFLICT OF INTEREST

None.

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Сенсорна оцінка плодів черешні для стійкого виробництва фруктів в умовах європейського ринку

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Анотація. Конкурентоспроможність свіжих фруктів на сучасному ринку суттєво залежить від сенсорних показників якості. Черешня є топ-фруктом, що високо цінується споживачами завдяки смаку і зовнішній привабливості. Для зростанню попиту фруктів на європейському ринку актуальним є дослідження сенсорних властивостей плодів черешні в комплексі з їх масою і діаметром. Метою дослідження було обґрунтування сенсорних показників для експертизи якості плодів черешні різних строків достигання та вибору найбільш конкурентоспроможних сортів для стійкого забезпечення свіжими фруктами відповідно до вимог сучасного ринку. У ході дослідження використано методи: польовий, лабораторний і порівняльний. Визначення маси, діаметру і сенсорної оцінки плодів проводили на 33 сортах черешні. Експерти проводили рейтингові тести за 9-ти бальною шкалою на десяти зразках плодів досліджуваних сортів. Плоди оцінювали за зовнішнім виглядом, ароматом, смаком і текстурою. На завершальному етапі оцінювання експерти підраховували середнє значення сенсорних показників. Сенсорний профіль було встановлено для плодів кожного сорту черешні та присвоєно бальну оцінку за наступними дескрипторами: інтенсивність кольору, смак, твердість та соковитість м'якоті, щільність шкірочки. Було удосконалено стандартну методику оцінки сенсорних властивостей свіжих плодів. Визначено середню масу (8,41 г) і діаметр (22,63 мм) плодів черешні для трьох груп достигання. Виділено сорти черешні (Казка, Ділема і Удівітєльна) з найбільшою масою і діаметром плодів. За комплексом сенсорних показників було виділено сорти Казка, Винка і Крупноплідна. За зовнішньою привабливістю, консистенцію і смаковими якостями плодів сформований сенсорний профіль для сортів різних строків достигання. Сенсорна оцінка плодів сортів черешні дозволить розподілити плодову продукцію та підібрати сировину для подальшого використання у свіжому вигляді, довготривалого зберігання, заморожування і виготовлення продуктів переробки методом теплової стерилізації

Ключові слова: маса; діаметр; сорти; експертиза; зовнішня привабливість; консистенція; смакові якості

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Productivity of winter wheat depending on sowing dates and fertilisation

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Abstract. Modern varieties of winter wheat have high genetic productivity potential that can be realised through improved cultivation techniques, including sowing dates optimisation, fertiliser system optimisation, and the application of microelements, which determines the relevance of this study. The purpose of the study is to substantiate the specific features of winter wheat productivity formation based on cultivation techniques in the Carpathian region. The research utilised field, laboratory (for grain quality determination), and statistical methods (for data reliability assessment). Field studies were conducted during 2021-2022 on grey forest surface-eroded soils. The

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growth and development characteristics of the Estafeta Myronivska, Dovira Odeska, and Akhim winter wheat varieties sown at different dates (September 20, October 5, October 20) were investigated. It was found that grain yield and individual productivity indicators of the studied winter wheat varieties varied depending on sowing dates, mineral fertilizer doses, foliar feeding, and varietal traits. The highest individual plant productivity indicators were achieved by the Estafeta Myronivska, Dovira Odeska, and Akhim varieties sown on October 5 with mineral fertiliser application $N_{120}P_{90}K_{90}$ (including $N_{30}P_{90}K_{90}$ applied during cultivation, N_{15} after soil thawing, N_{45} (in the BBCH 29-30 growth stage), N_{30} (BBCH 55-57) with dual application of micronutrients (Aidamin-complex foliar feeding). As a result of the studied factors, an increase in the number of productive stems, grains per stem, and grain weight per spike was observed. The highest grain yield among the studied varieties was achieved by the Estafeta Myronivska variety (5.65 t/ha) when sown on October 5 with $N_{120}P_{90}K_{90}$ and Aidamin-complex foliar feeding. The research results can be used to adjust the cultivation techniques of winter wheat in production conditions to increase yield and grain quality

Keywords: winter wheat; varieties; mineral fertilizers; foliar feeding; cultivation techniques

INTRODUCTION

An essential aspect of introducing new varieties of winter wheat into production is the improvement of existing cultivation techniques. In the current context of global warming and climate change, it is particularly important to justify and develop measures to mitigate the negative impact of changing temperature regimes and soil moisture deficits. According to L. Wilson *et al.* (2021), since the beginning of the 20th century, the average annual air temperature has increased by 2.0 degrees, including 1.2 degrees since the 1990s. Climate change, according to O. Tarariko *et al.* (2022), observed in recent decades, the extension of the autumn vegetation period, the increase in winter temperatures, and the reduction of the spring period, prompt the need to adjust cultivation techniques for agricultural crops, including reviewing sowing dates, which directly affect the growth, development, winter survival, yield, and grain quality of winter wheat plants.

B. Bliznyuk *et al.* (2019) described how sowing dates in various soil-climatic zones differ and significantly depend on weather conditions, soil moisture reserves, predecessors, and other factors. Only by sowing at optimal dates is it possible to achieve high grain yield and corresponding quality.

Several researchers, including U. Madhu *et al.* (2018) and A. Siroshtan *et al.* (2021), highlighted the influence of sowing dates and predecessors on the yield and certain quality indicators of winter wheat grain in their studies. S. Poltoretskyi *et al.* (2020) indicate the trend of shifting optimal sowing dates for winter wheat to later periods due to the rise in autumn temperatures. According to V. Petrychenko & O. Korniychuk (2018) note that the warming of the first half of November amounts to 1.8°C, significantly reducing the impact of late sowing dates on plant winter survival and yield formation, allows for the extension of acceptable sowing dates to later periods. I. Yarchuk & T. Melnyk (2018) similarly mention the 1.8°C warming in the first half of November, weakening the influence of late sowing dates on plant winter survival and yield formation, also permits the shift of acceptable sowing dates to later periods. Specifically, the shift of winter wheat sowing dates towards later periods is indicated by O.L. Ulich (2018): by 30 days compared to sowing dates in the 1950s, and by 10 days in the 1990s.

Equally important is the question of intensifying grain production by fully reaching the genetic potential of winter wheat varieties through the use of macro- and micronutrients that stimulate their growth and development. Agrotechnical measures should aim to create optimal conditions for ensuring high yields in agroecosystems. In particular, O. Markovska & T. Grechishkina (2020) highlighted the effectiveness of nitrogen fertilisation and foliar micronutrient application.

Correctly determined winter cereal sowing dates are among the most important conditions for increasing yields and reducing grain production costs, which directly influence yield indicators. Therefore, the purpose of this study is to determine the characteristics of productivity and yield formation elements of winter wheat varieties under the influence of mineral fertilisation and foliar micronutrient application at different sowing dates.

MATERIALS AND METHODS

The study was conducted during 2021-2022 in the fields of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine on grey forest surface-eroded loamy soil with the following agrochemical properties (prior to the experiment initiation): humus (according to Tyurin) – 1.97-2.2%, pH (soil extract) – 4.8-5.2, labile nitrogen – 99.0-114.2 mg/kg soil (determined by the Cornfield method according to DSTU 7863:2015 (2015)), available phosphorus and exchangeable potassium – 95.2-101.1 and 107.1-112.0 mg/kg soil, respectively (analyzed by the Kirzanov method according to DSTU 4405:2005 (2005)).

Factor A – Varieties:

1. Estafeta Myronivska; 2. Dovira Odeska; 3. Akhim;

Factor B – Sowing Dates: 1. 20.09; 2. 05.10; 3. 20.10.

Factor C – Fertilisation:

1. $N_{60}P_{60}K_{60}$ ($N_{30}P_{60}K_{60}$ under cultivation + N_{30} (BBCH 29-30);

2. $N_{120}P_{90}K_{90}$ ($N_{30}P_{90}K_{90}$ under cultivation + N_{15} – on permafrost soil + N_{45} (BBCH 29-30) + N_{30} (BBCH 55-57);

3. $N_{120}P_{90}K_{90}$ ($N_{30}P_{90}K_{90}$ (under cultivation) + N_{15} (on permafrost soil) + N_{45} and Aidamin complex foliar fertilisation (1.0 l/ha) (BBCH 29-30) + N_{30} and Aidamin complex foliar fertilisation (1.0 l/ha.) (BBCH 55-57).

Sowing area of the plot – 40.8 m^2, accounting – 25 m^2, with a repetition of 4 times. Predecessor: oat for green manure. Mineral fertilisers were applied according to the experimental scheme. Micronutrient fertiliser used: concentrated chelate Aidamin complex foliar fertilisation. Plant protection measures: seed treatment with Vitavax 200 FF, 34% active substance concentration (3.0 l/ton), weed control (herbicide – Grodil Maxi, 37.5% active substance concentration (0.09-0.11 l/ha)), disease control (fungicide Alto-Super, 0.5 l/ha), pest control (insecticide Karate, 0.2 l/ha), considering EDT (economic damage threshold). Field experiments were conducted according to V. Ushkarenko *et al.* (2019). Harvesting was done using the "Sampo-130" combined with subsequent adjustment to standard (14%) grain moisture content. Statistical analysis of the results was conducted using the "Statistica 6.0" and "Excel 2003" software.

Experimental plant research (both cultivated and wild species), including plant material collection, adhered to institutional, national, or international ethical principles. 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 AND DISCUSSION

The effectiveness of the technological elements is primarily determined based on the productivity and yield indicators of winter wheat. These indicators comprehensively reflect the impact of growing conditions on the individual growth and development processes of the plants. The sowing dates and the fertiliser application system throughout the winter wheat's growing period play a crucial role in the system of agronomic cultivation practices. They directly influence the course of vegetation, overwintering, and the specific formation of plant productivity.

The research results show that sowing dates and the application of mineral fertilisers and foliar microelement fertilisation significantly influence the formation of individual productivity of winter wheat (Table 1). In 2021, the varieties "Estafeta Myronivska" and "Dovira Odeska" formed the highest number of productive stems during the second sowing period, with an average of 536 and 532 stems/m^2, respectively. The "Akhim" variety formed an average of 471 stems/m^2 during the sowing on September 20th. During this sowing period, the maximum biological yield of varieties was also formed: "Estafeta Myronivska" averaged 7.27 t/ha, "Dovira Odeska" – 6.34 t/ha, and "Akhim" - 6.27 t/ha. Sowing 15 days earlier than the specified date (20.09) resulted in a reduction in biological yield compared to the maximum values: "Estafeta Myronivska" had an average reduction of 1.27 t/ha, "Dovira Odeska" – 0.83 t/ha, and "Akhim" – 0.09 t/ha. Later sowing dates (20.10) led to a decrease in this indicator by 1.99, 0.82, and 1.0 t/ha, respectively.

Table 1. *Yield structure and biological yield of winter wheat depending on sowing dates and fertilization, 2021-2022*

Var. No.	Elements of the crop structure									Biological yield, t/ha		
	product quantity, stems, pcs.			number of grains in an ear, pcs.			grain weight of 1 ear, g					
	2021	2022	Avg.	2021	2022	Avg.	2021	2022	Avg.	2021	2022	Avg.
1	2	3	4	5	6	7	8	9	10	11	12	13
Estafeta Myronivska Variety (sowing period I)												
1	418	460	439	31.5	30.24	30.9	1.23	1.20	1.22	5.14	5.52	5.33
2	488	514	501	32.6	31.60	32.1	1.30	1.28	1.29	6.34	6.58	6.46
3	480	519	500	33.3	32.90	33.1	1.36	1.34	1.35	6.53	6.89	6.71
Avg.	462	498	480	31.97	31.58	32.03	1.30	1.27	1.29	6.0	6.33	6.17
Estafeta Myronivska Variety (sowing period II)												
1	532	450	491	33.2	33.6	33.4	1.28	1.27	1.28	6.81	5.69	6.25
2	540	520	530	34.4	34.6	34.5	1.38	1.39	1.39	7.45	7.23	7.34
3	536	528	532	34.9	34.9	34.9	1.41	1.40	1.41	7.56	7.39	7.48
Avg.	536	499	518	34.2	34.4	34.3	1.36	1.35	1.36	7.27	6.77	7.02
Estafeta Myronivska Variety (sowing period III)												
1	413	450	432	30.3	33.3	31.8	1.13	1.25	1.19	4.67	5.62	5.14
2	469	494	482	33.6	34.2	33.8	1.27	1.37	1.32	5.95	6.77	6.36
3	471	502	487	34.2	34.6	34.4	1.30	1.38	1.34	6.12	6.93	6.53

Table 1, Continued

Var. No.	Elements of the crop structure									Biological yield, t/ha		
	product quantity, stems, pcs.			number of grains in an ear, pcs.			grain weight of 1 ear, g					
	2021	2022	Avg.	2021	2022	Avg.	2021	2022	Avg.	2021	2022	Avg.
Avg.	451	482	467	32.7	34.0	33.3	1.23	1.33	1.28	5.58	6.44	6.01
Dovira Odeska Variety (sowing period I)												
1	547	445	496	25.1	27.35	26.3	0.91	1.00	0.96	4.98	4.45	4.72
2	518	475	497	28.8	29.20	29.0	1.10	1.12	1.11	5.70	5.32	5.51
3	495	490	493	30.2	30.04	30.1	1.18	1.13	1.16	5.84	5.54	5.69
Avg.	520	470	495	28.03	28.9	28.5	1.06	1.08	1.08	5.51	5.10	5.31
Dovira Odeska Variety (sowing period II)												
1	508	485	497	30.7	30.02	30.4	1.19	1.04	1.12	5.90	5.04	5.47
2	553	518	536	30.9	30.78	30.8	1.20	1.17	1.19	6.52	6.06	6.29
3	537	534	536	31.6	30.98	31.1	1.25	1.18	1.22	6.61	6.30	6.46
Avg.	532	512	523	31.1	30.6	30.8	1.21	1.13	1.18	6.34	5.80	6.07
Dovira Odeska Variety (sowing period III)												
1	426	426	426	29.7	31.16	30.4	1.12	1.00	1.06	4.77	4.26	4.52
2	493	454	474	30.4	32.41	31.4	1.18	1.20	1.19	5.82	5.45	5.64
3	489	465	477	31.4	32.80	32.1	1.22	1.25	1.24	5.96	5.81	5.89
Avg.	469	448	459	30.5	32.1	31.3	1.17	1.15	1.16	5.52	5.17	5.35
Akhim Variety (sowing period I)												
1	446	449	448	35.1	33.48	34.3	1.27	1.07	1.17	5.66	4.80	5.23
2	474	475	475	35.4	35.64	35.5	1.31	1.23	1.27	6.21	5.86	6.04
3	494	482	488	35.9	35.80	35.9	1.35	1.27	1.31	6.67	6.12	6.40
Avg.	471	469	470	35.47	35.0	35.2	1.31	1.19	1.25	6.18	5.59	5.89
Akhim Variety (sowing period II)												
1	412	451	432	34.6	34.0	34.3	1.29	1.20	1.25	5.51	5.40	5.46
2	441	510	476	36.2	35.08	35.7	1.42	1.28	1.35	6.55	6.53	6.54
3	449	514	482	36.8	35.12	36.0	1.48	1.30	1.39	6.76	6.68	6.72
Avg.	434	492	463	35.87	34.7	35.3	1.4	1.26	1.33	6.27	6.20	6.24
Akhim Variety (sowing period III)												
1	373	441	407	33.3	34.00	33.7	1.15	1.10	1.13	4.47	4.85	4.66
2	406	474	440	37.4	35.00	36.2	1.37	1.27	1.32	5.60	6.02	5.81
3	410	480	445	37.9	36.02	37.0	1.41	1.30	1.36	5.74	6.24	5.99
Avg.	396	465	431	36.2	35.0	35.6	1.33	1.22	1.27	5.27	5.70	5.49

Source: *compiled by the authors*

In 2022, the highest number of grains per spike was observed in the "Akhim" variety, averaging 34.7-35.0 grains, followed by "Estafeta Myronivska" with 31.58-34.4 grains, and "Dovira Odeska" with 28.9-32.1 grains. In terms of grain weight per spike, the "Estafeta Myronivska" variety stood out with weights of 1.27-1.35 g. The "Akhim" variety had grain weights of 1.19-1.26 g per spike, while "Dovira Odeska" had grain weights of 1.08-1.15 g. Among the studied varieties, the highest biological yield was achieved by the "Estafeta Myronivska" variety sown on October 5th, 2021, with $N_{120}P_{90}K_{90}$ fertiliser and foliar microelement fertilization (7.48 t/ha).

Across all experimental variants, regardless of sowing dates, there was an increase in the structural yield indicators (number of grains per spike, grain weight per spike) and grain quality due to the application of mineral fertiliser at a rate of $N_{120}P_{90}K_{90}$ and foliar microelement fertilisation during the IV and VIII stages of organogenesis. According to the research results, among

all the varieties, the highest yield in 2021 was achieved by sowing the "Estafeta Myronivska" variety on October 5th (Table 2). The grain yield for the $N_{60}P_{60}K_{60}$ fertiliser treatment was 4.45 t/ha. Increasing the rate of mineral fertilisation to $N_{120}P_{90}K_{90}$ resulted in a significant yield increase of 1.3 t/ha compared to the control, and the use of the "Aidamin" complex fertiliser led to a yield increase of 0.25 t/ha.

Table 2. *Winter wheat yield depending on sowing dates, varieties, and nutrient backgrounds, 2021-2022, t/ha*

Variant	Yield, t/ha			Increase from fertiliser, t/ha			Increase from microfertilisers, t/ha		
	2021	2022	Avg.	2021	2022	Avg.	2021	2022	Avg.
1	2	3	4	5	6	7	8	9	10
Estafeta Myronivska Variety (sowing period I)									
$N_{60}P_{60}K_{60}$	4.09	4.00	4.05	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	5.04	5.03	5.04	0.95	1.03	0.99	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	5.26	5.27	5.27	1.17	1.27	1.22	0.22	0.24	0.23
Average	4.8	4.77	4.79						
Estafeta Myronivska Variety (sowing period II)									
$N_{60}P_{60}K_{60}$	4.45	4.32	4.39	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	5.75	5.54	5.65	1.3	1.22	1.26	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	6.0	5.65	5.83	1.55	1.33	1.44	0.25	0.11	0.18
Average	5.42	5.17	5.29						
Estafeta Myronivska Variety (sowing period III)									
$N_{60}P_{60}K_{60}$	3.75	4.15	3.95	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	4.76	5.18	4.97	1.01	1.03	1.02	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	4.93	5.30	5.12	1.18	1.15	1.17	0.17	0.12	0.15
Average	4.48	4.88	4.68						
Dovira Odeska Variety (sowing period I)									
$N_{60}P_{60}K_{60}$	3.56	3.23	3.40	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	4.51	4.07	4.29	0.95	0.84	0.90	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	4.68	4.24	4.46	1.12	1.01	1.07	0.17	0.17	0.17
Average	4.25	3.85	4.05						
Dovira Odeska Variety (sowing period II)									
$N_{60}P_{60}K_{60}$	4.36	3.79	4.08	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	5.35	4.81	5.08	0.99	1.02	1.01	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	5.47	4.92	5.20	1.11	1.13	1.12	0.12	0.11	0.12
Average	5.06	4.51	4.79						
Dovira Odeska Variety (sowing period III)									
$N_{60}P_{60}K_{60}$	3.47	3.26	3.37	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	4.66	4.35	4.51	1.19	1.09	1.14	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	4.78	4.45	4.62	1.31	1.19	1.25	0.12	0.10	0.11
Average	4.30	4.02	3.75						
Akhim Variety (sowing period I)									
$N_{60}P_{60}K_{60}$	4.08	3.54	3.81	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	5.13	4.57	4.85	1.05	1.03	1.04	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	5.28	4.70	4.99	1.2	1.16	1.18	0.15	0.13	0.14
Average	4.83	4.27	4.55						
Akhim Variety (sowing period II)									
$N_{60}P_{60}K_{60}$	4.26	4.13	4.20	-	-	-	-	-	-

Table 2, Continued

$N_{120}P_{90}K_{90}$	5.29	5.07	5.18	1.03	0.94	0.99	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	5.47	5.18	5.33	1.21	1.05	1.13	0.18	0.11	0.15
Average	5.0	4.79	4.90						
			Akhim Variety (sowing period III)						
$N_{60}P_{60}K_{60}$	3.54	3.68	3.61	-	-	-	-	-	-
$N_{120}P_{90}K_{90}$	4.68	4.81	4.75	1.14	1.13	1.14	-	-	-
$N_{120}P_{90}K_{90}$ + Aidamin	4.89	4.96	4.93	1.35	1.28	1.32	0.21	0.15	0.18
Average	4.37	4.48	4.43						
$HIP_{0.5}$ t/ha A (dates)	0.058	0.061							
B (fertilisers)	0.058	0.064							
C (varieties)	0.058	0.061							
ABC (interaction)	0.173	0.190							

Source: *compiled by the authors*

In 2021, the winter wheat varieties "Dovira Odeska" and "Akhim" also achieved their maximum yield during the second sowing date (05.10), with average yields of 5.06 and 5.0 t/ha, respectively. The yield increase from fertilisation was 0.99 and 1.03 t/ha, and from foliar fertilisation was 0.12 and 0.18 t/ha. For the sowing on October 20th, 2021, the "Estafeta Myronivska" variety formed an average yield of 4.48 t/ha, which was 0.94 t/ha lower than the yield from the second sowing date, and 0.62 t/ha lower than the yield from the sowing on September 20th, 2021.

The average yield of the "Dovira Odeska" variety (4.25 t/ha) for the first sowing date (20.09.2021) was lower than that for the October 5th sowing (5.06 t/ha) by 0.81 t/ha, and for the October 20th sowing, it was lower by 0.76 t/ha (4.3 t/ha). The "Akhim" variety also experienced a significant reduction in yield compared to the second sowing date, with an average reduction of 0.17 t/ha for the September 20th sowing and 0.63 t/ha for the October 20th sowing. The yield increase of the winter wheat varieties from applying $N_{120}P_{90}K_{90}$ mineral fertiliser was 0.95-1.05 t/ha for the first sowing date, 0.99-1.03 t/ha for the second sowing date, and 1.01-1.19 t/ha for the third sowing date. Applying foliar microelement fertilization twice during the phases of BBCH 29-30 (1.0 L/ha) and BBCH 55-57 (1.0 L/ha) resulted in a significant yield increase ranging from 0.12 to 0.25 t/ha.

In 2022, the highest yields across all sowing dates were achieved by the "Estafeta Myronivska" variety, ranging from 4.77 to 5.17 t/ha. The yield of winter wheat was lower in the "Akhim" variety, ranging from 4.27 to 4.79 t/ha, which was 0.38-0.5 t/ha less. The lowest grain yield in 2022 was also observed in the "Dovira Odeska" variety, ranging from 3.85 to 4.51 t/ha. The highest yields were achieved by all studied varieties for the October 5th sowing: "Estafeta Myronivska" averaged 5.17 t/ha, "Dovira Odeska" – 4.51 t/ha, and "Akhim" – 4.79 t/ha. For the October 20th sowing, the "Estafeta Myronivska" variety formed an average yield of 4.77 t/ha, which was 0.4 t/ha lower than the yield from the second sowing date, and 0.29 t/ha lower for the September 20th sowing (4.88 t/ha).

The average yield of the "Dovira Odeska" variety (3.85 t/ha) for the first sowing date (20.09) was lower than that for the October 5th sowing (4.51 t/ha) by 0.66 t/ha, and for the October 20th sowing, it was lower by 0.49 t/ha (4.02 t/ha). The "Akhim" variety also experienced a significant reduction in yield compared to the second sowing date, with an average reduction of 0.52 t/ha for the September 20th sowing and 0.31 t/ha for the October 20th sowing. The yield increase of the winter wheat varieties from applying $N_{120}P_{90}K_{90}$ mineral fertiliser for the first sowing date compared to the control ranged from 0.84 to 1.03 t/ha. For the second – 0.94 to 1.22 t/ha, and for the third – 1.03 to 1.13 t/ha. Dual foliar fertilisation of winter wheat crops with "Aidamin-complex foliar fertilization" in the BBCH 29-30 (1.0 L/ha) and BBCH 55-57 (1.0 L/ha) stages resulted in a significant yield increase ranging from 0.10 to 0.24 t/ha. Yield increase from applying $N_{120}P_{90}K_{90}$ ranged from 0.84 to 1.22 t/ha. Among the studied variants, the highest yield was observed for the "Estafeta Myronivska" variety (5.65 t/ha) sown on October 5th with the application of $N_{120}P_{90}K_{90}$ and Aidamin-complex foliar fertilisation.

The research results indicate that the productivity of winter wheat agrocenoses, the formation of yield elements, vegetation conditions, and plant overwintering directly depend on sowing dates. The timing of sowing proved to be a key factor for wheat yield. Early sowing dates promoted more active plant development, resulting in a higher number of spikes per plant. On the other hand, later sowing led to the formation of fewer spikes but with a greater number of grains per spike. These growth and development differences can be utilised depending on cultivation goals, either for obtaining higher yield or preserving grain quality. This is consist-

ent with data of V. Petrychenko & V. Lykhochvor (2020). L. Gandjaeva (2019) draws attention to a decrease in the level of achievement of the potential of crop productivity when the sowing time deviates from optimal. However, the question of optimal sowing dates remains debatable. According to V. Tkachuk & T. Tymoshchuk (2020), in the conditions of Polissya, the highest grain yield of winter wheat (3.56 t/ha) was achieved with a sowing date of September 10th. The yield decreased by 1.02 t/ha for the October 10th sowing.

I. Yarchuk & T. Melnyk (2018) established that plants sown on September 10th had the most significant parameters at the time of cessation of autumn vegetation. Later sowing dates resulted in a reduction in all biometric indicators: plant height, plant weight, number of stems, and nodal roots. Other researchers also point to better plant development for early sowing dates. According to A. Kryvenko *et al.* (2019), a higher yield of all studied winter wheat varieties (25.5% increase) was obtained for the October 5th sowing compared to the September 25th sowing. For this sowing date, the yield was 37.6 and 53.2% higher than for the October 15th and October 25th sowing dates, respectively. For the October 5th and 15th sowing dates, the winter wheat varieties formed the highest-quality grains by weight and 1000-seed mass.

However, the rise in temperature during the autumn vegetative period of winter wheat, along with the extension of its autumn growth and development period, encourages a reevaluation of sowing dates. As of the recommendation of G. Gutsol & I. Ovcharuk (2023), in the Right Bank Forest-Steppe zone, it is advisable to shift sowing dates by 11 days toward later dates, and in some years, these dates can be shifted even later. An increase in yield due to shifting sowing dates from September 10th to October 10th was obtained in H. Chuhrii's (2019) research. R. Vozhegova & V. Bily (2019) note that the highest number of productive stems and grains per spike was achieved with later sowing dates.

One of the main measures to increase the productivity of winter wheat and improve the quality of its grain is the use of mineral fertilisers. The obtained data confirm that fertilisation indeed affects the cultivation of wheat. The application of fertilisers contributed to yield increase, regardless of the sowing date. However, it is important to consider optimal doses, as excessive fertiliser application can lead to negative effects on plant health and product quality. The specified information is consistent with the data of M. Kulyk *et al.* (2020). V. Ivanina & I. Korotenko (2022) established that yield increase in cereal crops is achieved through mineral plant nutrition. In their study, applying $N_{80}P_{60}K_{60}$ under winter wheat in rotation with peas resulted in the highest grain yield (5.42 t/ha), exceeding the control without fertilisers by 1.02 t/ha. The application of fertilisers led to increased production regardless of the sowing date. Nevertheless, it is necessary to be cautious with fertiliser dosages, as their excessive use can lead to overgrowth of plants and adversely affect yield quality.

Thus, it is worth noting that the ongoing climate changes prompt a revision of established cultivation practices, particularly adjusting sowing dates. To achieve high yield performance in production, judicious use of foliar micro-fertilizers is recommended.

CONCLUSIONS

The results of the two-year study indicate that in the soil and climatic conditions of the Western Forest-Steppe, the maximum productivity of winter wheat sowing was achieved on October 5th. For this sowing date, the studied varieties achieved average yields of 4.79 t/ha (Dovira Odeska), 4.9 t/ha (Akhim), and 5.29 t/ha (Estafeta Myronivska). Shifting sowing dates either towards earlier (20.09) or later (20.10) resulted in yield reduction. Deviations from these indicators for the Estafeta Myronivska variety were 0.5 and 0.61 t/ha, for Dovira Odeska – 0.74 and 1.04 t/ha, for Akhim – 0.35 and 0.47 t/ha.

Increasing the rate of applying $N_{120}P_{90}K_{90}$ mineral fertilisers led to increased grain yield for all sowing dates. Depending on the variety and research variant, the yield increase ranged from 0.9 to 1.14 t/ha. Foliar fertilisation of plants with Aidamin-complex micro-fertiliser in the BBCH 29-30 and BBCH 55-57 stages resulted in additional yield growth of 0.11 to 0.23 t/ha. Among all varieties, the highest yield during the years of the study (5.65 t/ha) was achieved by the agrocenosis of the Estafeta Myronivska variety sown on October 5th, with the application of $N_{120}P_{90}K_{90}$ mineral fertilisers and Aidamin-complex foliar fertilisation (1.0 L/ha). The yield increase from mineral fertilisers was 1.22 t/ha, and from foliar micro-fertilisation, it was 0.11 t/ha.

The prospects for further research are associated with the selection of high-productivity winter wheat varieties, the search for new effective micro-fertilisers that would mitigate the impact of stress factors during the vegetation period and ensure yield stability. Another possible area is the influence of biological methods and modern technologies on the effectiveness of winter wheat cultivation.

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CONFLICT OF INTEREST

None.

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Анотація. Сучасні сорти пшениці озимої мають високий генетичний потенціал продуктивності, реалізувати який можна за рахунок удосконалення елементів технології вирощування, зокрема строків сівби, оптимізації системи удобрення, застосування мікроелементів, що обумовлює актуальність дослідження. Метою роботи було обґрунтувати особливості формування продуктивності пшениці озимої залежно від елементів технології вирощування в умовах Карпатського регіону. У процесі виконання роботи використовували наступні методи: польовий, лабораторний (для визначення якісних показників зерна пшениці), та статистичний (для оцінки достовірності даних). Польові дослідження проводили впродовж 2021-2022 рр. на сірих лісових поверхнево оглеєних ґрунтах. Досліджували особливості росту і розвитку сортів пшениці озимої Естафета миронівська, Довіра одеська і Ахім, висіяні в різні строки (20.09; 05.10; 20.10). Встановлено, що урожайність зерна і показники формування індивідуальної продуктивності досліджуваних сортів пшениці озимої змінювалися залежно від строків сівби, дози мінеральних добрив, листкового підживлення та сортових особливостей. Найвищі показники індивідуальної продуктивності рослин пшениці озимої сортів Естафета миронівська, Довіра одеська і Ахім сформовано за сівби 05.10 на фоні мінерального удобрення $N_{120}P_{90}K_{90}$ (із внесенням $N_{30}P_{90}K_{90}$ під культивацію, N_{15} – по мерзлоталому ґрунті, N_{45} (у фазу ВВСН 29-30), N_{30} (ВВСН 55-57) та дворазового внесення мікродобрив (Айдамін-комплексний листкове підживлення). У результаті дії досліджуваних факторів відзначено зростання кількості продуктивних стебел, зерен у колосі і ваги зерна з 1 колоса. Максимальну врожайність зерна з поміж досліджуваних сортів сформував сорт Естафета миронівська (5,65 т/га) за сівби 05.10 на варіанті внесення $N_{120}P_{90}K_{90}$ і листкового підживлення Айдаміном комплексним. Результати досліджень можуть бути використані для корегування елементів технології вирощування пшениці озимої у виробничих умовах для підвищення врожайності та якості зерна

Ключові слова: пшениця озима; сорти; мінеральні добрива; листкове підживлення; технології вирощування

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Study of the world collection of oilseed flax as a source material for selection in the conditions of Northern Kazakhstan

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Abstract. According to the modern requirements of cultivation, new varieties of oilseed flax are being created, differing in a complex of useful features. The basis of the selection of oilseed flax is the study, selection, and creation of new varieties based on the world collection and suitable for the agro-climatic conditions of Northern Kazakhstan. The purpose of the study is to investigate the collection samples of oilseed flax in the conditions of the Kostanay region of Northern Kazakhstan and to select the most promising pedigree material according to economically valuable characteristics in the conditions of a moisture deficit zone. The following methods were used: biological, phenological, laboratory, statistical, and information analysis of the adaptive capabilities of individual varieties of oilseed flax. An assessment of economically valuable traits was carried out for 14 varieties of oilseed flax from the world collection of various ecological and geographical origin for the period in 2020-2022. As a result of the research, samples characterised by high yield were identified:

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Linol – 82 g/m^2, Sibirskaya 38854 – 71 g/m^2, Antares – 78.3 g/m^2. Samples of the varieties Biryuza, Krokus, Kustanayskiy – 8.2 g, Iceberg – 8.1 g were distinguished by high indicators of the weight of 1000 seeds. A valuable and plastic source material for selection with the main valuable and economic characteristics was identified: the growing season for 85-92 days, with a seed yield of more than 47.5-82.2 g/m^2, a weight of 1000 seeds of 6.9-8.1 g, oil content in seeds of 43.7-47.5%, plant height of 45-60 cm. The selected samples are recommended for cultivation in Northern Kazakhstan: by precocity – Sibirskaya 38854 and Iceberg; productivity – Linol, Antares; weight of 1000 grains – Nebesniy, Biryuza, Linol, Krokus; oil content in seeds – Kostanayskiy-11, Iceberg; resistance to fusarium – Kostanayskiy-11, Sibirskaya 38854, Antares, Iceberg. The effectiveness of the breeding programme depends on the patterns of inheritance of economically valuable traits operating in a hybrid population, reducing the loss of valuable genotypes and reducing costs by culling less valuable traits

Keywords: productivity; adaptive abilities; yield; oil content; genotype; fusarium

INTRODUCTION

Oilseed flax (*Linum usitatissimum* L.*)* is a widely used food culture, a source of high-grade inexpensive vegetable protein for animal husbandry, and technical raw materials in industrial sectors, including paint, soap, and leather. The development of various industries has led to an increase in demand for vegetable oils of various quality. The greater the variety of technical products and food products, the more diverse the raw materials needed for their production should be. In search of promising additional sources for the production of oils and fats, producers are turning to an increasing number of cultivated crops, considering valuable morphological, biological, and economic characteristics. K.A. Akshalov *et al.* (2023) note that whole oilseed flax seeds are used as a popular additive in many types of bread. They are one of the richest sources of substances with a powerful antioxidant effect – lignans, valuable raw materials for the production of organic compounds such as esters, acetals, urethanes, and amides, from which various coatings, fibres, insulating foams, plasticisers, high-pressure lubricants can be produced.

In Kazakhstan, oilseed flax is a promising crop, and its acreage is increasing from year to year, reaching 1.5 million hectares. The main flax-growing regions are the North Kazakhstan, Kostanay and Akmola regions. The agro-climatic conditions of Northern Kazakhstan meet the requirements for growing oilseed flax, from which both oilseeds and livestock feed are obtained. As noted by A. Suleimenova (2019), oilseed flax seeds are relatively resistant to cold and begin to germinate at a soil temperature of 3-5°C. Lower temperatures and increased soil moisture can cause rotting. With optimal humidity and an average daily soil temperature of 7-8°C, seedlings appear after 5-7 days, and at a lower temperature, germination is delayed up to 15 days.

Since flax is an early sowing crop, there is a risk of damage and death of plants due to low temperatures, and the creation of varieties resistant to hypothermia is an urgent direction in flax breeding. G.S. Kaliakparova and Y.Y. Gridneva (2019) evaluate the most important varieties in the technology of growing and breeding oilseed crops adapted to specific agro-climatic conditions, ensuring sustainable yield and product quality. The new gene pool of oilseed flax is based on hybridisation methods using varieties from the VIR World Collection of Plant Genetic Resources (Vavilov All-Russian Institute of Plant Industry). Hybridisation when crossing varieties of different ecological and geographical origin is the most common way ton create a starting material for the selection of agricultural crops. As noted in the studies by A. Nogaev *et al.* (2021), before the cultivation of oilseed flax, the following tasks are to develop modern high-yielding varieties suitable for food and technical use, with high oil content in seeds of about 55%, crude protein – 35%, resistant to biotic and abiotic environmental factors. Y. Lan *et al.* (2020) note that oilseed flax seeds, due to the high content of polyunsaturated fatty acids, have a high iodine number – 170-200 units, forming a strong, stable film when dried.

According to the Food and Agriculture Organisation (FAO), in terms of linolenic acid content, linseed oil can be divided into four categories: more than 50% – high oil, suitable mainly for technical use; within 36-49% – medium oil, suitable for technical use in pharmaceuticals and perfumes; within 10-35% – low, mainly for food purposes; less than 10% – very low, only for food purposes (Bureau of National Statistics…, 2023). According to C. Qiu *et al.* (2020), linseed oil contains fatty acids such as: palmitic 5-7%, stearic 3-4%, oleic 16-20%, linoleic 14-17% and linolenic 50-60%. The selection of oilseed flax is aimed at creating technical varieties with a high content of linolenic acid >65%, food varieties with a low content of linolenic acid <40%, and medical varieties >40%.

According to J. Yang *et al.* (2021), flax cake is a product of the secondary processing of flax seeds and by biochemical composition contains 6-12% crude fat, 33-38% crude protein, 7% crude ash, and 9% crude fibre, and by nutritional value, 1 kg has 1.15 fodder units and contains 260 g of digestible protein. 1 kg of flax meal contains 1.12 fodder units and 285 g of digestible protein. I.V. Goudar *et al.* (2021) characterised the composition of flax fibres and their application. Oilseed flax stalks contain 12-18% crude fibre, which is used in the production of pressing material, coarse fabrics, rope,

twine, gaskets, packaging, and insulation. In addition, flax straw contains up to 50% pure cellulose, so it is suitable for the production of thin paper and cardboard by pressing. The flax husk obtained after threshing and cleaning of seeds is a valuable feed raw material for pigs, according to its nutritional value, 1 kg contains 0.27 fodder units and 20 g of digestible protein.

The right choice of varieties is important for the successful cultivation of oilseed flax, therefore, due to the efforts of breeders, the potential yield, quality, adaptability to local conditions, resistance to pests and diseases and tolerance to stress factors are improving. In view of the above, studying the characteristics of different flax varieties and hybrids is not only of theoretical but also of practical interest. The purpose of the study is to identify the most promising material for the selection of oilseed flax in the conditions of the zone of insufficient moisture in the Kostanay region of the Republic of Kazakhstan (RK).

MATERIALS AND METHODS

The research work was carried out in the Karabalyk Agricultural Experimental Station during 2020-2022. The object of the study was 14 varieties of oilseed flax of various ecological and geographical origin. Meteorological conditions during the years of research were diverse and reflected quite widely the features of the Kostanay region, located in Northern Kazakhstan, divided into three natural and climatic zones. The test site of the Karabalyk Station is located in the 1 natural and climatic zone. During the years of the research, there were no significant deviations from the climatic conditions of Northern Kazakhstan, as they were relatively favourable for the growth of oilseed flax. The following methods were used in experimental studies: biological, determining the parameters of environmental conditions and comprehensive analysis of the qualitative characteristics of the yield of oilseed flax varieties; phenological, monitoring the stages of plant development; laboratory, monitoring the biochemical composition of plant material; statistical, data analysis, and assessment of adaptive capabilities. The selection of oilseed flax was carried out considering specific conditions and was aimed at creating high-yielding medium-ripened varieties with high oil content in seeds, resistant to drought, diseases and pests, equally maturing, and suitable for double use. The solution to this problem was facilitated by the use of the world collection of oilseed flax.

The area of each plot was 10 m^2, in four repetitions, with a consistent systematic arrangement, the seeding rate was 7 million pcs./ha. Sowing was carried out using a low-volume system with an SN-10C seeder: in 2020 – May 6, in 2021 – May 13, in 2022 – May 19. Harvesting was carried out manually, using a frame method, flax threshing was carried out using a Heqe-125 breeding combine, and cleaning and sorting of seeds was carried out manually. Vegetation of plants proceeded in 2020 in conditions of moderate moisture (hydrothermal coefficient (HTC) – 1.24), in 2021 – insufficient moisture (HTC – 0.92), in 2022 – insufficient moisture (HTC – 0.87). The average duration of the growing seasons in 2020, 2021, 2022 was 97, 101 and 111 days, respectively. At the early stages of breeding, more than 4000 samples were studied. According to the complex of economically valuable features, 15 cultivars were identified, which were involved in the competitive variety testing: Kostanayskiy-1, Nebesniy, Biryuza, Linol, Severniy, Surpriz, Sokol, Triumf, Krokus, Sibirskaya 38854, Isilkulsky, Kustanayskiy yantar, Antares, Iceberg.

The temperature regime in the area of operation of the station was characterised by sharp fluctuations observed not only monthly, but also daily throughout the year, the average temperature is 2.8°C. In spring, there was a big difference between daytime and nighttime temperatures, sunny weather prevailed in summer, followed by an autumn cold snap and the first frosts at the end of September. Data on average daily air temperature are indicated in Table 1.

Table 1. *Average daily air temperature in the Karabalyk agricultural station, °C*

Years	2020	2021	2022
May	18.2	21.5	13.5
June	19.2	22.3	18.9
July	25.2	22.8	23.4
August	21.3	24.4	22.2
Total for May-August	20.9	22.7	19.5

Source: *compiled by the authors*

For the periods 2020, 2021, 2022, the sum of active temperatures was – 1977, 2055.5, and 2030°C, respectively. The average annual precipitation over the past 80 years is 328.3 m, June and especially July are the wettest and warmest months, but the intake of moisture and heat varies significantly from year to year. In general, there is more precipitation in the warmer months than in the colder ones. During the periods 2020, 2021, 2022, precipitation fell 273, 240, and 156.6 mm, respectively (Table 2).

Table 2. *Precipitation totals for 2020-2022 in the Karabalyk agricultural station, mm*

Year	2020	2021	2022
May	41.8	6.7	40.6
June	22.4	8.4	20.9
July	12.7	51.9	17.7
August	41.5	21.7	10.5
Total for May-August	118.4	88.7	89.7

Source: *compiled by the authors*

In 2020, precipitation in Karabalyk amounted to 41.8 mm in May, 28 mm in the summer months, and 118.4 mm in the entire growing season. In 2021, in May-June, there was a low amount of precipitation on average – 7.5 mm, in July – 51.9 mm, in August, when the vegetation is almost complete – 21.7 mm, on average for the entire growing season – 88.7 mm. In the conditions of May 2022, precipitation amounted to 40.6 mm, on average for the summer months – 16.4 mm, for the entire growing season – 89.7 mm. The soils of the Karabalyk agricultural zone belong to medium-humus chernozem soils, which are genetically typical for this zone, the humus content is 5.2-6%. According to the mechanical composition, it is a heavy loamy soil with a very high nitrogen content >5 mg/100 g according to Tyurin, with a potassium content >20 mg/100 g. The soil is characterised by good agrochemical properties: humus content – 4.6%, easily hydrolysable forms of nitrogen – average, mobile phosphorus – high, exchangeable potassium – increased. The degree of acidity of the soil according to the pH is slightly acidic – 4.2. Statistical processing of field experiment data was carried out by the method of variance analysis based on the study by L. Quillian *et al.* (2019). The study complied with the requirements of the Convention on Biological Diversity (1992).

RESULTS

The high demand for oilseed flax has made its cultivation highly profitable. In world agricultural production, flax occupies more than 3.5 million hectares, and the total seed yield ranges from 2.2 to 2.7 billion tonnes. According to the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2023), in 2020, the main flax grain-producing countries are Kazakhstan – 158.4 thousand tonnes, Canada – 578 thousand tonnes, China – 330 thousand tonnes, USA – 145 thousand tonnes, India – 112 thousand tonnes. Sunflower and oilseed flax are the leaders in the market of oilseeds in the Republic of Kazakhstan, both in terms of acreage and production, and export potential. Over the past six years, the total acreage of oilseeds in the Republic of Kazakhstan has increased by more than 1 million hectares and according to the data of 2020-2022 will exceed 3 million hectares, which is noted in detail in Table 3.

Table 3. *Areas of oilseed crops in the Republic of Kazakhstan, thousand hectares*

Cultures	2020/21	2021/22
Rapeseed	127.4	121.9
Flax	1526.4	1496.1
Sunflower	756.1	958.5
Corn	327.7	381.9
Soy	127.8	113.3
Other	32.9	21.9

Source: *Development strategy of the joint-stock company "National Company". Food contract corporation for 2021-2030 (2020)*

The most significant growth occurred in the oilseed flax cultivation sector, where the acreage in 2020-2021 amounted to 1526.4 hectares, and in 2021-2022 – 1496 hectares, which compared to the total oilseed crops amounted to 53 and 48%, respectively. Unlike sunflower, rapeseed and soybeans, the trend of growth in the volume of oilseed flax harvest in the Republic of Kazakhstan is due to the expansion of acreage, given the almost unstable yield in the wide range of 2-12 metric centners/ha. According to Kazakh Grain Union estimates, the production of oilseed flax in the Republic of Kazakhstan in 2021-2022 amounted to 744 thousand tonnes compared to 1.06 million tonnes in the previous year. The achievement of optimal production volumes of sparsely distributed oilseeds in the Republic of Kazakhstan was achieved by increasing yields and significant investments, which will continue to be obtained with the effective use of oilseed flax. Significant

achievements in breeding, seed production and technology of growing sparsely distributed oilseeds give grounds to increase the production of their seeds to 1.2 million tonnes by 2025, as noted in Table 4.

***Table 4**. Projected production of oilseed flax seeds in Kazakhstan until 2025*

Indicators	2020/2021	2021/2022	2024/2025
Acreage, thousand hectares	1526.4	1496.1	1650
Gross harvest, thousand tonnes	1058.4	744.1	1200
Yield, t/ha	0.79	0.59	1.1

***Source:** Development strategy of the joint-stock company "National Company". Food contract corporation for 2021-2030 (2020)*

Due to the severe drought during the growing season of flax and the unusually high level of pests and diseases for this crop, some acreage of oilseeds turned out to be unsuitable for harvesting, and producers did not consider it advisable to carry out harvesting on such areas. As a result, more than 200 thousand hectares of flax acreage were lost. In addition, the drought has had an extremely negative impact on the yield of oilseeds. As a result, even after significant losses, the total yield of this crop has significantly decreased despite the fact that it ranks second in the area of harvesting oilseeds. The leaders in the cultivation of oilseed flax in the Republic of Kazakhstan are the North Kazakhstan, Kostanay and Akmola regions with a sown area of 605, 282, 186 thousand hectares, respectively. It is previously known that in order to increase the productivity of oilseed flax cultivation, it is necessary to develop new high-yielding varieties that are adapted to local conditions, have a high oil content of seeds, are resistant to major diseases and adverse environmental factors. The growing season and the formation of the yield of the studied samples of oilseed flax are important biological signs in the natural and climatic conditions of the Karabalyk agricultural complex, noted in detail in Table 5.

***Table 5.** Duration of the growing season and the height of oilseed flax plants for the period 2020-2022*

Variety	Growing season, days				Plant height, cm			
	2020	2021	2022	Average	2020	2021	2022	Average
Kostanayskiy-11	88	91	93	90	55	58	50	54
Nebesniy	84	92	85	87	55	56	54	55
Biryuza	88	92	93	91	54	58	53	55
Linol	86	90	85	87	55	53	49	52
Severniy	89	94	93	92	54	48	45	49
Surpriz	87	90	91	89	53	51	44	49
Sokol	85	92	89	88	46	47	40	44
Triumf	88	93	93	91	44	49	40	44
Krokus	84	91	87	87	53	54	46	51
Sibirskaya 38854	82	90	87	86	54	58	50	54
Isilkulsky	87	90	89	88	58	55	50	54
Kustanayskiy yantar	86	93	89	89	54	55	52	53
Antares	85	90	91	88	49	50	45	48
Iceberg	81	90	85	85	52	56	50	52

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

The growth period of the varieties ranged from 85-92 days, but in most samples, this indicator strongly depended on the conditions of the year. Despite very different climatic conditions, some varieties cultivated in the Karabalyk agricultural complex had a stable growth period throughout the year: Kostanayskiy – 91-93 days, Isilkulsky – 87-90 days, Surpriz – 87-91 days. In general, according to the results of a three-year study, two early-ripening varieties were identified that grew 5-6 days earlier than the standard variety, namely, Sibirskaya 38854 and Isilkulsky, which ripened on 86 and 85 days, respectively. In addition, eight varieties ripened earlier than the standard varieties Nebesniy, Linol, and Krokus – 87 days; Sokol, Isilkulsky, and Antares – 88 days; Surpriz and Kustanayskiy yantar – 89 days. According to the duration of the growing season,

the varieties – Biryuza, Triumf, and Severniy, ripened 1-2 days later, in comparison with the standard.

When cultivating flax for oilseeds, an average plant height of 45-60 cm is sufficient. With double use, for seeds and fibre, it is necessary to create flax varieties with a plant height of 65 cm and above. For this purpose, it is necessary to involve tall varieties in crossing. The height of plants in the varieties under study largely depended on the weather conditions prevailing during the growing season, and varied between 44-54 cm with an average value of 51 cm. Three groups of plants were identified: with a height within 44-49 cm, 49-52 cm, and 52-58 cm. The standard plant height was 54 cm in the Karabalyk agricultural complex, Surpriz and Triumf varieties were marked below the standard – 44 cm, and the tallest were the Nebesniy and Biryuza varieties – 54 cm. Given the characteristic stunting of the varieties of oilseed flax, it can be emphasised that the varieties included in the crosses for spinning purposes are not suitable. Seed productivity is an important indicator of oilseed flax and includes related features, namely: the number of productive pods on the plant, the number of seeds in the box, the weight of 1000 g of seeds, which is described in detail in Table 6.

Table 6. *Seed productivity of oilseed flax for the period 2020-2022*

Variety	Number of productive boxes, pcs.			Number of seeds in a box, pcs.			Weight of 1000 seeds, g		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
Kostanayskiy-11	23	29	21	9	10	8	6.5	7.1	6.2
Nebesniy	20	28	26	9	9	8	6.5	7.7	6.8
Biryuza	31	34	33	9	10	10	6.6	7.6	6.8
Linol	21	26	22	9	8	8	7	7.4	6.6
Severniy	19	23	18	8	9	8	6.6	7.2	6.4
Surpriz	22	27	20	8	8	7	6.5	7.4	6.4
Sokol	21	29	24	7	8	7	6.8	7	6.2
Triumf	23	25	19	10	10	9	6.4	7	6.2
Krokus	25	29	21	9	10	10	6.6	7.7	6.8
Sibirskaya 38854	24	28	22	9	9	8	6.5	7	6.2
Isilkulsky	26	30	24	9	10	9	6.3	7.2	6.4
Kustanayskiy yantar	27	32	25	9	10	10	6.7	7.2	6.4
Antares	24	27	19	10	10	9	6.7	7	6.2
Iceberg	21	30	25	9	10	10	6.3	7.5	6.6

Source: *compiled by the authors*

The number of productive pods per plant is an important feature closely related to the seed productivity of oilseed flax; according to this feature, the varieties Biryuza – 32.7 and Kustanayskiy yantar – 28 are distinguished in the experimental farm. Severniy and Kaiser had the lowest productivity rates of 20 and 22 boxes, respectively. The number of seeds in the box varied between 7.1-7.3 pcs. Varieties Nebesniy, Linol, Severniy, Sibirskaya 38854 were slightly inferior to the standard – 8.3-8.8 pcs., the remaining varieties showed results at the level of the Kostanayskiy-11 variety. Achieving a high yield is ensured by the availability of complete information about the processes of photosynthesis, growth and development, air, water and heat regimes, mineral nutrition, plant structure, sowing quality. The main chemical component of flax seeds is oil, the amount of which, in terms of crude fat, averages from 27 to 48%, therefore, in terms of the content of biologically valuable components, linseed oil ranks first among other edible vegetable oils. Data on the yield and oil content of flax seeds are indicated in Table 7.

Table 7. *Indicators of flax yield and oil content for the period 2020-2022*

Variety	Oil content, %			Yield, g/m^2		
	2020	2021	2022	2020	2021	2022
Kostanayskiy-11	42.5	44.3	40.9	59	52	53
Nebesniy	40.2	40.8	39.3	78	75	56
Biryuza	41.5	43.7	41.1	73	71	60
Linol	42.4	42.3	42.7	84	90	72
Severniy	42.1	41.8	42.9	65	60	45

Table 7, Continued

Variety	Oil content, %			Yield, g/m²		
	2020	2021	2022	2020	2021	2022
Surpriz	41.9	43	41.3	57	52	39
Sokol	40.7	42.7	39.6	64	65	36
Triumf	41.6	43	41.5	59	50	35
Krokus	42.3	41.8	42	53	48	42
Sibirskaya 38854	42.8	43.4	41.8	84	81	48
Isilkulsky	43	43.9	38.8	76	71	44
Kustanayskiy yantar	42.9	43.1	42.3	68	65	47
Antares	41.9	42.5	42.1	89	90	56
Iceberg	43.2	44.2	43.7	44	39	59

Source: *compiled by the authors*

The average yield of oilseed flax in a three-year trial of the standard Kostanayskiy-11 variety was 54.2 g/m². At the same time, the yield of the tested varieties varied from 47.5 to 82.2 g/m². During the three-year research period, some samples consistently exceeded the standard in seed yield: Linol – 82 g/m², Antares – 78.3 g/m², and Sibirskaya 38854 – 71.2 g/m², consistently exceeding the standard by 28, 24 and 17 g/m². The varieties Nebesniy, Biryuza, Isilkulsky, and Kustanaiskiy yantar also exceeded the standard for these samples by 60-69.7 g/m². Surpriz, Triumf, Krokus, and Iceberg varieties were below standard with a productivity of 47.5-49.3 g/m². As a result of the research, a high oil content in seeds of all varieties was revealed in the range of 38.8-44.3%. In the standard variety Kostanayskiy-11, the oil content averaged 42.6% over three years, in the varieties Biryuza, Linol, Triumf, Krokus, Sibirskaya 38854, Isilkulsky, Kustanayskiy yantar, Iceberg oil content varied at the same level. The oil content of the standard Kostanayskiy-11 variety averaged 42.6% over three years, and also, in the varieties Biryuza, Linol, Triumf, Krokus, Sibirskaya 38854, Isilkulsky, Kustanayskiy yantar, and Iceberg, it varied at the same level. On the artificial complex infectious background of single-row plots of 0.4 m², the stability of ecological variety testing of oilseed flax was studied. 2 varieties were used as controls: Kostanaysliy-11, resistant to fusarium, and the unstable Isilkulsky variety. Stability was determined by counting plants after germination and before harvesting. Gathering was carried out when 75% of the plot area matured (Table 8).

Table 8. *Resistance to fusarium wilting of varieties of ecological variety testing*

Variety	Resistance to fusarium, %, pcs.			
	2020	2021	2022	Average
Kostanayskiy-11	96	95	97	96
Nebesniy	92	95	98	95
Biryuza	92	91	97	93.3
Linol	95	92	89	92
Severniy	96	92	94	94
Surpriz	96	90	92	92.7
Sokol	98	96	90	94.7
Triumf	94	95	87	92
Krokus	92	94	93	93
Sibirskaya 38854	93	95	96	94.7
Isilkulsky	92	91	89	90.7
Kustanayskiy yantar	92	95	93	93.3
Antares	93	94	95	94
Iceberg	96	94	92	94

Source: *compiled by the authors*

In addition to high yield, oil content of seeds and early maturation, the selection of oilseed flax should have high resistance to the most common and harmful linseed fungus *Fusarium oxysporum* v. The spread of the disease and the degree of damage to the crop depends on the presence of the pathogen and environmental

conditions (temperature, humidity, precipitation) and the degree of resistance of cultivated flax varieties.

DISCUSSION

In the current economic conditions, the production of oilseed flax is based on the cultivation of high-yielding varieties with high oil content, resistant to major pathogens and producing a marketable product that meets international quality standards. The reserve for increasing the productivity of the oilseed flax crop is the creation of new highly productive varieties adapted to local conditions, with high seed oil content and oil quality, resistant to major diseases and adverse environmental factors. The effectiveness of the breeding programme largely depends on the patterns of inheritance of economically valuable traits operating in the hybrid population of oilseed flax, allowing for more efficient selection, reducing the loss of valuable genotypes, saving costs by culling less valuable traits at an early stage of breeding. According to the study by G. Silska *et al.* (2022), interspecific crosses of oilseed flax can be used to breed varieties with greater plasticity and resistance to individual pathogens and complex diseases.

The reproductive success of oilseed flax cultivation includes the selection of flax samples from ecologically and geographically diverse world collections, and the development of methods for selecting parent pairs during crosses that determine the prospects for the future. The appearance of valuable traits in hybrids is associated with the possibility of combining the qualities of different parental forms. As a direction of breeding work, it is quite appropriate to attract wild species that can be significantly diversified in many ways due to interspecific crosses. As reported by A. Hoque *et al.* (2020), chromosomes of breeding traits of the genus *Linum* are important and valuable carriers of hereditary information, such as increased lateral branching and an increase in the number of pods on the plant, in addition to low content of crude fat, brittle pods, and small seeds. As noted by Z. Behzadi *et al.* (2022), a number of breeding methods are used to create new flax varieties, including microgametophytic selection, induced mutation, interspecific and intraspecific hybridisation, and electrophoresis of reserve seed proteins.

The creation of new crops is based on the theoretical development of models of varieties with specific characteristics and characteristics corresponding to high levels of yield and quality in specific environmental conditions. The diversity of genetic materials is an important characteristic for a sustainable breeding programme, as it provides the breeder with the best opportunities to select lines based on needs. B.J. Soto-Cerda *et al.* (2022) report that morphometric diversity is labour-intensive, often leads to false predictions, depends on the stage of development of plants sensitive to the environment, and diversity based on molecular markers is more accurate and economical since it allows breeders to select unrelated individuals among thousands of genotypes in a short period of time, which, in turn, reduces the workload in the field by evaluating only unrelated genotypes. The use of molecular biological methods and markers for the study of various cultivated plants has increased significantly. M. Yaşar (2023) describes various types of molecular markers and microsatellites for assessing the genetic diversity of the germ plasma of oilseed flax, such as: Random Amplified Polymorphic DNA (RAPD); Amplified Fragment Length Polymorphism (AFLP); Inter-Simple Sequence Repeat (ISSR); Simple Sequence Repeat (SSR); Inter-Retrotransposon Amplified Polymorphism (IRAP).

In breeding, a wide list of criteria reflecting different aspects of the process is used to assess the homeostaticity of oilseed flax culture, such as: ecological stability of varieties according to statistical indicators, and general, specific, and relative adaptive capacity. The general adaptive capacity describes the average value of a useful feature over the entire range of environmental conditions. Specific adaptive capacity is determined by differences in specific environmental conditions. Relative stability allows comparing different sets of features. According to A. Akrami *et al.* (2020), the ecological plasticity of the variety is a biological ability to adapt to growing conditions with the establishment of consistently high values of useful traits in various natural and climatic conditions. Varieties of oilseed flax with higher plasticity have greater stability of characteristics under fluctuations in environmental conditions, providing higher productivity under both favourable and unfavourable conditions.

Individual varieties of oilseed flax showed adaptive abilities in 2022 under sufficiently arid weather conditions, while new genetic sources of resistance were noted. This valuable source material distinguished the varieties of oilseed flax Biryuza, Linol, Iceberg with a significant, adaptive to drought potential, according to yield estimates. The productivity of agricultural crops depends on the moisture availability of crops. As noted by L. Ghobadi-Namin *et al.* (2022), in arid zones, growth conditions and crop formation will be determined by the provision of crops with moisture. Oilseed flax reacts less sensitively to moisture with the presence of a developed root system, but at the same time, moisture supply fundamentally reflects the level of yield.

The main economically valuable signs are: early maturity – recommended for cultivation in the northern and western regions of the Republic of Kazakhstan; tallness – for dual production use for vegetable oil and fibre; large-seeded and small-seeded; high yield. The varieties distinguished themselves by high yield: Linol – 82 g/m^2, Sibirskaya 38854 – 71 g/m^2, Antares – 78.3 g/m^2. The yield of oilseed flax is determined by the cultivation technology – the timing of sowing, the seeding rate, the provision of plants with nutrients, and varietal characteristics. According to K.K. Bharatya *et al.* (2022), crop yield is an integrated indicator reflecting the effectiveness of all elements in the technology of

crop formation of individual plants and the biosphere as a whole, while the highest genetic potential of oilseed flax is to obtain a yield of 2 t/ha or more.

Flaxseed oil ranks first among other edible oils in terms of biological value. The content and composition of the oil are genetically fixed traits, but natural and climatic conditions can affect its accumulation and fatty acid composition. According to biochemical indicators, varieties with a high oil content in seeds were identified: Kostanayskiy-11 – 44.3%, Iceberg – 44.2%, Isikulsky – 43.9%, Biryuza – 43.7%, respectively, are characterised as medium-oil. M.Z. Koçak *et al.* (2022) noted that as the oilseed flax matures, the crude fat content in the seeds continuously increases, at first more intensively, and then the process slows down. Thus, the highest oil content is observed in seeds that have reached full ripeness and, on average, is in the range of 42-48%.

Since flax is an early sowing crop, there is a risk of damage and death of plants due to low temperatures, therefore, the creation of varieties resistant to hypothermia is an urgent direction in flax breeding. At low temperatures, the risk of fungal diseases of oilseed flax increases, the main ones are: fusarium, anthracnose, ascochytosis, polysporosis. The intensity of diseases depends on the characteristics of the pathogen, soil conditions, agricultural technology and susceptibility of the variety. A high coefficient of adaptation of oilseed flax was noted in the varieties Kostanayskiy-11, Sibirskaya 38854, Antares, Iceberg. As noted by S. Zare *et al.* (2023), the spread of oilseed flax diseases and the intensity of damage depends on the presence of the pathogen and its virulence, depending on environmental conditions, such as temperature, humidity, precipitation, the degree of resistance of the cultivated variety, therefore, flax breeding requires high resistance to the most common and harmful flax disease – fusarium. As reported by M. Walkowiak *et al.* (2022), excessively early crops of oilseed flax suffer from fusarium wilt, flax rust. Processing of oilseed flax crops, during the budding phase, has a stimulating effect on the culture, increasing the coefficient of plant adaptability to abiotic and biotic conditions.

With regard to oilseeds and flax, it is important to apply appropriate cultivation techniques and technologies. Observing the basic rules of compatibility and crop rotation, irrigation, seed quality, and temperature regime – can provide high results. The importance of Kazakh oilseed flax increases annually, which indicates its further prospects for cultivation and expansion of the selection range.

CONCLUSIONS

Based on the data obtained, the genetic potential of oilseed flax was determined by identifying the optimal parameters of cultivation technology in the conditions of Northern Kazakhstan. As a result of the conducted research, the patterns of the impact of various meteorological conditions in 2022-2023 have been established. In 2020, the weather conditions for the growing season were favourable for the growth and development of oilseed flax. The agro-climatic conditions of 2021 differed somewhat from the average annual ones, and June and July were marked by lower air temperatures, affecting the development of culture. The weather conditions of 2022 in the region were characterised as abnormally dry, while creating extreme conditions for growth and development.

As a starting material for breeding, economically valuable signs of oilseed flax were identified: the growing season – 85-92 days, seed yield – 47.5-82.2 g/m^2, seed weight – 6.9-8.1 g, seed oil content – 43.7-47.5%, and plant height – 45-60 cm. Assessment of the resistance of modern oilseed flax genotypes to plant diseases of the genus *Fusarium*. Based on the assessment of the signs of biological and economic value of the three-year period 2020-2022, the following parameters can be recommended for the creation of varieties for use in the zone of moisture deficiency in the Kostanay region in the conditions of the Karabalyk agricultural complex: early maturity – Sibirskaya 38854 and Iceberg; productivity – Linol, Antares, and Sibirskaya 38854; weight of 1000 grains – Nebesniy, Biryuza, Linol, and Krokus; oil content in seeds – Kostanayskiy-11, Iceberg; resistance to fusarium – Kostanayskiy-11, Sibirskaya 38854, Antares, Iceberg. Moreover, flax indicators, distinguished by the height of plants, the number of productive boxes, and the number of seeds in the box, are recognised as promising for inclusion in the breeding process. High-yielding varieties were noted: Linol – 82 g/m^2, Sibirskaya 38854 – 71 g/m^2, Antares – 78.3 g/m^2. A high productivity index was shown in terms of the weight of 1000 grains in the varieties Biryuza, Krokus, and Kostanaysky – 8.2 g, and Iceberg – 8.1 g.

Theoretical developments are used to create new varieties with appropriate yield indicators and the quality of products grown in specific environmental conditions. To ensure the profitability of agricultural production, especially in the oil and fat industry, pest resistance, especially to the meadow moth, must be included in research. The low yield of flax is explained by its biological features, i.e., slow growth in the early stages, and the need to create a highly effective system of herbicidal protection to prevent the growth of crops such as chamomile, knotweed, and sow thistle, which compete for nutrients and water.

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CONFLICT OF INTEREST

None.

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Вивчення світової колекції льону олійного як вихідного матеріалу для селекції в умовах Північного Казахстану

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Анотація. За сучасними вимогами вирощування, створюються нові сорти олійного льону, що відрізняються за комплексом корисних ознак. Основою селекції льону є вивчення, відбір, створення нових сортів на основі світової колекції та придатних для агрокліматичних умов Північного Казахстану. Мета дослідження – вивчення колекційних зразків льону олійного в умовах Костанайської області Північного Казахстану та відбір найбільш перспективного селекційного матеріалу за господарсько-цінними ознаками в умовах зони дефіциту вологи. У роботі використовувалися методи: біологічні, фенологічні, лабораторні, статистичні, аналіз інформації адаптивних можливостей окремих сортів льону олійного. Проведено оцінку господарсько-цінних ознак за 14 зразками льону олійного світової колекції різного еколого-географічного походження за період 2020-2022 рр. В результаті досліджень виділено зразки, що характеризуються високою врожайністю: Лінол – 82,0 г/м^2, Сибірська 38854 – 71,0 г/м^2, Антарес – 78,3 г/м^2. Високими показниками маси 1000 насінин відрізнялися зразки сортів Бірюза, Крокус, Кустанайський – 8,2 г, Айсберг – 8,1 г. Виявлено цінний та пластичний вихідний матеріал для селекційної роботи з основними цінно-господарськими ознаками: вегетаційний період протягом 85-92 днів більше 47,5-82,2 г/м^2, масою 1000 насінин 6,9-8,1 г, вмістом олії в насінні 43,7-47,5 % рослин заввишки 45-60 см. Виділені зразки рекомендуються до обробки в Північному Казахстані: за скоростиглістю – Сибірський 38854 та Айсберг; продуктивності – Лінол, Антарес; масі 1000 насінин – Небесний, Бірюза, Лінол, Крокус; вмісту олії в насінні – Костанайський-11, Айсберг; стійкості до фузаріозу – Костанайський-11, Сибірський 38854, Антарес, Айсберг. Ефективність селекційної програми залежить від закономірностей успадкування економічно цінних ознак, які діють у гібридної популяції, скорочуючи втрати цінних генотипів і знижуючи витрати за допомогою відбраковування менш цінних ознак

Ключові слова: продуктивність; адаптивні здібності; врожайність; олійність; генотип; фузаріоз

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Production of *Bacillus subtillis* protein mass on the microbial mass of *Methylococcus capsulatus*

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Abstract. The growing demand for food of animal origin has contributed to the annual increase in the agricultural population of productive animals in the world, which in turn has led to a significant shortage of feeds and an increase in their cost. Therefore, the purpose of this research was to explore the qualitative composition of feed products obtained by culturing methanotrophic microorganisms *Methylococcus capsulatus* with probiotic bacteria *Bacillus subtillis*. Arbitrage methods for determining the quality of feeds, which are regulated by regulatory documents (ISO), were used in the research. The results of the research demonstrate that the protein product obtained by growing *Methylococcus capsulatus* culture has a high content of "crude" protein at the level of 60.9%, which corresponds to high-protein feeds of animal origin by its technical characteristics. The addition of probiotic microorganisms *Bacillus subtillis* to the medium for cultivation significantly improved the qualitative parameters of the synthesised protein by increasing by 1.5% the amount of essential amino acids, increasing by 3.8% fatty acids and increasing the concentration of calcium and phosphorus. The increase in the concentration of lysine, isoleucine, valine and asparagic acid, due to the co-cultivation of two microorganisms allowed increasing their nutritional value for cattle since these amino acids are the most demanded in ruminant diets when using corn silage and other plant feeds. The addition of *Bacillus subtillis* culture allowed reducing the content of "crude" fibre and improving its biological characteristics by changing the microbiological composition of the obtained product. In the future, the biotechnological method of obtaining feed protein for animals will reduce the dependence of animal breeding on the cultivation of fodder crops and weather conditions

Keywords: methanotrophs; microbial culture; probiotic culture; co-cultivation; feed product; amino acid composition

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INTRODUCTION

The growth of food consumption is closely connected with the increase in the world population, as a result of which agriculture has developed intensively in recent years. The demand for meat and dairy products is growing most intensively. High demand for food of animal origin contributes to the increase in the number of livestock and their productivity. S.A. Terry *et al.* (2020) indicate that cattle, compared to other domestic animals, have the lowest efficiency of meat production, despite the highest demand for this particular type of product. Therefore, one of the urgent directions of future livestock production will be the intensification of beef cattle breeding to meet the growing demand of the population. This shortly, is possible only through extensive growth of the population of animals of meat breeds. However, according to S.R. Fariña and P. Chilibroste (2019), in most developed countries such population growth will be artificially limited through existing environmental regulations and limited land resources. However, the main constraint is feed scarcity.

According to M.R.C. Cordeiro *et al.* (2022), increased livestock production will increase global demand for feed from 11 to 17% for food crops and from 6 to 15% for feed crops. Therefore, rapid and uncontrolled growth in animal numbers will lead to a situation where feed security becomes critical to meet future global meat demand and any increase in livestock production will only occur if sufficient feed is available. The Food and Agriculture Organisation (FAO) research (2023) indicates that an increase in the share of feed crops such as maize and soya in the world crop mix should be expected shortly. Only for the grain group FAO (2023) forecasts indicate an annual growth of 0.3-0.5% per year in the required volumes of feed grains for animal feed, which in physical equivalent becomes 783-1000 million tonnes per year. It will cause an increase in the area of arable land used for fodder production and, accordingly, a decrease in the area of land for food crops. And considering the annual increase in the number of animals, the situation will only worsen. Even countries with large areas of land suitable for agricultural production are experiencing shortages of animal feed.

Kazakhstan is no exception: the availability of roughage in 2023 is only 80%, succulent fodder 60% and concentrated fodder 50% of the need (The Ministry of Agriculture..., 2023). To ensure intensive development of livestock production, new approaches to protein feed production will have to be found and utilised more efficiently. Such a source, according to A.U. Fabiszewska *et al.* (2019) a biotechnological method of processing industrial and food wastes using microorganisms can become such a source. This method will allow accumulating of protein compounds due to the growth of microbial biomass. The most promising area is using methane-oxidising microorganisms as protein producers, which will allow, in addition to solving the problem of the lack of feed resources, to solve environmental problems associated with the emission of greenhouse gases by animals.

The intensification of production and the growth of the animal population have become one of the reasons for the increase in greenhouse gas emissions, which are leading to an ecological disaster on the planet. According to H. Guo *et al.* (2022) global greenhouse gas emissions from livestock production have increased by 51%, and methane accounts for 50% of total emissions. Ruminants are the largest producer of greenhouse gases, accounting for about 72% of the livestock sector, of which one-third is the highly hazardous methane gas (Gerber *et al.*, 2013).

Therefore, the purpose of this work was to develop an industrial biotechnological method that allows using live microorganisms with methane as a nutrient medium to produce protein mass suitable as feed in livestock production.

LITERATURE REVIEW

Biotechnological approaches have been used in forage production for a long time. They have been applied according to R. Kapoor *et al.* (2018) and M.A. Moselhy *et al.* (2022) in the preparation of green forages and their conservation for year-round use as mono-feed. R.R. Singhania *et al.* (2017) and S. Bala *et al.* (2023) proposed biotechnological approaches for utilisation of animal farm wastes, while R.P. Singh *et al.* (2022) and K.C.P. Cruz *et al.* (2022) conducted studies for microbiological synthesis of farm animal feed additives with therapeutic and preventive effects. However, research on using microbial synthesis products for animal nutrition using animal wastes themselves as nutrient media has become particularly relevant. The works of K. Rasool *et al.* (2023) and also A.E. Graham and R. Ledesma-Amaro (2023) indicate that microbially synthesized protein can be used without restrictions in animal feeding, and the amino acid composition of such products is more complete in comparison with plant proteins. B. Bajić *et al.* (2023) indicate that considering the composition and characteristics, and the huge amount of waste in livestock production, this approach to feed protein production has great potential for industrial production.

Environmental conditions have a significant influence on the yield of microbial protein during cultivation. S. Ismail (2022) identified the influence of temperature, pH level, and nitrogen and carbon sources on the yield of protein and nucleic acids in the cultivation of *Cupriavidus necator* bacteria. Using methane as a carbohydrate and energy source for biotechnological processes is described in M.L.K. Khider *et al.* (2021). Methanotrophs, unlike industrial microorganisms, do not compete for food, which is quite suitable for growing animal feed biomass. Similar conclusions were reached

by P. Tsapekos *et al.* (2018), who demonstrated that the resulting microbial biomass is suitable for use as an animal feed additive. A. Kuźniar *et al.* (2019) found that methanotrophic biomass contains high concentrations of K, Mg and Fe in addition to protein compounds, and it can be considered as a feed additive for enriching diets with protein, macronutrients and some trace elements.

Using microbial protein in diets of different types of productive animals can be traced in scientific works published recently, indicating the relevance of such research worldwide. The work of S. Polyorach *et al.* (2023) found no adverse effect of adding microbiological protein to the diets of dairy cows on their productivity compared to traditionally used vegetable proteins. Therewith, the researchers observed an increase in the level of diet digestibility ($p>0.05$) with the addition of biotechnological products. Similar results were obtained by E. Direkvandi *et al.* (2020) in research on sheep. The addition of microbial biomass to the diet had no effect on feed intake and live weight of lambs, but the positive result was a reduction in the methanogen population in the rumen and a reduction in greenhouse gas emissions. In addition to ruminants, studies have demonstrated positive results when feeding poultry E.G. Olson *et al.* (2022), hydrobionts-American eel W. Lu *et al.* (2023), and black sea bream B. Xu *et al.* (2021).

As reported by B. Valverde-Pérez *et al.* (2020), to date, the industrial production of protein compounds from methane is limited due to the explosive nature of the media in fermenters during production and needs further improvements in technology.

MATERIALS AND METHODS

Studies were conducted using the culture of methanotrophic bacteria *Methylococcus capsulatus*. For the cultivation of microorganisms, a bioreactor with a volume of 40 litres (working volume 25 litres), equipped with a stirrer with a speed of 3500 thousand revolutions per minute and having an operating pressure of up to 5 atmospheres was used. Methanotrophic microorganisms were cultured on depleted mineral nutrient media, which reduces the risk of contamination by pathogenic and opportunistic microorganisms. Bacteria *Methylococcus capsulatus* were grown on nutrient medium prepared according to the following recipe: KCl – 0.125 g/l, $MgSO_4*7H_2O$ – 0. 125 g/l, $FeSO_4*7H_2O$ – 10.75 mg/l, $CuSO_4*5H_2O$ – 10 mg/l; $MnSO_4*5H_2O$ – 9.5 mg/l, H_3BO_3 – 6.25 mg/l, $ZnSO_4*7H_2O$ – 1.5 mg/l, $Na_2MoO_4*2H_2O$ – 0.25 mg/l, $CoCl_2*6H_2O$ – 0.25 mg/l, H_3PO_4 (70%) – 0.35 mg/l. The PH value of this medium was maintained with 10% aqueous ammonia solution. Microbial biomass accumulation was conducted at 42°C and pH 5.8 for 48 hours.

To reduce the concentration of carbon dioxide in the fermenter, which in high concentration inhibits the growth of methanotrophic bacteria, a culture of *Chlorella vulgaris* was used. The gas phase separated in the degassing chamber was passed through the bioreactor with growing Chlorella before being returned to the bioreactor to reduce the carbon dioxide concentration. To improve the quality of protein products obtained by microbiological synthesis, after the end of *Methylococcus capsulatus* cultivation, *Bacillus subtillis* mother liquor was added to the fermenter in the amount of 5% by volume and cultivation was continued for another day at 38-40°C.

After completion of the cultivation process, a medium sample was taken from the fermenter. The resulting cell biomass was precipitated by centrifugation (4000 rpm, 15 min), and the cell precipitate was further dried at constant temperature. All subsequent results were obtained by dry matter examination. The obtained product was subjected to laboratory research for the purpose of determining a number of physicochemical parameters and nutritional value of the synthesised microbiological biomass. The content of:

- "crude" protein by Kjeldahl method (VELP Scientifica equipment set) (ISO 20588:2019, 2019);
- "crude" fat by Soxhlet method (ISO 1099:2010, 2010);
- "crude" fibre by extraction method (ISO 6865:2000, 2000);
- "crude" ash by ashing in a muffle furnace (ISO 5984:2022, 2022);
- amino acid content was determined using an Agilent 1260 Infinity II amino acid analyser (ISO 13903:2005, 2005);
- calcium – by titrimetric method (ISO 6490-1:1985, 1985);
- phosphorus – by spectrometric method (ISO 6491:1998, 1998).

The obtained research results were subjected to mathematical processing and grouping using Excel software product included in the Microsoft 365 core application package.

RESULTS

The main area of research, the results of which are presented in this research, was to obtain alternative sources of protein feeds for livestock farming, using wastes obtained as a result of animal housing or products of their vital activity. Therefore, it was decided to use methane as a source of nutrients for microbiological synthesis, based on its availability, cost and the need to utilise it as an associated gas resulting from the maintenance of ruminants, which in turn will reduce the impact of greenhouse gases on the environmental situation. A culture of the methanotrophic bacteria *Methylococcus capsulatus*, which is capable of consuming 85 to 90% of the methane dissolved in special nutrient media, was used for methane utilisation. An additional positive factor that contributed to the choice of these microorganisms as an object of research was their relatively high incubation temperature (from +38 to +48°C), which reduces the risk of contamination of the obtained biomass with pathogenic and opportunistic

microorganisms. Microorganisms causing fodder and other diseases in cattle have a lower cultivation temperature. Such characteristics of the selected microbiological culture guarantee the absence of infectious disease development in animals after using microbiological protein in diets.

As a gas nutrient mixture for the cultivation of methanotrophic bacteria *Methylococcus capsulatus*, the most favourable for their growth mixture of methane and oxygen with an oxygen content of 15% was used. Experimentally selected cultivation conditions based on the partial pressure of gases and their solubility, and mineral nutrient medium allowed obtaining microbial biomass of *Methylococcus capsulatus* with a concentration of 7-8 g/l of culture medium.

Although the results of microbial biomass growth of *Methylococcus capsulatus* under experimental conditions were at a high level, the selection of possible symbiotic microorganisms was performed to increase the productivity and growth rate of methanotrophic bacteria. The reasons for this approach were the findings of S. Golaghaiee *et al.* (2017), who managed to increase the yield of "crude" protein by co-culturing methanotrophic bacteria with microscopic fungi, and their report on the improvement of quality parameters of the resulting protein synthesis for animals. The culture of microorganisms that allowed increasing the efficiency of protein raw material synthesis were opportunistic fungi of the *Candida* genus. Considering that according to the conditions of the research programme, it is not recommended to use pathogenic or disease-causing microorganisms in the process of scientific work, therefore, using these symbionts or fungi with similar properties was not conducted. In this regard, it was decided to increase the quantity and quality of synthesised protein from one of the probiotic cultures that can develop in thermophilic conditions – *Bacillus subtilis* strain, which processes methanotrophs into protein raw material with positive feed characteristics. The absence of information about diseases caused by microorganisms of *Bacillus subtilis* strains or products of their vital activity allows considering them as safe organisms, which, moreover, have been identified as promising producers of probiotic compounds. This strain is actively cultured on metabolites of *Methylococcus capsulatus* and their microbial biomass, biotransforming them into its cell mass and contributing to the improvement of the quantity and quality of microbial protein. The properties of protein biomass obtained by biotechnological cultivation of *Bacillus subtilis* are well-explored, they have no contraindications for use as animal feed additives and additionally have probiotic properties.

For the purpose of increasing the quantity and quality of protein biomass, after the end of *Methylococcus capsulatus* cultivation time, *Bacillus subtillis* mother liquor was added to the fermenter in the amount of 5% of the volume and continued cultivation for a day at 38-40°C. The results of chemical composition of protein raw materials obtained under different variants of methanotrophs cultivation are presented in Table 1.

Table 1. *Chemical composition of microbiological biomass obtained as a result of cultivation of Methylococcus capsulatus and co-cultivation of Methylococcus capsulatus + Bacillus subtillis, %*

Name of indicator	*Methylococcus capsulatus*	*Methylococcus capsulatus + Bacillus subtillis*
Crude protein	60.89	55.67
Total moisture	7.24	13.02
Crude fat	0.59	4.36
Crude fiber	1.98	1.25
Crude ash	7.97	9.56
Nitrogen-free extractive substances (calculation method)	23.31	17.38
Calcium	0.6	1.04
Phosphorus	0.06	0.39

Source: *compiled by the authors*

The "crude" protein yield of *Methylococcus capsulatus* monoculture was 5.2% higher than that of co-cultivation with the probiotic bacteria *Bacillus subtillis*. However, despite the insignificant decrease in protein content, the quality of the obtained feed product was significantly higher when the two microorganisms were co-cultured. It was accompanied by a decrease in the amount of nucleic acids in the protein fraction by 14.4%, and an increase in the amount of "crude" fat and ash in the dry matter of microbial biomass, due to an increase in the concentration of macronutrients – calcium and phosphorus. It, in turn, allowed reducing the cost of purchasing mineral feed for animals when balancing rations.

In addition, when *Methylococcus capsulatus was co-cultured with Bacillus subtillis,* a decrease in the proportion of nitrogen-free extractives (NFE) was observed, which was associated with the replacement of

Gram-negative methanotrophic microorganisms, whose cell wall is covered with a protective layer of polysaccharides, by more digestible Gram-positive *Bacillus subtillis*. This assumption is confirmed by the decrease in the amount of "crude" fibre in the bacteriological mass, which indicates a change in the species composition of the microbial product and a decrease in the amount of structural (cellular) carbohydrates. In addition to the replacement of part of cells in the dry product of cultivation of one species of microorganisms for another, a significant increase in the quality of protein associated with the enzymatic activity of symbiotic bacteria, whose enzymes contribute to the destruction of the cell wall of *Methylococcus capsulatus*. Therefore, even against the background of a lower level of "crude" protein in the microbiological product during the joint incubation of methanotrophs and symbiotic bacteria, the protein quality appeared to be more nutritious and suitable for animal feeding. To explore protein quality in more detail under different cultivation options for methanotrophs, amino acid analysis of proteins was performed and the results are presented in Table 2.

Table 2. *Amino acid profile of "crude" protein obtained as a result of different variants of cultivation of methanotrophic bacteria Methylococcus capsulatus, %*

Name of indicator	*Methylococcus capsulatus*		*Methylococcus capsulatus + Bacillus subtillis*	
	Content in the product	**Protein content**	**Content in the product**	**Protein content**
Substituted amino acids				
Asparagic acid (Asp)	6.32	10.36	6.67	11.97
Threonine (Thr)	3.32	5.44	2.62	4.7
Serine (Ser)	1.9	3.11	1.71	3.07
Glutamic acid (Glu)	9.43	15.45	8.30	14.9
Proline (Pro)	2.78	4.55	1.51	2.71
Glycine (Gly)	4.03	6.6	3.18	5.71
Tyrosine (Tyr)	2.29	3.75	1.7	3.06
Alanine (Ala)	4.94	8.09	4.74	8.51
Cystine (Cys)	0.44	0.72	0.57	1.02
Arginine (Arg)	3.67	6.02	2.51	4.51
Valine (Val)	3.36	5.51	3.87	6.95
Total number of substituted amino acids	42.48	69.6	37.38	67.11
Essential amino acids				
Methionine (Met)	1.31	2.14	1.25	2.24
Isoleucine (Iie)	2.35	3.85	2.66	4.78
Leucine (Leu)	4.82	7.9	3.84	6.89
Phenylalanine (Phe)	2.89	4.74	2.02	3.63
Histidine (His)	1.14	1.89	0.8	1.44
Lysine (Lys)	3.24	5.31	4.66	8.37
Total amount of essential amino acids	15.75	25.83	15.23	27.35

Source: *compiled by the authors*

The amino acid composition of microbial raw materials obtained in different variants of microbial cultivation indicates some differences in the content of individual amino acids. Thus, a significant decrease of arginine and glutamic acid was observed in the final product in the co-synthesis of methanotrophs with *Bacillus subtillis* compared to the cultivation of *Methylococcus capsulatus*. Whereas for other substitutable amino acids, their levels were at the same level or not significantly higher than the protein obtained from the initial synthesis. The introduction of 5% hay bacillus culture into the substrate for cultivation allowed increasing the concentration of most essential amino acids, which are limited in protein compounds of grain crops (wheat, barley, maize). The greatest increase was observed in the concentration of lysine, isoleucine, valine, and asparagic acid. These amino acids are the most demanded amino acids in ruminant diets when using maize silage. Therefore, the addition of *Bacillus subtillis* in the industrial production of microbial protein will allow obtaining a feed product maximally suitable for cattle.

In the process of primary cultivation of *Methylococcus capsulatus* microorganisms, a significant amount of carbon dioxide is produced, which in small concentrations stimulates the growth of methanotrophic bacteria and completely inhibits their cultivation at high concentrations. Biosynthesis produces about 3.5 litres of carbon dioxide from 10 litres of methane. The removal of the gas phase from the bioreactor used in the research is done in a degassing chamber, due to the pressure difference. After analysing the concentration of ambient gases, the necessary additional injection of methane and oxygen up to the specified values was pumped back into the bioreactor.

All known methods of cultivation of methanotrophic bacteria provide, as a prerequisite, the need to remove carbon dioxide from the gas-air mixture of the bioreactor. It is achieved either by chemical methods, which significantly affects the final cost of the product; or by discharging unspent methane into the atmosphere together with oxygen and carbon dioxide. Therewith, several microorganisms require carbon dioxide for growth, *Chlorella vulgaris* being one such species. In the improved model of the bioreactor, the purification of the gas mixture from carbon dioxide is performed by cultivation of Chlorella algae on carbon dioxide, which is produced by methanotrophic organisms as a waste. The gas phase separated in the degassing chamber passes through a tank with growing chlorella before being returned to the bioreactor, where it is cleared of carbon dioxide and saturated with oxygen. In preliminary studies conducted on an additional source of protein animal feed derived from the accumulation of microbial biomass of the algae *Chlorella vulgaris*. more than 700 g of oxygen was obtained from one kilogram of carbon dioxide, allowing this approach to be used in biotechnological production. As a result of this improvement, atmospherically harmful carbon dioxide emissions were utilised to grow valuable plant protein and generate oxygen for the cultivation of methanotrophic bacteria. Therefore, future studies are planned to explore the possibility of obtaining additional feed protein from *Chlorella vulgaris* biomass and to analyse the qualitative and quantitative characteristics of this product.

In addition, future research is planned to explore the possibility of stimulating microbial growth by increasing or decreasing the concentration of individual ions that are the foundation of the mineral nutrient medium and obtaining the optimal concentration of macro- and microelements in the microbial biomass for animal feeding. In this block of research is planned to explore the influence of trivalent iron and calcium ions, and the introduction of these metals in the form of different salts of sulphates, phosphates or in the form of chlorides. A separate area of research will be the examination of the effect of different concentrations of copper salts on the activity of enzyme systems of *Methylococcus capsulatus* and the rate of methane oxidation.

DISCUSSION

The main trend of the 2015-2023 years in agricultural production in the world is the annual growth of animal population with a relative constancy of areas under fodder crops. This situation forces either to search for fodder crops with higher yields or to search for alternative sources of fodder for the growing needs of animal husbandry. The most promising method of obtaining high-grade protein feeds for animals is industrial biotechnological approaches using microbiological synthesis. In addition to the main purpose – to obtain dry microbial biomass, which can replace part of grain feed in the diet of farm animals, and thereby improve the situation with food safety, another positive factor of such production is to reduce the adverse impact of animal husbandry on the ecological situation of the planet. Using the wastes accumulated during animal housing and products of their vital activity in the process of microbiological production of fodder protein contributes to increasing the profitability of animal husbandry and reducing the environmental impact on nature.

Based on the analysis of scientific publications and preliminary studies, the most promising method appeared to be using methanotrophic bacteria as protein biomass producers, which combines high-intensity bacterial mass synthesis with using one of the most dangerous greenhouse gases – methane – as a nutrient. Therefore, similar conclusions were reached by several other authors: B. Valverde-Pérez *et al.* (2020), exploring the products of microbiological synthesis of methanotrophic bacteria, P.A. Zenkovich *et al.* (2022), when feeding Siberian sturgeon with dry feed obtained from the cultivation of *Methylococcus capsulatus*, and M. Rajesh *et al.* (2022) in a study conducted on rainbow trout individuals. All authors noted positive growth dynamics of fish when feed products obtained from microbiological synthesis were introduced into their diet. These additives were found to be on par with fish meal in terms of nutritional quality. In Kazakhstan, biotechnological approaches using methanotrophic microorganisms are only at the stage of research and implementation in limited volumes in industrial production, while in other countries these methods are already in full use mainly for wastewater treatment. R. Salem *et al.* (2021) indicate that wastewater treatment has yielded important products such as ectoine, polyhydroxyalkanoates and methanobactins, which are actively used in biotechnology and biomedicine.

Using methanotrophic bacteria *Methylococcus capsulatus* for industrial production of feed protein for ruminants using biotechnological methods was positively confirmed in the studies described in this publication. As a result of the laboratory experiment, an average of 7-8 g of dry microbial protein was obtained from each litre of nutrient medium. Therewith, the feed product was characterised by an increased content of essential amino acids and basic macronutrients. In addition, the

results obtained were confirmed by the publication of A. Kuźniar *et al.* (2019), indicate that as a result of the cultivation of methanotrophic bacteria of *Methylocystis* and *Methylosinus* species, the dry biomass of microorganisms contained high concentrations of potassium, 9.6-19.1, magnesium, 2.2-7.6, and iron, 2.4-6.6 g/kg, and it could be considered as a feed additive for the enrichment of animal diets with macronutrients and some trace elements. In addition, this mass had a high content of unsaturated fatty acids in its composition.

E.O. Sadykova *et al.* (2023) report that their studies of comparative evaluation of the amino acid profile of *Methylococcus capsulatus* protein demonstrated a balanced content of most amino acids, the level of which was comparable to chicken egg protein, which is a conventional benchmark of high-quality complete protein. All these results allow confirming with certainty that the *Methylococcus capsulatus* culture selected as a producer of protein biomass can be used for the industrial production of feed for animals of different species.

However, the industrial use of such a method of microbiological synthesis, according to X. Huang *et al.* (2022), is limited by the relatively low efficiency of carbon processing by methanotrophic cells. For this purpose, the studies conducted utilised symbiotic microorganisms, in particular the culture of the probiotic bacteria *Bacillus subtillis*. It was possible due to preliminary studies conducted by A.G. Kisten *et al.* (2022) on solid nutrient media. In this work, it was indicated that the activity of methane utilisation began to increase on the 2nd-4th day after the co-cultivation of microorganisms. Within the framework of the conducted research, *Bacillus subtillis* culture was used under the conditions of a mineral medium, which allowed obtaining positive results of symbiotic use of two microbiological cultures. This approach allowed microbiological mass production and improved the quality of the obtained fodder product. In comparison with the monocultivation of *Methylococcus capsulatus*, the addition of symbiont culture allowed, on the one hand, to increase the content of "crude" fat by 3.8% and limited essential amino acids by increasing the share of lysine, isoleucine and glutamic acid. On the other hand, this approach allowed reducing the amount of "crude" fibre and increasing its digestibility by changing the ratio of bacterial composition of the finished product. The increase in microbial biomass yield and quality of the obtained protein was also described by J.J. Nunes *et al.* (2016) when methanotrophs were co-cultured with heterotrophic bacteria *Alcaligenes acidovorans*, resulting in a 265% increase in biomass with a cell concentration of 10.3 g/l compared to 2.8 g/l in monoculture. Heterotrophic bacteria did not grow independently on mineral media with methane addition but increased biomass concentration when added to *M. capsulatus* culture.

No less dangerous than methane greenhouse gas is carbon dioxide, which is actively produced by methanotrophic microorganisms in the process of their cultivation (Zheng *et al.*, 2023). Modern production facilities do not allow the utilisation of carbon dioxide produced as a result of methane oxidation. It is in most cases released into the atmosphere, and the processing of 10 litres of methane produces 3-3.5 l CO_2 in the environment. Preliminary studies conducted within the framework of the research work programme to explore the effect of adding a tank with microscopic algae of *Chlorella vulgaris* species to the fermentation system allowed reducing both the amount of carbon dioxide emitted and increasing the level of effective carbon utilisation. Thus, when one kilogram of CO_2 was utilised, up to 700 g of oxygen was released into the environment, which was used for further oxidation of methane. Thus, such a minor modernisation of industrial feed protein production will allow obtaining an autonomous system without the need to control the gas mixture in the bioreactor and additional oxygen pumping. It, in turn, will allow reducing the cost of production of biotechnological feed products.

Future studies are planned to investigate the growth of microbiological biomass of algae and the quality of such a product as animal feed. In studies by N. Roberts *et al.* (2020) in the joint cultivation of *Chlorella sorokiniana* with methanotrophic bacteria *Methylococcus capsulatus* in comparison with microalgae monoculture, it was possible to obtain an increase in biomass production by 120%, improved assimilation of total nitrogen and total phosphorus by 71 and 164%, respectively, with the same amount of biogas produced. Therefore, in future studies, it is expected that in addition to the autonomy of the biotechnological system, there will be an additional increase in dry animal feed products. In addition, several studies are planned shortly to explore the influence of the concentration of different constituent elements of mineral nutrient medium for the cultivation of methanotrophs and the addition of copper ions, which can increase the activity of microbial enzyme systems responsible for methane oxidation.

CONCLUSIONS

Based on the results obtained during the experimental work on the cultivation of methanotrophic microorganisms *Methylococcus capsulatus and their co-cultivation with probiotic bacteria Bacillus subtillis* to obtain protein biomass for ruminant feeding, the following conclusions and suggestions for future scientific work can be made: using of *Methylococcus capsulatus* culture on depleted mineral medium in methane-oxygen atmosphere allowed obtaining microbial biomass yield with cell concentration of 7-8 g/l of nutrient medium and content of "crude" protein at the level of 60.9%, which corresponds to the indicators of high-protein animal feeds and significantly exceeds the protein feeds of plant origin.

The addition of the probiotic bacteria *Bacillus subtillis* to the bacterial culture of *Methylococcus capsulatus*

in the bioreactor allowed improving the quality characteristics of the feed product obtained as a result of the initial microbial synthesis. It was expressed in an increase in the amount of essential amino acids by 1.5%, "crude" fat by 3.8% and the main macronutrients – calcium and phosphorus. Therewith, due to the partial replacement of the microbiological composition of the product, the content of "crude" fibre decreased and its biological value increased. The inclusion of a tank with *Chlorella vulgaris* microalgae culture in the fermenter design allowed reducing the concentration of carbon dioxide in the bioreactor gas mixture and saturating it with oxygen. In the process of algae life activity, more than 700 grams of oxygen were obtained from one kilogram of carbon dioxide, which will allow establishing an autonomous bioreactor without the need for constant monitoring of carbon dioxide levels.

In future studies, it is planned to conduct a comprehensive study of the qualitative characteristics of the feed product obtained by the cultivation of *Methylococcus capsulatus* with symbiotic cultures of *Bacillus subtillis* and *Chlorella vulgaris*. In addition, to examine the effect of different concentrations of media components on the quantitative characteristics of the feed product and the possibility of activation of the enzyme system of *Methylococcus capsulatus* by increasing the concentration of copper ions in the nutrient medium.

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CONFLICT OF INTEREST

None.

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Отримання білкової маси *Bacillus subtillis* на мікробній масі *Methylococcus capsulatus*

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Анотація. Зростаючий попит на харчові продукти тваринного походження сприяв щорічному збільшенню чисельності сільськогосподарської популяції продуктивних тварин у світі, що, в свою чергу, призвело до суттєвого дефіциту кормів та зростання їх вартості. Тому метою роботи було дослідження якісного складу кормових продуктів, отриманих шляхом культивування метанотрофних мікроорганізмів *Methylococcus capsulatus* з пробіотичними бактеріями *Bacillus subtillis*. Під час проведення досліджень використовували арбітражні методи визначення якості кормів, які регламентуються нормативними документами. Результати досліджень

свідчать, що білковий продукт, отриманий при вирощуванні культури *Methylococcus capsulatus*, має високий вміст «сирого» протеїну на рівні 60,9 %, що за своїми технічними характеристиками відповідає високобілковим кормам тваринного походження. Додавання в середовище для культивування пробіотичних мікроорганізмів *Bacillus subtillis* дало змогу значно поліпшити якісні показники синтезованого білка за рахунок збільшення на 1,5 % кількості незамінних амінокислот, підвищення на 3,8 % жирних кислот і зростання концентрації кальцію та фосфору. Збільшення концентрації лізину, ізолейцину, валіну та аспарагінової кислоти внаслідок спільного культивування двох мікроорганізмів дало змогу збільшити їхню поживну цінність для великої рогатої худоби, оскільки ці амінокислоти є найзатребуванішими в раціонах жуйних тварин під час використання кукурудзяного силосу та інших рослинних кормів. Додавання культури *Bacillus subtillis* дало змогу знизити вміст «сирої» клітковини та поліпшити її біологічні характеристики за рахунок заміни мікробіологічного складу отриманого продукту. Використання в подальшому біотехнологічного методу отримання кормового білка для тварин дозволить знизити залежність тваринництва від вирощування кормових культур і погодних умов

Ключові слова: метанотрофи; мікробна культура; пробіотична культура; співкультивування; кормовий продукт; амінокислотний склад

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Technology of production and primary processing of milk in farm conditions

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Abstract. The introduction of new criteria for the safety of milk raw materials at the legislative level, on the one hand, made it possible to improve the supply of quality food to the population, and on the other hand, caused a decrease in the profitability of farms due to the deterioration of the marketability of milk and its price. Such a situation in the dairy business requires the search for solutions for commodity farms regarding possible ways to improve milk safety indicators as soon as possible in order to avoid a further reduction in the number of dairy cattle in Ukraine. The purpose of the research was to study the technology of obtaining and individual elements of the primary processing

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of milk for the number of somatic cells and the level of microbial contamination of milk raw materials. The work used general scientific methods, arbitration method, and the method of variational statistics. For this, combined samples of milk from 3 farms that used different approaches to keeping animals and technologies for obtaining milk from them, and a number of personal farms of the population were examined quarterly for one year to study the dynamics and relationships between indicators of raw material safety. A significant influence of paratypic factors on the number of somatic cells in milk was revealed, such as: milk production technology, seasonality of production, and the level of morbidity of animals for hidden forms of mastitis. At the same time, a direct correlation was established between indicators of the number of somatic cells and microbial contamination of milk at the level of 0.91 ($P<0.001$), which suggests that measures aimed at improving one of them will automatically improve the other. Violations of the requirements of the primary processing of milk caused a significant increase in the microbial load. Elimination of identified technological deficiencies will contribute to the increase of raw materials at milk processing enterprises

Keywords: number of somatic cells; raw milk; microbial contamination of milk; number of colony-forming units; correlation

INTRODUCTION

The dairy industry of Ukraine is a self-sufficient component of agrarian business, which is able to bring a stable income, despite the difficult economic and military factors that have developed at the moment. Milk production is provided both by large-scale dairy enterprises and individual peasant farms. Depending on the number of productive cows in the farm and the organization of the milking process, enterprises use different technological approaches to obtaining and further processing of dairy products. But, despite the differences in the organization of this process in farms of different types, the state provides uniform requirements for milk in terms of its quality and safety. Criteria for dairy raw materials supplied to processing enterprises are defined in a number of regulatory documents: Order of the Ministry of Agricultural Policy and Food of Ukraine No. 118 "On approval of the requirements for safety and quality of milk and dairy products" (2019) and DSTU 3662:2018 (State Standard of Ukraine, 2018). These requirements include control over technological indicators – freezing point, density of milk to prevent falsification, and more significant safety characteristics – the number of somatic cells and colony-forming units (CFU) of microorganisms per unit volume. More attention is paid to the latter indicators, which is evidenced by the reduction of threshold values of microbiological indicators in the latest editions of the above-mentioned by-laws.

If the technological parameters of dairy raw materials, in most cases, depend on the good faith of producers, then both genetic factors of animals from which milk is obtained and paratypical conditions of its production have a significant impact on safety indicators. The influence of genetic factors on the quality of milk raw materials in various breeds of cattle is traced in the work of M.N. Alhussien and A.K. Dang (2018). They note that the level of somatic cells was higher in high-yielding breeds (Holstein and Swedish) than in low-yielding breeds – Ayrshire, Jersey, and other breeds. Similar results were obtained in the work of M. Franzoi *et al.* (2020), who note the hereditary dependence between the number of somatic cells in animals of the Holstein, Swedish, and Simmental breeds, and the quality characteristics of the milk obtained from them.

The influence of economic (paratypical) conditions on the manufacturability of dairy raw materials is followed in the studies of A.R. Quintana *et al.* (2020), who revealed the influence of the general hygienic condition of the farm on indicators of microbial contamination of milk, and in the work of H. Yuan *et al.* (2022), which indicate the dependence of the quantitative and qualitative composition of raw milk microflora on the season. An equally important factor in ensuring the microbiological safety of dairy raw materials is its subsequent technological processing. In the work of L. Berhanu *et al.* (2021) indicates that during the storage and transportation of milk, an increase in both the total number of microorganisms and their individual species, including coliforms, was observed. Therefore, taking into account the significant difference in technological approaches to milking cows in different types of farms and ensuring optimal conditions for the productive keeping of animals for microbiological contamination of milk and the content of somatic cells in it, these indicators can become a criterion for the suitability of the applied milk production technology to the conditions of the farm, or for evaluating new technological solutions implemented in production.

In view of the above circumstances, the purpose of the work was to study the influence of genetic factors and paratypical conditions of keeping cows on indicators of the number of somatic cells and microbiological contamination of milk raw materials in farms with different technological approaches in the production and primary processing of milk.

LITERATURE REVIEW

A significant part of scientific studies, the authors of which studied the influence of technological aspects

on the productivity of cows in the conditions of individual farms, substantiated their analysis only with the involvement of individual indicators of milk yield and reproduction: the number of animals (Tse *et al.,* 2018; Ivanyos *et al.,* 2020), milk protein and fat content (Varpikhovskyi, 2019; Lutsenko *et al.*, 2021), reproductive indicators (Lyashenko *et al.,* 2022; Qi *et al.,* 2022) and others. Recently, more and more attention has been paid in publications to data on the safety of milk, in particular, the number of somatic cells in milk from different farms. The number of somatic cells (NSC) indicates the health of the mammary gland and serves as a marker of the development of a subclinical form of mastitis (Quality milk on..., 2020). Somatic cells include any cells or their remnants found in milk. They mainly include epithelial cells of the mammary gland and blood leukocytes (Alhussien & Dang, 2018). In the milk of healthy cows, the level of somatic cells is insignificant and does not exceed 250,000 cells per cm^3. When animals suffer from mastitis, the level of somatic cells increases several times, reaching the value of 1-1.5 million cells/cm^3 (Bublyk, 2019). The growth of NSC reduces the manufacturability of milk, it is not possible to produce high-quality dairy products from it. Studies conducted by G. Stocco *et al.* (2020) indicate that the quality of milk worsened with an increase in the number of somatic cells. In particular, a decrease in the content of milk fat, protein, casein, and casein index was noted, as well as an increase in the content of fatty acids in milk. Similar results were obtained by E. Kul *et al.* (2019).

At milk processing enterprises, NSC determination is carried out in collected milk, which makes it difficult to identify sick animals. In the research of M. Karavansky *et al.* (2021), it is indicated that with an increase in the number of somatic cells in the total milk sample, the incidence of mastitis in cows in the herd increases. They indicate a direct relationship between the average number of somatic cells in collected milk and the incidence of mastitis among animals in the herd. Different factors have a significant influence on NSC in milk. Thus, in the work of O.E. Admin and N.G. Admina (2022), a significant influence of the age of cows, the stage of lactation, the season of the year, and the conditions of keeping on the level of somatic cells was found, and in the studies of K.B. Sebastino *et al.* (2020) noted that the maximum level of somatic cells was observed in the warm season.

Recently, a new approach has been proposed to diagnose the subclinical form of mastitis – the differential number of somatic cells, which is based on the determination of only immune cells in milk. For differential diagnosis, automated devices are used to count them (Halasa & Kirkeby, 2020).

An equally important indicator for determining the safety of milk is the number of microorganisms and their species composition (Perin *et al.,* 2019). In Ukraine, before the abolition of martial law, milk in which the number of microorganisms does not exceed 300 thousand CFU/ml is allowed for processing (State Standard of Ukraine, 2018; Order of the Ministry..., 2019). Like the number of somatic cells in milk, the indicator of bacterial contamination largely depends on a number of paratypic factors (Yuan *et al.,* 2022). In the work of G. Celano *et al.* (2022), they found the predominance of microorganisms of the *Xanthomonadaceae*, *Enterobacteriaceae*, and *Pseudomonadaceae* families in the winter period, which leads to a decrease in milk quality. Whereas in the summer – *Streptococcaceae* (*Lactococcus*) and *Limosilactobacillus fermentum*, which contributed to better preservation of milk. J. McLauchlin *et al.* (2020) noted that an increase in the level of *Escherichia coli* in raw milk was correlated with an increase in the number of colony-forming units (CFU) of coagulase-positive staphylococci. Further primary processing of milk as reported by V. Mörschbächer *et al.* (2017) contributed to the improvement of the microbiological condition of raw milk and dairy products made from it.

MATERIALS AND METHODS

The study of milk indicators from farms that differed in conditions of keeping, milking technology, and primary processing of milk was carried out during March-December 2022. For this, milk samples were taken every month from a number of farms in the Cherkasy region, from which milk raw materials were supplied to milk processing enterprises. Households were surveyed with the same periodicity, milk from which was sold on the agricultural market. Farms that had different technological conditions for milk production and animal productivity were selected for the study, but at the request of the owners and managers, the names of the farms are not indicated. The study included:

- Farm 1 – a herd of 376 dairy cows; the breed is Ukrainian black-spotted dairy, the average yield for the past year is 7734 kg, the animals are kept without tethering, milking is in the milking hall on the "Yalynka" type installation (Bratslav, Ukraine);
- Farm 2 – a herd of 175 dairy cows; breed – Ukrainian black-spotted dairy, yield for the past year – 6542 kg, maintenance – tethered, milking in the milk duct;
- Farm 3 – livestock of 58 cows; breed – Ukrainian black-spotted dairy, yield for the past year – 5219 kg, maintenance – tethered, milking in milk buckets.

Milk for research from personal peasant farms was purchased from animal owners at the agricultural market. There is no information on the breed and productivity of the cows, their maintenance depends on the use of pastures in the spring-autumn period. Milking using milking machines and manually. The selected milk samples were stored at a temperature of 4-6°C during transportation to the laboratory. Laboratory analysis was performed on the day of sample collection.

Microbiological studies and determination of the number of somatic cells in the combined sample were

carried out in the microbiological department of the state laboratory on food safety and consumer protection. The number of somatic cells was determined in accordance with DSTU ISO 13366-1/IDF 148-1:2014 (State Standard of Ukraine, 2014). To do this, the prepared smear of milk was dyed for 15 minutes in a Newman-Lampert dye solution, and after drying, the number of somatic cells was counted under a microscope with a magnification of 500-1000 times. Calculation of NSC was carried out in accordance with methodical recommendations (Harkavenko *et al.,* 2021). Examination of cows for the subclinical form of mastitis was carried out using the mastidine test. For this purpose, 2 ml of diagnosticum and tested milk from each quarter of the udder were poured into the tablet, mixed, and the result was evaluated by colour and consistency.

Determination of the number of mesophyllic aerobic and facultatively anaerobic microorganisms (NMAFAnM) and lactic acid bacteria was carried out using dry ready-to-use chromogenic media Compact Dry. 1 ml of diluted milk (in a ratio of 1:1000 with the buffer solution included in the research kit) was transferred to a cup with a dry medium and diffused over its entire surface. After that, the cups were placed in a thermostat at a temperature of 35±2°C for 48 hours. After incubation, the determination of the number of microorganisms was carried out by counting colonies stained red, which acquired this colour due to the metabolic reduction of the indicator – tetrazolium salts. This made it possible to differentiate them from extraneous residues that remained unstained. In the case of germination of numerous colonies, a further series of dilutions was carried out from a collective sample of milk to facilitate calculations.

Statistical analysis of research results was carried out using the method of variational statistics in Microsoft Excel and Minitab® 21.3.1 software. Average arithmetic values and their errors and other statistical indicators were determined.

RESULTS

When evaluating the milk productivity of cows, preference is given to the quantitative characteristics of milk – how much milk is obtained, the content of protein, and milk fat in it, but recently, the requirements for the quality of milk raw materials in Ukraine have significantly increased (State Standard of Ukraine, 2018). This is connected with an effort to bring the legislation into line with the requirements of the European Union regarding the veterinary and sanitary rules of production and circulation of milk, and to improve the quality of dairy products due to its safety indicators. Therefore, determining the number of somatic cells and microbiological contamination of milk when it enters the milk processing enterprise became mandatory elements of the research.

One of the most significant innovations for milk producers was the almost two-fold reduction in the number of somatic cells in raw milk (State Standard of Ukraine, 2018). It is due to the reduction of permissible NSC in milk that the quality (merchantability) of milk in most farms has somewhat deteriorated. The results of research on the content of somatic cells in milk samples from controlled farms are shown in Table 1.

Table 1. *Indicators of the number of somatic cells in the milk of the collective sample in controlled farms (thousands)*

Household	Season of the year							
	Spring		Summer		Autumn		Winter	
	M±m	Cv, %	M±m	Cv, %	M±m	Cv, %	M±m	Cv, %
1	198±21.8	24	212±39.4	36	176±22.4	32	159±19.7	22
2	279±39.4	32	396±44.2	42	296±37.4	34	227±22.3	37
3	305±28.7	26	503±57.8	48	338±49.7	42	264±42.7	43
Single	156±21.3	18	166±19.6	22	144±16.6	21	124±15.4	19

Source: *compiled by the authors*

The obtained data indicate a significant influence on the level of somatic cells in the collective milk sample of the technology of its production. Thus, in the first farm, in any of the quarters of the year, NSC did not exceed the permissible requirements of regulatory documents for milk raw materials, while in the farm with milking cows in milk buckets, their number in all seasons was higher than the mentioned norm. At first glance, there is a direct relationship between the method of keeping and milking technology and NSC in milk raw materials. But the analysis of samples from private peasant farms, on the contrary, indicates a much better quality of milk from animals from single-person farms compared to those where more modern technological solutions are used for milking animals. Probably, this is a consequence of the stereotype that milk production on an industrial basis will always have better indicators than milk from cows from individual farms. After all, the technology of obtaining milk from cows, in addition to, in fact, the process of removing

the secretion of the mammary glands, also involves processing the udder before and after milking. The use of disposable napkins for dry processing of the skin of the mammary gland and preparations for disinfecting nipples contributed to the reduction of the number of subclinical cases of mastitis in the first farm. This was confirmed by the results of studies of the animal population with a mastidine sample (Table 2).

Table 2. *Results of detection of subclinical cases of mastitis in cows of the first farm, heads*

Indicator	Season of the year			
	Spring	Summer	Autumn	Winter
A total examined number of cows	344	327	362	359
Number of positive tests	20	27	19	16
% of mastitic cows	5.8	8.3	5.2	4.5

Source: *compiled by the authors*

Since the number of somatic cells in milk is an indicator of the inflammatory process in the mammary gland, and their increase in the combined sample indicates the intensity of mastitis in the herd. The obtained research results are correlated with the data on NSC in the collective sample of milk from the first farm specified in the first table. In the other two farms, only wet processing of the udder before milking was carried out, and there was no diagnosis of animals for hidden forms of mastitis, therefore there is no reliable information about the incidence of cows in those herds, but insufficient processing of the udder before and after milking could well be the reason for the growth of somatic cells in milk.

Despite the lack of specialized means for disinfecting the udders of cows in individual households, and the insufficiency of diagnostic measures aimed at detecting subclinical mastitis in them, milk from such animals had the best NSC indicators. This could be related to the daily monitoring of the state of the mammary gland and the quality of milk by the owner of the animal, and in the case of the slightest suspicions, its timely treatment.

An equally important indicator of the safety of milk is its microbial contamination, because, like the previous one, this indicator can be an indicator of both the sanitary and hygienic condition on the farm and the incidence of mastitis in animals. Therefore, in accordance with the requirements of regulatory documents regarding microbiological studies of milk raw materials, control over the latter is also entrusted to market operators – that is, milk processing enterprises. And accordingly, it also affects the quality of milk and, as a result, the profitability of the entire production of products. The results of microbiological studies of combined samples of milk from farms and the market are presented in Table 3.

Table 3*. Indicators of microbial contamination of raw milk of a collective sample in farms under control (CFU, 10^4)*

Household	Season of the year							
	Spring		Summer		Autumn		Winter	
	M±m	Cv, %	M±m	Cv, %	M±m	Cv, %	M±m	Cv, %
1	4.1±0.3	31	9.7±0.5	39	7.2±0.4	29	3.9±0.3	24
2	14.8±0.7	35	17.6±0.9	45	13.6±0.9	37	12.9±0.7	34
3	15.6±0.5	29	22.4±0.5	51	18.7±0.2	34	14.7±0.3	27
Single	71.6±16.7	58	157.3±35.2	107	72.1±15.2	88	52.4±3.8	49

Source: *compiled by the authors*

From the analysis of the presented material, it can be stated that regardless of the conditions of keeping animals and the technology of obtaining milk in the controlled farms, the microbiological indicators in all of them were within the permissible limits. Bacterial contamination of dairy raw materials turned out to be 2-3 times lower in the first farm compared to the others. That is, compliance with proper sanitary and hygienic conditions during the preparation of animals for milking guarantees a decrease in the level of microorganisms in milk raw materials. In parallel studies of combined milk samples from farms, the number of mesophyllic aerobic and facultatively anaerobic microorganisms (NMAFAnM) was correlated with the results of the number of somatic cells. The correlation coefficient between indicators was 0.91 ($P<0.001$) (Fig. 1).

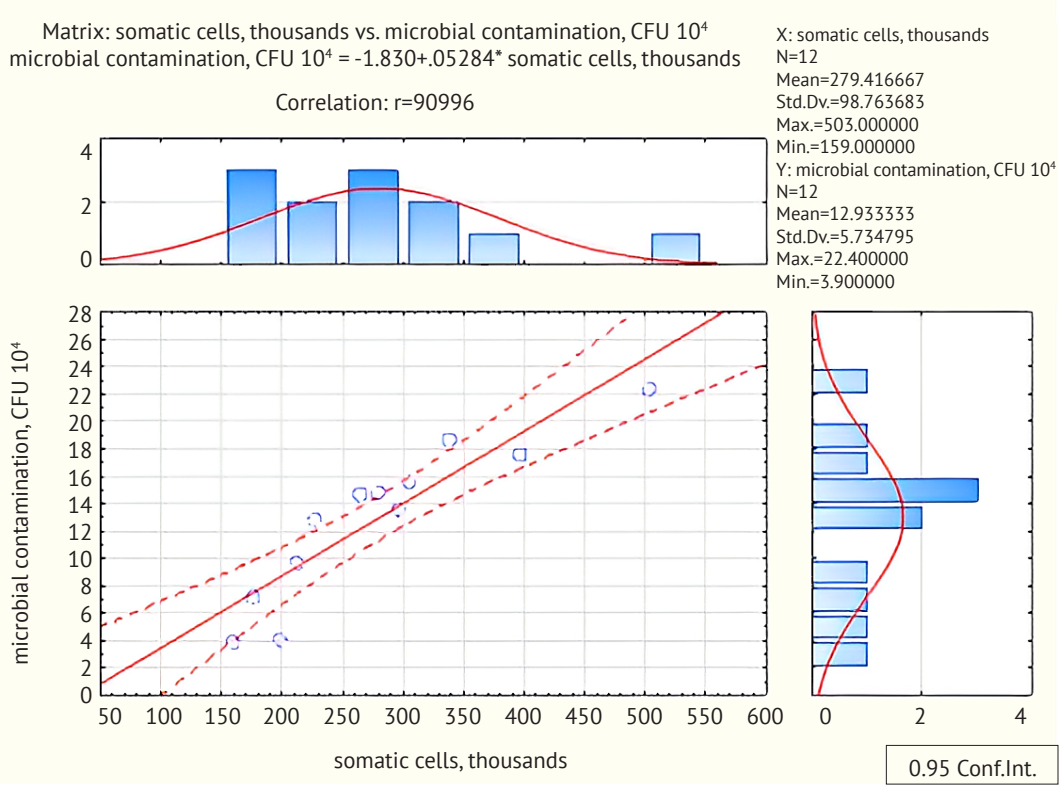

Figure 1. *Correlation matrix between indicators of somatic cell content and microbial contamination in combined milk samples*

Source: *compiled by the authors*

But indicators of bacterial contamination in milk from individual households did not fit into this system, so they were not taken into account when conducting correlation analysis. The microbiological indicators of milk samples from cows from private households exceeded the permissible norms by several times, despite the fact that this milk had the lowest indicators of the number of somatic cells. Their variability from sample to sample was also high. The coefficient of variation many times exceeded the values obtained for farms with an industrial type of milk production. Further analysis of the microbial contamination of milk from this category of farms also revealed a significant dependence of the fluctuation of the number of cone-forming microorganisms on the season of the year, while the seasonal fluctuations of this indicator in farms with industrial milk production technology were insignificant. Given that milk contains all nutrients in a form easily accessible to microorganisms and is a good nutrient medium, an important element of improving its safety is its further processing aimed at preventing rapid bacterial growth in it.

Therefore, in farms, freshly expressed milk is subjected to rapid cooling, which prevents the active development of microbiota, and this ensures compliance with the requirements of regulatory documents for the indicator of the number of colony-forming microorganisms in industrial milk production. At the same time, it is not possible to provide rapid cooling of a significant amount of milk in private households. Therefore, even some microorganisms that enter the milk during milking as a result of the exponential growth increase its quantity and thereby deteriorate the quality of milk raw materials. A significant seasonal variation in the bacterial contamination of milk sold on the market is also due to the increasing temperature of the environment in which transportation and its sale take place. To confirm this assumption, a microbiological study of milk was carried out, which was stored under different temperature conditions for 3, 12, and 24 hours. The results of the study are presented in Table 4.

Table 4. *Indicators of microbial contamination of raw milk during its storage under different temperature conditions (CFU, 10⁴)*

Temperature regime, °C	Milk storage time, hours			
	0	3	12	24
4±1	5.3	5.8	6.9	9.2

Table 4, Continued

Temperature regime, °C	Milk storage time, hours			
	0	3	12	24
10±1.5	5.3	7.4	21.3	83.2
18-20	5.3	8,9	49.3	208.8

Source: *compiled by the authors*

The results of the study shown in the table revealed a significant influence of the milk storage temperature on the number of microorganisms in it. This explains the increase in bacterial contamination of milk purchased on the agricultural market, with a few somatic cells in it. Therefore, in order to obtain high-quality milk according to safety indicators, it is necessary to strictly comply with all the requirements of the technological process of its production and primary processing, regardless of the method of keeping animals and the type of dairy equipment used.

DISCUSSION

The introduction of new safety criteria for milk and dairy products, as a step towards bringing domestic legislation into compliance with the requirements of the European Union, on the one hand, allowed to provide the population with high-quality food products, and to increase the export capacity of domestic goods. On the other hand, the introduction of stricter veterinary and sanitary requirements for the production and circulation of milk, aimed at improving the quality of milk raw materials at the expense of its safety indicators, reduced the profitability of the majority of farms due to a decrease in the marketability of milk and its price. Such a situation in the dairy business requires clear actions to find a quick solution for commodity farms and possible directions for further improvement of the state of dairy farming.

Solving the problems of improving the safety indicators of milk raw materials exclusively with the help of selection approaches did not have much success. After all, the level of somatic cells and microbial contamination of milk is a complex problem, which is affected by both genetic factors – the shape of the udder, the level of milk productivity, metabolism, the state of the immune system, and paratypical conditions – violations of the conditions of keeping and feeding animals, violations of milking technology and much more others This was confirmed in the works of domestic researchers – I.D. Filipenko *et al.* (2019), O.I. Shkromada *et al.* (2019a; 2019b), as well as foreign ones – S. Kaskous *et al.* (2023), D.S. Riveros-Galán and M. Obando-Chaves (2021), and others. Therefore, this work focused on certain technological aspects of milking and primary processing of milk.

The main reason for researching the level of somatic cells in milk raw materials is to determine the level of morbidity of herd animals for various forms of mastitis, since this indicator is the main indicator of the development of hidden inflammation in the mammary gland. This is indicated by the research of A. Egyedy *et al.* (2022) and R.M.C. Deshapriya *et al.* (2019). When analysing the situation in controlled farms, the increase in the number of somatic cells in the combined milk sample from the first farm with the number of detected cows with subclinical mastitis was monitored. Such studies were conducted only in one of the studied farms, so it can only be assumed that the reason for the increase in NSC in other farms was also the spread of cases of hidden mastitis in herds. But, taking into account that the composition of somatic cells, in addition to leukocytes that enter milk during the development of the inflammatory process, also includes other elements, in particular, cells of the epithelial tissue of the mammary gland, this assumption is no longer so unambiguous.

In addition, in the studies of R. Rainard *et al.* (2018) noted that a low number of somatic cells in milk indicates the insufficiency of the body's protective mechanisms to resist pathogens and is a manifestation of immunodepression, which can also cause mastitis. Therefore, these studies require further study and monitoring of the state of the herd in all farms on the subject of cow disease due to hidden mastitis. An equally interesting direction of future research will be the application of a method that a number of scientists have recently begun to use to more clearly establish a diagnosis of mastitis. The method of differential determination of the number of somatic cells (DSCC) allows determining the contribution of individual categories of cells in NSC (Dal Prà *et al.,* 2022). This approach will be able to more objectively interpret the increase in somatic cells in the milk of animals and distinguish the inflammatory nature of the increase in leukocytes in milk from the increase in the number of epithelial cells in various technological disorders of the milking process. What will become no less important when studying the impact of individual technological methods of preparing animals for milking and processing the udder after it, to clarify the nature of the accumulation of somatic cells in milk and their processes that lie behind them.

The study of the influence of the technological process of obtaining milk raw materials on the bacterial contamination of milk became more predictable. The higher the culture of keeping animals in the farm and observing the rules of sanitary hygiene, the lower was the level of microbial insemination of raw materials.

In a farm with a milking parlour, lower indicators of the content of colony-forming microorganisms in milk were found in comparison with the use of other milking technologies. This fully agrees with the results of the study by O.V. Borodina and D.K. Nosevych (2017), which states that milking in milking parlours using the "Parallel", "Yalynka", "Carousel" type installations in comparison with milking in portable buckets or a milk pipe increases productivity labour of machine milking operators and contributes to the reduction of bacterial contamination of milk.

Moreover, each producer had its own microbiota in the obtained milk raw materials, which at the same time differed significantly in terms of signal microorganisms. Also, in these studies, the influence of procedures related to the preparation of teats and cleaning of milking equipment on the composition and amount of microbiota of raw milk was noted. It was indicated that the number of microorganisms depended precisely on these procedures, and only then on the type of milking system used. In controlled farms, a decrease in the number of microorganisms in the milk of cows whose udders were disinfected before milking in the first farm, and a significantly higher microbial contamination in the wet toilet of the mammary gland in other farms, was also found. Therefore, in order to increase the safety indicators of milk during its production, it is necessary to implement modern approaches to preparing animals for milking and processing the udder after it. The studies also revealed a direct correlational interdependence between the number of somatic cells and the level of microbial contamination of milk obtained by the industrial technology of its production. This fully agrees with the assumption that clinical and subclinical forms of mastitis of bacterial aetiology are the main cause of NSC growth.

Unfortunately, monitoring for hidden inflammation of the mammary gland among farm animals was practised in only one of the farms among which the research was conducted. But even these results confirm the assumptions about the need to control not only the cleanliness of the milking equipment, but also the constant check of the health of the mammary gland in productive cows and their timely treatment. They fully agree with the studies of El-Sh.-N. Mehany *et al.* (2021) and O. Olatoye *et al.* (2018), who also indicate the interdependence between indicators of the number of somatic cells and its bacterial contamination obtained as a result of conducting experiments.

The authors would also like to draw attention to the sphere of milk production in Azerbaijan. Intensive increase in the production and primary processing of milk in the Republic of Azerbaijan is considered one of the main priorities of the development of agriculture. After gaining independence, breeding heifers from foreign countries are imported to the republic annually to increase the production of livestock products, including milk. In order to develop livestock breeding by the order of the President of the Republic of Azerbaijan, funds are regularly allocated from the reserve fund of the President of the Republic of Azerbaijan to JSC "Agroleasing" (Abbasov, 2013). At the expense of these funds, 770 heads were purchased in 2009, 900 heads in 2010, 6630 heads in 2015, 5074 heads of breeding heifers in 2020 and leased to economic entities producing livestock products on 50% preferential terms. The provision of exemplary service to dairy-breeding heifers imported to the republic has a serious positive impact on the country's animal husbandry culture.

The registration of breeding animals with a breeding passport (certificate) is carried out by the State Statistics Committee of the Republic of Azerbaijan once a year. As a result of the stimulating measures implemented by the state for the development of the non-oil sector, in particular, the introduction of new rules for subsidizing livestock, at the expense of highly productive animal breeds imported from abroad, favorable conditions have been created for the operation and development of state breeding enterprises, as well as private dairy farms (Decree of the Cabinet..., 2008).

The main task of the country's meat and dairy enterprises in the modern era should be to ensure the demand of the population for this type of product at the expense of domestic products. The gross agricultural output of the Republic of Azerbaijan in 2021 increased by 6.41% compared to 2003 and amounted to 50.77% in the share of livestock products. In 2021, 37.4% of the total milk volume in the country was produced in the Karabakh, Central Aran and Milsko-Mugan economic regions, which is 832,178 thousand tons. Separately, the Baku Dairy Plant produces 80.4% of the total volume of low-fat dairy products (in terms of milk). The analysis shows that milk processing enterprises operate exclusively on the basis of a large-scale raw material base. Thus, facing milk processing enterprises were organized mainly in the centers of consumption in the east of the republic and near them, and creameries -in the western and mountainous regions -in the raw material zones (The State Statistical Committee of the Republic of Azerbaijan, 2023).

The biggest surprise was the results of research on milk samples from the market, where products from private households were sold. There has always been a stereotype that milk from this category of farms was significantly inferior in quality to milk raw materials obtained from farms with industrial production technology (Maslak *et al.,* 2020). But the conducted studies, on the contrary, revealed that the lowest level of somatic cells was observed in milk from private farms of the population. And this is despite the least technological solutions when obtaining milk. Probably, this is connected with the constant control of the animal owners by the physiological and clinical condition of the animals, as well as regular monitoring of the main

infectious diseases by the state veterinary services. The increase in the level of bacteriological pollution is associated with non-compliance with the temperature regime during the storage and transportation of milk to the places of its sale, which is fully consistent with the reports of K.K. Dash *et al.* (2022). Therefore, taking into account the difficult situation with milk raw materials necessary to ensure the industrial capacity of milk processing farms, milk from this category of farms is quite suitable for further technological processing. It is only required to ensure the conditions for the primary processing of such raw materials.

CONCLUSIONS

As a result of the conducted research and based on the results of previous works of other researchers regarding the study of the influence of a number of technological approaches to the production and primary processing of dairy raw materials on its safety indicators, a number of the following conclusions can be drawn:

In the conditions of industrial milk production, the number of somatic cells, as one of the indicators of the safety of milk raw materials, has a significant impact on technological approaches to the organization of the processes of preparation and milking of cows. The level of somatic cells depends on compliance with the regulations of these procedures, as an indirect indicator of the incidence of hidden forms of mastitis in herd animals. Bacterial contamination of milk, determined by the number of mesophyllic aerobic and facultatively anaerobic microorganisms (NMAFAnM), in all farms that used industrial milk production technology was insignificant and did not exceed normative indicators in any of the seasons of the year. The detected seasonal fluctuations of milk safety indicators were characterized by an increase in the levels of both indicators in the summer period and a decrease in the winter.

A high correlation coefficient was found between the level of microbial contamination of milk and the number of somatic cells in it, with a high probability ($P<0.001$), which indicates a high dependence of safety indicators and their interrelationship. Therefore, measures aimed at improving one of them will be positively noted at the level of another indicator. Milk from private farms of the population had the best safety indicators in terms of somatic cells, but the violation of the requirements of the technology of primary processing of milk (lack of cooling) led to the subsequent growth of microbial cells in it. Therefore, ensuring a stable temperature of milk in the range of +4-+6°C during storage and transportation will allow increasing the amount of high-quality milk raw materials to ensure the capacity of milk processing enterprises.

In the following studies, it is planned to continue the study of the influence of the technological processes of preparing animals for milking and processing the udder after it on the level of somatic cells according to their differential content.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Технологія виробництва та первинної переробки молока в умовах фермерського господарства

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Анотація. Запровадження на законодавчому рівні нових критеріїв безпечності молочної сировини, з одного боку, дозволило покращити забезпечення населення якісними продуктами харчування, а з іншого - спричинило зниження прибутковості господарств через погіршення товарності молока та його ціни. Така ситуація в молочному бізнесі вимагає пошуку рішень для товарних господарств щодо можливих шляхів якнайшвидшого покращення показників безпечності молока з метою уникнення подальшого скорочення поголів'я молочної худоби в Україні. Метою досліджень було вивчення технології отримання та окремих елементів первинної переробки молока на кількість соматичних клітин та рівень мікробного обсіменіння молочної сировини. У роботі використовували загальнонаукові методи, арбітражний метод та метод варіаційної статистики. Для цього щоквартально протягом одного року досліджували об'єднані зразки молока з 3 фермерських господарств, які використовували різні підходи до утримання тварин і технології отримання молока від них, та низки особистих господарств населення з метою вивчення динаміки та взаємозв'язків між показниками безпечності сировини. Виявлено значний вплив паратипових факторів на кількість соматичних клітин у молоці, таких як: технологія виробництва молока, сезонність виробництва та рівень захворюваності тварин на приховані форми маститу. При цьому встановлено прямий кореляційний зв'язок між показниками кількості соматичних клітин та мікробного обсіменіння молока на рівні 0,91 ($P<0,001$), що свідчить про те, що заходи, спрямовані на покращення одного з них, автоматично сприятимуть покращенню іншого. Порушення вимог первинної обробки молока спричинило значне зростання мікробного навантаження. Усунення виявлених технологічних недоліків сприятиме збільшенню сировини на молокопереробних підприємствах

Ключові слова: кількість соматичних клітин; сире молоко; мікробне обсіменіння молока; кількість колонієутворюючих одиниць; кореляція

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Identification and interpretation of internal factors influencing the agricultural insurance market in Ukraine

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Abstract. The functioning of the agricultural insurance market in Ukraine is an objective reality and a necessity due to the urgent need to create a safe environment for agricultural production. The ability to consolidate financial resources in the field of insurance contributes to increased responsibility for probable risks distributed in space and time, so it is worth considering insurance relations in the agricultural sector. The purpose of the study is to theoretically and methodologically justify the processes of identifying internal factors influencing the further functioning of the agricultural insurance market in Ukraine. The methodological perspective of this study is based on

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the use of general scientific and specific methods of cognitive activity: abstract-logical, economic-statistical, structural-functional, deduction, induction, and formalisation. A panel database was formed for the period 2012-2021 broken down by the regions of Ukraine. The territorial features of changes in the ratio between insured and sown areas in the western, central, eastern, and southern regions of Ukraine are reflected. Based on the results of the conducted modelling (two models are presented simultaneously: a regular model and a one-year lag model), the influence on the insured area of such factors as sown area, yield, gross harvest, and internal price for agricultural products is established. A comparative characteristic of the statistical qualities of the presented models was made using indicators such as "Residual standard error", "Multiple R-squared", and "Adjusted R-squared". The results of the regression analysis showed the statistical significance of certain factors in motivating agricultural commodity producers to participate in the insurance process. The practical value of the proposed measures lies in formulating practical recommendations for enhancing cooperation among stakeholders in the agricultural insurance market during wartime and post-war periods

Keywords: agricultural insurance; insured area; insurance market stakeholders; agricultural risks

INTRODUCTION

The key priorities of the present and the future are to achieve sustainable capacity to meet the social, economic, and environmental needs of humanity in the face of inevitable challenges of modern civilisation. The formulated statement largely applies to the process of agricultural production. This is because, according to the UN forecasted data, the world population will reach 9.8 billion by 2050 and 11.2 billion by 2100. This indicates the objective need for a global increase in agricultural production to meet the current and potential demand for food products.

A systemic solution to the outlined problem requires the consistent use of effective financial and economic instruments capable of efficiently and, most importantly, timely counteracting various natural and anthropogenic risks. The long-standing experience of countries worldwide (such as the United States, Canada, China, European Union countries, Africa, and Latin America) demonstrates that addressing the challenges of modern civilisation requires the use of diverse forms and methods of insuring agricultural commodity producers. The values of insurance are primarily directed at creating an effective mechanism for accumulating and using financial resources distributed in space and time upon the occurrence of insurance events.

A critical review of studies demonstrates a significant interest of researchers in the functioning of insurance relations in the agricultural sector. O. Slobodianiuk *et al.* (2018) consider agricultural insurance as a primary mechanism for managing agricultural risks and protecting income from crop loss, repaying loans taken for agricultural business development, and ensuring food security. The insurance of agricultural products is interpreted as one of the essential risk management strategies related to food worldwide (Ker & Tolhurst, 2019). According to A. Möhring *et al.* (2020), insurance is capable of successfully reducing various shocks to agriculture caused by unforeseen events, including market fluctuations, natural disasters, and other disturbances. H. Wong *et al.* (2020) and M. King & A. Singh (2020) argue that compared to 'ex post' compensation, 'ex ante' insurance is a much more effective risk management tool.

Arguments in favour of the widespread use of the agricultural production insurance system can be outlined in the following sequence: climate change increases the likelihood of extreme weather events for agricultural commodity producers (Vroege & Finger, 2020), such as droughts, floods, strong winds, and more (Malhi *et al.*, 2021). In addition, it is worth highlighting the risks associated with price instability and the negative impact of new technologies on the activities of agricultural commodity producers, resulting in high costs for their acquisition and implementation in the production process, increased training expenses, and dependence on advanced technologies (Boyd & Bellemare, 2020; Mironkina *et al.,* 2020).

In the conditions of a state of war, Ukraine recognises its global mission to provide various countries with agricultural products. This fact significantly strengthens the argument for the use of security instruments in agricultural production, including insurance. The relevance of this study is based on the necessity of interpreting and identifying internal factors influencing the agricultural insurance market in Ukraine and justifying its further development in line with the needs for insuring agricultural risks.

The purpose of this paper is the theoretical and methodological substantiation of the processes of identifying internal factors influencing the further functioning of the agricultural insurance market in Ukraine. The hypothesis of this study assumes the existence of interconnections between sown areas, yields, gross harvest, and the internal price in the agricultural sector, and the influence of these factors on decision-making in the field of insuring agricultural risks.

MATERIALS AND METHODS

For the theoretical substantiation of the role and importance of agricultural production insurance in a risk-prone environment, the abstract-logical method was used. The application of inductive and deductive methods allowed the identification of key legal, institutional, financial-economic regularities in the development of relationships between stakeholders in agricultural insurance. The

economic-statistical method was used to reflect trends in the coverage of insurance for sown areas in the regions of Ukraine. The structural-functional method was used to justify the financial and economic guidelines for the development of agricultural insurance in post-war Ukraine. The formalisation method provided the opportunity for theoretical generalisations, formulation of proposals, and conclusions.

Modelling of the functioning of parameters of the agricultural product insurance market was performed using a panel database for the period 2012-2021, considering 24 regions of Ukraine. Given the level of filling official sources with statistical data, it should be noted that the data used exhaust all possible terms. Data on the insured area, harvested area, gross harvest, and yield broken down by regions and crops are only available for 2021.

The predictor was determined to be the insured area (Y), and the factors selected included the sown area, gross harvest, yield, and the price of crops such as cereals (S_cer_E, V_cer_E, Y_cer_E), wheat (S_wheat_E, V_wheat_E, Y_wheat_E, Price_wheat), corn for grain (S_corn_grain_E, V_corn_grain_E, Y_corn_grain_E, Price_corn_grain), corn for silage (S_corn_fod_E, V_corn_fod_E, Y_corn_fod_E), barley (S_barley_E, V_barley_E, Y_barley_E, Price_barley), rye (S_ryeW_E, V_ryeW_E, Y_ryeW_E, Price_rye), oats (S_oat_E, V_oat_E, Y_oat_E, Price_ oat), buckwheat (S_buck_E, V_buck_E, Y_buck_E, Price_ oat), soybeans (S_soya_E, V_soya_E, Y_soya_E, Price_ soya), rapeseed (S_rap_E, V_rap_E, Y_rap_E, Price_ rap), and sunflower (S_sunfl_E, V_sunfl_E, Y_sunfl_E, Price_sunfl). As a result, a panel database was obtained with a depth of 240 (24 regions for 10 years), a width of 48 indicators, and a total database capacity of 11,520 unique numerical values. It should be noted that all prices were presented in real 2012 prices, which eliminates the influence of inflationary processes in the country's economy.

Given the substantial volume of the database, this study used the econometric method of stepwise regression for factor selection. In this study, stepwise regression was used to reduce the number of variables and improve model quality by selecting the most statistically significant variables. The described algorithm allows for systematic factor selection and determining their influence on the dependent variable within multiple linear regression (Gooch, 2011). After obtaining statistically significant factors (predictors) through stepwise regression, the next step in building the econometric model used an econometric approach – panel data analysis to construct a regression model based on the entities of a single population (24 regions) over consecutive time periods (2012-2021). Based on the Hausman test (Wooldridge, 2010) in the analysis of panel data, the fixed effects regression method was chosen. This method allows investigating relationships between variables for each group, considering fixed effects (Cameron & Trivedi, 2013).

The information basis of the study included the regulations of Ukraine (Law of Ukraine No. 4391-VI, 2012; Resolution of the Cabinet of Ministers of Ukraine No. 1342, 2021), analytical data from the Ministry of Agricultural Policy and Food of Ukraine in cooperation with the Project "Development of Agricultural Sector Financing in Europe and Central Asia", implemented with the support of the World Bank and the International Finance Corporation (IFC) (Agricultural insurance market of Ukraine, 2018), official reporting materials from the State Statistics Service of Ukraine (State Statistics Service of Ukraine, 2012-2021), reports from the International Federation of Cooperative and Mutual Insurance (European Market Share, 2022), analytical data from insurance companies in Ukraine providing services in agricultural insurance ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA", 2022), and studies of foreign and Ukrainian researchers on the studied subject and their findings.

RESULTS

Considering the multifaceted relationships among stakeholders in agricultural insurance, aligning their insurance interests is essential to boost business and investment activities in the agricultural insurance market. These interests, from the perspective of agricultural producers, manifest in enhanced and diversified insurance protection, including coverage for various types of risks and different insurance service options. For insurance companies, a priority task is to expand coverage for agricultural risks, which ensures the formation of the necessary resource base to meet their financial obligations under existing agricultural insurance contracts.

Globally, the level of agricultural insurance development is often assessed by the ratio of insured to sown areas. For instance, in the United States, this ratio stands at 88.0%, in Canada at 72.2%, in China at 45.5%, and in Greece at 100% (World Bank Group, 2023). High levels of insurance coverage for agricultural risks have led to a nearly fourfold increase in the accumulation of global insurance payments from 8.7 billion USD to 31.9 billion USD between 2009 and 2019 (World Bank Group, 2023). Achieving this level of capitalisation in insurance payments became possible through various models of agricultural insurance, including liberal, public-private partnerships, mandatory insurance, and the rational combination of traditional and index-based insurance products.

In Ukraine, the ratio of insured to sown areas over the past two decades has remained below 5%. The variation of this parameter across regions during the study period (2012-2021) is rather heterogeneous. The study period was chosen before the start of the COVID-19 pandemic and the full-scale military invasion of the Russian Federation on the territory of Ukraine. It is worth noting that during the period from 2012 to 2019, annual data from the Ministry of Agrarian Policy and Food of Ukraine in collaboration with the "Development of Agricultural Sector Financing in Europe and Central Asia" project served as the source of information regarding the development of agricultural insurance in Ukraine. In 2019, the project was suspended.

To conduct further research in this segment of the insurance market, analytical data directly from Ukrainian insurance companies were used. These companies, including "ARX", "KRAYINA", "ORANTA", "PZU Group", and "UNIVERSALNA", positioned their services in the agricultural insurance market. The combined market share of these insurance companies in terms of insured areas exceeded 95%. The analysis of the state of insurance coverage for agricultural risks was performed based on geographic characteristics. In western regions, particularly Lviv, Ternopil, Rivne, and Khmelnytskyi, the level of insured areas ranged from 0.25% to 12.50%. The presented indicators are the highest among all regions of Ukraine. This can be explained primarily by the relatively high adaptability of agricultural commodity producers in western regions to European traditions in risk management and mitigation (State Statistics Service of Ukraine, 2021).

Among the northern and central regions of Ukraine, Vinnytsia, Zhytomyr, Dnipropetrovsk, Kyiv, Poltava, Sumy, and Chernihiv stood out, where the parameter under study ranged from 1.99% to 6.75% (State Statistics Service of Ukraine, 2021). These regions concentrate significant proportions of sown areas (in terms of the total area of Ukraine), which somewhat complicates the mechanism of interaction among stakeholders in the insurance process. This highlights the need for the development of a modern, well-branched infrastructure (i.e., clear coordination of actions among key stakeholders, insurance intermediaries, state and non-state institutions, etc.) for the agricultural insurance market and the improvement of communication between interested stakeholders.

The lowest level of insured areas during the study period was observed in the eastern and southern regions of Ukraine, in particular: Donetsk, Luhansk, Odesa, Mykolaiv, Kharkiv, and Kherson regions. The ratio of insured persons to acreage was in the range of 0.14% to 4.17%. This low level of insurance coverage for agricultural risks can be attributed to several reasons (State Statistics Service of Ukraine, 2021). First, many vegetable and pumpkin crops, which are widely grown in southern regions of Ukraine, exhibit high resistance to risks. This necessitates the development of innovative insurance products (e.g., index-based insurance) capable of aligning the financial and economic interests of stakeholders in the insurance process to the maximum extent. Second, the military aggression by the Russian Federation against Ukraine, starting in 2014, had quite negative consequences for the development of agricultural insurance. Therefore, the analysis of the level of insured agricultural areas in a territorial context for the years 2012-2021 attests to the untapped potential for the development of agricultural insurance in Ukraine compared to developed countries worldwide. Instead, it should be noted that over the study period, there was positive growth in cultivated areas, increased crop yields, and gross harvests. These changes are characteristic of grain crops, such as wheat, corn, rapeseed, and sunflower.

B. Iganiga & D. Unemhilin (2011) used an approach in which all factors in the model were lagged by one year. This means that, for example, the price of a particular agricultural crop in the previous year affects the decision of agricultural producers to insure their crops in the current year. To obtain scientifically significant results in the study, two models are presented: a standard model (Fig. 1) and a one-year lag model (Fig. 2). In the standard model, only the current values of the factors are considered, without considering their past values. In addition to examining long-term effects and identifying a more complete dependence between the factors, a one-year lag model is also used.

```
Call:
lm(formula = Y ~ V_cer_E + V_sunfl_E + V_soya_E + S_soya_E +
    S_rap_E + S_oat_E + Y_buck_E + Price_soya + Price_barley +
    S_barley_E + Price_wheat + Y_soya_E, data = DataBase)

Residuals:
    Min      1Q  Median      3Q     Max
-44.265 -13.420  -1.177  10.284  74.892

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   2.310e+01  8.039e+00   2.873  0.00449 **
V_cer_E      -5.568e-06  2.694e-04  -0.021  0.98353
V_sunfl_E     5.267e-03  8.598e-04   6.125 4.52e-09 ***
V_soya_E      8.633e-03  1.523e-03   5.670 4.79e-08 ***
S_soya_E      1.240e-02  2.775e-03   4.468 1.30e-05 ***
S_rap_E       1.809e-01  6.574e-02   2.752  0.00645 **
S_oat_E       3.198e-01  3.367e-01   0.950  0.34324
Y_buck_E     -1.389e+00  5.187e-01  -2.678  0.00801 **
Price_soya   -1.366e-03  1.109e-03  -1.231  0.21961
Price_barley  9.629e-03  3.636e-03   2.648  0.00872 **
S_barley_E   -7.259e-02  3.572e-02  -2.032  0.04344 *
Price_wheat  -7.520e-03  4.296e-03  -1.751  0.08151 .
Y_soya_E     -2.444e-01  1.717e-01  -1.424  0.15594
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 19.87 on 206 degrees of freedom
Multiple R-squared:  0.5326,    Adjusted R-squared:  0.5054
F-statistic: 19.56 on 12 and 206 DF,  p-value: < 2.2e-16
```

Figure 1. *Results of modelling the impact of cultivated areas, gross harvest, crop yields, and prices for agricultural crops on the insured area*

Source: *calculated based on data ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA", 2022; Agricultural insurance market of Ukraine, 2018; Chvertko et al., 2019; State Statistics Service of Ukraine, 2012-2021)*

The one-year lag model allows for the evaluation of the impact of past values of factors on the current dependent variable. This is particularly useful in the analysis of agricultural markets, where decisions on crop cultivation and harvest depend on many factors that occur over several years. The one-year lag model helps to track and account for time delays in the influence of factors on the dependent variable. This will contribute to identifying long-term trends, cycles, and other time-related dependencies that may be present in the studied agricultural system. Therefore, the inclusion of the one-year lag model allows for a more comprehensive understanding of the relationships between the factors and the dependent variable, and a better understanding of the processes and phenomena that affect the formation of the agricultural insurance market in Ukraine.

To compare the statistical quality of the two models, the focus can be on the following indicators (Table 1).

```
Call:
plm(formula = Y ~ V_soya_E + Y_cer_E + S_soya_E + V_sunfl_E +
    V_rap_E + S_cer_E + Price_soya + Price_sunfl, data = DataBase, model = "within")

Residuals:
    Min      1Q  Median      3Q     Max
-39.486 -14.015   0.068  12.118  60.442

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 21.1645891  6.7233699   3.148  0.00191 **
V_soya_E     0.0104234  0.0013949   7.473 2.70e-12 ***
Y_cer_E     -2.4666881  0.5017462  -4.916 1.89e-06 ***
S_soya_E     0.0151210  0.0026388   5.730 3.83e-08 ***
V_sunfl_E    0.0042900  0.0004344   9.875  < 2e-16 ***
V_rap_E      0.0065907  0.0020841   3.162  0.00182 **
S_cer_E      0.7913803  0.3017930   2.622  0.00944 **
Price_soya  -0.0029927  0.0011134  -2.688  0.00782 **
Price_sunfl  0.0029191  0.0010322   2.828  0.00518 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 19.68 on 192 degrees of freedom
Multiple R-squared:  0.5585,    Adjusted R-squared:  0.5401
F-statistic: 30.36 on 8 and 192 DF,  p-value: < 2.2e-16
```

Figure 2. *Results of modelling the impact of cultivated areas, gross harvest, crop yields, and prices for agricultural crops with a one-year lag on the insured area*

Source: *calculated based on data ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA", 2022; Agricultural insurance market of Ukraine, 2018; Chvertko et al., 2019; State Statistics Service of Ukraine, 2012-2021)*

Table 1. *Comparative characteristics of the statistical qualities of the presented models*

Indicator	Model 1 (direct)	Model 2 (lagged – one year)
Residual standard error	19.87	19.68
Multiple R-squared	0.5326	0.5585
Adjusted R-squared	0.5054	0.5401

Source: *calculated based on data ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA", 2022; Agricultural insurance market of Ukraine, 2018; Chvertko et al., 2019; State Statistics Service of Ukraine, 2012-2021)*

The first indicator, "Residual standard error", indicates the average difference between observed values and predicted values in the model. In this case, the value is slightly lower in model 2 (19.68 compared to 19.87), which may indicate better accuracy in the predictions of this model. The second indicator, "Multiple R-squared", indicates the proportion of the variation in the dependent variable that can be explained by the independent variables used. In model 2, the value of this indicator (0.5585) is higher, indicating a better ability of model 2 to explain the change in the dependent variable. The third indicator, "Adjusted R-squared", is a corrected version of the multiple R-squared coefficient, which considers the number of independent variables and the degrees of freedom of the model. The value of this indicator is also higher in model 2 (0.5401 compared to 0.5054), indicating a more adequate use of variables in model 2. Therefore, considering these indicators, model 2 has better statistical quality compared to model 1. The results of the regression analysis indicate the statistical significance of certain factors that influence the insured area of agricultural crops. Table 2 presents the statistical significance of each of the factors and justifies its impact on the dependent variable.

Table 2. *Reflection of the results of regression analysis of the statistical significance of certain factors influencing the insured area*

No.	Factors influencing the insured area	Coefficient Value	Financial-economic interpretation of coefficients
1	Gross soybean yield (thousand t) V_soya_E	0.0104	An increase in soybean yield by 1 thousand t contributes to an increase in the insured area of agricultural crops by 0.0104 thousand ha.
2	Grain crop yield (c/ha) Y_cer_E	-2.4667	An increase in grain crop yield by 1 c/ha leads to a decrease in the insured area of agricultural crops by 2.4667 thousand ha.
3	Soybean area (thousand ha) S_soya_E	0.0151	An increase in the area sown with soybeans by 1 thousand ha contributes to an increase in the insured area of agricultural crops by 0.0151 thousand ha.
4	Sunflower gross yield (thousand ha) V_sunfl_E	0.0043	An increase in sunflower gross yield by 1 thousand ha leads to an increase in the insured area of agricultural crops by 0.0043 thousand ha.
5	Rapeseed area (thousand ha) S_rap_E	0.0066	An increase in rapeseed gross yield by 1 thousand ha leads to an increase in the insured area of agricultural crops by 0.0066 thousand ha.
6	Grain crop area (thousand ha) S_cer_E	0.7914	An increase in the area sown with grain crops by 1 thousand ha leads to an increase in the insured area of agricultural crops by 0.7914 thousand ha.
7	Soybean price (thousand UAH per t) Price_soya	-0.0068	An increase in soybean price by 1 thousand UAH per ton leads to a decrease in the insured area of agricultural crops by 0.0068 thousand ha.
8	Sunflower price (thousand UAH per t) Price_sunfl	0.0041	An increase in sunflower price by 1 thousand UAH per ton leads to an increase in the insured area of agricultural crops by 0.0029 thousand ha.

Source: *calculated based on data ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA","2022; Agricultural insurance market of Ukraine, 2018; Chvertko et al., 2019; State Statistics Service of Ukraine, 2012-2021)*

The results of the presented regression analysis indicate that an increase in gross soybean yield, sunflower price, and the areas sown with grain crops, soybeans, and rapeseed showed a positive relationship with farmers' readiness to increase insurance coverage of agricultural crops. On the other hand, there was a negative relationship observed in the research, indicating that as grain crop yield and soybean prices increase, the areas that farmers are willing to insure decrease. Identified dependencies are formed under the significant influence of conjunctural features of the functioning of the agrarian market. Thus, with balanced prices for agricultural products and a well-established logistics system for their sale, the demand for insurance protection is likely to increase. If these conditions are not met, the demand for insurance among producers may tend to decrease.

Considering the above regression analysis, it should be noted that there is a different impact of changes in the internal prices of soybeans and sunflowers. From an economic perspective, soybean and sunflower prices have different impacts on the model of factors influencing the insured area of agricultural crops due to the varying responses of agricultural producers to price changes. In the case of soybean prices, there is a negative correlation. The regression coefficient Price_soya = -0.0068 indicates that an increase in soybean prices by 1 000 UAH per ton leads to a decrease in the insured area of agricultural crops by 0.0068 thousand hectares. This suggests that as soybean prices rise, agricultural producers choose to reduce the area they insure. This decision may be associated with the fact that an increase in soybean prices raises the costs of cultivating this crop, and agricultural producers may be less inclined to cultivate a larger area of soybeans that they subsequently insure. In the case of sunflower prices, there is a positive dependence. The regression coefficient Price_sunfl = 0.0041 indicates that an increase in sunflower prices by 1 000 UAH per ton leads to an increase in the insured area of agricultural crops by 0.0041 thousand hectares. The interpretation of this indicator implies that as sunflower prices rise, agricultural producers choose to expand the area they insure. This reaction is due to the fact that an increase in sunflower prices boosts income from cultivating this crop, and agricultural producers may be more interested in cultivating a larger area of sunflowers that they subsequently insure. These decisions regarding insuring their cultivated areas are made by agricultural producers to protect themselves from risks associated with the cultivation of agricultural crops. The insurance mechanism allows policyholders to receive compensation for losses in the event of specific occurrences, including adverse weather conditions, plant diseases, and pests.

Therefore, the final decision regarding the insurance of agricultural risks is made based on a complex interplay of factors related to natural and climatic influences on the results of the previous year's production, which ultimately impacts the price as the basis for potential profitability. The construction of a regression model involves evaluating and verifying certain assumptions, which helps ensure its reliability and adequacy. This analysis can help identify potential issues or shortcomings in the model, which should be considered when interpreting the results and making management decisions (Fig. 3).

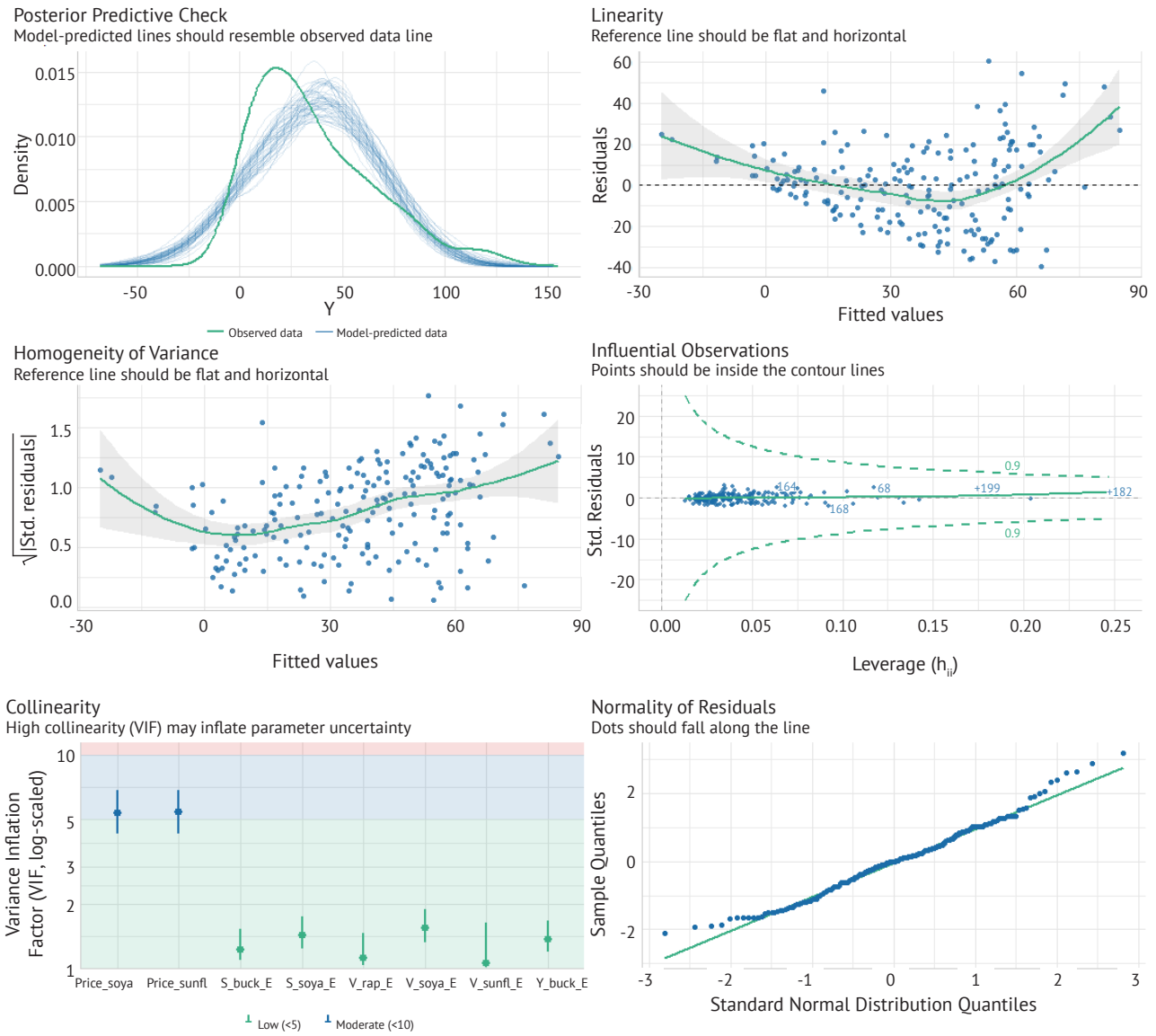

Figure 3. *Visual analysis of statistical properties of the model*
Source: *calculated based on data ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA", 2022; Agricultural insurance market of Ukraine, 2018; Chvertko et al., 2019; State Statistics Service of Ukraine, 2012-2021)*

To analyse the graphical panel that displays various aspects of model assumptions, it is advisable to focus on each graph separately and consider the following points: Normality of Residuals – analysis of the normal distribution graph of residuals, which is presented as a histogram of residuals and a Q-Q plot (quantile-quantile plot), where the quantiles of residuals are compared with quantiles of the normal distribution. The visualisation of the graph indicates that the residuals are distributed normally, and the points on the Q-Q plot approximately lie on the line. Normality of random effects (Influential Observations): the analysis of the corresponding graph shows the absence of structural elements in the sample that significantly affect the variation of the dependent variable (none of the points fall outside the permissible range).

Linear dependence (Linearity): the graph demonstrates a linear regression smooth curve that reflects how the dependent variable changes according to independent variables. The graph indicates a linear and adequate functional relationship. Homogeneity: the graph shows residuals concerning the dependent variable and indicates that the distribution of residuals is uniform across all levels of the dependent variable. Uniformity in the distribution of residuals suggests the absence of heteroscedasticity. Collinearity: the graph indicates the absence of correlation between predictors and suggests the absence of multicollinearity. To assess the reliability of the obtained model, a comparison was made between real and modelled insured areas of agricultural land at the national level (the sum of insured areas for the year across 24 regions) (Fig. 4).

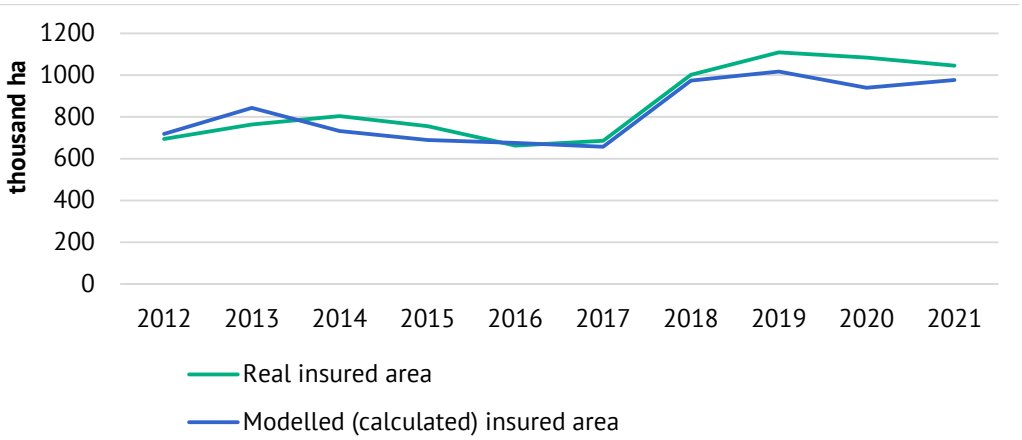

Figure 4. *Comparison of real and simulated insured area of agricultural land at the national level (Ukraine)*
Source: *calculated based on data ("ARX", 2022; "KRAYINA", 2022; "ORANTA", 2022; "PZU Group", 2022; "UNIVERSALNA", 2022; Agricultural insurance market of Ukraine, 2018; Chvertko et al., 2019; State Statistics Service of Ukraine, 2012-2021)*

The average reliability index of the model, determined as the absolute deviation of real insured areas of agricultural land in Ukraine from the modelled values, is 6.8%. This suggests a fairly high reliability of the model and can be used to develop proposals and tools for stimulating the development of the agricultural insurance market in Ukraine. Empirical results from this study confirm the hypothesis regarding the relationships between cultivated areas, yields, gross harvest, and internal prices in the agricultural sector and the influence of these factors on the level of insurance protection in the agricultural sphere. This provides a basis for scientifically substantiating the prospects for the development of agricultural insurance in Ukraine in both wartime and peacetime. Based on the results of the regression analysis model, the following practical recommendations can be formulated to enhance interaction among stakeholders in the agricultural insurance market.

Firstly, increasing the financial and economic interest in insurance among agricultural producers is possible under the condition of a positive trend in cultivated areas, gross harvest, and price parity for agricultural products. Activation of business and investment attractiveness in the insurance market is achieved through a rational combination of organisational, technological, and financial-economic measures. In organisational terms, the focus should be on establishing interdistrict branches of insurance companies to expand insurance coverage for agricultural risks and ensure broad access to insurance services both offline and online. The technological component of insurance companies' activities involves the development and positioning of innovative insurance services (both traditional and index-based) capable of meeting the demand of agricultural producers for insurance protection. The financial-economic aspect of insurance relations in the agricultural sector is driven by the need to address two key issues: firstly, ensuring broad access for potential policyholders to a diversified range of insurance services (in terms of price, coverage, etc.); secondly, guaranteeing the financial viability of insurers and ensuring their profitability and sustainability in the segment of agricultural insurance contract servicing.

Secondly, stakeholders in the agricultural insurance market are interested in expanding cultivated areas and maintaining high crop yields for grains and technical crops. This objective necessitates the objective need for the establishment of mutually beneficial cooperation among insurers, policyholders, and the government. Collaboration among participants in the insurance process within this specified triangle is fundamental to the successful functioning of the agricultural insurance market. It is acknowledged that under conditions of a state of war, such cooperation is complicated due to both objective and subjective reasons; however, its necessity is evident, given the need for effective mitigation of agricultural risks and the formation of a compensation mechanism for losses in the event of insurable events. It is worth noting that Ukrainian legislation provides for the mechanism of such cooperation, particularly under the Law of Ukraine "On Specifics of Agricultural Product Insurance with State Support" from February 9, 2012, No. 4391-VI (2012), and the Resolution of the Cabinet of Ministers of Ukraine "On Approving the Procedure for Providing State Support for Agricultural Product Insurance" from December 9, 2021, No. 1342 (2021). Key advantages of such cooperation include: a) reducing the cost of insurance services for farmers; b) expanding insurance coverage for agricultural risks; c) enhancing the insurance protection of agricultural producers. Furthermore, in the post-war period, coordination between state and non-state institutions in the agricultural insurance market can be based on the principles of public-private partnerships.

Thirdly, the activities of insurance companies in the context of a state of war should consider the existing threats and offer corresponding insurance services aimed at improving safety conditions for agricultural

production. This primarily concerns the possibility of utilising the following approaches to enhance insurance protection for farmers: Firstly, the successful implementation of the "Grain Initiative" project requires active involvement of insurance companies in insuring the export of agricultural products and logistical risks resulting from military actions. Secondly, direct losses from military aggression in agriculture (as of February 2023) amounted to $8 billion, of which $4.2 billion was attributed to destroyed agricultural machinery and equipment (Dmytrasevich, 2023). Therefore, it is relevant for agricultural producers to diversify their insurance coverage, which should encompass both agricultural products and the main production assets. Thirdly, military actions necessitate ongoing demining efforts, including in cultivated areas. Hence, insurance companies face the task of developing insurance programmes aimed at minimising the risks associated with demining territories. Fourthly, post-war recovery and attracting investments into the agricultural sector will undoubtedly require a well-established system for insuring agricultural risks.

The further functioning of the agricultural insurance market in Ukraine depends significantly on the infrastructure supporting the insurance process. This primarily involves improving communication systems (exchange of ideas, information, knowledge, etc.) among stakeholders in the insurance market, enhancing their motivation to enter into and renew agricultural insurance contracts. Questions regarding the digitalisation of insurance relations in the agricultural sector, such as providing services remotely, automated risk underwriting, the application of blockchain technology, and the use of smart contracts for timely identification of insurance events and processing of insurance claims, are becoming increasingly relevant.

Fifthly, self-organisation plays an important role in organising insurance relations in the agricultural sector. Examples of such self-organisation can be mutual insurance societies, which are quite active in their professional activities in countries like Germany, France, the Netherlands, and others (European Market Share, 2022). The most significant advantages of using this form of organisation for insurance relations in the agricultural sector include: 1) sellers and buyers of insurance services being the same entity; 2) the ability to apply an individual approach to selecting risks for insurance coverage; 3) ensuring accessibility and flexibility in forming tariff policies for insurance services; 4) exercising control over the formation and use of the insurance fund, and more.

Consequently, the role of insurance as a financial-economic instrument for risk mitigation due to objective circumstances will continue to increase. The results of the modelling conducted indicate that for the vast majority of agricultural producers, favourable conditions in entrepreneurial activities (prices for agricultural products, gross yields, crop yields, etc.) are significant arguments supporting insurance. In this context, insurance should be considered as an additional option for agricultural producers to mitigate the consequences of adverse events (unexpected expenses) in the event of an insurance claim. These outlined issues require scientific discussion and justification, which is the subject of the next section of this study.

The formation of insurance relations in the agricultural sector requires the identification and justification of key factors influencing the development of the agricultural insurance market. Analysis of scientific sources indicates that these factors include: Farmer's income and farm size, which play a significant role in shaping the demand for insurance in developing markets (Stojanović *et al.,* 2019); Financial and economic performance indicators of farms (Baráth *et al.,* 2017); The proportion of non-agricultural income in the farmer's household (Njegomir & Demko-Rihter, 2018); The cost of agricultural production, crop yield, soil quality, and planting intensity (Was & Kobus 2018); Transparency of insurance products (Linhoff *et al.,* 2022); The amount of insurance compensation in the event of an insurance claim (Stoeffler & Opuz, 2022).

Studies on cause-and-effect relationships in the field of agricultural risk insurance provide grounds to assert that the functioning of the agricultural insurance market depends on factors such as crop acreage, yield, gross production, and the domestic price of agricultural products. R. Goodhue & G. Rausser (2003) identified three probable dependencies in the agricultural insurance market: first, a decrease in acreage can increase the cost of insurance due to a higher risk of crop losses. Secondly, if the yield is lower than expected, the cost of insurance may increase. Third, changes in product prices may affect the level of risk for agricultural producers and the cost of insurance. A. Ker & T. Tolhutst (2019) emphasised that agricultural insurance can protect farmers' incomes and stabilise their production expectations, thereby promoting food production. L. Fields *et al.* (2012) share a similar perspective, asserting that the functioning of the insurance market can reduce risks associated with natural disasters and adverse weather conditions, which can increase profitability for farmers and boost agricultural production. It is widely accepted in the scientific community that insurance is the best way to ensure the continuity, balance, and stability of the agricultural market (Shirinian & Klymash, 2018).

The scientific arguments presented provide a clear understanding of the existence of many factors (farmers' incomes, agricultural product prices, gross yields) that influence the functioning of the agricultural insurance market. Research on these factors is a necessary condition for the scientific interpretation of insurance relations in the agricultural sector. A consolidating position among many researchers such as S. Kislingerová and J. Špička (2022), H. Wang *et al.* (2022), I. Ivashkiv *et al.* (2021) is that the effectiveness

of the agricultural insurance mechanism in mitigating agricultural risks depends on the ability to make management decisions considering various factors of natural, technological, agronomic, financial-economic, and others. Therefore, the focus of scientific discussion is oriented towards identifying key factors influencing the development of the agricultural insurance market, utilising potential insurance opportunities to minimise natural-climatic and production-economic risks in the agricultural sector, and diversifying forms and methods to enhance the insurance protection of agricultural producers.

CONCLUSIONS

The study established that Ukraine exhibits a certain territorial diversification in the relationship between insured and sown areas. The highest level during 2012-2021 was recorded in western regions (specifically, Lviv, Ternopil, Rivne, and Khmelnytskyi), where this indicator ranged from 0.25 to 12.50%. In contrast, the lowest level of insurance coverage was observed in eastern and southern regions (including Donetsk, Luhansk, Odesa, Mykolaiv, Kharkiv, and Kherson), ranging from 0.14 to 4.17%. The variability of this indicator depended on several factors, including the level of adaptation of agricultural producers to European traditions in insurance, the state of infrastructure readiness to provide agricultural insurance services, the riskiness of specific agricultural crops, and the availability of adequate services for their insurance protection, and the military actions on the territory of Ukraine.

To identify the internal factors influencing the agricultural insurance market in Ukraine, two parallel panel models were applied (based on the 24 regions of Ukraine): a standard model and a one-year lag model. In the modelling process, it was found that factors such as sown area, yield, gross harvest, and the price of agricultural products influence the level of insured area. Based on the results of the regression analysis, the statistical significance of certain factors (gross harvest and prices of soybeans and sunflower, yield and sown areas of cereal crops, and sown areas of soybeans, sunflower, and rapeseed) in influencing the insured area was established. This provides grounds to assert that expanding sown areas, increasing gross harvests, and improving crop yields are favourable factors for stimulating demand for insurance services among agricultural producers. Failure to meet one or more of these factors can lead to a decrease in motivation for insurance. The results of the modelling were validated at the national level, confirming a high level of reliability of the modelled indicators (insured areas). The calculation of the module of the ratio of real indicators to modelled ones is 6.8%, indicating that the model's reliability is 93.2%. The obtained results of modelling (regression coefficients) allowed for the formulation of practical recommendations to stimulate the development of the agricultural insurance market in Ukraine.

The modern model of the agricultural insurance market requires an increase in business and investment activity of participants in the insurance process, enhanced interaction within the "insurers, insured, state" triangle. Emphasis is placed on the need to enhance insurance protection for agricultural producers in conditions of a state of war, including the insurance of agricultural product exports, agricultural machinery and equipment, investment insurance, and more. Notably, the role and necessity of modernising infrastructure and improving communication ties between participants in the insurance space are increasing, and diversifying the organisational and legal forms of insurance companies' activities. Future studies will focus on utilising inclusive opportunities for the development of the agricultural product insurance market in Ukraine.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Ідентифікація та інтерпретація внутрішніх факторів впливу на аграрний страховий ринок в Україні

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Анотація. Функціонування ринку аграрного страхування в Україні є об'єктивною реальністю та необхідністю з огляду на нагальну потребу у формуванні безпекового середовища для виробництва сільськогосподарської продукції. Здатність до консолідації фінансових ресурсів у сфері страхових відносин сприяє посиленню відповідальності за ймовірні ризики, які розподілені у просторі й часі, тому варто розглянути страхові відносини у аграрній сфері. Метою дослідження було теоретико-методологічне обґрунтування процесів ідентифікації внутрішніх факторів впливу на подальше функціонування аграрного страхового ринку в Україні. Методологічний ракурс представленого дослідження базується на використанні загальнонаукових та специфічних методах пізнавальної діяльності: абстрактно-логічному, економіко-статистичному, структурно-

функціональному, дедукції, індукції та формалізації. Сформовано панельну базу даних за період 2012-2021 рр. у розрізі 24 областей України. Відображено територіальні особливості зміни рівня співвідношення між застрахованими та посівними площами у розрізі західних, центральних, східних та південних областей України. Базуючись на результатах проведеного моделювання (представлено паралельно дві моделі: звичайна модель та модель з лагом в один рік), встановлено вплив на застраховану площу таких факторних ознак, як: посівна площа, врожайність, валовий збір та внутрішня ціна на сільськогосподарську продукцію. Здійснено порівняльну характеристику статистичних якостей представлених моделей, використовуючи показники: «Residual standard error», «Multiple R-squared» та «Adjusted R-squared». За результатами регресивного аналізу виявлено статистичну значущість певних факторів щодо мотивації сільськогосподарських товаровиробників брати участь у страховому процесі. Практична цінність запропонованих заходів полягає у формулюванні практичних рекомендацій щодо посилення взаємодії між стейкхолдерами ринку аграрного страхування у воєнний та повоєнний період часу

Ключові слова: аграрне страхування; застрахована площа; стейкхолдери страхового ринку; сільськогосподарські ризики

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Prospective analysis of the implementation of the "green" economy in the agricultural sector of Ukraine for the next 10 years

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Abstract. The realities of modern economic development require significant changes in the existing economic system and a transition to a fundamentally new model based on the basic approaches of sustainable development. According to the world's scientists, one of the best options for ensuring this change is the concept of a "green" economy. The relevance of the topic of green economy development is based on its potential to solve urgent environmental problems and promote sustainable development that meets the needs of society and the international community. The purpose of the article is to assess the prospects of the agricultural sector of Ukraine's economy within the framework of the transformation strategy based on the principles of the green economy. This takes into account a whole range of factors in which agricultural enterprises exist and develop, as well as the conditions that have developed in connection with military aggression in the country. To achieve this goal, the following methods were used: system-structural analysis, method of analysis, synthesis, method of generalization, methods of deduction and induction, and methodology of modified, improved SWOT analysis. A number of factors influencing the investment and

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innovation processes at agricultural enterprises are identified, including external threats and opportunities and internal strengths and weaknesses. The study also summarizes the aspects of the transition from the concepts of "sustainable" development to the concept of "greening" the economy, taking into account international experience, and the inclusion of Ukraine in the list of countries that ensure the fight against climate change and harmful emissions. The conclusions obtained about the prospects of investment projects in the agricultural sector, namely investment and innovation projects of agricultural enterprises characterized by a high level of attractiveness for investors in terms of the directional vector of development, confirm the relevance of implementing the concept of a green economy in the agricultural sector of Ukraine. The use of such an assessment methodology in practice will make it possible to select and analyse promising areas of project financing and investment, as well as to adjust the development strategies of Ukrainian agricultural enterprises

Keywords: ecologization; globalization; development strategies; targets; sustainable development

INTRODUCTION

In recent years, starting from 2019, it has become evident that environmental threats due to climate change and deteriorating environmental conditions have become the primary risks for global development. This is confirmed by documents from the United Nations (UN) and its specialized agencies, as well as the outcomes of G20 and G7 meetings and the activities of the World Economic Forum, as reflected in the annual "The Global Risks Report" (Brende *et al.*, 2022). Restoring natural ecosystems to functional levels within the framework of ecological security and ensuring economic efficiency in economic and social spheres, as well as in terms of development sustainability, have become priorities in the political programs of countries worldwide. The first two decades of the 21st century have opened a "window of opportunity" for radical reforms and a transition to a different model of economic development, where the concept of a "green" economy plays a key role. This transition applies to European countries and the application of their experience in Ukraine, particularly in the agricultural sector.

Notable contributions to the development of this concept have been made by authors N. Fedorchuk (2021) and O. Pishchenko (2020), who have identified its fundamental principles and the necessity of transitioning to such a development model for agricultural enterprises. N. Fedorchuk (2021) examines the European experience of transitioning to a "green" path of economic development, using a new model for agribusinesses, and explores the opportunities and challenges that can arise when implementing such conceptual approaches in Ukrainian agribusinesses. The work of O. Pishchenko (2020) is dedicated directly to the development of the country's agricultural enterprises within the framework of the "green" economy concept. The author highlights all the obstacles that arise on the path of implementing such a business model in the context of a "green" course, and emphasizes the need for strategic and legal support at the state level. The work emphasizes the necessity of aligning state policy with the "greening" of the economy.

The "green" economy forms the basis for implementing the principles of sustainable development, specifically energy efficiency, environmentally friendly resource utilization, and reduction of carbon dioxide emissions. This takes into account the development of a socially integrated society and its characteristics. The agricultural sector is one of the industries showing the highest rates of dynamic development and is promising for transitioning to "green" development. This sector is constantly transforming under the influence of growing demands from the European market, which is one of Ukraine's most important trade partners. These assertions are noted in the works of authors L. Smolii and N. Dikhtyatenko (2023). In their work, they emphasize the necessity of building a transformational strategic model for "green" economy for agricultural enterprises, taking into account the main principles of the European Green Deal. However, it should be noted that the authors do not address the issue of sources for attracting investment funds for project implementation within the framework of strategic development. Technologies such as renewable sources are discussed in the research by A.A. Barylo *et al.* (2020). Authors dedicates their work to assessing the prospects and effectiveness of implementing different types of energy using "green" technologies, without harming the environment. It should be noted that several questions related to state support and providing investment flows for the realization of such projects remain open.

The European Union's (EU) Common Agricultural Policy (2022) envisions the "greening" of the agricultural sector and rural areas, and this is a strategic direction for the country's agricultural sector development. The EU provides financial support for implementing ecological schemes, safe technologies, biodiversity conservation, landscape preservation, climate support, and rural bioeconomy development. Funding for these measures can constitute up to 35% of the combined agricultural budget of EU countries. Considering Ukraine's strategic direction in foreign economic policy towards alignment with the EU and the existing conditions in the agricultural sector, there is a need to transform this development direction with the main principles of "green" economy in mind. This will ensure a proper level of national

food security, reduce environmental risks in the agricultural sector, meet social demands, and strengthen competitive positions in international markets.

The aim of the article was to determine the prospects for sustainable development of Ukraine's agro-sector based on the principles of "green" economy in the modern conditions of management, under the influence of various factors and strategic orientations in the next decade. Achieving the main research goal will enable the practical use of the toolkit in developing regional development strategies in the future, adjusting local programs and plans for the strategic development of agricultural enterprises, implementing "green" technologies, and attracting "green" investments.

MATERIALS AND METHODS

The following research methods were employed to achieve the objectives: systemic-structural analysis, methods of analysis and synthesis, generalization, deductive and inductive methods, as well as SWOT analysis (S – strengths, W – weaknesses, O – opportunities, T – threats). The systemic-structural analysis method was used to construct the research logic and systematize the terminology related to the conceptual framework of "green" economy and the dynamic changes of global trends in "sustainable development". Using the methods of analysis and synthesis, the essence of the "green" economy, its constituent elements, characteristics, and its impact on Ukraine's agricultural sector were determined, considering contemporary changes. Through synthesis, the peculiarities of strategic conceptual principles based on the European initiative "Green Deal" for Ukraine's agricultural sector were combined (Fedorchuk, 2021).

The generalization method was applied to systematize the directions of "greening" economies' development and evaluate international experiences and practices in the world and European countries. This was aimed at implementing such experiences in domestic enterprises in the near future, taking into account the country's specific conditions. The methods of deduction and induction were used to study trends in the transformation of economic relations within the framework of "greening" the economy under the influence of external factors, internal changes, opportunities for economic digitization, and the use of modern information resources and programs. The induction method allowed for studying trends in analytical indicators and drawing conclusions about the prospects of the country's "green" economy and the agricultural sector in particular. Through the deduction method, by assessing general transformational processes in the global economic space and the transition to a "green" economy worldwide, positive decisions were made on implementing measures for "greening" economic sectors and developing new strategic solutions.

SWOT analysis was employed to identify key factors influencing a strategic project or program and to identify "weak points" for further adjusting their effectiveness indicators. Through this method, by comparing potential opportunities and threats affecting Ukraine's agricultural sector with its strengths and potential opportunities, it's possible to determine the prospective direction of Ukraine's "green" economy development at the present moment and evaluate its future development prospects. Successful development and achievement of strategic goals for the "green" economy in Ukraine's agricultural sector will position the country among those minimizing ecological risks and effectively competing in international markets.

RESULTS

Starting from the 1970s and up to the present day, various aspects of the interaction between society, the environment, and the economy have been explored in global literature, leading to the emergence of a new direction known as "ecologization of the economy". According to the generally accepted definition, "ecological" economics studies the connection between ecological and economic systems. These interconnections form the basis of many contemporary issues such as global warming, increased acid rain, desertification, biodiversity loss, depletion of natural resources and energy, water and food shortages (United Nations, 2012; Selwyn, 2021). The rapid growth of global production over the last decades has resulted in increased levels of greenhouse gases (GHG), leading to global climate changes and significant ecological risks and threats to humanity. The dynamics of global CO_2 emissions indicate that the world economy has reached a critical level of carbon saturation. Since 2008, there have been instances where CO_2 emissions growth in the world has exceeded the growth rates of gross domestic product (GDP), primarily driven by populous countries like China, India, and Japan (European Union, 2022).

With each passing year, the pace of this process has accelerated, posing a threat to the socio-economic development of many nations. Addressing climate change, both in developed and developing countries, requires immediate political actions to implement unprecedented decisions in economic domains, changes in production technologies, and social welfare. Global leaders have agreed to collaborate in order to limit the rise of the global average temperature to a level significantly below 2°C compared to pre-industrial levels by the end of the century. Starting in the 1990s, countries actively joined the fight against climate change to avoid a global catastrophe in accordance with the terms of the Kyoto Protocol (United Nations, 1998). The transformative economy, focused on ecological development, laid the foundation for the concept of sustainable development, which became a crucial step in aligning environmental issues with plans for socio-economic growth and realizing the negative consequences arising from the activities of certain sectors on the environment and society. The definition of "sustainable development"

was officially adopted during the UN Conference in Rio de Janeiro (European Environmental Agency, 2012). It was during this time that the fundamental principles of sustainable development were also outlined (Fig. 1).

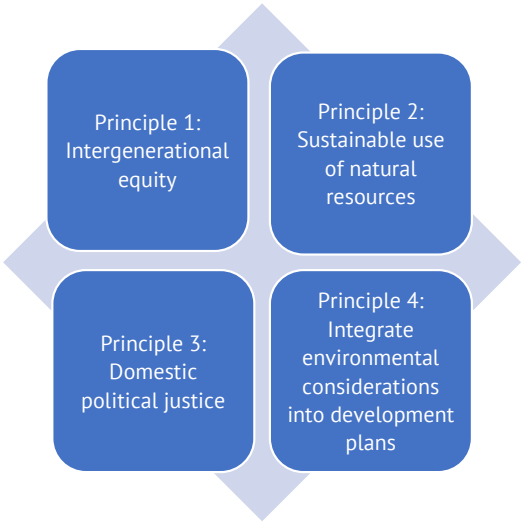

Figure 1. *Principles of the concept of sustainable development*
Source: *compiled by the authors based on European Environmental Agency (2012), K. Markevich and V. Sidenko (2019)*

The first principle is to protect natural resources for future generations; the second is to ensure the use of natural resources from the long-term perspective, considering their impact on the environment; the third is to take responsibility for the effects of national strategies on the use of natural resources, taking into account the needs of other countries; and the final principle is integration, where ecological considerations should be integrated into the development plans and projects of each country. Since then, the concept of sustainable development has been widely utilized in major international agreements. For example, around 200 countries joined the "GGGI Strategic Plan 2015-2020" (2015), which includes key global goals and tasks for sustainable development, aiming to balance economic, social, and ecological aspects to heal the planet and eradicate poverty.

The global financial crisis of 2008-2009 became a pivotal moment in the international growth of the "green" economy. This prompted global experts to reconsider the traditional model of economic development. During this period, the concept of the "green" economy gained widespread societal recognition and began to be actively discussed by governments and experts at various international forums and conferences. For instance, after the United Nations Environment Programme initiated the "Green Economy Initiative" at the beginning of 2008, the term "green" economy started being used in UN documents. Additionally, the UN issued a statement in support of the "green" economy as a means to address numerous social issues (United Nations Department..., 2009). The UN conference addressing key issues related to the principles of sustainable development, Rio+20 (European Environmental Agency, 2012), triggered the formulation of the core principles of the "green" economy and their implementation into international practice. The "green" economy was defined as a relevant tool linked to sustainable development (United Nations, 2023). During the same period, the fundamental structure of the "green" economy was established (Fig. 2).

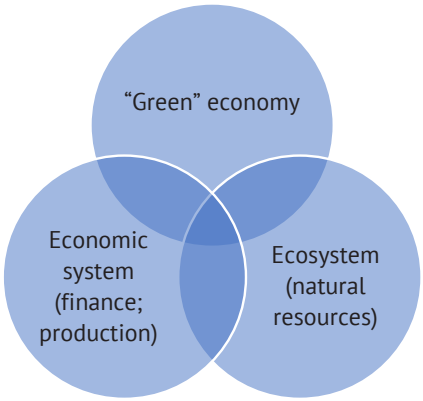

Figure 2*. The basic structure of the "green" economy*
Source: *L. Smolii and N. Dikhtyarenko (2023), United Nations (2023)*

The main goal of the "green" economic concept is to achieve significant progress in the interrelation of ecology and economy, which serves as the basis for implementing the concept of sustainable development. It encourages governments to transition towards balanced development, including investments in renewable energy resources, addressing energy efficiency and energy independence issues, solving problems related to the production of biological food products, rational land use, and optimal resource management. All of this is aimed at transitioning to an efficient economy, adopting environmentally friendly and resource-saving technologies that aim to reduce emissions of pollutants, cease the unrestricted use of valuable minerals, and mitigate the negative impact on climate change (European Commission, 2016). The core principles of the "green" economy have had a significant impact on the strategic and political development of most world-leading countries, emphasizing its role in various aspects of socio-economic orientation. For the UK, as well as France and China, the main directions have been defined as economic development and maintaining competitiveness. Conversely, African countries such as Rwanda and Morocco, as well as Ethiopia, Senegal, and South Africa, highlight their transformative opportunities that will allow them to "leapfrog" the current "polluting" development model and transition to a new, innovative, "clean" model. Countries in the Asia-Pacific region prioritize redirecting processes towards social issues, such as employment and retaining a skilled workforce, eradicating poverty, and achieving sustainable development (Georgeson *et al*., 2017).

Despite the lack of a universally accepted definition of the "green" economy on the international level, a widely used working version was developed in 2011. According to this definition, the "green" economy is an instrument that contributes to improving the environment. Human well-being and social equality also significantly mitigate the negative impact on the environment and minimize the risk of environmental degradation (OECD, 2023). It also underscores the connection between "green" economic concepts and sustainable development. However, it's important to note that the "green" economic concept cannot replace the concept of sustainable development. The realization of sustainable development largely depends on the economy's revival through creating conditions for innovation, investment, and competition. The European Environment Agency proposes a simplified interpretation: the "green" economy is a policy of investment and innovation that encourages society to develop production systems that preserve natural resources and implement projects focused on nature conservation start-ups, digitization projects, advanced technologies. Considering the above, "green economy" can be defined as an economic development concept that promotes ecological sustainability and social equality through reorienting production to a stable level, increasing resource and energy efficiency, developing renewable energy sources, implementing biological and innovative technologies, and increasing investment in projects aimed at popularizing "eco-friendly" production.

Similar to leading developed countries and fast-growing markets, Ukraine has embarked on a path towards sustainable development based on the "green" growth concept. This approach incorporates knowledge, innovation, energy-efficient production lines, advanced technologies, as well as social and environmental progress. This concept is significant worldwide for adapting the principles of sustainable development to the conditions of most countries, including Ukraine. Considering the current state of socio-economic development, the agro-industrial sector, the technological level of the industrial sector, the question of enhancing energy efficiency in both production and residential-communal sectors, as well as the negative geopolitical situation resulting from the military aggression of the Russian Federation, which has notably impacted policies related to carbon energy resources, the transition to a sustainable development model becomes a priority for Ukraine. The Association Agreement between Ukraine and the EU plays a crucial role in this context (Potapenko, 2013). According to the agreement, Ukraine commits to harmonizing its legislation with European standards in the specified area of sustainable development. The agreement explicitly emphasizes the importance of considering development and the state of the economy, ecology, and the social sphere, which impact not only the current situation but also the lives of future generations.

One of the key tasks facing Ukraine today is the transition of its national economy based on the principles underlying the core approaches of the "green" economic model, namely: sustainable production, energy efficiency, resource conservation, business support, ecological safety, and stable economic development. The agricultural sector of Ukraine, as a flagship of the country's economic development, has high prospects for the implementation of "green" economic principles. However, there are several unresolved issues that need to be addressed. Among these problems, the depletion and degradation of agricultural lands, pollution of water resources, and high levels of air emissions due to outdated equipment (Lishchuk *et al*., 2022) should be highlighted. According to a report by the National Institute for Strategic Studies of Ukraine, the state of agricultural lands in the country is highly vulnerable, especially considering the high level of landmines in certain areas. Natural processes of soil degradation and erosion also continue, affecting over half of the total agricultural area (Potapenko, 2013). Among other economic sectors, the agricultural sector stands as one of the main sources of undesirable waste production. According to the report from the National Cadastre of Ukraine, from 1990 to 2020, the volume of GHG

emissions from various categories of sources in Ukraine's agricultural sector accounted for nearly 13% of the total GHG emissions in 2020 (Table 1). Therefore, despite the implementation of global experience and eco-technologies in agricultural production, Ukraine's agribusiness still hasn't achieved a significant level of ecologization.

Table 1. *Changes in the volume of GHG emissions in different categories of sources of the agricultural sector of Ukraine, expressed in thousand tons of CO_2 equivalent*

Years	Names of agricultural industries in the agricultural sector with the most significant GHG emissions in Ukraine						Total
	in crop production				in animal husbandry		
	rice cultivation	agricultural land	liming	urea application	internal fermentation	manure management	
1990	216.43	35709.95	2592.08	270.14	45924.87	7308.44	92021.91
2000	187.12	15264.85	63.47	82.23	18468.6	2441.46	36507.73
2001	140.86	16769.07	71.47	117.02	18746.74	2399.3	38244.46
2002	140.75	16647.36	53.78	116.91	18926.94	2556.43	38442.17
2003	166.13	13927.54	49.37	191l.11	16984.02	2372.71	33690.88
2004	158.16	16962.84	83.33	35.83	16016.58	2179.28	35436.02
2005	158.57	17011.59	90.92	138.32	15719.51	2222.95	35341.86
2006	161.01	16979.44	105.99	171.32	15460.79	2314.25	35192.8
2007	156.72	15731.11	112.35	212.11	13998.08	2244.39	32454.76
2008	146.85	21054.47	124.95	355.18	13241.48	2187.15	37110.08
2009	181.97	19622.78	151.88	175.03	12767.38	2251.1	35150.14
2010	217.31	19348.96	127.46	334.73	12191.9	2334.19	34554.55
2011	219.98	24080.83	127.16	391.52	11784.12	2317.52	38921.13
2012	191.74	22948.71	161.72	351.36	12016.15	2357.81	38027.49
2013	179.32	27008.06	182.25	381.75	12257.78	2407.11	42416.27
2014	75.58	27413.42	156.26	386.03	11681.1	2344.2	42056.59
2015	86.72	25979.33	169.83	372.5	10970.24	2224.99	39803.61
2016	89.07	28876.25	140.09	457.62	10752.01	2126.43	42441.47
2017	94.11	29697.25	168.6	512.07	8597.04	2022.17	41091.24
2018	93.58	33479.29	163.74	201.18	8298.21	2002.73	44238.73
2019	94.83	33004.02	163.23	316.84	7918.02	1958.37	43455.31
2020	82.99	31845.54	131.35	235.51	7447.07	1944.65	41687.11

Source: *compiled by the authors based on the European Union (2022), Ministry of Environmental Protection and Natural Resources of Ukraine (2023)*

In order to transform the agricultural sector on the basis of the "green" economy, it is necessary to establish strategic guidelines, common principles, directions and define the mechanisms and appropriate tools for its implementation. These elements should form a single system of transformations aimed at preserving, increasing and restoring natural capital in the agricultural sector, which is the most important economic asset and source of public goods (Figure 3). Formulation of the strategy and its control should take into account the expected results in relation to all strategic priorities. The main goal is to achieve specific target indicators and perform the corresponding tasks. In the field of agriculture, it is important to take into account the goals of the European Union during the strategic planning of its development, taking into account the national characteristics of the development of the agricultural sector in Ukraine and based on the existing positions. The main principles of the ecologization of rural production should be increasing the level of food security, effective use of resources from the ecological and economic point of view, reducing energy dependence, improving the export image of the industry, ensuring the international competitiveness of agricultural enterprises.

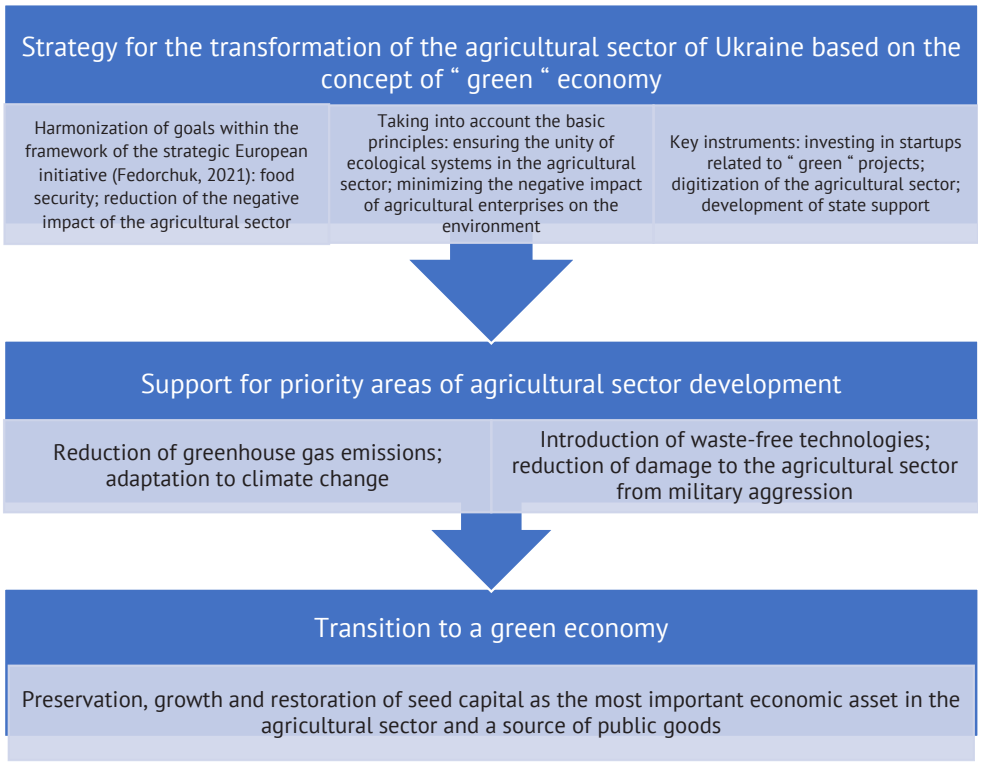

Figure 3. *Formation of the transformational strategy of the agricultural sector of Ukraine, taking into account the principles of the "green" economy concept*
Source: *compiled by the authors based on the European Union (2022)*

For the transformation of the agricultural sector based on the principles of the "green" economy, it is necessary to establish strategic guidelines, unified principles, directions, and mechanisms, as well as define the tools for its implementation. These elements should form a cohesive system of transformations aimed at conserving, increasing, and restoring natural capital in the agricultural sector, which is the most important economic asset and a source of societal benefits (Fig. 3). The formulation of the strategy and its monitoring should consider the expected outcomes in relation to all strategic priorities. The main goal is to achieve specific target indicators and accomplish corresponding tasks. In the sphere of agriculture, it's crucial to take into account the goals of the European Union while strategically planning its development. This should be done by considering national peculiarities of agricultural sector development in Ukraine and building upon existing positions. The core principles of agricultural production's ecological transformation should include increasing food security, efficient resource utilization from both ecological and economic perspectives, reducing energy dependence, enhancing the industry's export image, and ensuring international competitiveness of agricultural enterprises (Tables 2 and 3).

Table 2*. List of factors for evaluating the impact of Opportunities and Threats of the external environment on investment attraction*

	Opportunity		Threats
1	Strategy for the development of the "green" economy	1	Fall in GDP, gross rating point (GRP)
2	State programs for the development of the agricultural sector, support for the "European Green Course"	2	Inefficient industry structure
3	Creating an attractive investment climate for financing environmental protection measures and start-ups	3	Unsatisfactory level of financing of innovative projects in the agricultural sector
4	Defining the agricultural sector as the vanguard of innovative development	4	The riskiness of financing due to military aggression
5	Targeted programs for the introduction of innovations and staffing	5	Pressure from international competing manufacturers

Table 2, Continued

	Opportunity		Threats
6	Availability of high-tech production capacities of agricultural enterprises	6	Loss of part of the territories due to military actions
7	High rates of infrastructure development	7	Loss of part of highly qualified personnel

Source: *compiled by the authors based on S.V. Filippova et al. (2015)*

In order to carry out the assessment, all factors of the internal environment are grouped according to the principle of comprehensive analysis, for the assessment of the activities of enterprises in the agricultural sector.

Table 3. *List of factors for evaluating the internal environment of agricultural enterprises*

Group name's	No.	Internal environmental factors
Enterprise resource provision	1	The state of production facilities, the level of wear and tear, renewal plans, war losses
	2	The level of management of intangible assets, the dynamics of their use and implementation
	3	Energy efficiency and resource availability
	4	The level of staffing and personnel management
	5	The level of transport and logistics support
Organizational and production activity of enterprises	6	Strategic direction of enterprise development
	7	Organizational structure of enterprises
	8	The level of production quality, compliance with modern needs
	9	The level of marketing and sales activity
	10	The level of application of innovative technologies in production
"Greening" of enterprises and competitiveness	11	Positions of agribusiness among competing eco-enterprises
	12	Corporate ties and their strength
	13	The level of product safety from its environmental friendliness
	14	Ensuring market share
Financial and economic condition of enterprises	15	The level of solvency of enterprises
	16	Dynamics of available funds and working capital at agricultural enterprises
	17	The level of financial stability of enterprises
	18	Dynamics of production profits and losses
	19	The ratio of own and borrowed investment funds

Source: *compiled by the authors based on S.V. Filippova et al. (2015)*

The result of the SWOT analysis, according to the proposed algorithm, is the determination of the vectors of possible development directions of enterprises in the agrarian sector. In addition, it is important to characterize each quadrant of the matrix. When compiling a list of the main characteristics of each quadrant of the SWOT matrix, the author adheres to the principle of priority from the point of view of attractiveness for investors. For a potential investor, projects that are less dependent on environmental factors will be more attractive, as such factors are characterized by a high degree of uncertainty and risk. Table 4 shows the results of constructing the characteristics of the direction vector of the development of the investment and innovation project based on the results of the SWOT analysis.

Table 4. *Interpretation of the results of the SWOT matrix and determining vector of directed development*

Quadrant of the matrix	Characteristics	Possible reaction of a potential investor
I	Potentially very high level of Opportunities from the external environment + Strengths from the internal environment. The most favourable development option	Such a scenario is considered the most optimistic and causes the least expectations of risky and negative consequences of project implementation

Table 4, Continued

Quadrant of the matrix	Characteristics	Possible reaction of a potential investor
I	Internal Strengths + sufficiently high Opportunities from external factors. They differ from the previous ones by a lower probability of an optimistic forecast. The direction is promising.	It is considered by the investor as a promising and realistic investment option in the absence of additional threats
II	Opportunities of the external environment are high + Weaknesses of the internal environment are at a low level. It is attractive if it is possible to solve the problems of the internal environment with management solutions.	Such projects cause a positive reaction in case of cooperation with effective risk management
II*	High Internal Weaknesses + low External Environmental Opportunities. Potentially risky projects that require additional refinement.	As a rule, if an investor takes the risk of investing in such projects, he hopes for a fairly high-risk premium
III	High Strengths of the internal environment + low Threats of the external environment. Such projects are quite dependent on the influence and dynamics of changes in external factors.	The reaction can be positive if the investor assesses the risk and the expected effect and settles the issue of their ratio
III*	The factors of the internal environment characterize the low potential of Strengths + a high level of Threats from the external environment. Such projects require detailed diagnostics.	For an investor, such projects are riskier and, if there are alternatives, not attractive. They need refinement
IV	High level of Threats + Weaknesses of internal environment, low level. Such projects need to be refined.	From the investor's point of view, the project does not meet the expected results and requires detailed analysis and refinement
IV	High level of Threats + high level of Weaknesses of the internal environment. In this version of the development of events, the project needs a complete review.	The highest level of danger for the investor. It can receive financing with a very low probability only in the case of complete absence of alternatives

Source: *compiled by the authors based on S.V. Filippova et al. (2015), A. Sherafat et al. (2013)*

As can be seen from the proposed methodology, the main role of research at this stage consists in grouping projects according to the degree of their attractiveness for potential investors, according to the criteria of the direction of their development. This analysis compares external opportunities and threats with internal strengths and weaknesses. The next step is to determine the assessment of the level of influence of factors of the external environment according to the algorithm, which makes it possible to determine those that affect the enterprises of the agricultural sector the most (Tables 5 and 6).

In order to determine the final result according to the given analysis, only those connections were selected where the level of influence corresponds to rank 1-3, "Opportunity" is marked as a positive result, and threats as a negative one.

Correlations and evaluations for the factors of the internal environment are similarly determined (Table 7).

Table 5. *Analysis of the influence of environmental factors*

	Opportunities	Degree of impact (D_i)		Probability		Impact coefficient (C_i)	Association	Average rating	Rank
		Assessment	Score	Assessment	%				
1	Strategy for the development of the "green" economy (within the framework of the Green Deal)	high	3	average	50	150	Strategic direction of enterprise development	188	2
2	State programs for the development of the agricultural sector, support for the "European Green Course"	high	3	high	75	225			

Table 5, Continued

	Opportunities	Degree of impact (D_i)		Probability		Impact coefficient (C_i)	Association	Average rating	Rank
		Assessment	Score	Assessment	%				
3	Creating an attractive investment climate for financing environmental protection measures and start-ups	high	3	average	50	150	The level of application of innovative technologies in production	188	1
4	Defining the agricultural sector as the vanguard of innovative development	high	3	high	75	225			
5	Targeted programs for the introduction of innovations and staffing	average	2	high	75	150	The level of production quality, compliance with modern needs	150	3
6	Availability of high-tech production capacities of agricultural enterprises	average	2	high	75	150			
7	High rates of infrastructure development	average	2	average	50	100	Ensuring market share	100	4
	Threats	**Degree of impact (D_i)**		**Probability**		**Impact coefficient (C_i)**	**Association**	**Average rating**	**Rank**
		Assessment	**Score**	**Assessment**	**%**				
1	Inefficient industry structure	average	2	reality	100	200	The level of solvency of enterprises	-175	2
2	Unsatisfactory level of financing of innovative projects in the agricultural sector	average	2	high	75	150			
3	The riskiness of financing due to military aggression	high	3	high	75	225	Positions of the enterprise among competing eco-enterprises	-188	1
4	Pressure from international competing manufacturers	high	3	average	50	150			
5	Loss of part of the territories due to military actions	average	2	low	25	50	Corporate relations	-50	4
6	Loss of part of highly qualified personnel	high	3	low	25	75	The level of staffing and personnel management	-88	3
7	Inefficient industry structure	average	2	average	50	100			

Source: *compiled by the authors based on S.V. Filippova et al. (2015)*

Table 6. *Evaluation factors of the SWOT analysis of the external environment of the agricultural sector*

Opportunities			Threats		
Factor	**Rating**	**Rank**	**Factor**	**Rating**	**Rank**
Strategic direction of enterprise development	188	1	Positions of the enterprise among competing eco-enterprises	-188	1
Support for the development of agricultural enterprises	188	2	The level of solvency of enterprises	-175	2
The level of application of innovative technologies in production	150	3	The level of staffing and personnel management	-88	3
Average score	175		Average score	-150	

Source: *compiled by the authors*

Table 7. *Evaluation of Strengths and Weaknesses of the internal environment*

Group of factors	No.	Strengths	Summary score	Group of factors	No.	Weaknesses	Summary score
Resource support	2	The level of management of intangible assets	109	Organizational and production activity	9	The level of marketing and sales activity	-73
	4	The level of staffing and personnel management	82	"Greening" of entrepreneurship and competitiveness	12	The level of product safety from the point of view of its environmental friendliness	-55
Organizational and production activity	6	Strategic direction of enterprise development	145		13	Ensuring market share	-18
	7	The level of application of innovative technologies in production	18	Financial and economic condition	18	Dynamics of profits and losses	-200
	10	The level of production quality, compliance with modern needs	55		19	The ratio of own and borrowed investment funds	-55

Source: *compiled by the authors based on S.V. Filippova et al. (2015)*

Factors whose score exceeds the indicator (<=50) are considered more influential, then they are ranked from 1 to 3, the results of determining the average score are shown below (Table 8). After calculation, all data summarized in Table 9. Graphically, it was presented on Figure 4.

Table 8. *Determination of the average score based on the results of the analysis of the internal environment of the enterprise*

Group of factors	Rank	Strengths	Summary score	Group of factors	No.	Weaknesses	Summary score
Resource support	2	The level of management of intangible assets	109	Organizational and production activity	2	The level of marketing and sales activity	-73
	3	The level of staffing and personnel management	82	"Greening" enterprise and competitiveness	4	The level of product safety from the point of view of its environmental friendliness	-55
Organizational and production activity	1	Strategic direction of enterprise development	145	Financial and economic condition	1	Dynamics of profits and losses	-200
	4	The level of production quality, compliance with modern needs	55		3	The ratio of own and borrowed investment funds	-55
Average score			112	Average score			-109

Source: *compiled by the authors based on S.V. Filippova et al. (2015)*

Table 9. *Data for the graphic determination of the vector of prospects for the direction of the development of enterprises in the agricultural sector*

Factors of the external environment		Factors of the internal environment	
Opportunities	175	Strengths	112
Threats	-150	Weak sides	-109
Opportunities + Threats = X	25	Strong + Weak = Y	3

Source: *compiled by the authors*

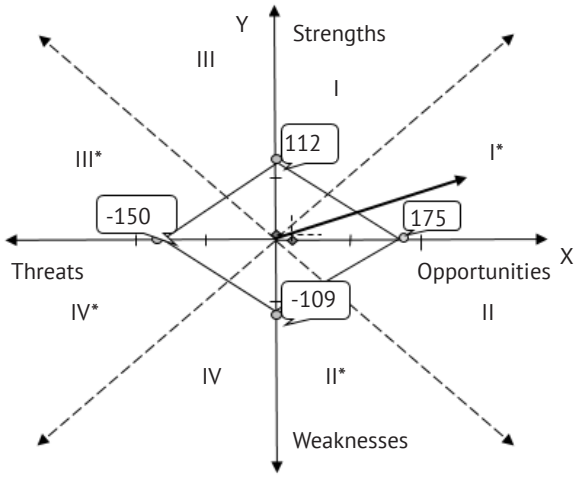

Figure 4. *Graphical definition of the perspective vector of the direction of the development of the enterprises of the agrarian sector of Ukraine*

Source: *compiled by the authors*

As seen from the presented vector scheme, the direction of development is situated in a quadrant that characterizes the potential for development with a high level of opportunities for investment attraction and the utilization of maximum levels of external opportunities and internal resources. However, it is necessary to consider the realities of time and the facts that, due to military aggression, the sown areas in Ukraine have decreased by 25% as of the year 2023. The agrarians suffer from losses caused not only by disruptions in markets and unfavourable new economic conditions, but also from the disruption of the "grain initiative", constant instability, equipment and personnel losses, animal deaths, and land losses due to landmines. Nevertheless, there are also positive aspects: the agricultural sector shows significant resilience and adaptation to new economic conditions; the opportunity for alignment with the requirements associated with the prospect of joining the European Union; the "grain initiative" has enabled the agricultural sector to realize a substantial portion of its production; in 2022, Ukraine exported agricultural products worth $21.1 billion; the prospects for the 2023 harvest are expected to be positive (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023).

It should also be noted that in Ukraine, the Decree of the President of Ukraine (2019) was signed. Among the main priorities, the development of agricultural enterprises is identified as a forefront in the innovative development of the agricultural sector. Additionally, the "Low-Carbon Development Strategy of Ukraine until 2050" (2018) has been developed and adopted, which envisions Ukraine's transition to a low-carbon development model, including the reduction of GHG emissions and the minimization of the use of fossil fuels. Simultaneously, an increase in investments in the development of renewable energy sources and the transition to environmentally friendly production using "green" technologies in all sectors of the economy, including agriculture, is planned. Particularly emphasized in the practical part are recommendations for steps related to the agricultural sector, which involve numerous innovations and new production requirements, innovative waste processing methods, improved energy efficiency, specifically:

1. Increase carbon absorption through the implementation of better climate-friendly agricultural methods.

2. Reduce GHG emissions, specifically methane and nitrous oxide, which are primarily associated with agricultural production, livestock farming, and resource extraction.

In conclusion, considering the obtained results of the assessment of prospects and the strategies developed by the Government, it can be concluded that overall, based on the analysis results and forecast expectations, the prospects for the agricultural sector are quite positive, even in the context of the current complex situation.

DISCUSSION

The trend of the "green" economy is gradually being incorporated into the development strategies of most countries worldwide, particularly in Europe. The support for climate agreements, the safety of agricultural and food production, the application of new soil processing technologies, waste recycling, everything related to emissions reduction and GHG reduction, the development of energy independence and security, energy efficiency, and numerous other issues in this direction are all encompassed by the concept of "greening" the economy. Even in works published in the 1990s, researchers like K.P. Bruce *et al.* (1996) pointed out that economic development would be impossible without the implementation of the "green" economy concept, given that

the impact of climate change is reflected in the activities of enterprises across all sectors of the economy. These authors emphasized that the implementation of the core elements of the "greening" concept is necessary both in the economic and social aspects of each country's development.

Scholars like K. Baylis *et al.* (2022) examined the implementation of the principles of the "green" economy in the production sectors of the United States and Canada. They studied the historical aspects and dynamics of these processes and highlighted the necessity of such an economic development model, especially in the agricultural sector. The importance of government support for agricultural sector development programs is noted. The agricultural sector in the Ukrainian economy has all the prospects for successfully adopting and implementing the fundamental principles of the "green" economy. However, this requires addressing a significant number of challenges that remain unresolved today, including the depletion and degradation of agricultural lands, water pollution, and significant atmospheric emissions resulting from outdated equipment and pollutants.

The orientation towards the ecologization of agricultural production should prioritize enhancing food security, elevating the environmental and economic efficiency of resource utilization, reducing energy dependency, and increasing the export potential of agricultural products, industrial sectors, and the entire national economy. This perspective is supported by researchers like O. Drebot and V. Tarnavskyi (2022), who underline the prospects for the development and implementation of the core principles of the "green" economy on Ukrainian agricultural enterprises. They emphasize the need to change strategic orientations, taking into account new realities related to the military conflict and the new perspectives provided by agreements with the EU. The transformation of the agricultural sector based on the "green economy" should have clear goals, principles, directions, and implementation tools. These elements will form a unified transformation system that will help preserve, enhance, and restore the natural capital in the agricultural sector as a crucial source of economic assets and societal well-being.

Achieving sustainable development goals by regions, countries, and society as a whole overcomes many problems related to food security, fosters the economic growth of the agricultural sector, and enhances its competitiveness in international markets. The implementation directions of the "green economy" concept encompass virtually all spheres of development and activities within the country's agricultural sector, making it a priority in the formulation of strategic programs and plans for the future. Similar perspectives on agricultural safety are revealed in the works of authors like B. Hasler *et al.* (2022), who examine the European approach to implementing the principles of the "green" economy and the political regulation of this process. The study extensively reviews the European agroecological policy, which has various and competing goals. The Common Agricultural Policy was the main political foundation that guided the development and implementation of mandatory and voluntary instruments of agroecological policy in the EU and its member states. The voluntary agroecological scheme, initiated in the 1990s, continues to play a central role in achieving the EU's environmental and climate goals. These programs have faced challenges in achieving their goals, including limited environmental impact, low farmer participation, and conflicts between ecological goals and income support objectives. Lessons from the past and potential future research and policy directions aimed at improving the EU's agroecological and climate goals can be informative for the development of strategic orientations in development programs. Furthermore, the works of G. Pe'er *et al.* (2020) highlight the necessity of control throughout the entire cycle of agricultural crop cultivation and the quality of agricultural products up to the point of consumption.

Considerable attention is also given to food security. For example, in the research of K. Eckerberg *et al.* (2023), questions of land policy are interconnected with other domains: food security, energy supply, environmental protection, stimulation of sustainable development. The values proclaimed by these new realities sometimes conflicted or were not always easily reconciled with the values of those who previously managed agricultural policies. Their research in this field shows that value conflicts are resolved differently, leading to various paths of inter-agency coordination and decision-making. The study of the formation of inter-agency policy in the field of agricultural development management has the potential to contribute to the theoretical development of state policy analysis, just as research on land policy did in the past (Eckerberg *et al.*, 2023). Defining new priority directions and implementing an enhanced SWOT analysis method based on characteristics of external and internal factors, as well as its interpretation, enables the evaluation of prospects based on the obtained results. In this regard, the list of Opportunities and Threats, as well as Strengths and Weaknesses for agro-sector enterprises in Ukraine, was determined considering all perspectives for investment and innovation projects, as well as the country's situation in relation to military aggression.

In the works of researchers S.V. Filippova *et al.* (2015) and A. Sherafat *et al.* (2013), examples of using the directional analysis methodology are provided to determine the attractiveness of investment and investment-innovation projects when selecting alternatives and assessing their prospects. An outstanding feature of the proposed method is its application to determine the direction vector of the agro-sector's development prospects, taking into account factors of strategic development for the "green" economy in

the country, maintaining sustainable growth despite external threats, supporting a course aimed at implementing principles within the "European Green Deal", endorsing investment-innovation development of agrarian enterprises, startup implementation, digitization of the agro-sector, ensuring high levels of safety and environmental friendliness of products, and their competitiveness in domestic and international markets, among others. The question of the necessity for financing "green" projects is explored in the works of Q. Yin (2023) and W. Pan *et al.* (2023). In their research, the authors address the issues of attracting investment funds into innovative projects and mechanisms for evaluating their effectiveness within the framework of environmental policies. All these issues resonate with the thematic focus of the aforementioned study and remain relevant in the context of Ukraine.

The further development of Ukraine's economy necessitates a complete transformation of the existing economic system, a shift towards a renewed business model, and the implementation of sustainable development concepts based on "green" economic principles. It holds prospects for realizing investment and innovation projects in the agro-sector in the coming decade.

CONCLUSIONS

The new challenges of modernity, created by threats to ecology under the influence of society's activities on climate change, require fundamental solutions at the economic, social and technological levels. More and more often, environmental issues are resolved at global conferences or summits, and their results require funding for implementation and new approaches to assessing the prospects for the development of the sphere of activity of enterprises in different countries. A "green" economy based on alternative sources of energy and fuel, ecologically clean production technologies, agricultural clean technologies, "green buildings" and programs for cleaning air, water and soil pollution, processing and disposal of waste is an urgent issue today. It is the "green" economy that can be promising, and the creation of a "green" economy model in Ukraine becomes a necessary and quite achievable goal.

The implementation of the European integration strategy of Ukraine and its goal of entering the European economic space requires an approach to the development of an economic policy aimed at ensuring the production of products that are environmentally safe for the environment and consumers, which at the same time will have competitive qualities at the national and international levels, as well as preserve the characteristics necessary for indicators of production efficiency. The conducted research confirmed that the agricultural sector is one of the most dynamic industries with the potential to transition to "green" development. The industry is undergoing constant transformation under the influence of growing demand from the European market, which is one of Ukraine's most important trade partners.

The principles of transformation of the agricultural sector to a "green" economy should be considered in the context of the implementation of the following strategic priorities: development with the use of new resource-saving technologies, taking into account climate change and the implementation of climate protection measures, the use of eco-production of food products; GHG emissions in the agricultural sector; provision of State support for the "green" economy; development of financing mechanisms with the participation of the State and other investment funds; implementation of monitoring and Methodology for assessing the prospects of investment and innovation projects in the agricultural sector in order to control their implementation, reduce the scale of environmental damage caused by military aggression in the agricultural sector. The specified strategic directions should become the basis for the rationalization and adoption of a unified strategy for the development of the Ukrainian agricultural sector and the economy as a whole, based on the principles of the "green" economy.

For the further development of such a model, it is necessary to resolve the contradictions of production, strengthen the stimulating role of the country in "green" investments and innovations, create conditions for increasing the competitiveness of Ukrainian producers of organic products, and form new ideas among the public in relation to the environment. This is the perspective of development and the basis for further research and implementation of the international experience of the "green" economy, the application of its concepts and principles in Ukraine.

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CONFLICT OF INTEREST

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Перспективний аналіз впровадження «зеленої» економіки в аграрний сектор України

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Анотація. Реалії сучасного розвитку економіки вимагають суттєвих змін існуючої економічної системи та переходу на принципову нову модель, в основі якої буде реалізовано основні підходи сталого розвитку. Одним із найкращих варіантів забезпечення цієї зміни вважається концепція «зеленої» економіки. Актуальність теми розвитку «зеленої» економіки заснована на її потенціалі у вирішенні нагальних екологічних проблем та сприянні сталому розвитку, що відповідає потребам суспільства та міжнародного співтовариства. Мета статті – це оцінка перспективності аграрного сектору економіки України в рамках стратегії трансформації, що сформована за принципами «зеленої» економіки. При цьому враховується цілий спектр факторів, в яких існують та розвиваються агропідприємства, а також ті умови що склались у зв'язку із військовою агресією в країні. Для досягнення визначеної мети були використані наступні методи: системно-структурного аналізу, метод аналізу, синтезу, метод узагальнення, методи дедукції та індукції, та методологія видозміненого, удосконаленого SWOT-аналізу. Визначено ряд факторів впливу на інвестиційно-інноваційні процеси на підприємствах агросектору з так званих зовнішніх загроз та Можливостей і внутрішніх Сильних та Слабких сторін. В процесі дослідження проводиться також узагальнення аспектів переходу від концепцій «сталого» розвитку до концепції «озеленення» економіки, врахування міжнародного досвіду, та включення України до переліку країн що забезпечують боротьбу із змінами клімату, шкідливими викидами. Отримані висновки про перспективність проектів інвестування в агросектор, а саме інвестиційно-інноваційні проекти підприємств сільського господарства, що характеризуються високим рівнем привабливості для інвесторів за показником спрямованого вектору розвитку, підтверджують актуальність реалізації концепції «зеленої» економіки в аграрну сферу України. Використання такої методики оцінки на практиці дасть змогу проводити відбір та аналіз перспективних напрямів фінансування та інвестування проектів, а також коригування стратегій розвитку українських агропідприємств

Ключові слова: екологізація; глобалізація; стратегії розвитку; цільові орієнтири; сталий розвиток

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Management paradigm improving the productivity of farms based on the principles of agricultural consulting

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Abstract. The agro-industrial complex, and farms in particular, is one of the riskiest types of business activity. To obtain high yields and increase production efficiency, reasonable and balanced decisions based on highly specialised knowledge and practical experience are necessary. The purpose of the study is to identify the role of consulting in the system of agricultural management paradigm. The study uses general scientific methods of cognition: logical and structural analysis, comparison, theoretical modelling, abstraction, induction and deduction, and statistical methods,

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concretisation, generalisation, formalisation, and tabular and graphical interpretation of theoretical information. In the course of the study, the current state of agricultural production in the sector of farms, infrastructure, and information support for agricultural producers are examined. It is determined that effective consulting in the field of agro-industrial complex is a basic prerequisite for intensifying the productivity and competitiveness of farm production. Priority vectors of agricultural consulting activities are highlighted. The specific features of the process of managing the productivity of farms with the involvement of agricultural consulting opportunities are examined, and further prospects for its development are outlined. The main measures to optimise the situation in the industry under study are proposed. The practical importance of the results is considered in the possibility of their application in developing appropriate programmes aimed at improving farm management efficiency, increasing production productivity, and product competitiveness, and forming a stable and effective agricultural consulting system in Ukraine

Keywords: nature conservation area; strategic management; monitoring; forecasting; competitiveness; profitability; consulting

INTRODUCTION

Destructive processes in the agricultural sector of Ukraine, caused by the decline of animal husbandry, the deepening of narrow specialisation in the cultivation of grain and oilseeds in crop production, against the background of increased labour migration from rural areas and irrational use of Natural Resources, cause a deterioration in the quality of agricultural land and a decrease in productivity indicators.

World practice convincingly shows that consulting activities is one of the most effective mechanisms for solving problems in the agricultural sector, for which the term "agricultural advisory activity" is often used in Ukraine. The short history of practical implementation of such activities on the territory of Ukraine in the new economic conditions requires the implementation of the accumulated paradigm of agricultural consulting development in the world practice, which aims to increase the productivity of farms through the use of effective management tools. Many studies by modern researchers are devoted to the essence of consulting in agriculture. Thus, O. Svitovyi (2022) and O. Berbenets (2022) define agricultural consulting as a process that aims to generate useful information about optimising the activities of farms. N. Mazur and A. Nikolashyn (2021) argue that consulting is the use of information to form optimal solutions by a business entity and create prerequisites for their implementation.

Considering the essence of consulting, V. Zbarsky and M. Talavirya (2023) decompose it into specific vectors, which include the purpose, means, and communication between participants in the consulting process. Therewith, G. Pruntseva (2020) emphasises that the duty of a consultant is to act for the benefit of their partner, while the business entity reserves full independence in decision-making and responsibility for the consequences of their implementation. The problem of consulting in the agricultural sector is multidimensional. It combines legal, technological, environmental, social, and economic aspects. Researchers O. Klenin and M. Bilopolskyi (2017) include the features of the concept of consulting, its meaning and functions in the system of agricultural transformations, prospects for consulting in the context of the formation of a market economy in the content of economic aspects.

Today, in the agricultural sector of Ukraine, there is a process of destruction of the productivity of business entities, which is largely due to the instability of the economy and a decrease in production volumes. Modern researchers T. Grober and O. Grober (2020) see the essence of the impact of negative factors in the fact that many farms develop without synergy with market laws, in conditions of inadequate material and technical base of production, in the absence of the possibility of using innovative technological solutions and established economic ties. In addition, today, there is a phenomenon of disparity in the economic processes of farms, which is caused by price liberalisation, weakening of state regulation, strengthening of inflation processes, complication of credit policy, and together with disproportionate phenomena – the redistribution of responsibility for overcoming them (Williams & van Triest, 2023).

Quite thoroughly general problems of farm management are examined in the studies of modern researchers C. Li *et al.* (2021) and M. Masud *et al.* (2022). Certain issues of improving the productivity and competitiveness of farm formations are reflected in the papers of E. Mohamed *et al.* (2021). However, the problems associated with the analysis of the algorithm of the successful functioning of farm formations and effective management of their activities using the capabilities of agricultural consulting, which aims to increase the competitiveness and productivity of production, remain insufficiently examined today and require further scientific consideration.

The purpose of the study was to analyse the use of consulting to improve the efficiency of agricultural production. An additional task was to examine the possibilities of management tools based on agricultural consulting to stimulate the productivity of farms in Ukraine.

MATERIALS AND METHODS

In the course of the study, a number of general scientific and special methods of cognition were used, including methods of logical, structural, functional, comparative analysis, abstraction, induction and deduction, and methods of concretisation and formalisation. The theoretical and methodological base of the study is formed based on the dialectical method, a systematic approach, and priority principles for conducting comprehensive research. Therewith, the systematic approach allowed examining the object and subject of study as a system in the entire set of relationships.

The comparison method was used to determine the specific features of development and the dynamics of quantitative and qualitative characteristics of farm productivity. Methods of analysis and synthesis were used in the process of identifying the stages and factors of development, and the most influential elements of the object under study. The inductive method was used to predict development indicators. Deduction was applied in the course of developing proposals for optimising management processes in farm production. Methods of system analysis and synthesis were used to identify the essence of the organisational and economic mechanism of the object under study and to determine strategic vectors for the development of effective management in the farming sector. Through system analysis, structural connections between the elements of the phenomenon under study are established.

The abstraction method was used in the course of the study to identify the main concepts and categories. Through this method, the concept of an integral process of the management system in the agricultural farming sector is formed as a structural and consequence system of relationships, where the consulting process occupies a prominent place along with the main production and organisational factors. The historical-logical method is used to identify historical and structural connections in the production system of agricultural production. Abstract-logical and dialectical methods of scientific knowledge, and the method of scientific abstraction, are used in the study to form theoretical generalisations, clarify the conceptual apparatus, and formulate conclusions. In addition, mathematical methods were applied in the course of the study to develop a methodology for assessing the feasibility of integrating farms.

The concretisation method is used to fix the efficiency and expediency of agricultural consulting in the process of increasing the productivity of farms and to identify optimal conditions and solutions for levelling risks in the field of agricultural production. The method of formalisation in the study was used at the stage of deriving priority vectors for optimising the productivity management system of farms based on agricultural consulting and in the process of fixing the results of the study aimed at active practical implementation in the process of agricultural sector management. The theoretical basis of the study includes legislative and regulatory acts of Ukraine, scientific literature on thematic areas, monographs, scientific and analytical publications of Ukrainian and World researchers on the examined issues, results of independent observations and practical recommendations on ways to optimise management processes in the agricultural sector in the aspect of consulting farms.

RESULTS

The dynamics of economic relations and the reorientation of agriculture with the priority of private property led to substantial development of the farm sector (Berbenets, 2022). Ensuring their effective functioning, productivity growth, and economic efficiency requires solving a whole range of problems regarding the growth of competitiveness, innovative development prospects, the introduction of the latest effective tools of the management mechanism, and the development of a set of appropriate measures that could mitigate adaptation processes in conditions of increased competition. Ultimately, the market economy forms the main goal of agricultural production – increasing profitability, which is directly related to productivity growth, so the active development of farms, in particular, is determined by indicators of economic performance (Klenin & Bilopolskyi, 2017).

Given the current situation, the role of agricultural consulting in the structure of the management system in the agricultural sector cannot be overestimated. In general, consulting is an optimisation process based on professional advice. Notably, the resulting effect can have a different form of expression and be achieved by different methods and means. For example, along with an increase in the volume of farm production, organisational-managerial or personnel changes are used. Consulting is a process that results from the interaction of three systems: the consultant, the client organisation, and the external environment (Mohamed *et al.*, 2021). Therewith, the concept of a consultant is a set of all means of production and personnel directly involved in the formation of certain decisions and programmes, that is, in the production process of a consulting product. It is worth emphasising the integrity of the consulting process because external factors – economic, social, political, natural and climatic (Latif *et al.*, 2020; Hu *et al.*, 2020) affect the process.

Notably, as a rule, any solution formed in the process of professional consulting differs substantially from the established practice. As a result, its implementation requires the participants of the consulting system not only the expected changes in knowledge and qualifications but also an active perception of innovations and the ability to find and effectively implement solutions to problematic issues that constantly arise

in the process of production activities. In this case, it is worth highlighting the essence of the consultant's work, which consists in the practical growth of the pace of agricultural development, in particular, farming, that is, in performing a stimulating function. From the standpoint of economic efficiency, the consulting process should have a constant character and be positioned as a long-term cooperation, initiating positive dynamics of transformations within the economy and stimulating it to constant self-development.

The practice of managing the productivity of business entities in the agricultural sector of Ukraine indicates the need to develop and implement appropriate individual management methods, functions, organisational structure and management system as a prerequisite for effective management of the competitiveness of farms. Based on the examination of the theoretical foundations of consulting and the possibilities of their adaptation in real conditions, it is considered appropriate to form the concept of strategic management of farms, which aims to increase their productivity, should ensure the orientation of production to demand and current market needs, cultivate effective relationships between labour, financial and information resources, stimulate the desire to increase production efficiency, and obtain optimal results with cost minimisation. Notably, effective management involves flexibility, adaptability, and regular review of goals and programmes depending on market conditions. In addition, the basic prerequisite for successful optimisation of the management system in the agricultural sector is the use of modern innovative programming, modelling, and forecasting capabilities.

The current strategy of the farm management system to increase their productivity should be a kind of hub of interrelated organisational and information principles, tools and levers that contribute to increasing the level of competitiveness of farm formations. The main components of ensuring the implementation and development of a farm development strategy are proposed to be the following:

- technical-technological, which involves the analysis of statistical data and diverse information, the introduction of the latest innovative strategies, technologies and concepts;
- legislative-scientific, which implies an understanding of the legislative framework of Ukraine and the ability to predict possible legislative changes, investigate foreign experience, develop and implement strategic innovations;
- personnel motivated by regional development potential, awareness of local needs, communication between farmers and the authorities.

The primary principles of strategic management of farm productivity are consistency, efficiency, flexibility, balance, risk minimisation (Table 1).

Table 1. *Principles of Strategic Management*

No.	Principle	Essence
1	Adaptability	It provides for the possibility of changes in the process of implementing strategic management under the influence of external and internal factors
2	Possibility of implementation	Defining an organisation's strategic development goals involves considering its external and internal resources to assess the possibility of their implementation
3	Structure	The strategic management process should have a structure, regulation, and implementation algorithm
4	Perspective	The priority is the prolonged development of the organisation in the future
5	Economic effect	The implementation of management measures should, at a minimum, bring the effect of cost compensation
6	Monitoring	The implementation of management measures should be a fully controlled process, with established benchmarks and performers
7	Consistency	The implementation of strategic management should be conducted for the entire organisation, and not for individual divisions, which implies a common focus on a single goal

Source: *M. Horikhovskyi (2018)*

Evidently, agricultural consulting services are an important element of the management system of agricultural enterprises. Consulting is a process in which the real state of processes in the enterprise is analysed, reserves are identified to increase production volumes and save resources. The results of the analytical work serve as a basis for the development of a set of measures that, with minimal costs, bypassing the substantial restructuring of the organisational structure of the enterprise, allow a substantial increase in productivity and production efficiency, increasing the competitiveness of manufactured products. Thus, it can be argued that agricultural consulting is able to increase the productivity and efficiency of farms with minimal costs of material resources and, therefore can be used as an effective tool for reducing costs per unit of production. In developed countries, the process of providing agricultural advisory services is an effective tool as part of a

management algorithm for increasing the productivity of the agricultural segment, in particular, farms.

Notably, agriculture is an industry that is extremely subject to the influence of natural and climatic factors, and often, even their timely forecasting cannot protect the producer of agricultural products from losses. Thus, the prospects for the development of agricultural enterprises should mainly be based on modelling production processes in the entire set of factors of influence and interdependence. Since any performance indicator is influenced by various factors, it is necessary to identify these factors, predict them, and, if they are negative, neutralise them. The general structure of the strategic management process in a farm is shown in Figure 1.

Notably, strategic management of farms has its own characteristics. The main factors affecting the process are shown in Table 2.

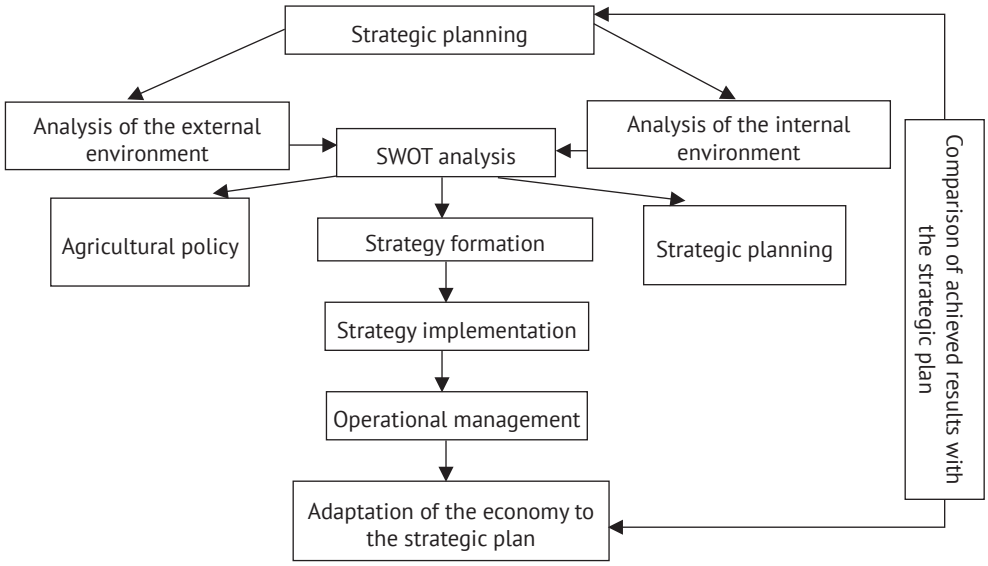

Figure 1. *The process of strategic management in farms*

Source: *M. Horikhovskyi (2018)*

Table 2. *Factors influencing the farm management process*

Factors	The essence of influence
Natural-climatic conditions	Direct influence of the natural environment on production activities
Territorial dispersion of production	Complexity of timely operational decision-making and adjustment of strategic plans
Seasonality	High level of risk when implementing selected productivity strategies
Limited product diversification	Disparity in prices for agricultural products
Organisational and legal forms of business management	Farms are substantially affected by external factors of varying strength and degree of action

Source: *M. Horikhovskyi (2018)*

Difficulties in the field of agricultural consulting are primarily due to the fact that many factors affect the efficiency of agriculture in complex and contradictory ways. Recently, a number of effective formats of consulting operations aimed at solving existing problems and creating favourable conditions for the effective development of farms have been formed (Kovalska, 2014; Goncharova, 2015; Karpenko, 2018). Today, evidently, agricultural consulting services, in the context of modern globalisation challenges, should perform, along with increasing productivity and competitiveness, related relevant functions, such as establishing links with highly competitive and export markets, promoting the ecological development of rural areas, and establishing a closed production cycle on them, and intensive use of the results of research and development in production turnover, ensuring the activation of innovation processes based on the improvement of information, consulting, and implementation activities, the creation and development of innovative infrastructure facilities (Panitz & Glückler, 2020; Van Rossem, 2021).

The main components of the innovation sector in the field of agricultural consulting should be agricultural advisory centres, united in a single system and an extensive network close to the commodity producer of agricultural products, raw materials, and foodstuffs

(Griffin & Gammon, 2020; Agnolucci *et al.*, 2020; Emirhüseyinoğlu & Ryan, 2022). Today, in Ukraine, the functions of agricultural consulting centres are mainly performed by specialised consulting organisations operating at the regional and district levels. There is a primary need to assess the effectiveness of their activities, based on which, as a rule, budget financing and further development strategies of consulting organisations are formed to improve the effectiveness of their activities (Randall & James, 2012; Junior *et al.*, 2019; Giua *et al.*, 2021). Therefore, the activities of agricultural consulting facilities have their specific features and individual characteristics. Considering the above, separate methods of agricultural consulting aimed at improving the productivity and competitiveness of farms can be separated. Their choice and implementation depend on the conditions in which the consulting subjects are located and the tasks facing them. The main methods of agricultural consulting include the following.

1. Advising a separate project. It involves collecting and analysing data to solve the current problem, analyse the state of activity, and form appropriate recommendations. The decision is formed within a short period, and the involvement of the business entity in its formation is minimised. This approach is recommended for optimising the organisational structure of the farm, revising the marketing system, and reviewing business projects.

2. Support service. The method is the periodic involvement of a consultant at different stages of a particular project. It is characterised by the low cost of services of this type of consulting.

3. Expert advice. It provides for the involvement of a consultant at the stage of identifying the problem. The consultant structures the problem, investigates the possibilities of its solution, formulates hypotheses, and suggests a solution method or alternative options.

4. internal counselling. The method involves the permanent work of a consultant in the staff of a business entity.

Notably, the effectiveness of a particular method of consulting depends on a combination of factors, including the flexibility and adaptability of the client to changes, the qualification of the consultant, and the type of problem being solved. In case of unsatisfactory results, the consumer of the consulting service can review the initial conditions of the problem in terms of the features of the activity identified by the consultant, which were not previously considered, and in case of serious disagreements, contact other consultants.

The agricultural production sector is one of the main sectors of the Ukrainian economy. The agro-industrial complex has a substantial resource potential and has all the prospects for successful development. Farms are currently positioned as full-fledged entities in the agro-industrial complex. As a diminutive form of entrepreneurship, they have substantial advantages over larger forms of agricultural production. These include the brevity of the organisation, the ease of entering the market, increased adaptability in economic activities due to the small scale of production, and a quick response to the dynamics of market conditions. Farms have evident advantages along with other agricultural entities: savings on on-farm transportation, management costs, and an interest in improving operational efficiency. Successful further development of the farm segment requires optimisation of the methodological base and practical measures to increase their competitiveness and profitability (Knierim *et al.*, 2019).

Notably, one of the prefaces to the practical improvement of agricultural production efficiency indicators is the economic effect of reducing the initial cost of production, which, in turn, requires improving the cost management system. Therewith, the qualification of managers within the framework of a farm, for the most part, does not allow effectively solving the tasks of such a plan, which makes it necessary to use management consulting services. Today, the level of demand for agricultural advisory services in Ukraine needs to be more substantial. This state of affairs is mainly due to farmers' low solvency level and ignorance of the advantages and benefits of consulting services. In the vast majority, managers of agricultural enterprises are not sure of the proper level of confidentiality of information about their commercial activities. However, it is essential to understand that consulting can encourage substantial economic benefits, including introducing innovative approaches and technologies (Kernecker *et al.*, 2019; Romero-Padilla *et al.*, 2022).

Agricultural consulting can become the management lever that, when used effectively, will allow achieving a substantial increase in the productivity of farms while not separating their functional activities from the principles of a closed-loop economy and sustainable production (Reddy *et al.*, 2021).

The purpose of a promising study in the field should be to highlight strategic priorities for forming a stable professional agricultural consulting system and integrating an information monitoring system as the main initial resource for optimising the situation. Therewith, an important role is assigned to attracting international practical experience in developing new and improving existing methods within the framework of an integrated multi-factor approach to managing farm productivity.

DISCUSSION

Most modern researchers see consulting as the basis for the development of entrepreneurship in agriculture, which creates a number of organisational and economic prerequisites for technical reproduction and efficient use of agricultural production. M. Horikhovskyi (2018) argues that management consulting services are one of the most effective tools for optimising the production activities of farms. According to the researcher, the

main goal of the consulting process is to help clients solve management problems. This goal can be achieved using various effective advisory algorithms. In addition to that, the author notes that the process is influenced by a number of factors, in particular, time constraints, financial capabilities, and the level of intellectual resources of personnel. The researcher is convinced that, as a rule, consultants, providing a service stipulated by the agreement rarely encourage the farmer to form a solution to the problem by themselves. In addition, the researcher considers coaching on identifying and solving problematic phenomena the most promising area of agricultural consulting. Given the current state of infrastructure support for the agricultural sector in Ukraine, according to the author, the state management of the farm advisory system requires further research. Therewith, he convinces of the need to use information resources and the successful experience of developed countries for the needs of the agricultural market of Ukraine. The researcher notes that today, only a small number of agricultural producers are consumers of technological and managerial innovations, while small farms do not have such an opportunity. In this regard, insufficient access to information and lack of readiness for its independent practical implementation are the most substantial factors limiting farms' potential.

X. Hu *et al*. (2020) believe that agricultural counselling is primarily an activity that is advisory in nature and helps rural producers implement goals and objectives by finding solutions to various problems, identifying new opportunities, implementing changes, and coaching. Researchers suggest understanding that agricultural consulting services are a necessary element of the market and non-market relations system in the agro-industrial complex. Researchers argue that they represent an essential component of the infrastructure of the agricultural market, and it is difficult to disagree with them. Researchers consider the institutional transformation of the agricultural complex in synergy with the need to develop consulting for the effective functioning of agriculture and rural areas or monitoring information and consulting activities as the basis of farm management. Results of scientific research by X. Hu *et al*. (2020) show that small forms of agricultural production – farms have a higher resource efficiency level than large and medium-sized agribusiness structures. Given the limited availability of land, they exhibit higher productivity and self-reproduction ability. The forecast of the trend in the development of agricultural production shows that conjunctural industry requirements in the future will increasingly depend on the supply of a small sector of agricultural production.

Researchers D. Cheng *et al*. (2023) identify specific prerequisites for agricultural consulting, among which the main ones are the following:

– features of the living conditions of the rural population that form the system of functioning of the farmer community and, accordingly, the need to ensure the conditions for its reproduction;

– characteristic features of production, which is a biological process that involves living organisms (soil, plants, animals), which determines the synergy of economic processes in farming activities with the processes of natural reproduction;

– seasonality of agricultural production, which causes uneven use of labour, land, machinery, and other material resources by period of the year;

– dependence on natural and climatic conditions and features makes it necessary to ensure the reproduction of a strong material and technical base.

Taking the listed prerequisites as a basis, the main specific features of agricultural consulting of farms can be listed, including: high labour intensity of the process; instability, uncertainty, and complexity of forecasting related to weather and climatic conditions of the area; urgent need to optimise production processes due to seasonal shortage of basic resources (labour, material, financial); high responsibility and risk level due to the presence of living biological objects and short shelf life of products; the need to track many processes occurring in parallel and characterised by mutual influence; the need for large amounts of information from different sources; high urgency of solving problems due to seasonality of production; complexity problems of farms.

Based on the findings of M. Väre *et al*. (2021), which consider consulting support as the main prerequisite for the development of innovation activities in rural areas, it can be argued that consulting of the agro-industrial complex, and farms, in particular, has substantially expanded the scope of its functioning today, becoming a basic element of the agricultural market system. Therewith, researchers note that increasing the productivity of farms based on agricultural consulting provides for a gradual and effective achievement of goals that include:

– optimisation of the overall financial and economic situation by increasing production volumes, effective saving of resources, and efficient use of assets;

– strengthening the status in the agricultural market, developing new sales areas and diversifying production;

– formation of high indicators of production stability through the stabilisation of resource reserves and the use of risk insurance opportunities.

In the study by R. Weir *et al*. (2023), it is noted that the formation of a highly productive competitive agricultural sector, and farms in particular, largely depends on the economic motivations of participants in the production process. Therewith, according to researchers, the main condition for the formation of positive economic dynamics in this industry is the competitiveness of the proper level. It is necessary to supplement such conclusions of researchers with the fact that competitive ability is primarily associated with an effective management system and strategy for developing agricultural market entities, which is ensured by the

effective attraction of agricultural consulting opportunities. Therewith, the researchers note that consulting in the field of agriculture, particularly in the case of farms, is characterised by a high dependence on environmental factors and, therefore, requires prompt adaptation of the structure to the dynamics of tasks depending on needs. In addition, management measures to increase farm productivity require integrating and combining efforts with scientific, educational, and statistical opportunities, their synergy to maintain an up-to-date database and develop innovative technologies, innovations, and best practices. According to researchers, the success of management tools to increase the productivity of farms based on agricultural consulting depends mostly on flexibility, the ability to change and develop, and the predominance of informal relations over formal ones.

Based on the results obtained in this study and the conclusions of the authors of the above-analysed studies, it is possible to predict the growth of the role of agricultural consulting in the implementation of successful management policies of farms, which will substantially increase their productivity indicators, implement innovative solutions and ensure compliance with the principles of a closed-cycle economy.

CONCLUSIONS

As a result of the study, it was possible to analyse the multi-factorial management paradigm of increasing farm productivity based on agricultural consulting to assess the role and place of consulting in the system of agrarian transformations. In the course of the study, it was established that the development of agricultural advisory services plays a substantial role in increasing agricultural productivity, strengthening food security, and optimising the population's living standard in rural areas. It is determined that consulting provides practical and effective support to rural producers who can quickly respond to new challenges, including transformations in the global food and agricultural system, growing importance of food safety standards, increased competition in agribusiness, degradation of the natural resource base and climate change. Objective conditions of the functioning of advisory services in the modern market economy in Ukraine are analysed. It is proved that the government should play a leading role in developing agriculture and its information support. In addition, its appropriate functions should be innovative production, control of the impact of agricultural production on the environment, and regulation of food quality and safety standards. It is established that implementing these goals is possible due to advisory support and support of agricultural activities. It is noted that strategic planning, operational management, and developing an effective farm policy should be positioned as integral components of strategic management.

The paper examines the economic-organisational components of the consulting process, identifies its specific features in the market economy of developing countries, and trends and prerequisites for its dynamic development. The levers of economic regulation of information transformations in agricultural production are examined, and the main elements of the mechanism for ensuring stable, effective consulting activities are identified. Special attention is paid to examining the management system's effectiveness in the farms' competitiveness and productivity. In addition, it is established that the regulatory and legal environment should perform the primary function of forming performance indicators, which should include developing adapted models of management tools and professional and effective agricultural consulting. A practical approach to the farm management system involves a hub of methods and tools in a set of relationships that can increase the level of productivity and competitiveness of farms. It should be based on implementing a development strategy formed based on professional agricultural consulting as an integral part of the management paradigm.

Based on the results obtained in the paper, priority vectors of further research on the subject are proposed, and the need to organise the availability and systematisation of information on agricultural consulting of farms is justified. There is a need to study further the possibilities of applying management measures, using international practical experience and developing optimal programmes for increasing the productivity of agricultural production. Together, such measures will allow solving the existing complex situations in the field of farm production and identifying reserves to increase its efficiency, considering the combination of factors affecting the internal and external environment.

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CONFLICT OF INTEREST

None.

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Управлінська парадигма підвищення продуктивності фермерських господарств на засадах сільськогосподарського консультування

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Анотація. Агропромисловий комплекс, і фермерські господарства, зокрема, є одним з найризикованіших видів підприємницької діяльності. Для отримання високих урожаїв і підвищення ефективності виробництва необхідними є обґрунтовані і виважені рішення на основі вузькоспеціалізованих знань і практичного досвіду. Метою статті є ідентифікація ролі консалтингу в системі аграрної управлінської парадигми. Дослідження проводилось з використанням загальнонаукових методів пізнання: логічного та структурного аналізу, порівняння, теоретичного моделювання, абстрагування, індукції та дедукції, а також статистичних методів, конкретизації, узагальнення, формалізації, табличної та графічної інтерпретації теоретичної інформації. У ході роботи досліджено сучасний стан сільськогосподарського виробництва в секторі фермерських господарств, інфраструктурне і інформаційне забезпечення аграрних товаровиробників. Визначено, що ефективний консалтинг в сфері агропромислового комплексу є базовою передумовою для інтенсифікації продуктивності та конкурентоспроможності фермерського виробництва. Виділено пріоритетні вектори діяльності сільськогосподарського консалтингу. Досліджено специфіку процесу управління продуктивністю

фермерських господарств з залученням можливостей сільськогосподарського дорадництва, окреслено подальші перспективи його розвитку. Запропоновані основні заходи з оптимізації ситуації в досліджуваній галузі. Практична значимість результатів дослідження розглядається в можливості їх застосування в процесі розробки відповідних програм, що мають на меті підвищення ефективності управління фермерськими господарствами, зростання показників продуктивності виробництва та конкурентоспроможності продукції, а також формування стабільної ефективної системи сільськогосподарського консалтингу в Україні

Ключові слова: природоохоронна територія; стратегічний менеджмент; моніторинг; прогнозування; конкурентоспроможність; рентабельність; дорадництво

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