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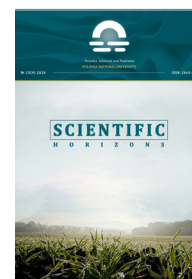
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Determination of the Therapeutic Effect of the Use of *Bacillus Coagulans* in Calf Dyspepsia

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Abstract. The relevance of this study lies in the use of the probiotic strain of the microorganism *B. coagulans ALM 86* for the treatment of diarrhoea in dairy calves and the reduction of the use of antibiotics in animal husbandry. The purpose of this paper was to establish the therapeutic effect in the treatment of diarrhoea in calves, the composition of the microflora, physiological indicators and metabolism using *Bacillus coagulans ALM 86*. The study used the following methods: microbiological, microscopic, biochemical, physiological, statistical. Studies have shown that the use of *B. coagulans ALM 86* contributes to a decrease in the number of opportunistic microflora *E. coli* – by 90.8%, *S. aureus* – by 92.4%, *S. enterica* – by 88.01, an increase in *Lactobacillus sp.* by 130.8-151.58% and Bifidobacterium sp. by 272.7-469.8%. Administration of *B. coagulans ALM 86* at a concentration of 1×10^9 , CFU/g at a dose of 3-5 g helped stop diarrhoea and accelerate the development of scar digestion for four days in dairy calves, compared to the group where the antibiotic was used. An increase in average daily growth and feed consumption was found in the first experimental group by 19.7-15.0%, in the second – by 23.4-19.9% ($p \leq 0.05$). A decrease in the level of total cholesterol with the use of *B. coagulans ALM 86*, an increase in the level of total protein by 18.57-22.6%, as a result of an increase in the content of total globulins by 49.3-57.37%, respectively ($p \leq 0.05$), were proven. Administration of *B. coagulans ALM 86* at a concentration of 1×10^9 , CFU/g at a dose of 3-5 g helped stop diarrhoea and accelerate the development of scar digestion for four days in dairy calves, compared to the group where the antibiotic was used. The obtained results of the study indicate the absence of toxic effects of the proposed dose of *B. coagulans ALM 86* for the treatment of dyspepsia in calves and obtaining a positive effect. The practical value of the obtained results lies in the possibility of using *B. coagulans ALM 86* in the treatment of diarrhoea in dairy calves without the use of antibiotics on animal farms of various designation

Keywords: diarrhoea, probiotic, microbiome of the gastrointestinal tract, average daily growth in calves, lactic acid bacteria



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INTRODUCTION

Raising young cattle is a difficult and responsible task for producers. New-born calves immediately encounter an environment for which the body is not sufficiently prepared or poorly prepared (Brar *et al.*, 2017). The lack of formed thermoregulation and immunity in calves makes them very vulnerable to microbial associations. The only protection for calves is the mother's colostrum. One of the frequent diseases of calves up to one-month-old is neonatal dyspepsia (Slanzon *et al.*, 2022). Sick calves suffer from body intoxication, dehydration as a result of liquid stool, electrolyte imbalance and acidosis (Feldmann *et al.*, 2019). Neonatal dyspepsia has various aetiologies of occurrence, which include viruses, bacteria, protozoa, and facts of violation of housing conditions (Constable *et al.*, 2021).

It has been proven (Lee *et al.*, 2019; Goto *et al.*, 2021) that new-born calves are particularly susceptible to enteropathogenic infections. *Escherichia coli*, rotavirus, coronavirus, and *Cryptosporidium parvum* were isolated from calves suffering from dyspepsia.

The study by (Puppel *et al.*, 2020) proved that the quality of colostrum directly affects the formation of intestinal microflora and daily weight gain of calves.

One of the causes of calf diseases is drinking milk from cows with mastitis, where *Staphylococcus aureus* was isolated in 22% of cases (Shkromada *et al.*, 2022; Sharon *et al.*, 2021), *Streptococcus agalactiae* in 20% (Shkromada *et al.*, 2019), in 18-25% – *Streptococcus uberis* and *Escherichia coli* (Ashraf & Imran, 2020).

The spectrum of pathogenic microflora in different dairy farms is different, and therefore there is a problem of prevention and treatment of diarrhoea in calves (Conboy *et al.*, 2022). Antibiotics and sulphonamides are usually used for this purpose, which are included by the World Health Organisation in the list of "highest priority" agents due to their danger to animal and human health. (World Health Organisation, 2017). Due to restrictions on the use of antimicrobial agents, scientists (Wang *et al.*, 2020; Xu *et al.*, 2021) are searching for alternative methods of treating infectious diseases in animals.

Scientists (Amin & Seifert, 2021) investigated information about a range of factors that affect the timing of microbial colonisation of the gastrointestinal tract of calves. The relationship between the animal and the microbiome in the formation of the intestine and the immune system has been determined. Diarrhoea alters the composition of the intestinal microbiome of calves. Research (Yan *et al.*, 2022) found changes in 14 genera, which included *Bacteroides*, *Shigella*, *Fournierella*, *Escherichia*.

An antimicrobial peptide was tested and proposed by researchers (Zhao *et al.*, 2021) to destroy pathogenic *Escherichia coli* O157:H7. The study by (Karpun *et al.*, 2021) proved the antimicrobial effectiveness of a new synthesised triazole-based compound against strains of *Salmonella pullorum*, *Escherichia coli* O2, and *Salmonella enteritidis*.

Furthermore, as an alternative to antibiotics, scientists (Zhou *et al.*, 2020) suggest using probiotics for the treatment of varied species and age groups of animals.

Studies (Cantor *et al.*, 2019) have proven that the use of probiotics based on lactic acid contributes to an increase in average daily gains and a decrease in milk consumption in young calves.

Probiotics are considered beneficial for the gastrointestinal tract as an alternative to antibiotics (Khaizhmetov *et al.*, 2020). Intestinal microflora plays a vital role in the assimilation of organic substances. Bacteria produce specific amino acids that regulate host immunity, microflora composition, and metabolism. Recent data (Chuang *et al.*, 2022) show that synbiotics, probiotics, and phytochemicals promote the mobilisation of amino acids by intestinal microflora. Scientists (Abdallah *et al.*, 2020) recognise probiotics as a live microbial feed additive that benefits animal health.

Bacillus coagulans (*B. coagulans*) is used as a probiotic strain that produces lactic acid in metabolism in animal husbandry (Liu *et al.*, 2019). *B. coagulans* spores are very hardy, are activated in the stomach, and grow and multiply in the animal's intestine (Xie *et al.*, 2022). In the study by (Aulitto *et al.*, 2021) it was established that *B. coagulans* can replace lactic acid bacteria in the intestine.

In (Shinde *et al.*, 2020) it was proven that synbiotic supplements with *B. coagulans* reduced irritable bowel syndrome in mice. The obtained result (Wang *et al.*, 2022) proves that *Bacillus coagulans* TL3 suppresses the reproduction of harmful bacteria in the intestine of rats. Research (Zhang *et al.*, 2021) proved that the administration of *B. coagulans* to broilers contributed to an increase in body weight, improved antioxidant status and immunity.

However, there are insufficient data on the effect of *B. coagulans* on the intestinal microflora, physiological parameters, metabolism, and rumen development in dairy calves. In addition, different strains of *B. coagulans* have certain differences in properties and effects on the animal body.

The purpose of this study was to investigate the microflora composition, metabolism, productivity and therapeutic effect of the use of *Bacillus coagulans* ALM 86 for calf dyspepsia by adding it to the main diet.

The tasks of the study were as follows: the study of the spectrum of the gastrointestinal microflora of calves with dyspepsia, the determination of physiological indicators and metabolism in calves using *Bacillus coagulans* ALM 86.

MATERIALS AND METHODS

The research was carried out during March-May 2022 in the conditions of the farm of "Lan" agrofirma LLC of the Sumy district of the Sumy Oblast, Ukraine for the cultivation of dairy cattle. Animals with symptoms of diarrhoea were selected into two experimental and control groups, 10 heads each. In the control group, calves

were kept, which were given a colostrum substitute and an antibiotic – ceftiofloxacin, which was used according to the instructions. *Bacillus coagulans* ALM 86 at a concentration of 1×10^9 , CFU/g at a dose of 3 g was drunk daily in the first research group together with colostrum substitute, in the second – 5 g per animal, until the signs of diarrhoea disappeared. The total number of animals involved in the experiment was 30 heads. The duration of the experiment was 21 days. During the experiment, the clinical condition of the calves, the composition of the gastrointestinal microflora, weight gain, feed consumption, the frequency of diarrhoea and metabolic changes in the blood were determined. The beginning of the rumen in dairy calves of the experimental and control groups was also recorded. Each animal was kept separately in individual houses. An experimental sample of the strain *Bacillus coagulans* ALM 86, series No. 86 and batch number No. 75 (Kronos Agro) was used.

All research on animals was carried out according to Directive 2010/63 and approved by the regulations on ethics and bioethics of the Faculty of Veterinary Medicine of the Sumy National Agrarian University (Order No. 15 dated 13.08.2022).

Determination of the composition of the gastrointestinal microflora in calves. Faeces of calves with dyspepsia were collected in the control and experiment. Samples of the material were examined by bacteriological methods to establish the intestinal microbioscenes in animals. The number of bacteria of the group of *Escherichia coli*, sulphite-reducing clostridia, lactobacteria, bifidobacteria, staphylococci, pseudomonas, yeast-like fungi, salmonella, and other bacteria from the Enterobacteriaceae family was determined. The presence of microorganisms with pathogenicity factors, including haemolysins, lecithinase, and plasmocoagulase, was established in the material.

Selective media for microorganisms, depending on species characteristics, were used when examining samples of calf faeces. For the cultivation of lactic acid bacteria, Blaurock's medium was used, for intestinal bacteria – bismuth-sulphite-agar, endo, staphylococci – salt agar, microscopic fungi – Czapek, clostridia – Wilson-Blair agar. Based on the results of cultivation, colony-forming units were counted in 1 g of pathological material (CFU/g). Species membership of bacteria was determined using Bergey's Manual of Systematics Bacteriology tests, Himedia Laboratories Prv. Limited.

Determination of sensitivity of microflora to antibiotics. Previously isolated microorganisms were tested for sensitivity to antibiotics by the method of disks on agar in Petri dishes. 20 drugs from diverse groups were investigated for maximum results.

Study of physiological indicators of calves. In control and experimental group calves, weight gain, feed consumption, frequency of diarrhoea, and the beginning of scar digestion were determined from the first to the

21st day of life. Live weight of calves was determined on scales with an accuracy of 1 kg.

The average daily gain of calves was calculated according to the formula:

$$ADG = \frac{W_t + W_0}{t} \quad (1)$$

where W_t is live weight (diameter) at the end of observation; W_0 is the value of the indicator at the beginning of the observation; t is the time interval (days) between the previous and the next weighing (by measuring) calves.

The frequency of diarrhoea was established by visual observation of the animals. The beginning of scar digestion was determined by the method of auscultation and palpation of the scar, as well as the appearance of belching and chewing in calves was noted by inspection.

Study of the effect of *B. coagulans* ALM 86 on the biochemical parameters of the blood of calves. To find the metabolic changes in the body of the calves, the biochemical parameters of blood serum were studied at the beginning and at the end of the study. The total number of animals involved in the experiment was 30 heads. The level of total cholesterol was determined (SOP-BP-07-2017); total protein (SOP-BP-02-2017), albumin (SOP-BP-25-2018), total globulin (calculated method), alanine aminotransferase (ALT) (SOP-BP-09-2017), aspartate aminotransferase (AST) (SOP -BP-08-2017), urea (SOP-BP-03-2017), alkaline phosphatase (LF) (SOP-BP-04-2017) using an automatic biochemical analyser and appropriate diagnostic systems. Creatinine was studied using a photoelectric colorimeter-nephelometer FEK-56M, glucose – glucose-oxidase. Seromuroids were found according to the method of Weimer and Moshin; circulating immune complexes (CIC) by precipitation with a 3.5% solution of polyethylene glycol PEG-test OSH 280.

Statistical analysis. The analysis of experimental studies was carried out using the Microsoft Excel 2010 program. The results obtained in this study were statistically calculated using the Fisher-Student method, considering statistical errors and the probability of the indicators compared. Indicators with a level above 95% ($p < 0.05$) were considered probable.

RESULTS AND DISCUSSION

Results of determining the spectrum of gastrointestinal microflora in calves. Dairy calf diarrhoea has a multi-vector aetiology, which also depends on the level of resistance and pathogenicity of the pathogen (Morrison et al., 2019). Enterohaemorrhagic *Escherichia coli*, *Staphylococcus aureus* and *Salmonella enterica* are the most frequent pathogens that cause dyspepsia in newborn young animals (Coelho et al., 2022). The presence of one or more of these microorganisms in the gastrointestinal tract can increase calf morbidity and mortality (Vega et al., 2020).

Since calves are highly dependent on a safe food source of milk, a milk substitute was used in the study to rule out contamination. In addition, the milk of each cow has differences in the content of fats, proteins, vitamins,

and minerals. The spectrum of microflora of the gastrointestinal tract was determined in calves with diarrhoea in the control and experimental groups (Hartung, 2010), before the beginning and at the end of the study (Fig. 1).

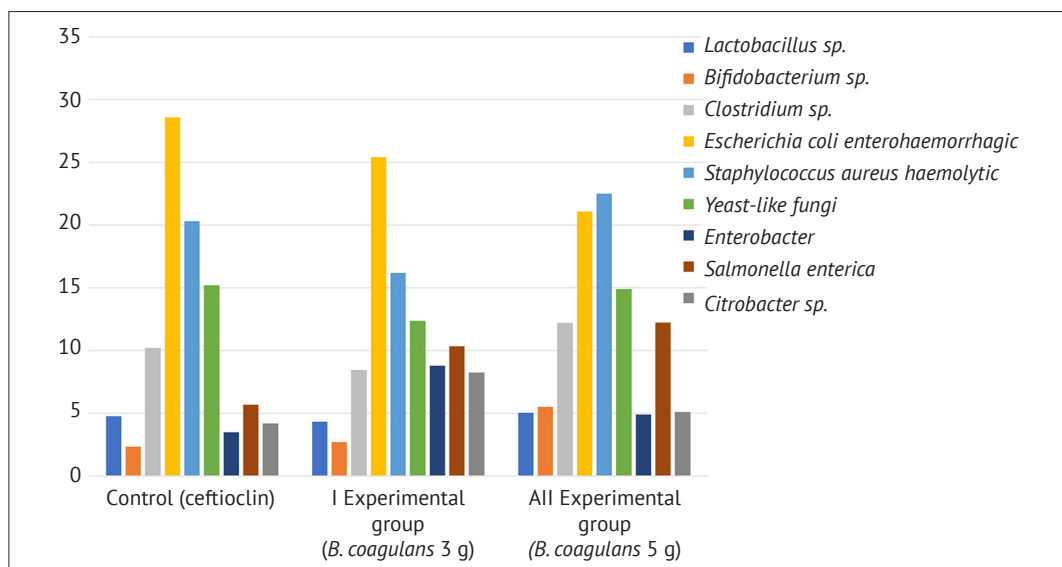


Figure 1. The results of the study of the spectrum of the microflora of calves with diarrhoea at the beginning of the study
Source: developed by the authors of this study

According to the results obtained during the experiment, it was established that at the beginning of the treatment, the level of enterohaemorrhagic *E. coli* was isolated in the range of 21.08-28.06 CFU/g in the faeces of calves suffering from dyspepsia in the control and experimental groups. Haemolytic *Staphylococcus aureus* and *Salmonella enterica* at the beginning of the calf disease were isolated from the experimental material

in the amount of 16.18 and 22.52 CFU/g, respectively (Caffarena *et al.*, 2021). Yeast fungi accounted for 12.38-15.21 CFU/g in the control and experimental groups.

Calves of the experimental group were treated with *Bacillus coagulans* ALM 86 in different concentrations (Garkavenko *et al.*, 2021). In the control group, the calves received an antibiotic to which the isolated pathogenic microflora showed maximum sensitivity (Table 1).

Table 1. Sensitivity of isolated gastrointestinal opportunistic microflora to antibacterial drugs

	Antibiotics	Sensitivity of isolates	
		<i>S. aureus</i>	<i>E. coli</i>
Group of penicillins	Ampicillin	-	+
	Amoxicillin+clavulonic acid	-	-
	Cloxacillin	+	+
Group of aminoglycosides	Gentamicin	+	+
	Streptomycin	-	±
	Kanamycin	+	-
	Neomycin	+	+
Group of macrolides	Tylosin	-	-
	Azithromycin	-	+
	Spiramycin	-	-
Quinolone derivatives	Enrofloxacin	±	+
	Norfloracin	±	-
	Ciprofloxacin	±	+
	Levofloxacin	±	+

Table 1, Continued

	Antibiotics	Sensitivity of isolates	
		<i>S. aureus</i>	<i>E. coli</i>
Different groups	Oxytetracycline	+	+
	Levomycesin (Chloramphenicol)	+	+
	Co-Trimoxazole	-	+
	Ceftioclin	+	+
	Cephalexin	+	+
	Novobiocin	-	+

Note: “+” – sensitive to the antibiotic, “±” – moderately sensitive to the antibiotic, “-” – not sensitive to the antibiotic

Source: developed by the authors of this study

According to the results of determining the sensitivity of antibiotics to the isolated microflora of *S. aureus* and *E. coli*, it was established that of the twenty drugs tested, maximum sensitivity was shown to seven drugs. Among the antimicrobial agents, a broad-spectrum

antibiotic – ceftioclin was chosen for the treatment of control group calves with diarrhoea symptoms.

After the end of the treatment, the composition of the microbiome was determined in the calves of the control and experimental groups (Fig. 2).

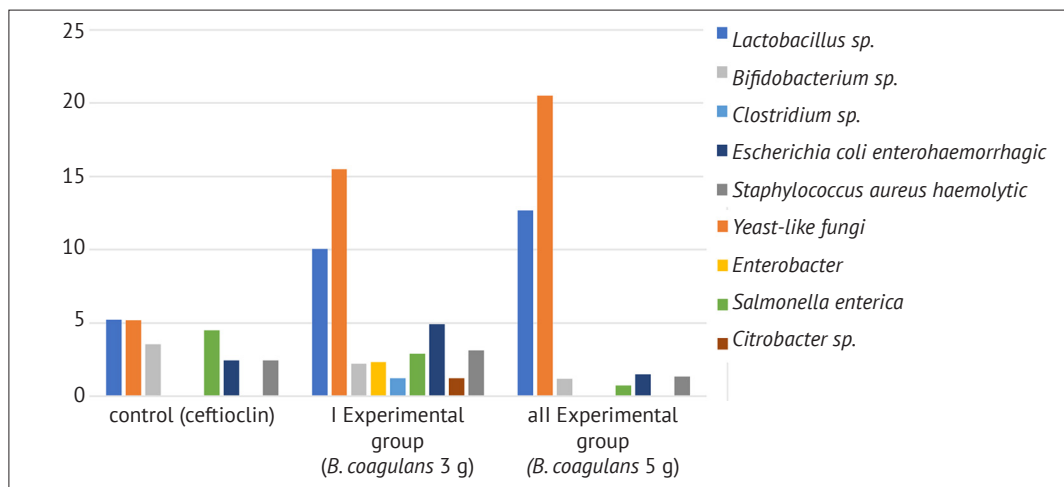


Figure 2. Composition of the microbiome of the calves of the experimental and control groups after the end of the treatment

Source: developed by the authors of this study

In the control group, after the use of the antibiotic, a reduction of *Clostridium sp.* by 65.3%, yeast-like fungi – by 70.41%, *Enterobacter* – by 30.0% and *Citrobacter sp.* – by 41.8%, compared to the beginning of treatment. *E. coli*, *S. aureus* and *S. enterica* were not released after treatment in calves of the control group with faeces, which indicates a correctly selected antimicrobial drug. However, the number of beneficial microflorae did not significantly increase due to the inhibitory property of the antibiotic (Hassan et al., 2021; Schrijver et al., 2018). The amount of *Lactobacillus sp.* after treatment increased by 9.8%, *Bifidobacterium sp.* – by 12.3%, which is a low indicator compared to the experimental groups.

In the first experimental group of animals, at the end of the study, less *E. coli* was isolated – by 90.8%, *S. aureus* – by 92.4%, *S. enterica* – by 88.01%. (Kawarizadeh et al., 2019). The reduction in the release of pathogens is associated with the properties of *B. coagulans*, which

upon metabolism releases bacteriocin – coagulins. In addition, the probiotic strain *Bacillus coagulans* ALM 86 acts on the principle of bacterial antagonism, when the bacterium in growth and development displaces other microorganisms (Peterson et al., 2020). In the second experimental group of animals, *E. coli*, *S. aureus* and *S. enterica* were not isolated at the end of the experiment.

Furthermore, during the study, it was found that the level of lactobacilli in the experimental group increased during the treatment compared to the control group of calves. Scientists (Mu & Cong, 2019) found that the mechanism of action of *Bacillus coagulans* on the intestinal microflora consists in replacing the functions of lactobacilli in the gastrointestinal tract. Due to the insufficient amount of *Lactobacillus sp.* and *Bifidobacterium sp.* probiotic *B. coagulans* performed a bactericidal function during treatment and took part in metabolism. At the end of the study, the level of *Lactobacillus sp.* and

Bifidobacterium sp. increased in the first research group by 130.8-469.8%, in the second – by 151.58-272.7%, respectively, compared to the beginning of treatment. At the same time, *B. coagulans* cannot colonise the intestine and is there only for a brief time (Maity *et al.*, 2021), it must be constantly administered into the animal's body to support the required concentration (1×10^9 , CFU/g).

In vital activity, *B. coagulans* produces an antibacterial peptide substance, as well as lactic acid, which is an inhibitor for microorganisms *Enterobacter sp.* and *Citrobacter sp.* (Aulitto *et al.*, 2022). After treatment, the number of *Enterobacter sp.* decreased in the first research group – by 44.3%; in the second – by 69.38%. The level of *Citrobacter sp.* decreased by 62.18% in the group of calves that drank *B. coagulans* in a dose of 3 g. In the second experimental group, the number of *Citrobacter sp.* decreased by 75.97%.

Yeast-like fungi were found in the composition of the gastrointestinal microflora of calves. They are

permanent representatives of normal microbiota, but their number can significantly increase during inflammatory processes in the intestine. In the first experimental group, at the end of the experiment, there was a decrease in yeast-like fungi by 76.5%, in the second – by 95.16%, compared to the beginning of treatment.

Animal experiments (Acuff *et al.*, 2021; Majeed *et al.*, 2018) demonstrate that *B. coagulans* is effective in both the treatment and prevention of *Clostridium diarrhoea*. During the experiment, it was established that the number of *Clostridium sp.* decreased with the addition of *B. coagulans* in the first experimental group by 73.7%, in the second – by 90.18%.

Results of the study of physiological parameters of calves. During the study, it was found that the frequency of dyspepsia in calves was significantly reduced, especially after 14 days of treatment (Table 2).

Table 2. Results of the study of physiological parameters of calves

Indicators	Control group	I Experimental group	II Experimental group
0-7 days of research			
Frequency of diarrhoea, %	8.56±0.10	10.35±0.12	6.22±0.15
Average daily increase, g	518.10±0.69	508.22±0.35	510.30±0.44
Average daily feed consumption, g	522.12±0.34	500.22±0.25	508.07±0.45
7-14 days of research			
Frequency of diarrhoea, %	4.56±0.10	2.42±0.08	0.42±0.06
Average daily increase, g	600.25±0.59	605.17±0.45	607.50±0.59
Average daily feed consumption, g	1,003.27±0.56	905.20±0.46	908.34±0.72
14-21 days of research			
The onset of the work of the scar	11.30±0.4	7.80±0.32*	7.50±0.18*
Frequency of diarrhoea, %	Missing	Missing	Missing
Average daily increase, g	622.52±0.74	745.45±0.79*	768.34±0.38*
Average daily feed consumption, g	1,429.12±0.38	1,610.37±0.43*	1,680.12±0.75*

Note: * $P < 0.05$ – results are probable compared to control

Source: developed by the authors of this study

The conducted study showed that the average daily gain of week-old calves and feed consumption were not equally high in all groups due to digestive problems, which manifested themselves in the form of diarrhoea (Ma *et al.*, 2020; Medrano-Galarza *et al.*, 2018). In two-week-old calves, the frequency of diarrhoea decreased, compared to the beginning of the study. The average daily gain and feed consumption was practically the same in calves of the control and experimental groups and did not differ significantly.

On the twenty-first day of the experiment, no manifestations of diarrhoea were observed in the control and experimental groups of calves. Furthermore, the average daily growth in the first experimental group increased by

19.7%, in the second – by 23.4%, compared to the control. Accordingly, feed consumption in the first experimental group increased by 15.0%, in the second – by 19.9%.

In this study, it was proven that the introduction of *B. coagulans* ALM 86 at a concentration of 1×10^9 , CFU/g at a dose of 3-5 g per animal reduces the frequency of diarrhoea, contributes to an increase in average daily growth and feed consumption (Gupta & Maity, 2021). The study by (Ji *et al.*, 2018) shows that the use of antibiotics in the diet of calves prevents rumen bacteria from breaking down cellulose and producing volatile fatty acids. It was also established (Li *et al.*, 2019) that the use of antibiotics in calves increased fermentation processes in the rumen and delayed the growth of scar tissue.

During the experiment, it was established that the start of rumen work in experimental groups of calves was earlier by four days, compared to the control group, which is confirmed by the results obtained in the work (Chang *et al.*, 2022). It was established that *B. coagulans* ALM 86 accelerated the development of cicatricial digestion in dairy calves. The results (Arshad *et al.*, 2021) confirm that the colonisation of the intestines of animals with beneficial microflora accelerates

the development of the scar. This became possible thanks to the probiotic, which accelerates the settlement of the microflora of the scar and the development of scar digestion.

Results of the study of the effect of *B. coagulans* ALM 86 on the biochemical parameters of the blood of calves.

To establish the effect of *B. coagulans* ALM 86 on the metabolism of calves, a biochemical study of blood serum was performed at the end of the experiment (Table 3).

Table 3. Results of the influence of *B. coagulans* ALM 86 on biochemical parameters of calves ($M \pm m$), $n=10$

Indicators	I Experimental group	II Experimental group	Control	Reference level
Total proteins, g/l	71.74±0.24*	74.21±0.31*	60.50±0.20	55.0-76.0
Albumins, g/l	35.40±0.12	33.22±0.10	30.41±0.17	25.0-37.5
Total globulins, g/l	35.34±0.14*	37.25±0.20*	23.67±0.25	25.0-38.5
Urea, mmol/l	4.56±0.04	4.47±0.05	3.05±0.02	3.0-6.5
Total cholesterol, µmol/l	2.02±0.03*	1.42±0.02*	3.46±0.02	1.3-4.0
Glucose, mmol/l	3.55±0.07	3.63±0.02	3.22±0.04	3.0-4.2
ALT, mmol/h l	0.70±0.04*	0.65±0.05*	1.76±0.02	0.6-1.8
AST, mmol/h l	1.36±0.08*	1.20±0.03*	3.25±0.02	0.6-3.0
Creatinine, µmol/l	80.4±0.52*	75.5±0.45*	97.0±0.32	70-110
Circulating immune complexes, mg/ml	0.05±0.03	0.07±0.05	0.08±0.03	-
Seromucoids, mg/ml	0.14±0.04	0.15±0.05	0.16±0.02	-

Note: * – $p \leq 0.05$ compared to the control

Source: developed by the authors of this study.

The obtained results (Table 3) prove that the level of total protein was higher in the first experimental group by 18.57%, in the second by 22.6%, compared to the control, due to an increase in the content of total globulins (Wenker *et al.*, 2022). Since the nutrition of the calves was high-quality and complete in all groups, the albumin level was within the reference level. In addition, the elevated level of protein metabolism in the blood of calves is more evidence of the successful treatment of diarrhoea in calves of the experimental and control groups. However, the level of total globulins was significantly higher in the first experimental group by 49.3%, in the second by 57.37% ($p \leq 0.05$), compared to the control. Other researchers have also found (Kober *et al.*, 2022) that the use of probiotics in animals improves the microbial population by stimulating the immune response and competitively crowding out pathogens in the gastrointestinal tract.

The content of urea in the calves of the experimental and control groups was within the physiological norm, but the level of urea in the animals of the control group approached the minimum values. A decrease in the level of urea (hypozotemia) in animals can be a consequence of nutritional depletion, impaired liver function, or combined kidney and liver pathology (Tsukano *et al.*, 2018). We believe that the body of the calves of the control group was more depleted because

of diarrhoea than the calves of the experimental groups that received the probiotic (Gultekin *et al.*, 2019).

Furthermore, because of the application of *B. coagulans* ALM 86 to calves, it was established that the level of total cholesterol decreased by 41.61% in the first experimental group, and by 58.95% in the second, compared to the control group (Wu *et al.*, 2018). Cholesterol levels in the body are associated with cardiovascular disease (Papotti *et al.*, 2021). An increase or decrease in cholesterol can have a negative effect on the health of animals. According to the results of the study, the creatinine level was within the biological norm in all groups of calves. However, in the first research group, the content of creatinine in the blood was probably lower by 17.11%, in the second – by 22.16%, compared to the control ($p \leq 0.05$). The level of creatinine may increase with dehydration of the body because of diarrhoea and intoxication of the body.

The level of glucose in the animals of the experimental and control groups was practically at the same level within the physiological norm, which also indicates normal metabolism in the body.

The activity of the enzyme alanine aminotransferase (ALT) in the control group of calves was at the maximum permissible limit of the reference level, which indicates intoxication of the body as a result of dyspepsia. In calves, thanks to the use of probiotic *B. coagulans* ALM 86,

ALT was significantly lower in the first group by 60.22%, in the second – by 63.06% ($p \leq 0.05$), compared to the control group. Since the maximum concentration of alanine aminotransferase is localised in the liver, the increased level of the enzyme indicates organ damage and at the same time the level of digested protein decreases (Trefz *et al.*, 2021), which can be seen from the obtained results.

The enzyme aspartate aminotransferase (AST) is also an indicator of the functioning of the liver and muscle organs (Ma *et al.*, 2022). An increase in AST indicates damage to the liver and heart muscle. In the calves of the first experimental group, the level of AST enzyme was lower by 58.15%, in the second by 63.07% ($p \leq 0.05$), compared to the control.

Circulating immune complexes and seromucoids are indicators of the manifestation of toxic reactions and inflammatory processes in the animal's body. Based on the results of the study, it was established that the level of circulating immune complexes and seromucoids in calves of the control and experimental groups was the same within physiological limits. It was reported (Yin *et al.*, 2019) that calves given probiotics had up-regulation of immune factors in serum, intestinal mucosa and mesenteric lymph nodes. This became possible thanks to the activity of *B. coagulans ALM 86*.

According to the results of the conducted research, a positive effect of *B. coagulans ALM 86* on the metabolism and physiological indicators of calves was established. The work also proved the therapeutic effect of *B. coagulans ALM 86* for dyspepsia in dairy calves.

CONCLUSIONS

Research has established that the isolated microflora from calves showed maximum sensitivity to seven antimicrobial drugs out of twenty proposed.

It has been proven that *B. coagulans ALM 86* reduces the number of conditionally pathogenic microflora and contributes to the increase in beneficial microflora in calves with the symptom of diarrhoea. At the end of the study, in the first experimental group of animals, less *E. coli* was isolated – by 90.8%, *S. aureus* – by 92.4%, *S. enterica* – by 88.01%, *Enterobacter sp.* – by 44.3%,

Citrobacter sp. – by 62.18%, *Clostridium sp.* – by 73.7%, for yeast-like fungi – by 76.5%. In the second experimental group of animals, *E. coli*, *S. aureus* and *S. enterica* were not isolated at the end of the experiment; the level of *Enterobacter sp.* decreased – by 69.38%, *Citrobacter sp.* – by 75.97%, *Clostridium sp.* – by 90.18%, yeast-like fungi – by 95.16%. The level of *Lactobacillus sp.* and *Bifidobacterium sp.* increased in the first research group by 130.8-469.8%, in the second – by 151.58-272.7%, respectively, compared to the beginning of treatment.

Studies have shown that administration of *B. coagulans ALM 86* at a concentration of 1×10^9 , CFU/g at a dose of 3-5 g per animal reduces the frequency of diarrhoea, improves physiological indicators, and accelerates the onset of scar digestion in dairy calves for four days. An increase in average daily growth and feed consumption in the first experimental group by 19.7-15.0%, in the second – by 23.4-19.9%, respectively, compared to the control was established.

An increase in total protein was recorded in the first experimental group by 18.57%, in the second by 22.6%. The level of total globulins was probably higher in the first experimental group by 49.3%, in the second by 57.37% ($p \leq 0.05$). Creatinine content in the first experimental group was lower by 17.11%, in the second by 22.16%, compared to the control ($p \leq 0.05$), which indicates intoxication of the body of calves that used antibiotics.

It was established that the level of total cholesterol decreased by 41.61% in the first experimental group, and by 58.95% in the second experimental group, compared to the control group. The activity of the alanine aminotransferase enzyme was significantly lower in the first group by 60.22%, in the second group by 63.06% ($p \leq 0.05$). The level of the enzyme aspartate aminotransferase in the calves of the first experimental group was lower by 58.15%, in the second by 63.07% ($p \leq 0.05$), compared to the control. The amount of circulating immune complexes and seromucoids was within the physiological norm, indicating no negative effect of the proposed dose of *B. coagulans ALM 86* for the treatment of dyspepsia in calves.

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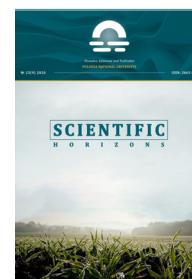
Визначення терапевтичного ефекту від застосування *Bacillus coagulans* при диспепсії телят

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Анотація. Актуальність дослідження полягає у застосуванні пробіотичного штаму мікроорганізму *B. coagulans* ALM 86 для лікування діареї у молочних телят та зменшення використання антибіотиків у тваринництві. Метою роботи було визначення терапевтичного ефекту при лікуванні діареї у телят, складу мікрофлори, фізіологічних показників та метаболізму за використання *Bacillus coagulans* ALM 86. В роботі використовували методи: мікробіологічний, мікроскопічний, біохімічний, фізіологічний, статистичний. Дослідженнями встановлено, що використання *B. coagulans* ALM 86 сприяє зменшенню кількості умовно-патогенної мікрофлори *E. coli* – на 90,8 %, *S. aureus* – на 92,4 %, *S. enterica* – на 88,01, збільшенню *Lactobacillus* sp. на 130,8–151,58 % та *Bifidobacterium* sp. на 272,7–469,8 %. Введення з *B. coagulans* ALM 86 в концентрації 1×10^9 , КУО/г у дозі 3–5 г сприяло припиненню діареї та прискоренню розвитку рубцевого травлення на чотири доби у молочних телят, порівняно з групою, де застосовували антибіотик. Встановлено збільшення середньодобового приросту та споживання корму у першій дослідній групі на 19,7–15,0 %, у другій – на 23,4–19,9 % ($p \leq 0,05$). Доведено зниження рівня загального холестерину за використання *B. coagulans* ALM 86, збільшення рівня загального протеїну на 18,57–22,6 %, за рахунок збільшення вмісту загальних глобулінів на 49,3–57,37 % відповідно ($p \leq 0,05$). Введення з *B. coagulans* ALM 86 в концентрації 1×10^9 , КУО/г у дозі 3–5 г сприяло припиненню діареї та прискоренню розвитку рубцевого травлення на чотири доби у молочних телят, порівняно з групою, де застосовували антибіотик. Отримані результати дослідження вказують на відсутність токсичного впливу запропонованої дози *B. coagulans* ALM 86 для лікування диспепсії у телят та отримання позитивного ефекту. Практична цінність отриманих результатів полягає у можливості застосування *B. coagulans* ALM 86 при лікуванні діареї у молочних телят без використання антибіотиків на тваринницьких фермах різного спрямування

Ключові слова: діарея, пробіотик, мікробіома шлунково-кишкового тракту, середньодобовий приріст у телят, молочнокислі бактерії



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Pathomorphological Changes in Intestinal Yersiniosis in Cats

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Abstract. Mammalian yersiniosis is of interest to researchers around the world, due to the expansion of the range of spread of the disease. Most publications of previous years concerned productive animals and the spread of the pathogen in environmental objects. Recently, isolated reports have begun to appear about the isolation of pathogens, yersinioses, from unproductive animals and a rather specific course of diseases. The interest of bacteriologists and epidemiologists is based on the increasingly frequent detection of *Y. Enterocolitica* pathogen in the body of so-called companion animals, which are often directly in close contact with the host. To date, the possibility of human infection from a bacterial carrier has already been proven. The purpose of this study was to clarify the main vectors of pathogenesis of spontaneous feline intestinal yersiniosis by investigating changes in the architectonics of parenchymal organs. The materials for the study were the internal organs of cats that died as a result of spontaneous intestinal yersiniosis, the diagnosis of which was established based on the clinical picture and the determination of diagnostic titres of antibodies to standard yersiniosis antigens. It was found that the feline disease is mostly asymptomatic, and due to the affinity of many pathogens of yersiniosis in animals and humans, it becomes both epizootological and epidemiological in nature. The most significant pathomorphological changes were found in the organs of cats with intestinal yersiniosis; in the organs of the gastrointestinal tract (stagnant phenomena, uneven damage to intestinal villi, sometimes crypts of the submucosal layer and vascular walls, active cell proliferation in desquamation areas); in the liver, mainly protein dystrophy, local areas of necrobiosis and cytolysis of hepatocytes; in the kidneys, congestive hyperaemia and the development of haemorrhagic diathesis, signs of vascular fragility and diapedesis bleeding, and in the case of chronisation of the process – a response to vascular endothelial damage in the form of migration of mononuclears to the future focus of inflammation; in the spleen and lymph nodes, delymphotisation of white pulp was observed, in other cases, an increase in the number of secondary lymph nodes with the formation of large reactive centres was detected in the spleen

Keywords: feline yersiniosis, pathomorphology, *Y. enterocolitica*, cellular changes



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INTRODUCTION

Earlier studies have established that intestinal yersiniosis is a zoonotic disease caused by a gram-negative bacterium from the *Yersinia* genus (Yagüe-Muñoz *et al.*, 2019; Maliy, 2016).

The disease is characterised by damage to the gastrointestinal tract, respiratory organs, arthritis, septicopyaemia, infertility in females, the birth of non-viable offspring (Tuompo *et al.*, 2017; Miyata *et al.*, 2022). Most reports indicate the dominance, prevalence, and increase in pathogenicity of *Y. enterocolitica*, among other *Yersinia* biovars (Orekhova, 2015; Razzuoli *et al.*, 2020).

Therefore, when describing the pathoanatomical picture, the greatest attention was paid to intestinal yersiniosis. Furthermore, this is also conditioned upon the important epidemiological significance of the disease. Catarrhal-haemorrhagic gastroenterocolitis, serous peritonitis, synovitis, hepatosis of lesions of female genital organs, less often – other pathologies, especially complications of the underlying disease, are described in the published materials upon the autopsy of the corpses of various animals for intestinal yersiniosis (Remsty & Tennant, 2019). Scientific information about feline yersiniosis is still limited. The study of this problem in cats was influenced by the opinion of scientists J. Remsty and B. Tennant that *Y. enterocolitica* can be a natural commensal of the autochthonous microflora of this animal species (Remsty & Tennant, 2019). The authors believe that there has recently been a powerful impact on the ecosystem of many biotic and abiotic factors, which adversely affected the environment and one of its components – saproic microflora, a representative of which is *Yersinia*. The biological properties of these bacteria were also changed by their pathogenic potential, which led to bacterial carrier and bacteraemia in many animals.

Most of the published research on this issue concerns the study of the biological properties of the pathogen, their contamination of products of animal and plant origin, diseases of productive animals (Marsicano *et al.*, 2020; Nesbakken, 2021; McNally *et al.*, 2004). But there is a lack of information regarding the pathological manifestation of feline intestinal yersiniosis. Considering the recent trend to popularise the breeding of small domestic animals prone to yersiniosis, or to being bacterial carriers of pathogenic variants of pathogens, the study of the problem of spread and transmission of this disease is truly relevant. Yersiniosis is also dangerous for humans. This fact is confirmed by the estimates of the Center for Disease Control and Prevention of the United States, which were presented in 2016. (Chlebicz & Śliżewska, 2018).

The purpose of this study was to establish characteristic pathoanatomic changes in cats with intestinal yersiniosis, which occurred spontaneously and tended to spread among other domestic animals, within the same farm.

LITERATURE REVIEW

According to existing information, *Yersinia enterocolitica* of biovars 2, 3, 4 and serotypes O:3 and O:9 are most often isolated in cats, which, as pathogens, are also common to humans (Marsicano *et al.*, 2020; Shestakova *et al.*, 2005; Wang *et al.*, 2013).

Y. enterocolitica produces an enterotoxin, the effect of which is to activate adenylate cyclase of enterocytes, as a result of which the permeability of membranes increases and causes an active release of water and electrolytes – this very process causes the occurrence of diarrhoea and, as a result, causes dehydration. At the same time, the above-mentioned enterotoxin is rather difficult to distinguish from its counterparts (McNally *et al.*, 2000). It is also noted that during parasitocoenosis of *Y. enterocolitica*, there is an increase in E prostaglandin, which confirms the role of sensitisation of the body in the development of the disease (Shestakova *et al.*, 2005).

According to J. Remsty, B. Tennant, *Y. enterocolitica* most often does not cause a disease with pronounced clinical signs in cats and dogs (Remsty & Tennant, 2019). There is even an assumption that feline *Yersinia enterocolitica* is a natural intestinal commensal and therefore does not cause clinical manifestations of the disease and these animals can be long-term carriers (Smith, 2016; Cully, 2010).

The disease proceeds in the form of acute diarrhoea with mesodenitis. The causative agent not only causes inflammation of various parts of the intestine but is also capable of affecting parenchymal organs. The pathogen was isolated from cats with chronic peritonitis (Truba & Zon, 2021). Feline intestinal yersiniosis also revealed inflammation of regional lymph nodes (mainly pharyngeal), fever, arthritis, depression and apathy, anorexia and polydipsia, shortness of breath resulting from pneumonia (pulmonary form, rare), oedema, signs of septic shock, blood clotting disorders (McNally *et al.*, 2000). A rather ambiguous signal about the disease is the presence of reactive arthritis, which affects the wrists, knee joints, and metatarsals and can turn into a chronic form and worsen even a month after the first episode of short-term diarrhoea (Bohn *et al.*, 2019). The scientific literature describes the following changes, for spontaneous canine intestinal yersiniosis, during autopsy: catarrhal-haemorrhagic gastroenterocolitis, serous peritonitis, hepatosis, focal pneumonia, nephrosis, less often – other pathologies, especially for complications of the underlying disease (Maliy, 2016). Premature births, abortions, malformed fetuses, congenital anomalies, or infertility may result from infection with *Yersinia enterocolitica* in the first stage of pregnancy. The degree of severity of the disease differs in animals of the same age group and gender (Grahek-Ogden *et al.*, 2007).

A review of the literature on this issue indicates a wide range of damage to organs and systems and does not allow identifying pathognomonic signs of the disease in cats, which substantially reduces the probability of a timely diagnosis.

MATERIALS AND METHODS

The study was conducted in 2017-2021 at the Department of Virology, Pathological Anatomy and Poultry Diseases of Sumy National Agrarian University, and during 2018-2021 – in private clinics of veterinary medicine in the Chernihiv and Sumy Oblasts of Ukraine.

Experimental studies, the results of which are presented in this paper, were based on the principles of moral values and compliance with all bioethical requirements defined by the Law of Ukraine No. 692 “On Humane Treatment of Animals” of 2008. All studies were conducted according to the bioethical requirements of the “Declaration of universal norms of bioethics (UNESCO, 2005) and Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes) and designed per Order No. 624 “On Changes to the Composition of the Commission on Bioethical Expertise of Scientific Research” of October 28, 2020.

In this paper, pathological material from the corpses of cats was used, which during *ex vivo* diagnosis gave a positive indirect hemagglutination reaction (IHAR) and an agglutination reaction (AR) with yersiniosis antigens O:3 and O:9 produced by RAO “Biopreparat” (St. Petersburg), and antigens O:3, O:6.30 and O:9 of Ukrainian production, manufactured by the State Enterprise “Veterinary Medicine” of the National Research Centre “Institute of Experimental and Clinical Veterinary Medicine” of the National Academy of Agrarian Sciences of Ukraine (Kharkiv). The IHAR was established according to the macro method, by adding equal doses of antigen-sensitised erythrocytes to successive two-fold dilutions of serum. The finished mixture was left for 2-3 hours at room temperature. The results were evaluated as follows: if the serum contains antibodies to the pathogen that sensitised red blood cells, in this case, antibodies to *Y. enterocolitica*, hemagglutination will be noticeable, which is evaluated in crosses. The highest serum dilution was taken as the serum antibody titre, which provided hemagglutination by at least two crosses. According to the results of the study, a dilution of 1:200 was considered as the diagnostic titre.

Pathological autopsy and selection of pathological material was performed from four cat corpses according to the general “Rules for the selection of samples of pathological material, blood, feed, water, and their forwarding for laboratory research”, which were approved by the head of the veterinary medicine department of the Ministry of Agriculture and Food of Ukraine P.P. Dostoevsky dated April 15, 1997, No. 15-14/111. Different clinical diagnoses were established in animals subjected to autopsy, *in vivo*, but all of them were serologically positive for intestinal yersiniosis.

Pathological material (pieces of the stomach, small and large intestines, lymph nodes, liver, spleen, kidneys) was fixed in a 10% aqueous neutral formalin solution for up to 30 days, then washed in tap water and dehydrated with alcohol solutions of increasing concentration from 40° to 96° for a day in each and double treatment with absolute alcohol (100°) for 12 hours in each solution. The material was embedded in paraffin, forming blocks, from which sections were made on a microtome, which were subsequently stained with Carazzi’s haematoxylin for 10 min and with a 1% aqueous solution of eosin for 30 sec. Stained and dried sections were placed in a Canadian balm. The section was examined under a Biolam R 15 light microscope with a primary magnification of 100 and an added magnification of 400 times. The photo was taken using a Digital Camera M 1000 PLAS series LEVENHUK Microscope using a Lenovo G 50-70 with Microsoft 10 software.

RESULTS AND DISCUSSION

Pathoanatomical examination of cats with spontaneous yersiniosis revealed mainly catarrhal enteritis or enterocolitis with single petechial haemorrhages. The mucous membrane with local redness, swelling, without natural shine, with manifestations of folding and loosening. An excessive accumulation of mucus was found in the lumen of the intestine, sometimes with splashes of blood. The vessels of the mesentery are excessively filled with blood, the lymph nodes are enlarged, the features of serous lymphadenitis with hyperaemic areas are visible on the section (Fig. 1 a-d).

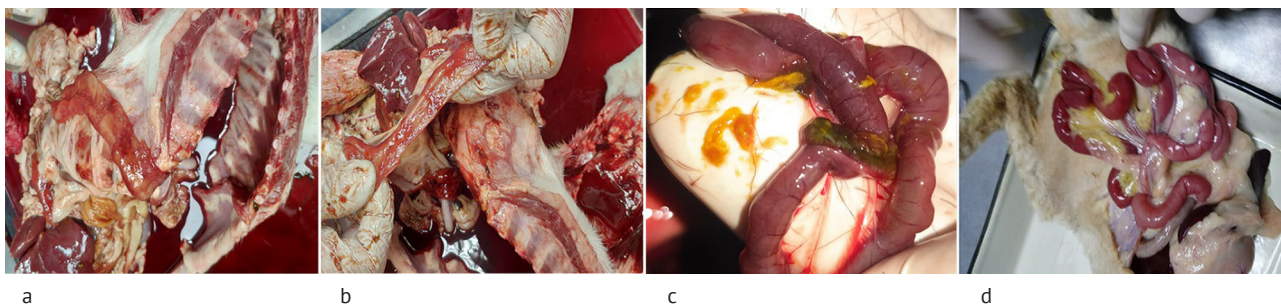


Figure 1. 1 a-d. Pathoanatomical manifestation of acute enterocolitis with petechial haemorrhages

Signs of serous peritonitis with polyserositis were observed in the abdominal cavity, which indicated the presence of fibrin flakes. In this case, parenchymatous organs showed signs of local maceration (Fig. 2 a-b). An

autopsy of one of the cat's corpses revealed a changed shape of an enlarged heart, a myocardium of flaccid consistency with thinned walls (Fig. 3 a-b).

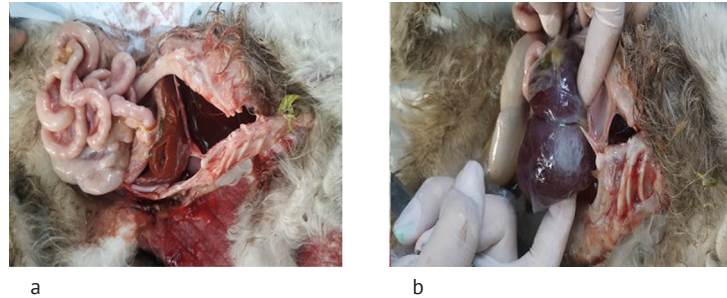


Figure 2. Serous peritonitis (a) and fibrinous overlays (polyserositis) on the internal organs of a cat (b)

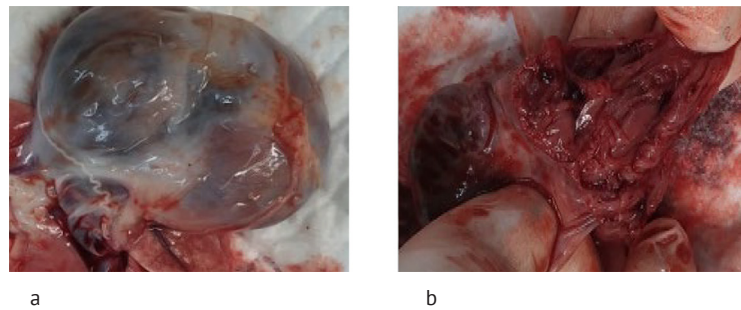


Figure 3. Changes in heart shape (a), thinning of the myocardial walls(b)

Pathoanatomically, blunted edges, discoloration, and capsule tension were detected in the liver. The colour is heterogeneous, it has a shade from dark cherry to clay, the consistency is loose, the pattern is smoothed

on the section, the scraping is moderate. The gallbladder was full of bile in all cases. The kidneys had signs of hyperaemia and granular dystrophy (Fig. 4 a-b).

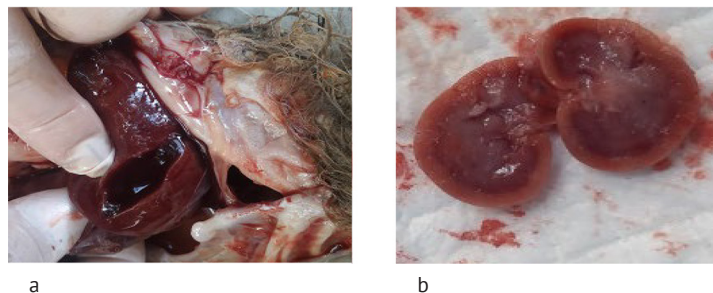


Figure 4. Hyperaemia and granular dystrophy of the liver (a) and kidney (b) of a cat

Examination of the lungs revealed congestive hyperaemia and petechial haemorrhages (Fig. 5 a-b), which occurred due to difficult outflow of blood from the organ due to compression of the heart and compaction of the lungs themselves. Hypoxia occurred in the tissues and the hydrostatic pressure in the vessels

increased, as a result of which the permeability of the capillary walls increased, which led to irreversible changes at the micro level. Furthermore, there was a growth of connective tissue in the interalveolar septa, which led to compaction of the lungs and disruption of their functioning.

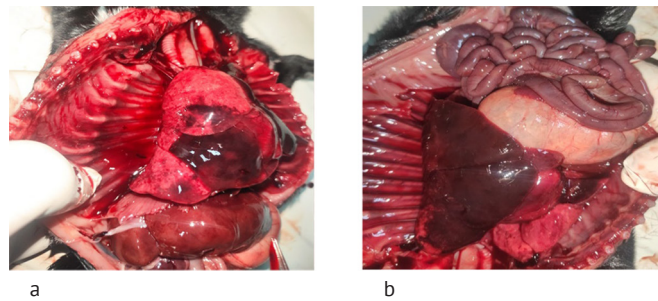


Figure 5. Congestive hyperaemia (b) and petechial haemorrhage (a) in the lungs of cats

At the microscopic level, signs of congestive processes and catarrhal bronchopneumonia were found in the affected areas of the lungs. Histological changes in

the liver were characterized by granular dystrophy, with signs of focal necrosis of hepatocytes and liver beams (Fig. 6).

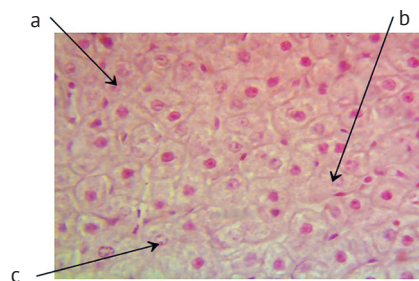
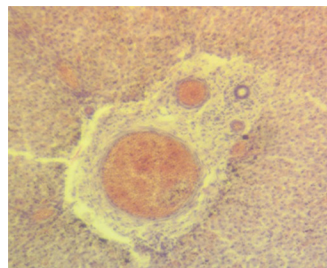


Figure 6. Granular dystrophy and signs of liver necrosis, H+E, x400

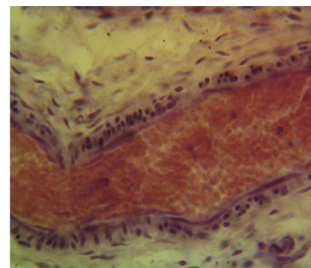
Note: a – pyknosis, b – rhexis, c – lysis of hepatocyte nuclei

Hyperaemia and perivascular oedema were observed due to effusion of fluid from the liver vessels. A substantial sign of the duration of this process is the pronounced

reproduction and proliferation of various populations of macrophages, which are located both in the vascular membranes themselves and in their surrounding space (Fig. 7).



a, H+E, x100

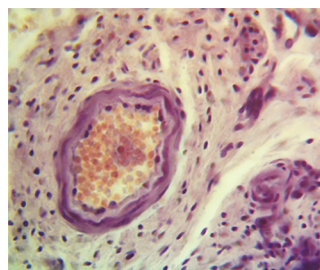


b, H+E, x400

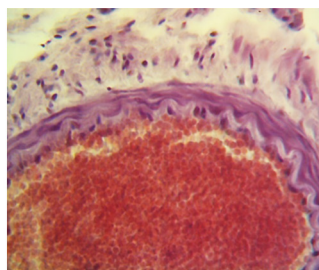
Figure 7. Hyperaemia of the liver (a) and perivascular oedema (b)

A change in the morphological state of the endothelium of vessels is quite noticeable, which can affect their anatomical and physiological features, namely rigidity, elasticity, plasticity, etc. Filled with blood, large

vessels exert pressure on their smaller representatives in the microcirculatory channel and on the bile ducts of the liver, which provokes their further dysfunction (Fig. 8 a-b).



a, H+E, x100



b, H+E, x400

Figure 8. Perivascular proliferation (a) on the background of congestive hyperaemia in the liver

When assessing morphological changes in the kidneys, it should be noted that the infectious process is accompanied by congestive hyperaemia and the development of haemorrhagic diathesis. Foremost, long-standing septic processes destroy the endothelial layer of vessels and the basal membrane, thereby causing vessel fragility and diapedesis bleeding (Fig. 9). However, in the case of chronicity of the process, a response to

vascular endothelium damage was observed in the form of migration of mononuclear cells to the future focus of inflammation, which indicates the possible permanent presence of microorganisms in these areas. Furthermore, the limited number of polymorphonuclear leukocytes in these sites indicates that the absence of stimuli for the development of exudative-destructive inflammation (Fig. 10).

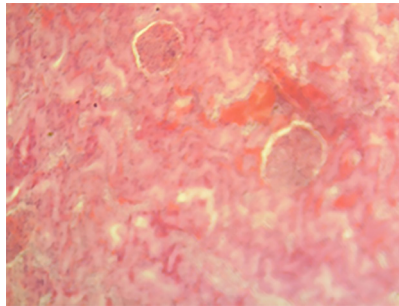


Figure 9. Hyperaemia and haemorrhagic diathesis in the kidney, H+E, x100

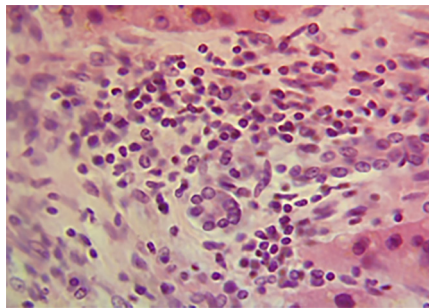


Figure 10. Active cellular response in the structures of the brain layer of the kidneys, H+E, x400

In the lymph nodes, a general decrease in lymphocytes, cellular devastation of the reactive centres of the follicles was observed, which can be a sign of both the chronic course of the disease and the development

of secondary immunodeficiency (Fig. 11). Under these conditions, the percentage ratio of stromal elements increased relative to the parenchyma of the organ.

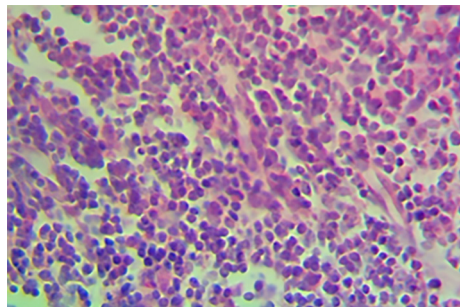


Figure 11. Lymph node delymphotisation, H+E, x400

Morphological changes in the spleen in some cases were characterised by an increase in the number of secondary lymph nodes with the formation of large reactive centres, where numerous blast forms and cells

are found in a state of mitosis. The periarterial zone increased insubstantially against the background of a substantial increase in the marginal zone of lymphatic follicles (Fig. 12 a-b).

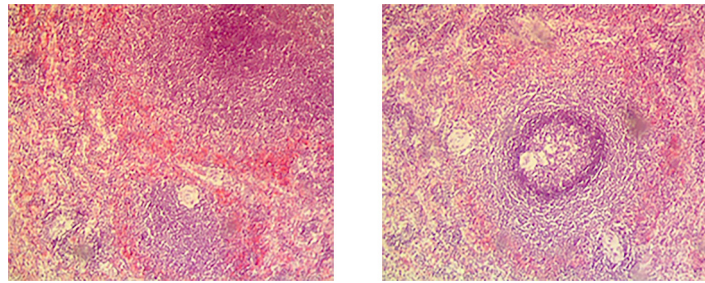


Figure 12. Hyperplasia of the lymphoid nodule of the spleen (a) with an enlarged reactive centre (b), H+E, x200

In other cases, pronounced delymphotisation of the white pulp of the organ was found, and in some cases, the formation of small cystic cavities. The nuclei

of reticulocytes in such cases were more poorly detected against the background of an increase in the number of haemosiderophages (Fig. 13 a-b).

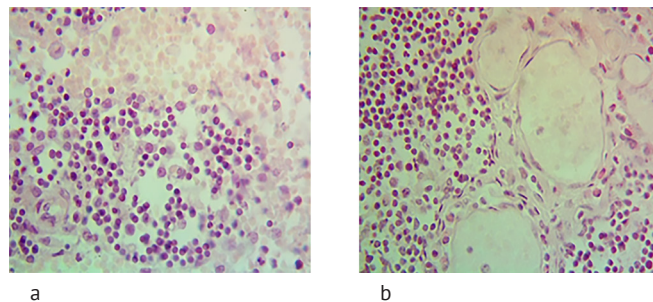


Figure 13. Delymphotisation (a) and formation of small cystic cavities (b), H+E, x400

Changes in the intestine: uneven damage to the villi, less often crypts of the submucosal layer. In certain areas, the destruction of the walls of blood vessels

is detected. Active cell proliferation is observed in the foci of damage, especially against the background of desquamative catarrh (Fig. 14).

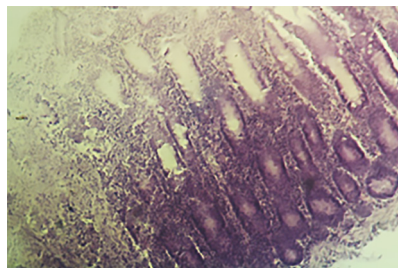


Figure 14. Uneven damage to the villi of the small intestine

Goblet cells, mostly crypts, were filled with secretions. Lymphoid nodules and Peyer's patches are swollen in places, hyperplastic due to the active movement of

lymphoid elements towards the alterative areas; their content was often depleted (Fig. 15 a-b).

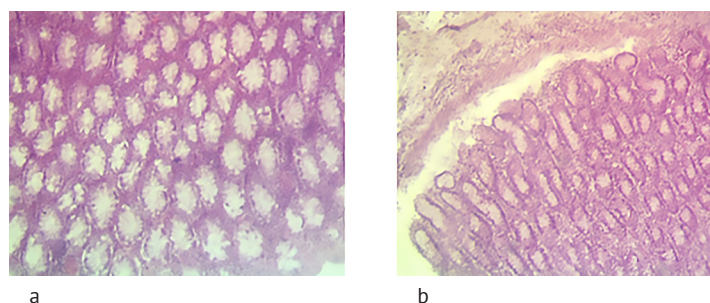


Figure 15. Hypersecretion of goblet cells (a) script of the small intestine (b), H + E, x200

Catarrhal desquamative processes were less pronounced in the large intestine. A pronounced reaction

was mainly observed on the part of goblet cells, in which mucus accumulated in excessive amounts (Fig. 16).

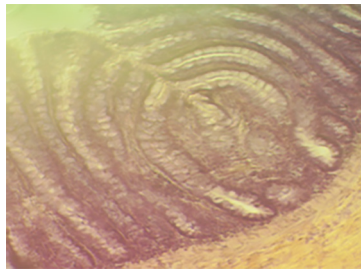


Figure 16. Reaction of goblet cells of the large intestine, H+E, x200

Pathoanatomical studies of cats with spontaneous yersiniosis revealed mainly catarrhal processes on the mucous membranes of the gastrointestinal tract. Petechial haemorrhages were found in the small intestine. Against this background, the intestinal vessels were excessively blood-filled, lymphadenopathy was observed, and the lymph nodes themselves, on the incision, had signs of serous lymphadenitis. According to the testimony of various researchers (Marsicano, *et al.*, 2020; Truba & Zon, 2021; Chebanyuk, 2013), catarrhal and haemorrhagic processes with a desquamative tendency are detected in various animals with intestinal yersiniosis, less in the stomach, and mainly in the small and large intestines. Cytoarchitectonic changes in the intestine contained signs of catarrh with uneven villi damage. In isolated cases, damage to the submucosal crypt and vascular walls was found. A rather significant cellular response was also recorded in places where the submucosal layer is disturbed, especially against the background of intense damage. The mucous membranes were swollen and riddled with haemorrhages.

Histological changes in the liver were characterised by granular dystrophy, signs of focal cytolysis of hepatocytes and liver beams. Hyperaemia and perivascular oedema were observed due to effusion of fluid from the liver vessels. The duration of this process is indicated by the pronounced reproduction and proliferation of various macrophage populations, both in the membranes of blood vessels and in the surrounding space. The studies covering intestinal yersiniosis in animals and humans describe active dystrophic-necrotic processes, especially during the pathogenic effect on the liver of *Yersinia enterocolitica* serovars O:9 and O:4 (Borysevich *et al.*, 2015; Ochoa & O'Ryan, 2018; Byun *et al.*, 2011). In the authors' research, during spontaneous infection of cats with *Yersinia enterocolitica* serovar O:9, similar data were obtained, which indicates a pronounced effect of this serovar on the gastrointestinal tract of animals.

Evaluating the detected morphological changes in the kidneys, it should be noted that the disease causes stagnant hyperaemia and the development of haemorrhagic diathesis. It is probable that bacteremia and toxemia destroy the vascular endothelial layer and

basement membrane, causing vascular fragility and diapedesis bleeding. However, in the case of chronicity of the process, a response to vascular endothelium damage occurs in the form of migration of mononuclear cells to the future focus of inflammation, which indicates the possible permanent presence of microorganisms in these areas. Furthermore, the limited number of polymorphonuclear leukocytes in the specified areas indicates the absence of stimuli for the development of exudative-destructive inflammation. Studies of some scientists describe mainly dystrophic, less often – inflammatory processes in these organs (Smith, 2016; Chebanyuk, 2013; Maliy, 2016). According to the authors, the expansion of the spectrum of lesions may be due to many factors that, for certain reasons, may not be considered due to the lack of anamnestic data and the possibility of diagnostic studies.

In the lymph nodes, a general decrease in lymphocytes, cellular devastation of the reactive centres of the follicles was observed, which can be a sign of both the chronic course of the disease and the development of secondary immunodeficiency.

Morphological changes in the spleen in some cases were characterised by an increase in the number of secondary lymph nodes with the formation of large reactive centres, where numerous blast forms and cells are found in a state of mitosis. The periarterial zone increased insubstantially against the background of a substantial increase in the marginal zone of lymphatic follicles. In other cases, pronounced delymphotisation of the white pulp of the organ was found, and in some cases, the formation of small cystic cavities. The nuclei of reticulocytes in such cases were worse against the background of an increase in the number of haemosiderophages.

It is known that when a bacterial antigen enters the body, a serous-fibrinous inflammation develops in the local tissue, which is initially accompanied by a microphagic (neutrophil) reaction, which is later replaced by a macrophage reaction. Under the conditions of antigenic stimulation (sensitisation), characteristic changes in organs of the lymphoid tissue occur.

Antigenic irritation of any nature in infectious and invasive diseases causes some morphological changes

in the organs of the central and peripheral immune system (Shestakova *et al.*, 2005; Razzuoli *et al.*, 2020). Therefore, the changes in the relevant organs detected by the authors can be associated with the influence of *Yersinia enterocolitica* on the body of cats.

Immunomorphological changes in the organs of the immune system are known to be characterised by the following reactions of the same type. The micro- and macrophage reaction is accompanied by an increase in the number of neutrophils and macrophages in the sinuses, blood vessels, organ parenchyma, antigen phagocytosis by them, the same changes are present during infection in the lymph nodes, spleen, bone marrow, tonsils, Peyer's plaques, and lungs. That is why the authors chose these organs for research, where active immunogenesis occurs.

The so-called blast reaction of B-lymphocytes (blast transformation) is characterised by an increase in the number of secondary lymphoid follicles with large reactive centres containing B-lymphoblasts in the lymph nodes, spleen, tonsils, Peyer's patches, and lungs. The authors also determined signs of this reaction during pathomorphological studies.

The authors also found the blast reaction of T-lymphocytes, which is accompanied by the expansion of the thymus-dependent zones of the paracortical layer of lymph nodes and the periarterial zone of the lymphatic follicles of the spleen due to the intensive proliferation of T-lymphoblasts, in the corresponding parts of the organs. An increase in the number of secondary lymph nodes in the spleen, tonsils, Peyer's patches (aggregated lymph nodes) was usually pronounced when bacterial antigens were administered. However, the devastation of the lymph nodes, revealed during the study, is considered to be a consequence of impaired immunogenesis.

Thus, the identified changes in the peripheral lymphoid tissue are most inherent in antigenic stimulation (sensitisation) of the body and are manifested by a macrophage reaction, hyperplasia of lymphocytes, with

their successive plasmacytic transformation, increased permeability of microvessels, and interstitial oedema. Established changes in the intestine may indicate an enzymopathy of the intestinal glands, and damage to lymphoid nodes is one of the causes of impaired immune response in general.

CONCLUSIONS

1. Intestinal yersiniosis of cats, during a spontaneous course, is patho-anatomically characterised by pronounced catarrhal changes mainly in the small intestine, inflammation of abdominal lymph nodes, stagnant, dystrophic processes in the liver and lungs. In the abdominal cavity, in several cases, signs of serous peritonitis with polyserositis were observed, and in the kidneys – signs of hyperaemia and protein dystrophy, in the lungs – stagnant hyperaemia and petechial haemorrhages.

2. Histological changes in spontaneous intestinal yersiniosis in cats were characterised by hyperaemia and perivascular oedema, granular dystrophy with signs of focal necrosis of hepatocytes and liver beams, in the kidneys – stagnant hyperaemia and the development of haemorrhagic diathesis, in the lymph nodes by lymphotisation, in the spleen, in some cases, an increase in the number of secondary lymph nodes with the formation of large reactive centres, and others with pronounced devastation of the white pulp of the organ. Changes in the intestine were defined as an uneven catarrhal inflammation with partial or complete damage to the villi, sometimes the crypt and the endothelium of the vessels.

Further research will be aimed at developing diagnostic tests for intestinal yersiniosis in small animals on a molecular genetic basis.

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Патоморфологічні зміни за кишкового ієрсиніозу котів

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Анотація. Ієрсиніози ссавців викликають зацікавленість дослідників різних країн світу, у зв'язку з розширенням ареалу розповсюдження хвороби. Переважна кількість публікацій минулих років стосувалась продуктивних тварин та розповсюдження збудника в об'єктах довкілля. В останні роки почали з'являтися поодинокі повідомлення про виділення збудників, ієрсиніозів, від непродуктивних тварин та досить специфічний перебіг хвороб. Зацікавленість бактеріологів та епідеміологів базується на все частішому виявленні збудника *Y. Enterocolitica* в організмі так званих тварин-компаньйонів, які часто безпосередньо знаходяться в тісному контакті з господарем. На сьогоднішній день вже доведена можливість інфікування людини від бактеріоносія. Метою досліджень було з'ясувати головні вектори патогенезу спонтанного кишкового ієрсиніозу котів шляхом вивчення змін в архітектоніці паренхіматозних органів. Матеріалами для досліджень були внутрішні органи котів, які загинули внаслідок спонтанного кишкового ієрсиніозу, діагноз який встановлювали на підставі клінічної картини та визначення діагностичних титрів антитіл до стандартних ієрсиніозних антигенів. Встановлено, що захворювання у котів перебігає переважно безсимптомно, а у зв'язку зі спорідненістю багатьох збудників ієрсиніозу у тварин і людини набуває як епізоотологічного, так і епідеміологічного характеру. Виявлені найбільш суттєві патоморфологічні зміни в органах котів за кишкового ієрсиніозу; в органах шлунково-кишкового тракту (застійні явища, нерівномірне пошкодження ворсинок кишечнику, іноді крипт підслизового шару та стінок судин, активна клітинна проліферація в ділянках десквamacії); в печінці – переважно білкові дистрофії, локальні ділянки некробіозу і цитолізу гепатоцитів; в нирках виявляли застійну гіперемію та розвиток геморагічного діатезу, ознаки ламкості судин та діapedезну кровоточивість, а в разі хронізації процесу – відповідь на ушкодження ендотелію судин у вигляді міграції мононуклеарів у майбутнє вогнище запалення; в селезінці та лімфатичних вузлах спостерігалась делімфотизація білої пульпи, в інших випадках в селезінці виявляли збільшення кількості вторинних лімфатичних вузликів з утворенням великих реактивних центрів

Ключові слова: ієрсиніоз у котів, патоморфологія, *Y. enterocolitica*, клітинні зміни

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Sickness Rate of Service Dogs in Cynological Centers of Ukraine

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Abstract. Service dogs are an important asset of law enforcement agencies. Therefore, understanding their medical problems, knowing general characteristics such as numbers, age, breed, gender, and purpose is crucial to maintaining their health and readiness to perform complex tasks. Analysis and dissemination of such information is an urgent task for specialists and scientists dealing with the problems of keeping, providing, and veterinary care for service dogs. The purpose of this study was to analyse the results of statistical reports on the incidence of service dogs from 24 regional canine centres of law enforcement agencies of Ukraine. In total, data on 822 service dogs and records of 839 cases of diseases were considered. Data on the number, age, gender, and direction of use of service dogs were also analysed. It was found that internal non-contagious ailments were identified among the diseases. Most of the problems were with the gastrointestinal tract: dyspepsia, alimentary enteritis, and gastritis. It was found that among the diseases of the visual and hearing organs, otitis media and cataracts were most often detected. Traumatic injuries accounted for 16.7% of all records, most of which were classified as wounds. It was found that every seventh disease was related to the skin. Among them, two diseases had a considerable predominance: dermatitis and eczema. Another group was detected with a frequency of more than 5% – parasitic diseases, of which babesiosis was the most common. The study also found that one in twenty animals had diseases of the musculoskeletal system, of which arthritis and hip dysplasia were mainly found. Statistical calculations have shown heterogeneity in the distribution density of dogs, both in relation to the population and the area of the region. Chernivtsi Oblast had the best density indicators, and Zhytomyr Oblast had the lowest. Among service dogs, females have an advantage – sexual differentiation was 1/1.15. An even distribution of the number of service dogs by age was found, ranging from 2 to 7 years, with a weighted average age of 4.9 years. The most common breeds were: German and Belgian shepherds, as well as Labrador. Special and search dogs prevailed for their intended purpose. The practical value of this study lies in the fact that certain patterns of morbidity of service dogs provide an opportunity to change the strategy of their selection, training, and treatment to use this valuable resource more effectively

Keywords: cynological units, differentiation of diseases, number, age, breeds, sex, areas of use of service dogs



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INTRODUCTION

Since their domestication over 30,000 years ago, dogs have played a significant role in human evolution (Wang *et al.*, 2016). Domestic dogs (*Canis lupus familiaris*) are common in modern society, helping people in various situations. Among domestic animals, dogs have the most developed intelligence. In tests of elementary mental activity, they demonstrate high results, inferior only to great apes, dolphins, and some birds. For instance, dogs successfully solve cognitive tasks to extrapolate the direction of movement of an object and tasks to operate with the empirical dimension of shapes. S. Coren (2016) points out that according to several behavioural indicators, the mental abilities of dogs are close to those of a human child aged 2 to 2.5 years. The strongest instinct of a dog is social behaviour, which manifests itself not only in relation to its species, but also in interspecific interaction. After studying about 500 mammals, Oxford University scientists S. Shultz & R. Dunbar (2010) reported that dogs are the most social of domestic animals. The listed aspects made it the best friend and helper of human from all domesticated animals.

However, dogs have some qualities that allow using them as helpers for special needs. The value of dogs lies in the ability to perform tasks that humans cannot perform, such as detecting odours. Search for explosives, drugs, psychotropic substances, search work, security, and protection – these are functional properties that allowed distinguishing some breeds in the group of service dogs for performing specialised tasks.

Bezpalova *et al.* (2019) note that today, both in Ukraine and around the world, service (working) dogs are used for a vast range of activities – from protection to involvement in combat operations. They are usually used in the field of law enforcement and rescue structures (army, border guards, police, fire departments, customs, mountain rescue services, etc.) where the conditions of maintenance and use differ substantially from the environment where domestic dogs exist.

Service dogs of cynological units of law enforcement agencies perform a variety of tasks, which are usually characterised by considerable deviations from the average loads inherent in pets. This determines the specific features of their maintenance and use, which in turn creates the presence of specific health issues.

Issues with the incidence of service dogs are widely covered in the scientific literature. Currently, there is no centralised method for tracking traumatic injuries or illnesses in service dogs used in law enforcement or the armed forces. However, a memorial site has been created that contains an extensive list of service dogs that have died or been euthanised in service from 1940 to the present day, and new cases are regularly added (Cortina, 2022). M. Martini *et al.* (2017) note that collecting data on the causes of injury or death in dogs can help develop new treatment, care, and training strategies that can increase their survival.

Numerous results of studies on the incidence of service dogs have been published. Various causes of their death, euthanasia, or culling are reported in the studies, the main ones being osteoarthritis, degenerative joint disease (Parr *et al.*, 2013; Moore *et al.*, 2001), neoplasia (Evans *et al.*, 2017; Jennings & Butzin, 1992), as well as diseases of the gastrointestinal tract (Moore *et al.*, 2008; Andrews *et al.*, 2018). Among similar studies conducted in Ukraine, it is necessary to pay attention to the papers of Levchenko (2008), Fasolia (2011), Gudyma (2013), Demchuk *et al.* (2005).

The development of a progressive approach to animal husbandry sets new, more humane requirements for animals. M. Demchuk and O. Staennyi (2005) point out that the realisation that an animal is not a mechanism endowed with receptors and reflexes, but a living being with its inherent behaviour, feelings of fear, pain, joy, with its individual needs and personality, not only physiological, but also mental, is necessary for every person. M. Cobb *et al.* (2021) emphasise that the issue of morbidity of any dog, including service dogs, should be considered in a broader aspect, namely, from the standpoint of the animal welfare concept. D. Mellor *et al.* (2020) argue that the current idea of animal welfare comprises 5 domains: 1 – nutrition, 2 – physical environment, 3 – health, 4 – behavioural interactions, 5 – mental state. Two of them, the health and mental state of the animal, directly affect the incidence of service dogs.

Data collection for all domains is of broad practical importance. The identified quantitative characteristics allow analysing and identifying the causes of diseases, generalising by breed, age, features of maintenance and performance of official tasks, etc. Equally important is the creation of open databases, based on which to determine the full profile of the risk to which dogs are exposed. Maintaining healthy police dogs costs up to \$1,500 per year (Royal Canadian Mounted Police, 2022). Given the massive costs of acquiring, training, and maintaining highly qualified animals, such as service dogs, information from such databases can change strategies for selecting, training, and treating animals to make better use of this valuable resource.

In modern society, statistics is one of the main tools for analysing any data. Processing and analysis of information allows obtaining the necessary generalisations and draw conclusions about further correction at the macro- and micro-levels of the phenomena and processes under study. *The purpose of this study* was to evaluate statistical data on the morbidity, breed, age, and gender structure of service dogs in the dog training centres of law enforcement agencies of Ukraine.

MATERIALS AND METHODS

To fulfil this purpose, statistical research methods were used, namely: a one-time observation plan and a variational method of grouping by the features under study.

Indicators for calculations were taken from a specialised reporting form, developed by scientific and pedagogical staff of the department, which was sent by the organisation department of the canine service of the National Police of Ukraine to all canine centres. Statistical observations were based on the annual reports of 24 dog training units of the law enforcement agencies of Ukraine for 2021. The objects of observation were service dogs. The study took place in four stages.

The first stage included receiving reports from 24 dog training centres according to a specialised reporting form. The main information concerned the incidence of service dogs. A total of 839 cases of pathologies and lesions were described. The reports also contained information on the total number of dogs, their gender, and breed differentiation, the age of the animals and the number depending on the area of application. The status of animal sterilisation was not recorded.

At the second stage, the received data was verified.

At the third stage, two databases were formed: database 1 – indicators of morbidity of service dogs;

database 2 – indicators of the number, age, breeds, gender, and area of use of service dogs.

The final fourth stage included statistical calculations and analysis of the results obtained.

Calculations were performed in the standard Microsoft Excel 2013 package.

RESULTS AND DISCUSSION

The extent of diseases in dogs depends on many factors. The study of Uddin *et al.* (2021) shows that such dependence can be based on age, gender, breed, and even season. For service dogs, the risk level for pathologies and lesions increases due to the specifics of the tasks they perform. Therefore, first, the authors consider the statistical calculations regarding the number, breed, age, and gender differentiation and the distribution by purpose of service dogs from 24 cynological centres of Ukraine.

Number of service dogs. The study used data on 822 dogs. The number of service dogs in regional dog training centres of Ukraine is presented in Figure 1.



Figure 1. Number of service dogs in dog training centres of Ukraine

The number of service dogs involved in the law enforcement agencies of different countries varies substantially. There are also no registers of their number, which generates different information. In 2010, D. Watson, director of the North American Police Dog Association, estimated that there could be about 50,000 active police dogs in the United States. But that figure may be higher now, given the growing need for trained pups to help officers and sniff out bombs and drugs (Surprising cause of..., 2021). There are about 2,500 animals working in the UK police force (Who we help, 2004). The official police report of the Ministry of Defence shows that the real number of dogs in this department from 2012 to 2018 ranged from 210 to 283 individuals (Police Dog and Police Horse..., 2019).

The kennel unit of the Sri Lanka Police currently has about 250 working dogs in 56 different locations in the country (Dissanayake *et al.*, 2021). The Finnish police employ 260 police dogs and 240 dog handlers (Police dogs, 2022). There are about 2,500 combat and service dogs in the service of the US Army (Lagutchnik *et al.*, 2018).

However, an essential point of such statistics is not the quantity, but the quality of providing service dogs to certain regions in different countries. Therefore, truthful information is statistics of relative indicators that show the density of dogs per unit area or the population of the region where the dog training unit patrols. The following is a comparison of the results of the authors' own research and data from three urban and county dog training centres in Poland, which geographically borders

Ukraine and has many similar socio-cultural features (Gąsiorowski, 2019). The comparison results are presented in Table 1. Ukraine is represented by three regions:

Chernivtsi, Dnipropetrovsk, and Zhytomyr oblasts, respectively, with the highest, average, and minimum density in terms of the ratio of population and service dogs.

Table 1. Density of service dogs in different regions of Ukraine and Poland

Regions	Number of service dogs (N)	Population, people (P)	Area, km ² (S)	P/N	S/N
Ukraine					
Dnipro	79	3,176,648	31,914	40,211	404
Zhytomyr	24	1,208,212	29,832	50,342	1243
Chernivtsi	30	901,632	8,097	30,054	270
Poland					
Bydgoszcz	89	2,086,210	17,972	23,441	202
Białystok	64	1,188,800	20,187	18,575	315
Gorzów	29	1,018,084	13,988	35,106	482

Source: compiled by the author

Density indicators for Ukraine are worse than in Poland, except for the Chernivtsi Oblast. But the real need for service dogs is mainly determined by the number of tasks they have to perform, although relative indicators usually correlate with the population density of the region (Shichor *et al.* 1979; Nolan, 2004).

Distribution by gender. The generalised results of the study of the sexual differentiation of service dogs showed that females are more often used in cynological units of Ukraine, and the ratio between males and females is 1/1.15.

Both males and females are excellent service dogs. But statistics from the United States, Canada, Great Britain, Australia, and New Zealand show that males significantly outnumber females. Thus, females make up only 15% of working dogs in Alberta (Canada). In the United States, most dogs that work for the police are males (Is There a Reason..., 2022). During operations Desert Shield and Desert Storm, the United States deployed 118 military working dogs to the Persian

Gulf theatre. The sex ratio was 80% of intact males, 12% of neutered females, and 8% of neutered males (Burkman *et al.*, 2001).

Gender plays a substantial role in the abilities of a service dog, such as the ability to detect drugs. German Shepherd males are much easier to train than females. Intact German Shepherd males and females are much more trainable than castrated dogs (Abdel Fattah & Abdel-Hamid, 2020). Male dogs are more aggressive and stronger, so they are often chosen for police service. Most K9 dogs are males. However, females are increasingly joining the work as K9 service dogs (K10 Workingdogs, 2022). But they are used more for a special purpose: detecting bombs, drugs, contraband, etc.

Age indicators. Analysis of the distribution of service dogs by age in selected cynological centres of Ukraine showed a uniform distribution of the number with a gradation of 12 months, except for young (up to 1 year, 1.95%) and old dogs (over 7 years, 17.9%) (Table 2). The weighted average age of a service dog was 4.9 years.

Table 2. Distribution of service dogs by age

Age of the dog	Up to 1 year	1-2 years	2-3 years	3-4 years	4-5 years	5-6 years	6-7 years	Over 7 years
Amount, %	1.95	11.9	14.8	16.2	14.8	13.5	8.2	17.9

Source: compiled by the author

Since different breeds are used in law enforcement, the lifespan of service dogs can vary greatly. In general, their life age can range from 9 to 15 years. According to a survey of police canines in New Zealand, the average age of 158 service dogs was 3.2 years (Baltzer *et al.*, 2019). A similar figure for 1,220 police dogs referred to Baghdad Veterinary Hospital in 2015-2017 was 4.6 years (Tamimi & Wali, 2019). The average age of military working dogs used during Operation Iraqi Freedom II was 6.33 years (Toffoli & Rolfe, 2006).

A thorough investigation of the age indicators of service dogs divided into seven categories of service is presented in the paper (Kania-Gierdziewicz *et al.*, 2018). Considerable variability in the age of dogs at the time of discharge was observed depending on the type of service. Thus, dogs used in riot control units were released at the age of 5.1 years, and service dogs of the patrol and investigative service and anti-terrorist units – at the age of 7 years. The oldest age at the time of release was reached by dogs of the patrol, investigative, and guard

service, which were 9 years old or older at the time of discharge. Service life was highest in patrol and investigative dogs, at 7.6 and 7.5 years, respectively. The length of service in certain groups showed similar trends to those observed for the previously considered indicator, i.e.,

the age at dismissal. Gender differentiation. The service dog breeds in 24 cynological centres of were analysed. It was established that 6 breeds are mainly used in law enforcement agencies, among which Labrador, German and Belgian Shepherds are most often involved (Fig. 2).

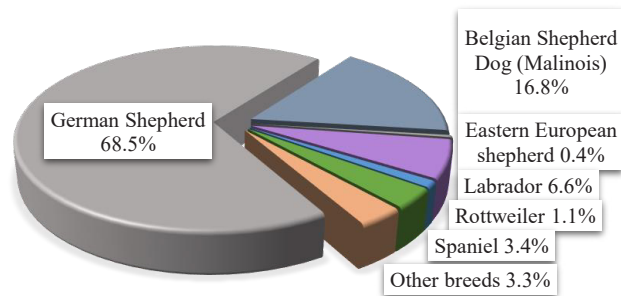


Figure 2. Number of service dogs in dog training centres of Ukraine

According to K-9, the most popular breeds are German Shepherds, Belgian Malinois, Dutch Shepherds, and sometimes hybrids of these breeds. Rottweiler, Doberman, and Flemish Bouvier are less popular. Other breeds are more commonly used as searchers (National Police Dog Foundation, 2021).

The UK Metropolitan Police has approximately 320 dogs working in 6 key locations in North, South, East, and West London, including a dog training facility. Approximately 60% are general purpose dogs. These are mainly German Shepherds or Belgian Malinois. The remaining 40% are specialised search dogs (English springer spaniels, Labradors, and cocker spaniels) (Metropolitan Police Service, 2016).

In the Polish police, the best breed is the German Shepherd. Research results show that more than 73% of dog handlers work with dogs of this breed. Belgian Shepherds are less popular, as only 14.9% of the surveyed dog handlers work with them. The Labrador breed is the least used (1.95%) (Gašiorowski, 2019).

Similar information can be found in the review (Zink & Schlehr, 2020), which states that the German Shepherd, Belgian Malinois, and Labrador Retriever are the most common breeds of working dogs.

A similar pattern is observed among military dogs. An analysis of the release of 268 US Department of Defense service dogs between 2000 and 2004 found that the main breeds were German Shepherds (120 animals) and Belgian Malinois (100 animals) (Evans, 2007).

Areas of use. Service dogs relate to perform various tasks. They are used in activities related to the search for narcotic drugs (weapons, money), prevention of terrorist manifestations, search for explosives, detention of individuals who are trying to leave the crime scene, when searching for tools or means of committing an offence, to help search for the bodies of dead or missing people, to identify traces of blood, to maintain public safety and order, etc. (Allsopp, 2012). Therefore, the number of service dogs and how they are used may vary. This is also related to the developed strategies of countries according to their policies and needs to achieve the most efficient operation of the dog training service.

In practice, depending on the functional use, the following groups of service dogs are most often distinguished: search, patrol-search, special, convoy, sentry. According to this distribution, an analysis of the use of service dogs of the law enforcement agencies of Ukraine was carried out (Table 3).

Table 3. Distribution of service dogs of law enforcement agencies of Ukraine depending on the application

Search	Special	Patrol and search services	Convoys	Sentries	Backup services	Other
38.81	41.73	7.66	1.46	2.31	7.3	0.24

Source: compiled by the author

As of April 2019, 646 dog handlers and 929 service dogs worked in the dog training units of the National Police of Ukraine, of which 390 or 42% were search dogs (Garmash, 2019).

For instance, in Turkey, dog handlers are trained in six different areas: narcotics, explosives, arms smuggling,

intelligence, corpses and patrol dogs, and the most suitable field of activity for each dog is determined through special ability tests, after which training is carried out in a particular area (Sebnem Ozcan *et al.*, 2009).

In Poland, most dog handlers work with patrol and tracking/sniffing dogs (50.65%). They accompany

police officers on patrol and take part in measures to ensure and restore public order during mass events, mass gatherings and pursuits of suspected criminals, ambushes, and blockades. Overall, more than half of the dogs have single skills compared to individuals that have “dual” skills. Among the categories of dogs with special abilities, the group of dogs trained to detect the smell of drugs is most represented (11.69%). A small

percentage of dogs are trained to detect the smell of explosives (3.25%) (Gąsiorowski, 2019).

Morbidity of service dogs. In the study, 839 records of diseases of service dogs in the cynological centres of Ukraine were analysed. They are divided into 10 sectors (Fig. 3). This differentiation allows identifying the 5 most common groups of diseases (together 82.9%), for further and more thorough analysis.

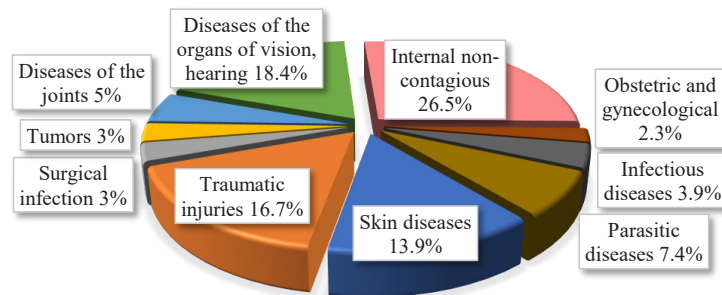


Figure 3. Group differentiation of diseases of service dogs of canine centres of Ukraine

It was found that more than a quarter of all cases are related to internal non-infectious diseases, most of which are associated with the gastrointestinal tract. The following positions were taken by diseases of the visual and hearing organs, injuries, skin diseases, and parasitic ones.

There are some scientific papers that provide generalised data from large-scale studies on the incidence of service dogs. Thus, an analysis of the incidence of 1,220 police dogs sent to the Baghdad Veterinary Hospital in 2015-2017 (mainly German Shepherds and Belgian Malinois, whose average age was 4.6 years) showed that congestive heart failure, babesiosis, various malignant tumours, and intestinal parasites were diagnosed most often (Tamimi & Wali, 2019).

In the paper cited earlier, Uddin *et al.* (2021) analysed data on 1,557 cases of various diseases collected in the registration book of the Dhaka Central Veterinary Hospital (Bangladesh). The results showed that the highest proportional morbidity was noted for infectious diseases (53.8%), followed by non-infectious diseases (23.4%) and the lowest for non-specific (22.7%) cases.

Quantification of medical problems in 774 military working dogs (US) and analysis of factors associated

with common diseases between one and six years of age (mean 2.6 ± 0.5) revealed that 83% of dogs had non-surgical medical problems. The most common of these were dermatological (25%), alimentary (21%), dental (15%), soft tissue injuries (10%), and musculoskeletal conditions (4%) (Schuh-Renner *et al.*, 2021).

A retrospective study of the causes of death or euthanasia of 927 U.S. military working dogs found that 76.3% of cases were associated with appendicular degenerative joint disease, neoplasia, spinal cord disease, non-specific ageing, and stomach inversion. The authors of the study also claim that for most military service dogs, death or euthanasia is the result of several diseases usually associated with old age (Moore *et al.*, 2001).

Analysis of the incidence of service dogs in Ukraine showed that the largest share of problems is associated with internal non-infectious diseases (26.5%), most of which are related to the gastrointestinal tract (69.8%). Among the pathologies of the gastrointestinal tract, there are three problems: dyspepsia, alimentary enteritis, and gastritis (Fig. 4). These diseases cover almost three-quarters of all problems with the digestive system and just over half (51.3%) of all internal non-infectious diseases.

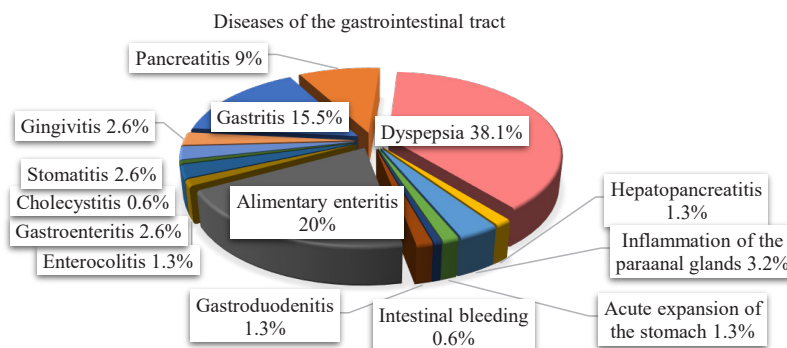


Figure 4. Distribution of gastrointestinal diseases in service dogs of Ukraine

Among other non-infectious diseases that are not related to the digestive system, most of the records were related to the respiratory system (8.1%) and allergies (5.4%).

The study by J. Alves *et al.* (2021) analysed dyspepsia problems in service police dogs. Among 188 animals with an average age of 5.2 years (80 Malinois, 52 German Shepherds, 25 Labradors and 19 Dutch Shepherds), the prevalence of diarrhoea was 10.6%, and 4% were diagnosed with a liquid form. In 151 police dogs (sentries and search for explosive objects) used to protect organisations of high economic importance and tourism in Egypt, diarrhoea occurred in 9.1%, vomiting – in 5.2% (Haithem *et al.*, 2011). G. Rakha *et al.* (2015) conducted an extensive study of 3,864 dogs in the city of Cairo, which showed that diarrhoea with vomiting occurred in 29.2% of animals.

Alimentary enteritis is mainly caused by improper feeding of dogs, i.e., it occurs due to problems with the

upkeep and maintenance of animals. This arouses the interest of researchers in this problem rather as management and upkeep features than the morbidity of dogs, despite their purpose. In a study of military dogs, Schuh-A. Renner *et al.* (2021) showed that among the most common non-surgical medical problems, alimentary problems were also in second place (21% of records).

Regarding gastritis, the study by N. Tamimi and A. Wali (2019) indicated a small proportion of animals that had a similar pathology in service dogs (0.66%). In the study of J. Alves *et al.* (2021), a comparable situation was found in domestic dogs (1.94%).

Problems with the organs of sight and hearing in Ukrainian service dogs were noted in 154 records. Most diseases of the visual organs are associated with cataracts (7.75% of all records), hearing organs – with otitis media (9.65% of all records) (Fig. 5).

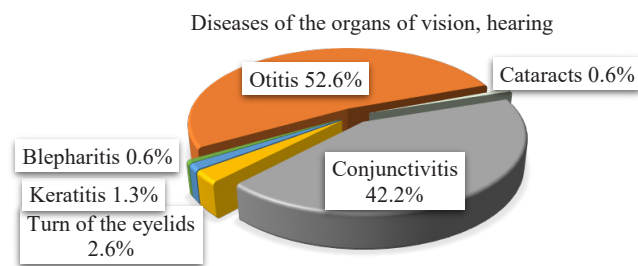


Figure 5. Diseases of the visual and hearing organs in service dogs of Ukraine

Eye diseases substantially affect the professional fitness of dogs. Thus, ophthalmic diseases in police and military dogs were the cause of 1.4% of medical emergencies (Parr *et al.*, 2013), 2.4% of discharges from service (Evans *et al.*, 2007) and 11% of deaths and euthanasia (Moore *et al.*, 2001). In a study of 71 service dogs (61 police, 10 handlers), eye abnormalities were found in 38 (54%) animals, the most common of which was primary cataract (Oliveira *et al.*, 2020).

Analysis of the spread of otitis media had different results. In the previously cited work (Tamimi & Wali, 2019), the prevalence of otitis in service police dogs is

2.95%. In the general population of dogs, otitis is more common. A detailed analysis of a random sample of 3,884 dogs in England revealed that otitis externa was the most common type (prevalence 10.2%, 95% CI: 9.1-11.3) (Neill *et al.*, 2014). Comparable results were obtained in South Korea, where ear and mammary gland diseases accounted for 10.4% (Kim *et al.*, 2018). In the study of pathologies of service dogs of Ukraine, traumatic lesions were found to be the third most common. It is logical that for this category of pathologies, the predominant share is occupied by wounds (62.1%) because most of the tasks performed by dogs are associated with traumatic risks (Fig. 6).

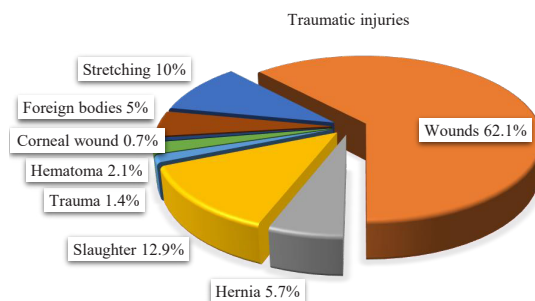


Figure 6. Traumatic lesions of service dogs of Ukraine

Trauma, defined as tissue damage caused by violence or accident that occurs suddenly and involves physical damage to the body, is a common cause of morbidity and death in dogs. In Fleming *et al.* (2011), large-scale

epidemiologic studies of age-, size-, and breed-specific mortality in North American dogs from 1984 to 2004 show that trauma accounts for 11-13% of all animals evaluated in urban veterinary hospitals. Among the

causes of death of 74,556 dogs, trauma was the second most common cause of death in young dogs (after infectious diseases) and adult dogs (after neoplasia).

A statistical evaluation of the trauma of 315 client dogs from 4 veterinary hospitals (USA) showed the following distribution of injuries: blunt (54.9%), penetrating 34%, unknown 11.1% (Hall *et al.*, 2014).

A retrospective study of the deaths of 867 civilian U.S. law enforcement dogs in the line of duty from 2002 to 2012 found that in 318 cases, the deaths were classified as traumatic. Causes of death or euthanasia included: motor vehicle collision (25.8%), heatstroke (24.8%) and penetrating ballistic injury (23%) (Stojsih *et al.*, 2014).

Interesting results were obtained in the works of P. Fox *et al.* (2008) and K. Slensky *et al.* (2004), which identified the types and incidence of acute injuries and illnesses to working dogs during deployment and rescue operations at the World Trade Center following the September 11, 2001, terrorist attack. The first study examined 27 dogs of the New York City Police Department, the

second – 96 search and rescue dogs. Specific conditions related to cuts accounted for 9.3 cases per 1,000 hours of active deployment in the first study, and 5 cases per 1,000 hours of search in the second.

Another study (Edwards *et al.*, 2021) compared the prevalence of injury types among military working, operational, and civilian dogs (193, 35, and 20,699 records, respectively) showed that all groups showed similar trends in injury type. Penetrating injuries were the most common, followed by blunt injuries for civilian and operational dogs. An equal proportion of blunt and penetrating injuries was observed in military dogs. Furthermore, in the study by Takara & Harrell (2014) it is shown that, among the biggest problems of military dogs, non-combat-related soft tissue injuries accounted for 21%.

The next part of the presented study concerns skin diseases in service dogs of Ukraine. Most skin problems related to two diseases: eczema and dermatitis (Fig. 7). In 117 records about skin diseases, eczema accounted for 6.67%, dermatitis – 6.91% (of the total number of records).

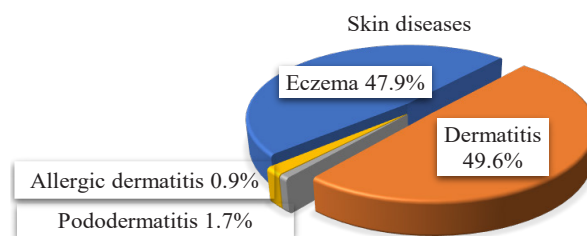


Figure 7. Skin diseases in service dogs of Ukraine

The skin is the largest organ of the body with many functions such as thermoregulation, immune defence, sensory perception, vitamin D production, and it acts as a barrier between the animal and its environment.

For instance, according to the results of research by Hierdieva *et al.* (2020) on the spread of diseases of non-contagious aetiology in the city of Dnipro, it was established that 20.75% of all cases concern skin diseases. In the structure of these pathologies, dermatitis and eczema are found in the absolute majority, which make up 38.16% and 24.32% of cases, respectively.

Police dogs in Egypt had serious skin diseases. Itching as a sign of a skin problem was recorded in every fourth animal (24.8%) (Haithem *et al.*, 2011). Ticks (16.4%) created more problems. A similar result was obtained for military dogs. The most common non-combat-related problems were dermatological conditions (25%) (Takara & Harrell, 2014). Thus, every fourth to fifth dog has problems with skin diseases. This applies to both special animals and pets. In the study of the incidence of service dogs in Ukraine, the fifth place in frequency of distribution belongs to parasitic diseases (Fig. 8).

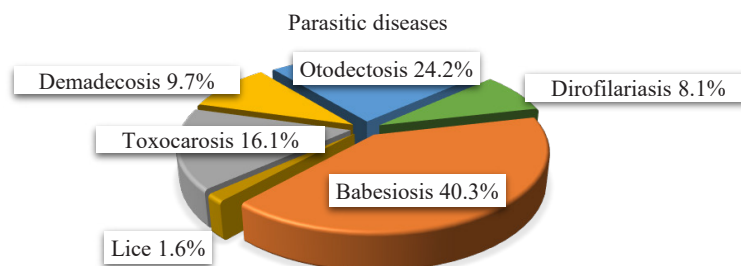


Figure 8. Parasitic diseases of service dogs of Ukraine

More than 80% of the problems related to three parasitic diseases. The following were the most common of them: babesiosis (40.3%), otodectosis (24.2%) and toxocarosis (16.1%).

Studies of the incidence of service dogs in Ukraine have established significant problems with babesiosis. This disease is spreading rapidly in Central and North-Eastern Europe, and its appearance correlates with the rapid and successful spread of the decorative dog tick (*Dermacentor reticulatus*) population in this area (Bajer *et al.*, 2022). As a result of epizootological monitoring of babesiosis in dogs (Mokryi & Ksyonz, 2017), 7,866 cases of the disease were registered in Poltava over a 9-year period (from 2007 to 2016). Among sick animals, males outnumber females by 20%. Dogs aged 2 to 3 years are the most affected (11.1-16%). Regarding the breed ratio, most cases concern pure-bred dogs (20.9%), German shepherds (13.9%) and Rottweilers (7.5%).

Comparable results were found in a study of 242 blood samples from K9 police dogs in Egypt. Haematological, biochemical, and oxidative stress analysis of blood performed together with expression analysis using two genes (interferon-gamma [IFN- γ] and tumour necrosis factor-alpha [TNF- α]) showed that 25.6% of blood samples were positive for *B.vogeli* infection. Infection rates were higher in males than in females (Zaki *et al.*, 2021).

Some canine parasitic infections, even if they have little or no effect on the dog itself, are zoonotic and capable of causing disease or disease in humans (Saari *et al.*, 2019).

Studies of non-systemic ecto- and endoparasitism in dogs in Spain (Martínez-Carrasco *et al.*, 2007) showed that faecal stages of parasites were found in 25% of dogs. The species frequency was 6-10% for *Toxocara canis*, *Ancylostomatidae spp.*, *Toxascaris leonina* and *Isoospora canis* and 0.4-1% for *Trichuris vulpis*, *Giardia lamblia* and *Dipylidium caninum*. Fleas, ticks, and lice were found in 38%, 6% and 2% of stray dogs.

A study of the prevalence, intensity, and risk factors of ectoparasite infection among 333 dogs was conducted in Nigeria. Two hundred and seventy-one dogs (81.4%) were infected with at least one type of ectoparasite, and multiple infestations were registered, mainly among females. Six species of ectoparasites of three taxa were identified: ticks (*Rhipicephalus sanguineus sensu lato*, *Haemaphysalis leachii* and *Amblyomma variegatum*), fleas (*Ctenocephalides canis* and *C. felis*) and louse (*Heterodoxus spiniger*). The most common was *R. sanguineus s.l.* (70.3%), followed by *C. felis* (42.1%) and *H. spiniger* (30%) (Abdulkareem *et al.*, 2018).

Faecal samples from 180 police and domestic dogs in Egypt were collected and then analysed (Ahmed *et al.*, 2014) by various flotation and sedimentation methods. The prevalence of gastrointestinal parasites in police dogs was 7.5%, and in domestic dogs – 40%. Examination of the faeces of 120 police dogs revealed *Toxocara canis* eggs in 0.8%, *Ancylostoma caninum* in 1.7%, *Trichuris vulpis* in 0.8%, *Cystoisospora canis* in 4.2%, and *Giardia species* in 1.7%.

A study of 39 police dogs in Iraq aged 6 months to 12 years showed that 15 (38.46%) animals were diagnosed with moderate or severe microfilariasis (Al-Salihi *et al.*, 2019). A monitoring programme, aimed at diagnosing subcutaneous heartworm and heartworm in working (police and military) dogs in Slovakia, was performed in the period from September 2007 to February 2008. 710 dogs (591 police and 119 military) were examined for the presence of microfilariae in the blood. They were found in the samples of 118 (20%) police and 10 (8.4%) military dogs. In several areas of southern Slovakia, the prevalence of subcutaneous dirofilariasis in working dogs exceeded 40% (Miterpáková *et al.*, 2010).

In a study of 668 dogs in Sri Lanka, 25.3% were infected with 7 variants of haemoparasites. The prevalence of infections among military dogs was 22.5%, of which *B. gibsoni* was the most common (13.8%) (Rajakaruna *et al.*, 2021). Among other pathologies, it is important to pay attention to diseases of the musculoskeletal system because the mobility of service dogs can be decisive for the performance of most of the tasks set before them, and, as a rule, is the main reason for the culling of animals. In our study, 5% of animals with such diseases were found, of which arthritis and hip dysplasia were found in 66.7% and 23.8% of cases, respectively.

It is known that the peculiarity of German shepherds, which comprise the majority of personnel in canine units, is orthopaedic problems. Thus, according to A. Worth *et al.* (2013), the reasons for the loss or retirement of New Zealand police German Shepherds of the nominal age for planned retirement (8 years) reached only 40% of dogs. The main reason for culling was the inability to cope with physical demands (65%) due to diseases of the musculoskeletal system. A comparison of emergency department medical records at the University of Pennsylvania Veterinary Hospital from July 2008 to July 2010 showed that orthopaedic issues in German Shepherds were significantly more common in police dogs compared to domestic dogs (Parr & Otto, 2013).

Within the scope of this work, it is practically impossible to give a comprehensive description of all diseases and pathologies of service dogs of the security forces of Ukraine. Out of more than 80 names, a significant part of the diseases in the records occupies less than 1%. In addition, a dog can have two or more diseases at the same time (Galatyuk *et al.*, 2019). The reports did not indicate the presence of multiple pathologies, but many animals had more than one disease, as evidenced by the preponderance of the number of entries (839) over the official number of dogs (822). Therefore, this topic requires further research on the study of multiple pathologies of service dogs.

CONCLUSIONS

An analysis of the records of the incidence of service dogs in 24 cynological centres of Ukraine showed that 82.9% of all cases refer to five groups of diseases: internal

non-contagious diseases (26.5%), organs of vision and hearing (18.4%), traumatic lesions (16.7%), diseases skin (13.9%) and parasitic diseases (7.4%).

The most common diseases and pathologies were dyspepsia, alimentary enteritis, gastritis, otitis, cataract, traumatic wounds, dermatitis, eczema, and babesiosis. It was found that one in twenty animals had problems with the musculoskeletal system, of which arthritis and hip dysplasia were the most common.

Statistical features of the number, breed, age, and sex structure of service dogs have been established. In the cynological centres of Ukraine, the most common breeds were the German Shepherd – 68.5%, the Belgian Shepherd – 16.8% and the Labrador – 6.6%, while special (41.9%) and search (39%) dogs prevailed by purpose. The predominance of females (53.4%) over males was also revealed, which is not characteristic of canine units of the power structures of other countries.

Given the high costs incurred by state and local governments in acquiring, training and maintaining highly trained dogs, as well as the entire infrastructure that supports the canine service, it would seem appropriate to create a broad database that would be distributed across government levels and include all issues that refer to

service dogs considered in this work. It is also important to study these issues in dynamics. This will enable a more thorough determination of the full risk profile to which service dogs are exposed. Open information provides the opportunity to identify certain patterns that can be used to change selection, training, and treatment strategies to more effectively use this valuable resource.

Because service dogs are an indispensable asset to law enforcement agencies, gaining a better understanding of their common medical problems and associated risk factors is critical to maintaining their health and readiness for challenging tasks. Identifying the diseases and their causes that shorten a dog's life span would allow the introduction of preventive medicine and treatment methods to increase their longevity. In addition, improved knowledge of medical data can improve preparedness and focus training for veterinary canine service professionals responsible for the comprehensive veterinary care of service dogs. Thanks to veterinarians and scientists working to advance service dog knowledge, service dog care can be improved to help secure the future of this valuable resource that helps humanity solve complex problems.

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Захворюваність службових собак в кінологічних центрах України

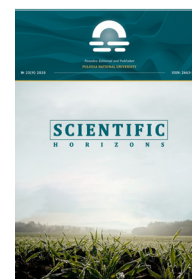
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Анотація. Службові собаки є важливим активом силових структур. Тому розуміння їх медичних проблем, знання загальних характеристик, таких як чисельність, вік, порода, стать, призначення є вирішальним для підтримки їх здоров'я та готовності до виконання ними складних завдань. Аналіз та поширення подібної інформації є актуальним завданням для спеціалістів та науковців, які займаються проблемами утримання, забезпечення, та ветеринарного обслуговування службових собак. Тема науково-дослідної роботи полягає в аналізі результатів статистичних звітів щодо захворюваності службових собак з 24 регіональних кінологічних центрів силових структур України. Всього розглянуто дані по 822 службовим собаками та записи про 839 випадків захворювань. Також проаналізовано дані щодо чисельності, віку, статі та напрямку використання службових собак. Було виявлено, що серед захворювань визначалися внутрішні незаразні хвороби. Найбільше проблем було з шлунково-кишковим трактом: диспепсія, аліментарний ентерит і гастрит. Встановлено, що серед хвороб органів зору та слуху найчастіше виявлялися отити та катаракта. Травматичні ураження склали 16,7% від усіх записів, більшість яких класифікувалася як рани. Встановлено, що кожне сьоме захворювання було пов'язано зі шкірою. Серед них значне переважання мали дві хвороби: дерматит та екзема. З частотою понад 5% виявлялася ще одна група – паразитарні хвороби, з яких найбільш поширеним був бабезіоз. Також у дослідженні виявлено, що кожна двадцята тварина мала захворювання опорно-рухового апарату, з яких переважно зустрічалися артрит і дисплазія кульшового суглобу. Статистичні розрахунки показали неоднорідність щільності розподілу собак, як по відношенню до чисельності населення, так і до площі регіону. Найкращі показники щільності мала Чернівецька, а найменші – Житомирська. Серед службових собак перевагу мають самки – статева диференціація склала 1/1.15. Виявлено рівномірний розподіл чисельності службових собак за віком в межах від 2 до 7 років з середньозваженим значенням віку у 4,9 року. Найбільш поширеними породами виявилися: німецька та бельгійська вівчарки, а також лабрадор. За призначенням переважали спеціальні та розшукові собаки. Практична цінність даного дослідження полягає в тому, що визначені закономірності захворюваності службових собак, дають можливість для зміни стратегії їх відбору, навчання та лікування, щоб більш ефективно використовувати цей цінний ресурс

Ключові слова: кінологічні підрозділи, диференціація захворювань, чисельність, вік, породи, стать, напрями використання службових собак



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Monitoring of Heavy Metals in Fodder and Animal Husbandry Products of the Polissia Zone of Ukraine

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Abstract. With a significant concentration of pollutants in the environment, they accumulate in plants, the feeding of which will lead to the transfer of toxic elements to the animal's body. Even a small concentration of heavy metals or radionuclides adversely affects both the animal and human bodies. Therefore, the monitoring of Pb and Cd in feed, milk, and meat during their production in the territory of the Polissia zone of Ukraine is relevant and requires further comprehensive study. The purpose of this study was to investigate the content of heavy metals in feed and slaughter products of animals raised in the Polissia zone with various levels of radioactive contamination. The research was carried out on young pigs and steers, which were put to fattening. The paper used the atomic absorption method for determining the content of toxicants in samples and the method of variation statistics for processing the results of the study. The results of studies of the content of Pb and Cd in the samples indicate the presence of substantial fluctuations in heavy metals within individual farms. As the level of ¹³⁷Cs soil contamination increases, the concentration of toxicants in feed, milk, and the longest back muscle of the animals under study increases. Exceeding of the maximum permissible concentration of Pb in milk (33.8%) and Cd (41.2%) was established. The concentration of Cd exceeded the established level in 72.2% of the examined samples of the longest back muscle of cattle and 80.0% of the samples of the longest back muscle of pigs. The Cd content in all feed samples under study was considerably higher than the established norm. The greatest excess of the toxicant was found in samples of hay, straw (41.9%), cake and meal (60%). Thus, indicators of the quality of feed and livestock products produced in the farms of the Polissia zone of Zhytomyr Oblast, affected by the accident at the Chernobyl Nuclear Power Plant, indicate that the concentration of Pb and Cd in the milk of dairy cows, muscle tissue of young cattle and pigs in most of the analysed sample exceeds sanitary and hygienic requirements. Therefore, to obtain milk and meat within the limits of current regulatory requirements, reducing the accumulation of heavy metals in feed for feeding animals and poultry stays a topical issue

Keywords: Lead, Cadmium, concentration, pollution, milk, the longest back muscle



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INTRODUCTION

Ukraine still feels the consequences of the explosion at the Chernobyl Nuclear Power Plant to this day. In the 36 years that have passed since this terrible accident, many studies have been conducted to find the level of radiation pollution in the affected areas and to establish ways to reduce the impact of radiation on the body of animals and people. Minimisation of the consequences of an accident in the agricultural sphere on territories contaminated with radionuclides, which includes the implementation of radioprotective measures in crop and animal husbandry, is one of the main elements of the radiation safety system (Hudkov & Lazariev, 2018; Landin *et al.*, 2017; Romanchuk *et al.*, 2019). Therefore, one of the priority tasks of modern radioecological science is the systematic control of ^{137}Cs and ^{90}Sr contamination of plant and animal products and the study of the specific features of their migration in agricultural ecosystems.

Even today, a significant area of the Ukrainian Polissia zone is contaminated with radionuclides after the Chernobyl Nuclear Power Plant explosion. There are still cases of prominent levels of contamination with ^{137}Cs and ^{90}Sr isotopes of soil samples, feed crops, agricultural products, products of animal origin, etc. At the same time, in this zone, the development of industrial and intensive agricultural production led to an increase in the concentration of heavy metals in the agricultural landscape, which led to a disturbance in the ecosystem balance (Razanov *et al.*, 2022; Peng *et al.*, 2015a). An increase in the number of sick, weakened animals is an indicator of a violation of metabolic processes in the body. Upon feeding farm animals with feed contaminated with heavy metals, increasingly more harmful components gradually accumulate in their bodies, leading to a decrease in productivity and product quality (Peng *et al.*, 2015b; Martyshuk *et al.*, 2019; Zinko, 2017).

According to the authors' reports (Wang *et al.*, 2018), heavy metals of high toxicity – Pb, Cd, Hg, As, Se, F, Zn – pose a special danger to farm animals and humans. Referring to the results of research by WHO experts, including other international organisations, Pb is the largest environmental toxicant. Due to its high biological activity, lead can accumulate in all internal organs and tissues of animals and poultry (Trakhtenberg *et al.*, 2015). The reason for such distribution of this metal in the natural environment is the rather wide scope of its application and use. At its blood concentration of 200-400 $\mu\text{g}/\text{l}$, people may develop signs of poisoning (Yabe *et al.*, 2015).

Cadmium is a natural heavy metal, one of the most toxic elements, it belongs to class II hazardous substances (Chen *et al.*, 2019; Lavryshyn *et al.*, 2018). Cd enters the body of animals mainly with feed and water, accumulates in tubular bones, pancreas, spleen and, above all, in the liver and especially in the kidneys, while the half-life of Cd from the body is from 10 to 30 years (Lavryshyn *et al.*, 2018). Upon reaching a significant

concentration in the body, Cd can affect the nervous system, as well as cause pathological changes in the tissues of organs (kidneys, lungs, bone tissue, organs of the reproductive and endocrine systems), suppressing the erythropoiesis (Peng *et al.*, 2015a; Ostapyuk & Gutyj, 2019). Namely, under the action of Cd, a decrease in functional activity was observed in bone marrow blood cells (CFU-E). Upon long-term cadmium feeding, an increase in the number of micronuclei in the bone marrow cells of animals was observed. This is what causes damage to DNA molecules. Cadmium, due to its high coefficient of biological accumulation, adversely affects the health and condition of animals (Ostapyuk & Gutyj, 2020; Knoell & Wyatt, 2021). The main danger of Cd is determined by long-term exposure to animal health, since it has a high coefficient of biological accumulation (up to 40 years) (Lavryshyn & Gutyj, 2019).

Recently, the accumulation of heavy metals and their hazardous compounds in the Ukrainian environment has increased several times, especially after the Chernobyl accident (Razanov & Kabachenko, 2018; Savchenko *et al.*, 2017). Environmental consequences of the use of mineral fertilisers and pesticides in violation of regulatory requirements adversely affect agroecosystems. The intensification of conventional agriculture not only in Ukraine, but also in the countries of the European Union, the development of industry in large cities increase the anthropogenic burden on the environment (Bigalke *et al.*, 2017). The entry of heavy metals into the soil, even in small concentrations, leads to their accumulation in feed in considerable quantities, feeding which to farm animals can lead to the production of livestock products with an increased content of dangerous pollutants, and therefore raw materials for food production (Mamenko & Portiannyk, 2019; Aloud *et al.*, 2022).

According to the results of research by international authors, it was found that when using feed for feeding animals that were grown in industrially developed areas, the concentration of Pb and Cd in muscle tissue and by-products turned out to be much higher compared to similar indicators of animals from ecologically clean zones (Caldasa *et al.*, 2016; Pilarczyk, 2014; Hashemi, 2018). Furthermore, it is known from literature sources that contaminated feed is the main source of heavy metals entering the animal body, and therefore in 99% of cases it is feed that is the source of danger (Satarug *et al.*, 2017; Heina *et al.*, 2019). Heavy metals decompose in the environment and accumulate in the tissues and organs of living organisms. Their main danger lies in the ability to accumulate in human food products, including products of animal origin (Wang *et al.*, 2018).

Since heavy metals are characterised by significant stability, pronounced cumulative properties, and a negative effect on the internal organs and systems of animals, the need to monitor them in feed and livestock products deserves attention. *The purpose of this*

study was to identify the content of Pb and Cd in feed, milk, and muscle tissue of cattle and pigs, which are produced in farms of the Polissia zone at various levels of radioactive contamination of the territory as a result of the accident at the Chernobyl Nuclear Power Plant.

MATERIALS AND METHODS

Heavy metal contamination of feed and milk of dairy cows during stall keeping was monitored in agricultural

enterprises of the Zhytomyr Oblast with a level of contamination of the territory with radioactive caesium from 0.1 to 15 Ki/km²: up to 1 Ki/km² – DPDG “Nova Peremoha” of Liubarskyi and PAF “Yerchyky” of Popilnyanskyi districts; 1-5 Ki/km² – experimental field and physiological yard of the PIRE of the NAAS of Ukraine, Korostenskyi district; above 5 Ki/km² – WWTP “Vidrodzhennia” of Korostenskyi and FG “Kavetskoho” of Narodytskyi districts (Table 1).

Table 1. Scheme of sampling of feed and whole milk in farms of Zhytomyr Oblast

Group No.	Agricultural land contamination density (¹³⁷ Cs)	Farm name	Location	Number of samples taken, pcs.	
				Feed	Milk
1	Up to 1 Ki/km ²	SE EF “Nova Peremoha” of the PIRE of the NAAS	Liubarskyi district, village of St. Chortoryia	41	12
		PAF “Yerchyky”	Popilnianskyi district, village of Yerchyky	30	12
2	1-5 Ki/km ²	physiological yard of the PIRE of the NAAS of Ukraine	Korostenskyi district, village of Hrozyne	60	18
3	Over 5 Ki/km ²	Vidrodzhennia ALLC	Korostenskyi district, village of Kupech	19	8
		Kavetskoho Farming	Narodytskyi district, village of Noryntsi	19	18

Experimental studies on full-aged dairy cows were conducted in the winter-stable period of 2020-2021. The experimental cows were fed three times a day, the rations included cereal hay and alfalfa, barley straw, forage and alfalfa hay, corn and forage silage, grain mixture, sunflower cake and meal. The animals' feeding diets were balanced in terms of basic nutrients.

Pb and Cd contamination of pig and steer meat was also monitored in the territories with different levels

of ¹³⁷Cs contamination according to the following scheme (Table 2). Feeding of animals in private farms was provided at the expense of feed grown on household plots and the territory of the community. Young pigs were fed various grain mixtures, wheat bran, boiled potatoes, fodder beets, pumpkins. The diet of steers included cereal hay, oat straw, cereal grain, fodder beet was used as juicy feed. Feeding of experimental animals in private sector farms was twofold – in the morning and in the evening.

Table 2. Scheme of sampling of the longest back muscle of experimental animals in private subsidiary farms of Zhytomyr Oblast

No. groups	Agricultural land contamination density (¹³⁷ Cs)	Locality	District	Number of samples taken of the longest back muscle, pcs.	
				Steers	Young pigs
1	Up to 1 Ki/km ²	Village of Mala Derevychka	Liubarskyi	4	3
		Urban-type settlement of Liubar	Liubarskyi	5	4
		Village of Yerchyky	Popilnianskyi	4	4
		Village of Pochuiky	Popilnianskyi	5	3
2	1-5 Ki/km ²	Village of Nemyrivka	Korostenskyi	3	3
		Village of Synhai	Korostenskyi	3	3
		Village of Hrozyne	Korostenskyi	6	3
		Physiological courtyard of the Institute	Korostenskyi	6	3
3	Over 5 Ki/km ²	Urban-type settlement of Narodychi	Narodytskyi	–	2
		Village of Lasky	Narodytskyi	–	2
		Village of Hrustynivka	Narodytskyi	–	3
		Village of Kupech	Korostenskyi	–	2

Feed sampling was carried out according to DSTU ISO 6497:2005 (2005), milk – DSTU ISO 707:2002 (2003), muscle tissue – according to DSTU 7992:2015 (2015).

Samples of the longest back muscle of pigs at the age of 10-12 months were taken for laboratory analyses. The age of steers upon slaughtering and selecting the longest back muscle of steers for further studies was 18-20 months, the weight of the selected meat samples was 1 kg. The samples were packed in thick plastic bags with a zip. The bags were tagged, indicating the place of sampling, the code of the sample, and the age of the animals. Milk from dairy cows was taken after morning milking in sterile glass jars with labels. The volume of milk samples taken for the study was 1 litre. Each container was labelled, indicating the place of selection, time of selection, and sample number.

Feed samples from farms were taken in plastic bags with labels with the name of the farm, the name of the feed, and the date of selection. The average weight of the feed sample for the studies was 1.5 kg. The selected samples were delivered to the site of further research on the day of selection.

Laboratory studies of milk, animal muscle tissue and fodder for Pb and Cd content were carried out in the laboratory of ecological safety of land, environment, and product quality of the Zhytomyr branch of the state institution “Institute of Soil Protection of Ukraine”. The content of heavy metals was determined according to the atomic absorption method per DSTU 7670:2014 (2015), the analysis was carried out on the atomic absorption spectrophotometer “Kvant – 2A”.

The method of variational statistics was applied based on the calculation of the arithmetic mean (M), the root-mean-square error (m) and the reliability of the difference between comparative indicators (P) and the materials of the conducted studies were processed (Ruban *et al.*, 2020).

All manipulations with animals were carried out according to the European Convention for the Protection of Vertebrate Animals Used for Experimental and Scientific Purposes, as well as the Law of Ukraine “On the Protection of Animals from Cruelty and the Procedure for Conducting Experiments and Experiments on Animals by Scientific Institutions” (European Convention for the Protection..., 1986; Law of Ukraine No. 3447-I..., 2006; Order of the Ministry of Education..., 2012).

RESULTS AND DISCUSSION

Studies of the content of heavy metals in the feed-animal-livestock products trophic chain in different biogeochemical provinces of Ukraine are relevant and necessary in view of clarifying their distribution in the environment, investigating the biogenic migration of pollutants and accumulation in livestock products.

The content of heavy metals in feed included in the animal feeding diet can cause chronic intoxication of the body, accumulation of pollutants in organs and tissues, migration to milk and meat (Tóth *et al.*, 2016). Studies conducted in farms of the Polissia zone of Ukraine indicate that the content of Pb and Cd in feed substantially depends on their type (Table 3).

Table 3. Concentration of heavy metals in feed, mg per 1 kg of natural feed

Feed	Heavy metals					
	Pb			Cd		
	n	M ± m	% of samples above MPC	n	M±m	% of samples above MPC
Grain and legume hay, winter straw	43	2.462±0.134	0	43	0.323±0.023	41.9
Alfalfa and mixed grass haylage	24	1.201±0.075	0	24	0.179±0.017	8.3
Corn and mixed grass silage	31	0.768±0.077	0	31	0.091±0.014	6.4
Grain mix	46	1.084±0.086	0	40	0.186±0.016	10.0
Sunflower cake and meal	25	1.639±0.134	0	25	0.478±0.053	60.0
Maximum permissible concentration (MPC)	x	5.0	x	x	0.3	x

Source: results of the authors' research

For the most part, the highest concentration of Pb is determined in soils located along highways. Within a radius of 200 m from the roadway, the level of contamination reaches 100-1000 mg/kg. Considering the above data, it is safe to say that plants grown on soils near highways contain a considerable amount of heavy metal. According to

the conducted studies, it was found that of all the surveyed feeds, coarse feed accumulates the most Pb – hay of cereals and legumes and straw of winter crops (2,462 mg/kg). Sunflower cake and meal imported to the farms of the Polissia zone also contain a significant amount of this element – 1,639 mg/kg. In other feeds, the Pb content

varies from 0.768 mg/kg (corn silage and mixed grasses) to 1.201 mg/kg (alfalfa hay and mixed grasses). Notably, none of the analysed feed types exceeds the maximum permissible concentration (5.0 mg/kg) for this element.

Sources of cadmium ingress into the soil are products of diesel fuel combustion, ore smelting, and various fertilisers. The accumulation of Cd in products of plant origin, in geochemical provinces, is from ones to tens of mg/kg, more often this indicator does not exceed 100-180 mg/kg (Shevchuk *et al.*, 2021).

The highest Cd concentration was found in sunflower cake and meal – 0.478 mg/kg. Furthermore, 60% of samples of this type of feed exceeded the maximum permissible concentration for this metal. A substantial accumulation of Cd in hay and straw was found – 0.323 mg/kg. Moreover, 41.9% of the analysed coarse feed samples in terms of Cd content were higher than

the regulatory requirements (0.3 mg/kg). The average concentration of Cd in silage, hay, and grain mixture was 0.091 mg/kg, 0.179 mg/kg, and 0.186 mg/kg, respectively. Currently, these feeds also contain samples that exceed the maximum permissible concentration for this heavy metal: 6.4% in corn and mixed grass silage, 8.3% in alfalfa and mixed grass hay, and 10.0% in grain mixes. The high Cd content in feed can be explained by the considerable introduction of phosphate and potash fertilisers into the soil. Thus, according to Bondareva *et al.* (2012), with phosphate fertilisers, 3-4 g/ha of Cd is applied to the soil annually.

To establish the accumulation of heavy metals (Pb, Cd) in feed, they were researched in farms of the Polissia zone of Ukraine depending on the level of radioactive contamination of the territory by ^{137}Cs : up to 1 Ki/km², 1-5 Ki/km² and above 5 Ki/km² (Figs. 1; 2).

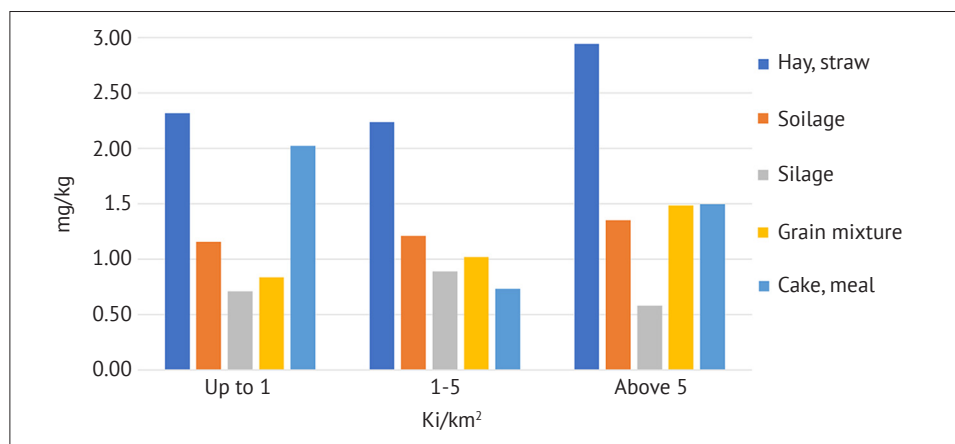


Figure 1. The Pb content in feed depending on the density of radioactive contamination of the territory with ^{137}Cs

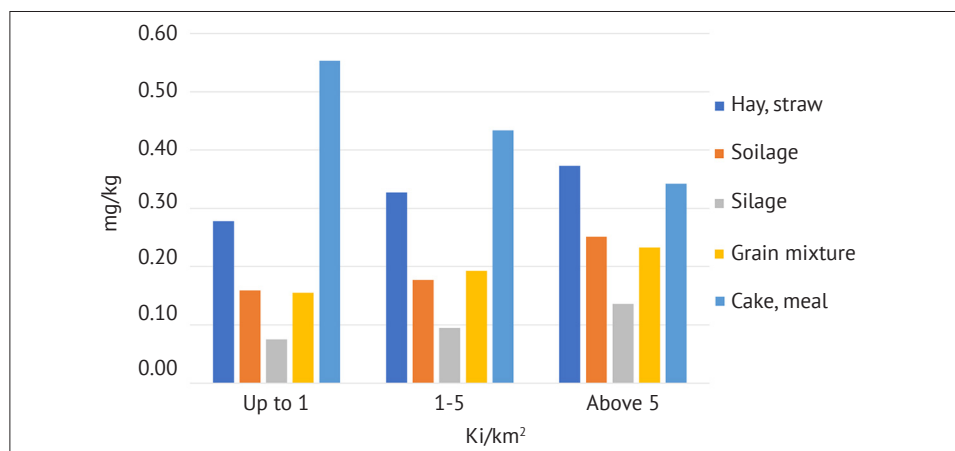


Figure 2. The Cd content in feed depending on the density of radioactive contamination of the territory with ^{137}Cs

A clear pattern was established between the content of Pb in feed and the density of radioactive contamination of the territory – with an increase in the level of soil contamination by ^{137}Cs , the concentration of the heavy metal increases in roughage from 2.317

to 2.942 mg/kg (by 27.0%, $P>0.95$), hay – from 1.155 to 1.351 mg/kg (by 17.0%, $P<0.95$), grain mixtures – from 0.834 to 1.484 mg/kg (by 77.9%, $P>0.95$). At the same time, the lowest Pb content in silage was found in farms with the maximum level of radioactive contamination of

the territory with ^{137}Cs (0.579 mg/kg), and the highest (0.889 mg/kg) in farms with a soil contamination level of 1-5 Ki/km². The concentration of Pb in sunflower cake and meal varied from 0.733 to 2.023 mg/kg and did not depend on the density of radioactive ^{137}Cs contamination of the territory.

An even more direct relationship was established between the content of Cd in feed and the density of radioactive contamination of the territory with ^{137}Cs (Fig. 2). Thus, with an increase in the level of soil contamination with radioactive caesium from 1 to 5 Ki/km² and more, the concentration of the element in feed increases (except for sunflower cake and meal): in hay and straw – from 0.278 to 0.373 mg/kg, or by 34.2%, hay – from 0.159 to 0.251 mg/kg, or by 57.9%, silage – from 0.075 to 0.136 mg/kg, or by 81.3%, in grain mixture – from 0.155 to 0.233 mg/kg, or by 50.3% with a statistically significant difference ($P>0.95$). An inverse linear relationship

was established for the content of Cd in sunflower cake and meal and the level of ^{137}Cs soil contamination – the concentration of the element decreases from 0.553 to 0.342 mg/kg, or by 38.2%. This is probably due to the import of these high-protein feeds to the farms of Zhytomyr Oblast from processing enterprises of Ukraine using various technologies of their preparation.

Thus, to obtain environmentally safe livestock products, it is urgent to control the content of harmful substances in crop products and feed. With a high content of pollutants in feed rations, the risk of their accumulation in the body of animals and milk and meat above sanitary and hygienic requirements increases (Order of the Ministry of Health of Ukraine No. 368, 2013).

According to the conducted studies, it was established that livestock products produced in Zhytomyr Oblast farms are also heavily contaminated with heavy metals (Table 4).

Table 4. Pb and Cd content in animal milk and muscle tissue, mg/kg

Products	Heavy metals					
	Pb			Cd		
	n	M±m	% of samples above MPC	n	M±m	% of samples above MPC
Milk	68	0.145±0.008	33.8	68	0.027±0.001	41.2
Maximum permissible concentration	x	0.10	x	x	0.03	x
The longest back muscle of steers	36	0.239±0.011	0	36	0.074±0.007	72.2
Longest back muscle of pigs	35	0.232±0.008	0	35	0.061±0.002	80.0
Maximum permissible concentration (MPC)	x	0.5	x	x	0.05	x

Thus, when examining 68 samples of cow's milk, it was found that the maximum permissible concentration of Pb in milk exceeded 1.45 times, as a result of which 33.8% of products for this element were higher than sanitary and hygienic requirements. On average, the Cd content in cow's milk was 0.027 mg/kg, which is lower than the maximum permissible concentration, but 41.2% of milk samples were higher than this indicator.

The longest back muscle of steers and pigs, compared to milk, is slightly less polluted with Pb – 0.239 mg/kg and 0.232 mg/kg, respectively, which does not exceed the maximum permissible concentration. At the same time, Cd accumulation in the muscle tissue of steers and pigs is quite high – 0.074 mg/kg and 0.061 mg/kg, respectively, which is 1.48 and 1.22 times

higher than the maximum permissible concentration. Furthermore, 72.2% and 80.0% of samples of the longest back muscle in cattle and pigs exceeded the regulatory requirements for Cd content in products.

According to the data obtained, cow's milk produced in the farms of Polissia of Ukraine contains a considerable amount of both Pb and Cd, and the muscle tissue of cattle and pigs is characterised by a high concentration of Cd.

The content of heavy metals in the milk of cows in the winter-stalling period, beef, and pork during their production in the farms of Zhytomyr Oblast at various levels of radioactive contamination of the territory with ^{137}Cs was analysed: up to 1 Ki/km², 1-5 and above 5 Ki/km² (Figs. 3; 4).

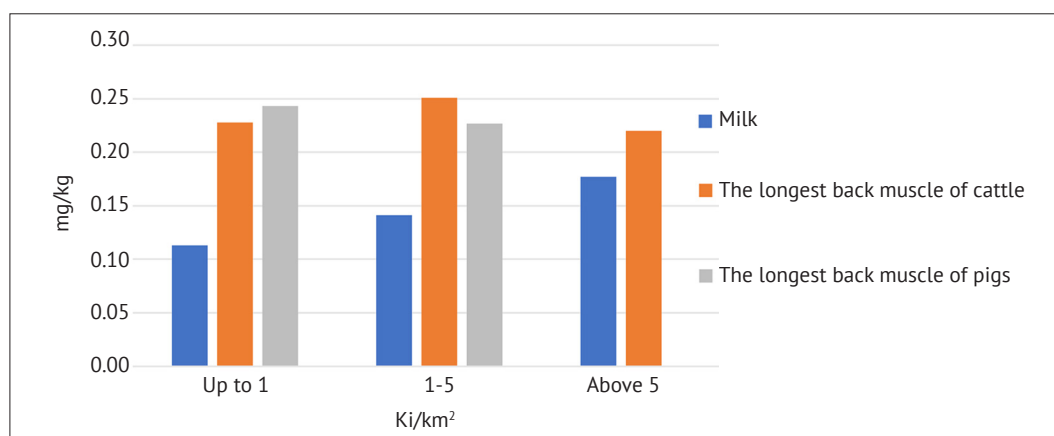


Figure 3. Accumulation of Pb in livestock products, depending on the density of radioactive contamination of the territory with ¹³⁷Cs

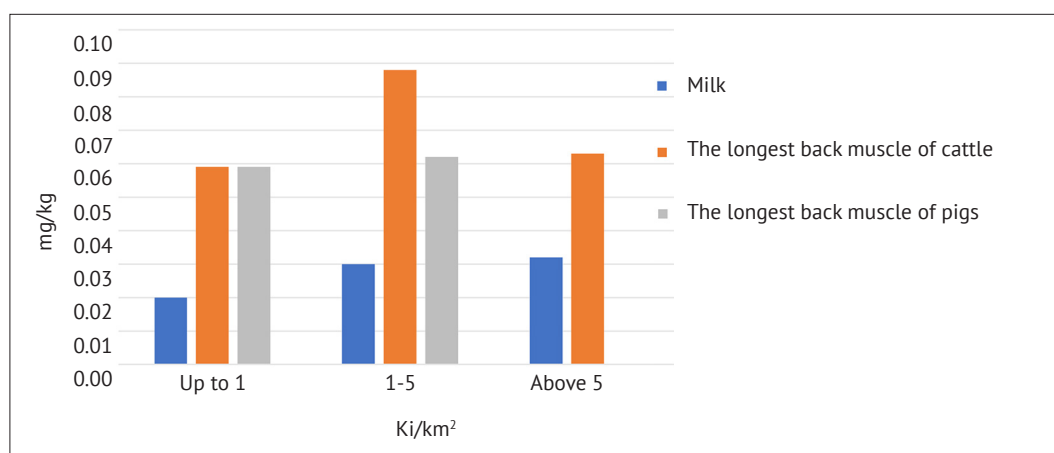


Figure 4. Accumulation of Cd in livestock products, depending on the density of radioactive contamination of the territory with ¹³⁷Cs

According to the given data, the highest content of Pb was noted in the milk of dairy cows kept in farms with the highest level of radioactive contamination of the territory with ¹³⁷Cs (above 5 Ki/km²) – 0.177 mg/kg. According to this indicator, they predominate animals from other groups by 0.036-0.064 mg/kg, or by 1.25-1.57 times with a highly reliable difference ($P > 0.999$). Furthermore, 96.1% of milk samples from cows in this group exceeded the maximum permissible concentration for Pb content.

With an increase in the level of soil contamination with radioactive caesium, the concentration of Pb in the longest back muscle of steers also increases – from 0.228 to 0.251 mg/kg, or by 10.1% ($p < 0.95$), while in the muscle tissue of pigs, the content of the element decreases from 0.243 to 0.220 mg/kg, or by 9.5%. This can be explained by different technologies of feeding young pigs in the farms of the forest-steppe and Polissia zones of Zhytomyr Oblast.

As the density of radioactive ¹³⁷Cs contamination of the territory increases from 1 to 5 Ki/km² and more, the content of Cd in livestock products also increases: in milk – from 0.020 to 0.032 mg/kg, or 1.60 times ($P > 0.999$);

in the longest back muscle of steers – from 0.059 to 0.088 mg/kg, or 1.49 times ($P > 0.95$); in the longest back muscle of pigs – from 0.059 to 0.063 mg/kg, or 1.07 times ($P < 0.95$) (Figure 4).

Thus, the analysis of the ecological quality of livestock products produced in the farms of the Polissia zone of Zhytomyr Oblast, affected by the accident at the Chernobyl Nuclear Power Plant, proved that the concentration of Pb and Cd in the milk of dairy cows, muscle tissue of young cattle and pigs in most of the analysed samples exceeds sanitary and hygienic requirements. Therefore, for the production of milk and meat within the current regulatory requirements, reducing the accumulation of heavy metals in animal feed remains an urgent issue.

The results obtained are consistent with the data of other researchers who have investigated the ability of heavy metals to accumulate in pig organs and tissues (Zhukorskyi et al., 2018; Savchuk et al., 2021). According to their data, the presence of heavy metals in feed rations 10 times higher than the maximum allowable level leads to the accumulation of Pb and Cd mainly in the bones, liver, kidneys, and meat of animals. According to other authors, the Cd content in the liver of geese

exceeded the maximum permissible concentration by 8 times (Razanov & Voitko, 2017). Other studies found that upon fattening steers for meat within the territory belonging to Zone III of radioactive contamination, the accumulation of Pb in muscle tissue did not exceed regulatory requirements and amounted to 0.067-0.112 mg/kg, while the concentration of Cd was much higher than sanitary and hygienic requirements (Savchuk *et al.*, 2021). International researchers are also concerned about the content of heavy metals in animal products. Thus, according to J.L. Han *et al.* (2022), analysis of 1,066 samples of fresh meat (pork, beef, lamb, and poultry) revealed average levels of heavy metal concentrations: Pb – 0.029 mg/kg, Cd – 0.002 mg/kg of raw weight.

CONCLUSIONS

More than 36 years after the Chernobyl accident, the environmental situation in the Polissia zone of Ukraine stays difficult, which is confirmed by the elevated content of heavy metals in feed, milk, beef, and pork. A high concentration of Pb was found in coarse feed and sunflower

cake and meal (2,462 mg/kg and 1,639 mg/kg), 41.9% and 60.0% of samples of these types of feed, respectively, exceeded the maximum permissible concentration in Cd content. With an increase in the density of ¹³⁷Cs soil pollution, the content of heavy metals in fodder also increases: in hay and straw – 1.27-1.34 times; hay – 1.17-1.58; silage – 1.25-1.81; grain mixtures – 1.50-1.78 times. According to the results of the analysis of livestock products for the content of heavy metals, it was found that the maximum permissible concentrations of Pb in milk were exceeded by 1.45 times, Cd – in the longest back muscle of cattle and pigs – by 1.48 and 1.22 times, respectively. The Cd content in milk was within the regulatory requirements, while 41.2% of the analysed milk samples exceeded the maximum permissible concentration for this element. With the increase in the level of radioactive contamination of the territory by ¹³⁷Cs from 1 to 5 Ki/km² and more, the content of Pb and Cd in livestock products also increases: in milk – by 1.57-1.60 times, in the longest back muscle of cattle – by 1.10-1.49, the longest back muscle of pigs (excluding Pb) – 1.07 times.

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Моніторинг важких металів у кормах і продукції тваринництва зони Полісся України

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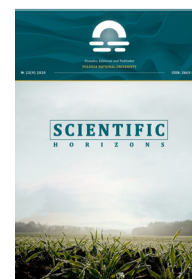
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Анотація. При значній концентрації забруднювачів у навколишньому середовищі відбувається їх нагромадження у рослинах, згодуювання яких у подальшому призведе до переходу токсичних елементів до організму тварини. Навіть невелика концентрація важких металів чи радіонуклідів має негативний вплив як на організм тварини, так і на організм людини. Тому моніторинг Pb і Cd у кормах, молоці та м'ясі за їх виробництва на території зони Полісся України є актуальним і потребує подальшого всебічного вивчення. Метою роботи було дослідити вміст важких металів у кормах і продуктах забою тварин, що вирощуються на території зони Полісся з різним рівнем радіоактивного забруднення. Дослідження проводили на молодняку свиней та на бугайцях, які поставлені на відгодівлю. У роботі були використані атомно-абсорбційний метод визначення вмісту токсикантів у зразках та метод варіаційної статистики для обробки результатів дослідження. Результати досліджень вмісту Pb і Cd у зразках свідчать про наявність істотних коливань важких металів у межах окремих господарств. Зі збільшенням рівня забруднення ґрунту ^{137}Cs підвищується концентрація токсикантів у кормах, молоці, найдовшому м'язі спини досліджуваних тварин. Встановлено перевищення гранично допустимої концентрації Pb у молоці (33,8%) і Cd (41,2%). Концентрація Cd перевищувала встановлений рівень у 72,2% досліджуваних зразків найдовшого м'язу спини великої рогатої худоби та 80,0% зразків найдовшого м'язу спини свиней. Вміст Cd у всіх досліджуваних зразках кормів був значно вищим встановленого нормативу. Найбільше перевищення токсикантом встановлено у зразках сіна, соломи (41,9%), макухи та шроту (60%). Таким чином показники якості кормів та тваринницької продукції, яка виробляється у господарствах поліської зони Житомирщини, постраждалих внаслідок аварії на ЧАЕС, свідчать про те, що концентрація Pb і Cd у молоці дійних корів, м'язовій тканині молодняку великої рогатої худоби і свиней у більшості проаналізованих проб перевищує санітарно-гігієнічні вимоги. Тому для одержання молока і м'яса у межах діючих нормативних вимог нагальною проблемою залишається зменшення накопичення важких металів у кормах для годівлі тварин та птиці

Ключові слова: Плюмбум, Кадмій, концентрація, забруднення, молоко, найдовший м'яз спини



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Elements of Plant Productivity and Biological Yield Capacity of Grain Sorghum Hybrids Depending on the Inter-row Width and Seed Sowing Rate

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Abstract. Sorghum is one of the most important food, fodder, and energy crops in the world. The crop is resistant to stress factors, especially moisture deficiency. This biological feature allows it to form high and stable grain yields in conditions of moisture deficiency and hot temperature. Grain sorghum has a significant advantage in terms of several physiological, biological, yield characteristics compared to other crops, but the acreage under it in Ukraine stays limited. The main reason for this is, first, the lack of varietal technologies for its cultivation with improved elements. Therefore, the study of the complex influence of the rate of sowing seeds and the width of the row spacing on the formation of productivity elements is currently a relevant area of research. The main goal of the research was to study the influence of a complex of factors: row spacing, seed sowing rates on the productivity and biological yield of sorghum grain. The research was carried out in 2019-2021 at FE "Diunis", Kreminskyi district, Luhansk region. The scheme of the experiment: width between rows – 35, 45 and 70 cm, hybrids – Svat and Flagg, sowing rates – 100,000 pieces/ha, 140,000, 180,000 and 220,000 pieces/ha. The Flagg hybrid formed a higher panicle productivity of the main and side stem systems. As to sorghum hybrid Flagg, the grain mass from panicle of the main and lateral stems was 45.1 and 39.0 g, respectively; that of hybrid Svat were 39.5 and 31.1 g. A higher panicle productivity of hybrid Flagg was formed due to a much larger mass of 1,000 grains (by 35-40%); sorghum hybrid Svat had a larger number of grains in panicle of both stem systems. The biological grain productivity of both stem systems was higher for sorghum hybrid Flagg – 5.87 t/ha, as compared with that of early-ripening hybrid Svat, which was equal to 4.75 t/ha

Keywords: the number of panicles, main stems, side stems, grain size of the panicle, weight of 1,000 grains, correlation



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INTRODUCTION

Ukraine is characterized by remarkably diverse soil-climatic conditions, which is why crop production in the east zone of the north Steppe is to be based on the effective use of the agro-climatic potential by a proper choice and location of the crops which can develop high yield capacity and good quality output in certain conditions. The efficient cultivation of the field crops in the areas with moisture deficit and high summer temperatures appears to be possible due to their high ecological resistance, the latter levels the effect of stress factors (Kalenska *et al.*, 2017).

A typical representative of these crops is sorghum (grain, sugar, technical sorghum, Sudanese grass). Owing to their high plastic and adaptive nature, the area of sorghum crop cultivation can be very widespread (from tropical and semi-desert regions to temperate latitudes); sorghum crops have a high ability to resist negative weather conditions during their vegetation (Klymovych *et al.*, 2011; Fedorchuk *et al.*, 2016; Aliksieiev, 2021).

Sorghum can easily adapt to moisture deficit and use it sparingly. This biological feature makes it possible for sorghum to develop high and stable grain yields in the conditions of moisture deficit and elevated temperatures. In this respect, sorghum is a leader among other field crops (Polovyi *et al.*, 2020).

Mostly sorghum is grown with a fodder purpose; the crop is widely used to produce grain forage, mono-fodder, hay, haylage, green fodder, and fodder molasses. In recent years sorghum has been widely used in food and technical industry for the manufacture of flour, cereals, starch, glucose-fructose sugar, bioethanol, and other renewable energy sources (Nosko *et al.*, 2015; Mehmood *et al.*, 2017; Kalenska & Naidenko, 2018).

Despite a considerable advantage of sorghum based on several features (e.g., yield capacity, biological and physiological characteristics) as compared with other crops, proper attention has not been paid to sorghum yet, as its sown areas in Ukraine remain to be rather limited. This situation is explained by the lack of varietal technologies of its cultivation with the improved elements and updated innovations. Thus, nowadays it is expedient to work out varietal, adaptive technologies of the cultivation which can realize a genetic productivity potential of the crop, and in this way to encourage the producers to grow sorghum.

Until now the results of the research which dealt with the development of the elements of the varietal technologies of sorghum cultivation in various soil-climatic zones were summed up; it helps make a complex analysis of their efficiency which will result in a further improvement of the varietal farm practices of its cultivation (Storozhik & Muzyka, 2019; Svyrydova, 2017; Kalenska & Naidenko, 2019). There is a certain disagreement among scientists as to the seed sowing rate and the inter-row width, which is associated with the cultivation region, varietal features, the intensification level of the cultivation technology, etc. (Gondal *et al.*, 2017; Mekasha *et al.*, 2021; Makarov, 2006).

Usually, grain sorghum is grown with the inter-rows which range within 60-75 cm; but with the development of new production technologies and the introduction of new herbicides, innovative approaches appear on the spread of narrower inter-rows when this crop is grown (Kovalenko, 2014 Ovsiienko, 2015; Gondal *et al.*, 2017).

Researchers G.K. Dremlyuk *et al.* (2013) note that under conditions of a dry growing season, the most effective cultivation of sorghum is by wide-row sowing with 45 cm between rows, and in the case of best conditions – by row sowing with 15 cm between rows.

In the opinion of L.A. Svyrydova (2017), in the conditions of the Forest-steppe zone, regardless of a ripening group and a seed sowing rate, the highest yield of sorghum grain is formed by sowing when the inter-row is 45 cm. For instance, the combination of this inter-row width with a seed sowing rate 200 thous. pcs/ha was the best for grain hybrids Prime, Dash E and Sprint W, for hybrid Stepovyi 8 – with a seed sowing rate 160 thous. pcs/ha. (Svyrydova, 2017). In the conditions of the educational-scientific-production centre of the Uman University of Horticulture, the highest grain yield of modern grain sorghum hybrids was provided by the combination of the seed sowing rate of 250,000 seeds/ha with 45 cm between rows (Snider *et al.*, 2012; Boiko, 2016).

In the conditions of a steppe zone of the Crimea, the highest yield capacity of grain sorghum hybrids was formed in the treatments of the combination of a seed sowing rate 100-140 thous. pcs/ha with the inter-rows of 45 and 60 cm (Samoilenko, 2009).

The analysis of the reference sources proves the following: firstly, the importance of a complex effect of the inter-row width and a seed sowing rate on the formation of the grain sorghum productivity; secondly, the necessity to consider the features of a morphological biotype of hybrids, the level of farm practices and the cultivation area. Besides, the analysis made confirms the lack of the research results as to the studies of the optimal combinations of a seed sowing rate and the inter-row width for different regions of Ukraine, namely for the conditions of the east zone of the north Steppe; it is this area that is the most promising one for sorghum cultivation.

Based on this, *the purpose of this study* was to investigate the complex effect of a seed sowing rate and various treatments of the inter-row width on the formation of the productivity elements and the biological yield capacity of sorghum in the conditions of the north Steppe.

MATERIALS AND METHODS

In 2019-2021, the research was carried out by the generally accepted methodology at farm enterprise “Diunis”, Kreminskyi district, Luhansk Oblast (Yeshchenko *et al.*, 2005). The soil in the area under study was sod-podzolic low-humus chernozem. Humus content in a ploughing layer was 2.4-2.8%, that of mobile phosphorus – 11.6 mg, potassium content was 9.1 mg per 100 g of the soil.

The trial was started by a randomized method with four replications. Three treatments of the inter-row width (factor A) – 35, 45 and 70 cm, two hybrids (factor B) – Svat and Flagg and four treatments of sowing rates (factor C) – 100 thous. pcs/ha, 140, 180 and 220 thous. pcs/ha were studied in the experiment. The sown and accounting areas were 100.0 and 80.0 m², respectively. Farm practices in the trials were the generally accepted ones for the area of the research, except for the elements under study.

Two new hybrids of grain sorghum – Svat and Flagg – were studied in the research. An early-ripening high yielding Ukrainian hybrid Svat has been included in the National registry since 2017, a medium-early ripening French hybrid Flagg – since the year of 2018. These hybrids are drought-resistant, they have high indicators of their resistance to pathogens, and they are recommended to be grown in the Steppe.

In 2019-2021 weather conditions of sorghum vegetation were contrasting, and it particularly concerned moisture regime. In addition, during these years a general tendency of the precipitation distribution was recorded, namely, more precipitation occurred at the beginning of sorghum vegetation. In 2019 in the first decade of May the amount of precipitation exceeded the indicator of a climatic standard by two times. In May 2020 and 2021 and in June 2021, the amount of precipitation was much higher compared with long-term indicators. For instance, in May 2020 and 2021 the amount of precipitation was equal to 108 and 72 mm, while climatic standard was 49 mm. In June most of the precipitation occurred in the first two decades – 53 and 78 mm, respectively. In these years there was no precipitation beginning from the third decade of June and up to the end of sorghum vegetation.

Totally, in the years under study less than 200 mm of precipitation were recorded during sorghum vegetation, which was much lower than an average long-term indicator, i.e., 240 mm. Along with this, considering the sufficient moisture supply of the sown areas at the first stages of their growth and development as well as a

global warming tendency and the decrease of the annual precipitation amount, weather conditions of the area under study can be classified as favourable for sorghum.

In the years of the study, the best temperature conditions for plant growth and development were in 2021. That year, air temperature at the beginning of plant vegetation was a bit higher compared with that in 2020, and it was lower than the indicators of climatic standard. In July 2021, except for a few days in the second decade, the temperature ranged within optimal indicators for sorghum plants – 20-25°C, whereas in 2020 in the first and second decade of this month it was over 35.0°C on some days.

In general, the weather conditions of sorghum vegetation differed considerably from the average long-term indicators; however, their comparison with the weather conditions recorded during the last 10 years proved the fact that they were quite typical, as due to global climate changes the weather conditions of the area under study tended towards warming and decreasing the precipitation amount.

RESULTS AND DISCUSSION

Factors under study had different effect on the variability of elements of the productivity of panicles of grain sorghum stems. In particular, the number of main stem panicles, as well as the panicle grain number of the sorghum main and lateral systems, underwent the greatest changes under the effect of a 220 thous./ha seed sowing rate; the mass of 1,000 grains from the panicles of the stem main and lateral system was under the effect of a hybrid morphotype, and the influence of the studied treatments of the inter-row width was mostly seen in the variability of the panicle number of the lateral stems.

The effect of a sowing rate was mostly displayed in the change of a panicle number of the sorghum main stems. According to the studied treatments of the inter-row width and hybrids, on average the number of main stem panicles increased more than twice – 49.1 thous. pcs/ha with the increase of a sowing rate – 100 thous. pcs/ha; and it was 107.2 thous. pcs/ha at a sowing rate 220 thous. pcs/ha (Table 1).

Table 1. Panicle productivity of the main stem depending on the inter-row width and a seed sowing rate (average in 2019-2021)

Inter-row width, cm (factor A)	Hybrid (factor B)	Sowing rate, thous./ha (factor C)	Panicle number, thous. pcs/ha	Panicle graininess, pcs	Mass of 1,000 grains, g	Grain mass from panicle, g
35	Svat	100	49.1	2,017	20.6	41.5
		140	67.1	2,004	20.5	41.0
		180	87.0	1,970	20.5	40.3
		220	106.0	1,899	20.3	38.6
	Flagg	100	49.5	1,648	29.5	48.6
		140	68.5	1,635	29.6	48.4
		180	88.8	1,577	29.5	46.5
		220	108.5	1,484	29.2	43.3

Table 1, Continued

Inter-row width, cm (factor A)	Hybrid (factor B)	Sowing rate, thous./ha (factor C)	Panicle number, thous. pcs/ha	Panicle graininess, pcs	Mass of 1,000 grains, g	Grain mass from panicle, g
45	Svat	100	49.1	1,998	20.5	40.8
		140	68.1	1,991	20.5	40.8
		180	86.7	1,946	20.4	39.6
		220	107.1	1,854	20.3	37.5
	Flagg	100	48.5	1,640	29.6	48.6
		140	67.8	1,619	29.6	47.9
		180	88.5	1,560	29.4	45.8
		220	108.2	1,452	29.3	42.5
70 (c)	Svat (c)	100	49.0	1,975	20.5	40.5
		140	67.7	1,946	20.3	39.5
		180 (c)	87.4	1,896	20.2	38.3
		220	105.3	1,762	20.1	35.3
	Flagg	100	49.3	1,612	29.4	47.3
		140	68.6	1,576	29.3	46.1
		180	88.1	1,402	29.1	40.7
		220	108.3	1,237	28.9	35.7
Average by factor A		35	78.1	1,779	25.0	43.5
		45	78.0	1,758	25.0	42.9
		70 (c)	78.0	1,676	24.7	40.4
Average by factor B	Svat (c)		77.5	1,938	20.4	39.5
	Flagg		78.6	1,537	29.4	45.1
Average by factor C		100	49.1	1,815	25.0	44.6
		140	68.0	1,795	25.0	44.0
		180 (c)	87.8	1,725	24.9	41.9
		220	107.2	1,615	24.7	38.8

The effect of a sowing rate on the variability of the panicle number of grain sorghum hybrids in the studied of the inter-row width was the same. When a seed sowing rate increased from 100 to 220 thous. pcs/ha, the panicle number of an early-ripening hybrid Svat in the treatments with the inter-row width of 35, 45, and 70 cm increased by 216%, 218%, and 214%, respectively, a sowing rate increased by 220%. A similar tendency was seen in the fields of an average-early-ripening hybrid of French selection Flagg.

The number of panicles from the stems of a lateral system underwent fewer changes under the effect of a

100 to 180 thous. pcs/ha seed sowing rate, besides, the trend of this connection changed. For instance, with the increase of a sowing rate from 100 to 180 thous. pcs/ha one can see the increase of the panicle number of a stem lateral system; contrary to this, with the increase over 180 thous. pcs/ha their number decreased. On average, by other factors, the number of panicles of a lateral system increased by 24.5 thous. pcs/ha (58.5%) when a sowing rate increased from 100 to 180 thous. pcs/h and it decreased by more than 8.0 thous. pcs/ha (14.1%) when a sowing rate increased up to 220 thous. pcs/h (Table 2).

Table 2. Panicle productivity of the lateral stem depending on the inter-row width and a seed sowing rate (average in 2019-2021)

Inter-row width, cm (factor A)	Hybrid (factor B)	Sowing rate, thous./ha (factor C)	Panicle number, thous. pcs/ha	Panicle graininess, pcs	Mass of 1,000 grains, g	Grain mass from panicle, g
35	Svat	100	41.8	1,618	20.4	32.9
		140	55.5	1,609	20.3	32.7
		180	67.1	1,583	20.2	32.0
		220	58.5	1,524	20.1	30.6
	Flagg	100	43.8	1,429	29.3	41.9
		140	59.7	1,420	29.2	41.4
		180	72.5	1,391	29.2	40.6
		220	69.3	1,316	29.0	38.1

Table 2, Continued

Inter-row width, cm (factor A)	Hybrid (factor B)	Sowing rate, thous./ha (factor C)	Panicle number, thous. pcs/ha	Panicle graininess, pcs	Mass of 1,000 grains, g	Grain mass from panicle, g
45	Svat	100	42.2	1,610	20.4	32.8
		140	54.0	1,582	20.3	32.1
		180	64.8	1,546	20.1	31.1
		220	53.2	1,479	20.1	29.7
	Flagg	100	43.7	1,422	29.3	41.6
		140	58.1	1,405	29.2	41.0
		180	70.2	1,362	29.0	39.5
		220	64.0	1,290	29.0	37.3
70 (c)	Svat (c)	100	38.3	1,590	20.2	32.1
		140	50.3	1,543	20.1	30.9
		180 (c)	57.0	1,456	20.1	29.2
		220	48.2	1,374	19.9	27.3
	Flagg	100	41.3	1,398	29.2	40.7
		140	54.3	1,371	29.2	39.9
		180	66.9	1,195	29.0	34.6
		220	55.7	1,082	28.7	31.0
Average by factor A		35	58.5	1,486	24.7	36.3
		45	56.3	1,462	24.7	35.6
		70 (c)	51.5	1,376	24.6	33.2
Average by factor B	Svat (c)		52.6	1,543	20.2	31.1
	Flagg		58.3	1,340	29.1	39.0
Average by factor C		100	41.9	1,511	24.8	37.0
		140	55.3	1,488	24.7	36.3
		180 (c)	66.4	1,422	24.6	34.5
		220	58.2	1,344	24.5	32.3

Similar regularities were recorded in the fields of both hybrids with different inter-row width. These changes are quite common, because when seed sowing rate increases productive bushiness will decrease because of a growing competitiveness among plants; increase in the lateral stem number will take place when sowing rate increases to a certain point due to higher plant density; when certain bushiness is reached, further plant density will not overlap the damage of productive plant activity. Other researchers also mentioned similar regularity (Sviridova, 2017; Makarov, 2006; Gondal *et al.*, 2017).

The effect of the inter-row width on the changes of the panicle number of the stem system was not recorded, but this factor had a profound effect on the panicle number of the lateral system. And again, it relates to the level of competitiveness in agro-phytocenosis. Thus, in treatments with a more even distribution of plants on the nutrition area which can be reached at the inter-row width of 35 cm, on average the panicle number of a lateral stem system by other factors was 58.5 thous. pcs/ha, while in the treatments with the inter-row width of 70 cm it was 51.5 thous. pcs/ha (smaller by 14.0%). Hence, only due to the panicle number of a lateral stem system, provided all other elements of the yield structure are the same, in the treatments with the inter-row width of 35 cm, the grain yield capacity of a

lateral stem system will be higher by 14.0% as compared with that at the inter-row width of 70 cm.

Panicle graininess of the stems of the main and lateral system was much higher in the fields of an early-ripening hybrid Svat which could be explained by its morphotype. On average, according to the sowing rates and treatments of the inter-row width under study, the number of grains in panicle of the main and lateral stem system of sorghum hybrid Svat was 1,938 and 1,543 pieces, respectively, as to hybrid Flagg these indicators were 1,537 and 1,340 pieces, respectively. Along with this, hybrid Flagg had a much higher average panicle productivity of both stem systems, as its peculiar feature was a larger mass of 1,000 grains. On average, by the studied treatments of the inter-row width and seed sowing rates, the mass of panicle grain of the main and lateral stem system was 39.5 and 31.1 g, respectively, while for hybrid Flagg the indicators were 45.1 g and 39.0 g.

Totally in the trial, the largest mass of panicle grain of the main stem system was formed in the treatments with the widest distance between plants, i.e., in the treatments with the inter-row width of 35 cm and a seed sowing rate 100 thous. pcs/ha. In the years under study, on average, the mass of panicle grain of the central stems of sorghum hybrids Svat and Flagg in these treatments was 41.5 and 48.6 g, respectively.

In the field of both hybrids the effect of a seed sowing rate on the changes of the mass of panicle grain of the stem system was much higher in the treatments with the inter-row width of 70 cm. For example, with the increase of a seed sowing rate up to 220 thous. pcs/ha, grain mass from the central panicle of hybrids Svat and Flagg decreased by 14.7 and 32.4%, respectively, in the treatments with the inter-row width of 70 cm, while in the treatments with the inter-row width of 35 cm this indicator decreased only by 7.5 and 12.2%.

The interaction between the inter-row width and a seed sowing rate had a greater effect on the changes of the indicators of the mass of panicle grain of a stem lateral system. Thus, when seed sowing rate increased from the smallest to the largest one, in the treatments with the inter-row width of 70 cm, the mass of panicle grain from a lateral stem system of hybrids Svat and Flagg decreased by 17.8% and 31.0%, respectively; this indicator decreased by 7.5% and 10.0%, respectively, in the treatments with a two-time narrower inter-row.

As to sorghum hybrid Flagg, when a nutrition area and its patter were changed, the grain mass from both panicle systems varied in a wider range; which is why it is advisable to have a serious approach to the choice of a plant nutrition area and its pattern for this hybrid. This hybrid forms a much larger mass of panicle grain of both stem systems in more "favourable" conditions, which is an important precondition for the formation of its higher yield capacity. As the plant density grows, the difference by this indicator between the studied hybrids partially levels.

The variability of the mass of panicle grain from the lateral and main stem system of the studied hybrids under the influence of a seed sowing rate was first connected with the change in panicle graininess, as the mass of 1,000 grains did not change much.

The analysis of the indicators of the panicle productivity elements of both sorghum hybrids showed that their decrease took place mainly because a seed sowing rate increased from 180 to 220 thous. pcs/ha. This was particularly seen in the treatments with the inter-row width of 70 cm. Furthermore, as was mentioned earlier, the number of panicles of the lateral stem system increased when a seed sowing rate was higher – up to 180 thous. pcs/ha; then, on the contrary, the larger

plant density led to the decrease of their number. Authors are very much interested in a final result, i.e., the plant grain productivity per unit of a sown area; the best option is the one which will ensure the highest yield capacity of the fields. In view of this, it is not correct to give preference to a certain treatment based only on the indicators of the individual plant productivity. Thus, the indexes of the biological productivity of the studied sorghum hybrids were analysed. Besides, to better understand a mechanism of the influence of the studied factors, authors considered their influence on the level of the grain biological productivity of sorghum stems of the main and lateral systems.

The grain biological yield capacity of the main stem system of both sorghum hybrids in all treatments of the inter-row width was the highest when a seed sowing rate was the largest – 220 thous. pcs/ha. With the increase of a seed sowing rate the individual stem productivity of the main system decreased, but due to the increase of a seed sowing rate, and accordingly that of the plant number per unit of the sown area, the biological grain yield capacity of the main stem system was the highest when seed sowing rate was the largest.

When a seed sowing rate was gradually increasing to the established point – 40 thous. pcs/ha, the indicator growth decreased. Logically, the individual panicle productivity decreased more intensely. This tendency was mostly recorded in the treatments with the inter-row width of 70 cm. Thus, it is in the treatments with this inter-row width that the difference of the indexes of grain yield capacity of the main stem panicles was the lowest.

In the conditions of "a better" pattern of the plant nutrition area, namely, in the treatments with the inter-row width of 35 cm, when sorghum plants did not suppress each other very much, the effect of a seed sowing rate was considerably higher. When the grain biological productivity of the main sorghum stems (hybrids Svat and Flagg) increased by 1.73 t/ha (87.0%) and 1.56 t/ha (66.6%), respectively, in the treatments with the inter-row width of 70cm and with the increase of a seed sowing rate from 100 to 220 thous. pcs/ha; then in the treatments with the inter-row width of 35 cm the biological productivity increased by 2.05 (100.5%) and 2.30 t/ha (95.4%) (Table 3).

Table 3. Biological grain yield capacity of sorghum hybrids of the different stem systems under the effect of the inter-row width and a sowing rate, t/ha (average in 2019-2021)

Inter-row width, cm (factor A)	Hybrid (factor B)	Sowing rate, thous. pcs/ha (factor C)	Biological grain yield capacity		
			Main stems	lateral stems	Total
35	Svat	100	2.04	1.46	3.50
		140	2.75	1.91	4.66
		180	3.50	2.23	5.73
		220	4.09	1.87	5.96
	Flagg	100	2.41	1.92	4.33
		140	3.32	2.57	5.89
		180	4.14	3.08	7.22
		220	4.71	2.75	7.46

Table 3, Continued

Inter-row width, cm (factor A)	Hybrid (factor B)	Sowing rate, thous. pcs/ha (factor C)	Biological grain yield capacity		
			Main stems	Lateral stems	Total
45	Svat	100	2.00	1.44	3.44
		140	2.78	1.81	4.59
		180	3.43	2.12	5.55
		220	4.02	1.70	5.72
	Flagg	100	2.36	1.92	4.28
		140	3.25	2.49	5.74
		180	4.07	2.92	6.99
		220	4.62	2.54	7.16
70 (c)	Svat (c)	100	1.99	1.29	3.28
		140	2.68	1.62	4.30
		180 (c)	3.35	1.74	5.27
		220	3.72	1.40	5.12
	Flagg	100	2.34	1.79	4.13
		140	3.15	2.28	5.43
		180	3.60	2.44	6.04
		220	3.90	1.82	5.72
Average by factor A		35	3.37	2.22	5.59
45		3.32	2.12	2.12	5.44
70 (c)		3.09	1.80	1.80	4.89
Average by factor B		Svat (c)	3.03	1.72	4.75
Flagg		3.49	2.38	2.38	5.87
Average by factor C		100	2.19	1.64	3.83
140		2.99	2.11	2.11	5.10
180 (c)		3.68	2.42	2.42	6.10
220		4.18	2.01	2.01	6.19
SSD ₀₅ main effect of factor A			0.11	0.12	0.19
SSD ₀₅ main effect of factor B			0.09	0.10	0.16
SSD ₀₅ main effect of factor C			0.13	0.14	0.22
SSD ₀₅ interaction of AC			0.22	$F_{\phi} < F_m$	0.39

Note: when SSD₀₅ was calculated, years were taken as replications. A difference as compared with the control is shown in a dominator

In the area under study, the effect of a seed sowing rate on the grain biological yield capacity of the stem lateral system was manifested a bit differently, namely: with its increase to 180 thous. pcs/ha the panicle grain biological productivity of the lateral stem system of both sorghum hybrids increased, and with its further increase the biological productivity decreased. This tendency was recorded in all studied treatments of the inter-row width. For instance, with the increase of sowing rate up to 220 thous. pcs/ha and in the treatments with the inter-row width of 35 cm the panicle grain biological productivity of the lateral stem system of sorghum hybrids Svat and Flagg decreased by 0.36 and 0.33 t/ha (19.3 and 12.0%); in the treatments with the inter-row width 4 cm this indicator decreased by 0.42 and 0.38 t/ha (24.7

and 15.0%); in the treatments with the inter-row width of 70 cm the biological productivity decreased by 0.38 and 0.62 t/ha (24.3 and 31.9%), respectively.

The decrease of the panicle grain biological productivity of the lateral stem system when the seed sowing rate increases from to 220 thous. pcs/ha occurs for two reasons: on the one hand – the decrease of the lateral panicle number (due to a severe competitiveness among plants), on the other hand – the decrease of their individual productivity. According to the statistical analysis made, the highest grain biological yield capacity of the lateral sorghum stem system was formed at a seed sowing rate 180 thous. pcs/ha. Both the increase and the decrease of a seed sowing rate led to its significant decrease.

Among the studied treatments of the inter-row width, the narrowest inter-rows of 35 cm formed the highest panicle grain yield capacity of both stem systems. As compared with the control treatment of factor A (the inter-row width of 70 cm), on average the grain biological yield capacity of the main and lateral stem system by other factors increased by 0.28 and 0.42 t/ha, respectively.

The total yield capacity was the highest in the treatments with the inter-row width of 35 cm and a seed sowing rate 220 thous. pcs/ha. In this treatment it was 5.96 t/ha for the early-ripening hybrid Svat, the medium-early ripening hybrid Flagg had it at the level of 7.46 t/ha. However, according to the statistical analysis, it did not differ statistically from the indicator received with a sowing rate 180 thous. pcs/ha.

Among the studied correlations of the factors, only the interactions of a seed sowing rate and the inter-row width was significant. This is natural, because in the treatment with the inter-row width of 35, 45 and 70 cm, the effect of a seed sowing rate on the overall biological yield capacity of sorghum grain was seen in diverse ways. In the treatments with the inter-row width of 70 cm the highest total biological grain yield capacity of both sorghum hybrids was formed in the treatments with a seed sowing rate 180 thous. pcs/ha (5.27 t/ha for hybrid Svat and 6.04 t/ha for hybrid Flagg), while in the treatments with the inter-row width of 35 cm, as noted above, a seed sowing rate was 220 thous. pcs/ha.

It has to be noted that there is no significant difference between the indicators of the biological grain yield capacity of hybrids in the treatments with the inter-row width of 35 and 45 cm. Regardless of this, the narrower inter-rows (35 cm) are more preferable, because in the

context of the studied hybrids and a seed sowing rate the tendency towards the yield capacity increase is recorded with the decrease of the inter-row width from 45 to 35 cm. Other researchers confirm this fact (Snider *et al.*, 2012; Semin *et al.*, 2016; Mekasha *et al.*, 2021). Furthermore, there is an increased difference between the biological grain yield capacity in these treatments when a seed sowing rate is larger. It is quite logical since when the plant density grows the role of the nutrition area pattern is higher. Since the increase of a seed sowing rate (180 and 220 thous. pcs/ha) resulted in the formation of a higher biological yield capacity, then the preference is given to the 35 cm inter-rows. For instance, at a seed sowing rate 100 thous. pcs/ha and in the treatments with the inter-row width of 35 cm the total biological grain yield capacity of sorghum hybrids Svat and Flagg was higher only by 0.06 and 0.05 t/ha than in the treatments with the inter-row width 45 cm, while in the treatments with a seed sowing rate 220 thous. pcs/ha the yield capacity was 0.24 and 0.30 t/ha, respectively.

It is of a certain interest to determine the density and the trend of the connections of the biological grain yield capacity and the panicle productivity elements of the various stem systems of the studied grain sorghum hybrids with a seed sowing rate of the various treatments of the inter-row width. The inter-row width of 35 cm and 70 cm, i.e., the control and the best treatment, were taken as an example. In the studied area the closest direct connection was between a seed sowing rate and the panicle number of the main stems. In the fields of sorghum hybrids Svat and Flagg in the treatments with the inter-row width of 35 cm it was as follows: $r=0.98$ and $r=0.97$, with the inter-row width of 70 cm – $r=0.97$ and $r=0.96$ (Fig. 1).

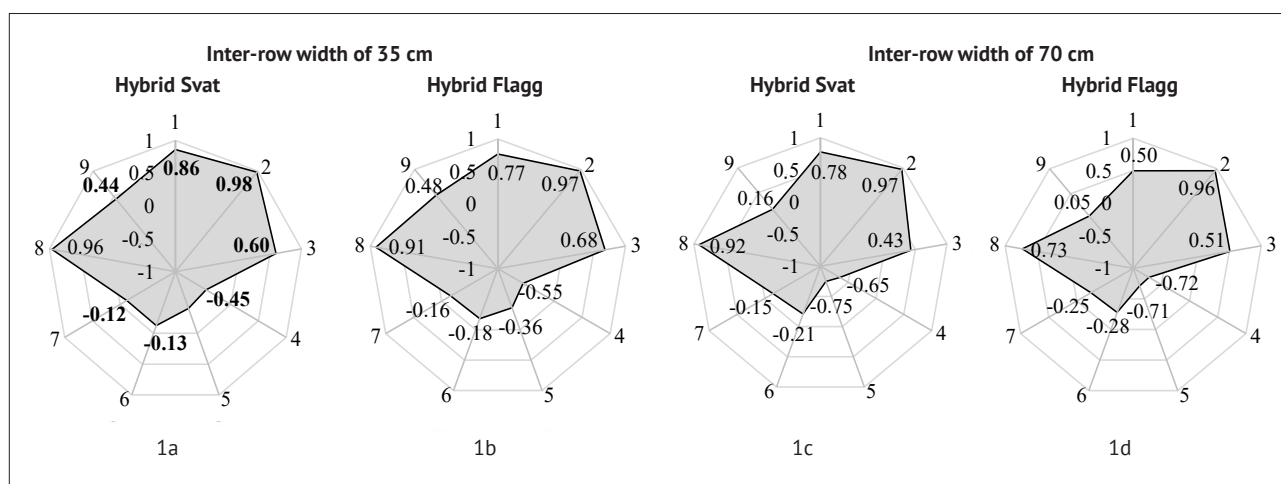


Figure 1. Strength and trend of the connections between a seed sowing rate with the elements of the plant productivity and the biological grain yield capacity of grain sorghum (Inter-row width of 35 cm:

1a – Hybrid Svat, 1b – Hybrid Flagg; Inter-row width of 70 cm: 1c – Hybrid Svat, 1d – Hybrid Flagg)

Note: 1 – biological grain yield capacity; 2 – panicle number of the main stems per 1 ha; 3 – panicle number of the lateral stems per 1 ha; 4x – graininess of the central panicle; 5 – graininess of the lateral panicle; 6 – mass of 1,000 grains from the central panicle; 7 – mass of 1,000 grains from the lateral panicle; 8 – biological grain yield capacity of the main stem system; 9 – biological grain yield capacity of the lateral panicle system

A close direct connection between a seed sowing rate and the biological grain yield capacity of the central stem panicles was common for both hybrids in the treatments of the inter-row width ($r=0.73-0.96$), as well as the average direct connection with the panicle number of the lateral stems ($r=0.43-0.68$) and a weak reverse connection with the mass of 1,000 grains from the central ($r=-0.13-0.28$) and lateral panicle ($r=-0.12-0.25$).

The strength of the connection of a seed sowing rate with other productivity elements depended on the inter-row width. In particular, in the treatments with the inter-row width of 35 cm a seed sowing rate had a weak direct connection with the biological grain yield capacity of the lateral stems of both hybrids ($r=-0.44-0.48$), whereas in the treatments with the inter-row width of 70 cm this connection was weak ($r=-0.05-0.16$). In the treatments with the inter-row width of 35 cm an average reverse connection ($r=-0.36-0.47$), ($r=-0.36-0.47$) was recorded between a seed sowing rate and panicle graininess of the lateral stem system of both hybrids, whereas in the treatments with the inter-row width of 70 cm there was a strong reverse connection ($r=-0.71-0.75$).

CONCLUSIONS

The results of this study allow drawing the following conclusions: among the treatments of the inter-row width under study, the preference is given to the narrowest one – 35 cm. A higher biological yield capacity of the main stem system on these inter-rows was formed due to a larger number of grains in the panicle, as the mass of 1,000 grains did not in fact change. A higher grain yield capacity of both sorghum hybrids in

the treatments with the inter-row width of 35 cm was formed both due to a larger number of lateral panicles per area unit and to their higher graininess; the total biological grain yield capacity was the highest in the treatments with the inter-row width of 35 cm and a seed sowing rate of 220 thous. pcs/ha. By the years, on average, in the case of hybrids Svat and Flagg it was 5.96 and 7.46 t/ha, respectively. At the same time, according to the statistical analysis, it did not differ much from the treatment with a seed sowing rate 180 thous. pcs/ha. Based on this, it is inexpedient to increase a seed sowing rate to 220 thous. pcs/ha. Moreover, the research was carried out in favourable weather conditions which are rare for the area under study. And with moisture deficit, a seed sowing rate is to be set at a lower level of an optimal range, hybrid Flagg developed the highest panicle productivity of the main and lateral stem system. Grain mass from panicle of the main and lateral stems was 45.1 and 39.0 g, respectively, for hybrid Svat these indicators were 39.5 and 31.1 g. The higher productivity of sorghum panicles of hybrid Flagg was formed due to a much larger mass of 1,000 grains (by 35-40%), while the number of grains in the panicles of both stem systems was higher in sorghum hybrid Svat. Sorghum hybrid Flagg had a higher biological grain yield capacity of both stem systems – 5.87 t/ha as compared with that of early-ripening hybrid Svat which amounted to 4.75 t/ha. However, these hybrids are of a different morphotype, and they belong to different ripening groups. Svat is an early-ripening hybrid; having many advantages, it presents certain interest for the production.

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Елементи продуктивності рослин та біологічна врожайність зерна гібридів сорго зернового залежно від ширини міжрядь та норми висіву насіння

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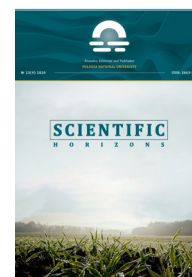
Анотація. Сорго є однією з найбільш важливих продовольчих, кормових та енергетичних культур в світі. Культура є стійкою до стресових чинників, особливо дефіциту вологи. Ця біологічна особливість дозволяє йому формувати високі та стабільні врожаї зерна в умовах дефіциту вологи і високої температури. Сорго зернове має значну перевагу за рядом фізіологічних, біологічних, врожайних ознак порівняно з іншими культурами, але посівні площі в Україні під ним залишаються обмеженими. Основною причиною цього є, насамперед, відсутність сортових технологій його вирощування з удосконаленими елементами. А тому вивчення комплексного впливу норми висіву насіння та ширини міжрядь на формування елементів продуктивності є наразі актуальним напрямом досліджень. Основною метою досліджень було вивчення впливу комплексу чинників: ширини міжрядь, норми висіву насіння на продуктивність та біологічну врожайність зерна. Дослідження проводили протягом 2019–2021 рр. на базі ФГ «Дюніс» Кременського району Луганської області. Схема досліду: ширина міжрядь – 35, 45 і 70 см, гібриди – Сват і Флагг, норми висіву – 100 тис. шт./га, 140, 180 і 220 тис. шт./га. Гібрид сорго зернового Флагг сформував вищу продуктивність волоті головної і бічної систем стебел. Маса зерна з волоті головних і бічних стебел у нього становила 45,1 і 39,0 г відповідно, тоді як у гібрида Сват – 39,5 і 31,1 г. Вища продуктивність волотей гібриду Флагг формувалася за рахунок значно вищої маси 1000 зерен (на 35–40 %), при цьому кількість зерен у волоті обох систем стебел більшою була в гібриду сорго Сват. Біологічна врожайність зерна обох систем стебел вищою була також у гібриду сорго Флагг – 5,87 т/га, проти 4,75 т/га – у ранньостиглого гібрида Сват

Ключові слова: кількість волотей, головні стебла, бічні стебла, озерненість волоті, маса 1000 зерен, кореляційний зв'язок

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The Formation of the Productivity of Winter Wheat Depends on the Predecessor, Doses of Mineral Fertilizers and Bio Preparations

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Gamayunova, V., Kovalenko, O., Smirnova, I., & Korkhova, M. (2022). The formation of the productivity of winter wheat depends on the predecessor, doses of mineral fertilizers and bio preparations. *Scientific Horizons*, 25(6), 65-74.

Abstract. Wheat is the main agricultural crop in many countries of the world, as well as the main food in the steppe zone, so the system of agrotechnical measures should be aimed at creating favourable conditions for obtaining a high yield. The issue of intensification of grain production is inseparable from the production and use of new biogenic effective drugs that have a positive effect on the growth and development of cultivated plants. The purpose of this study was to establish the effect of foliar fertilisation with bacterial preparations, precursors, and doses of mineral fertilisers on grain yield and productivity elements of winter wheat. The paper provides data on the results of the research of winter wheat of the Duma Odeska variety in the conditions of the Educational and Practical Centre of the Mykolaiv NAU in 2019-2021. During the study, generally accepted methods were used: monographic, systematic approach and systematic analysis, analysis and synthesis, field and statistical. The influence of the precursor, foliar feeding with modern bacterial biopreparations and the use of different doses of mineral fertilisers on the elements of the crop structure and grain yield of winter wheat was analysed. It was established that the yield level depended and changed on the precursor taken for foliar feeding of the bacterial preparation, the level of mineral nutrition and to a large extent on the influence of the weather conditions of the growing year. Over the years of research, precursors, mineral fertilisers, and treatment of plant sowing with biological preparations affected the number of productive stems, the number of grains from an ear, the mass of grain from one ear and the mass of 1,000 grains of winter wheat. The conducted studies confirmed the expediency of foliar fertilising in the main periods of vegetation with biological preparations to optimise the nutrition of winter wheat plants with the aim of forming a stable grain yield. The obtained scientific results of the research will contribute to the wide application of biological preparations, which will ensure the rapid and full growth and development of winter wheat plants, which will further contribute to increasing the yield and gross harvest of grain

Keywords: grain yield, top dressing, productive stalks, number of grains from 1 ear, weight of 1000 grains



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INTRODUCTION

Of all the environmental factors in the conditions of the south of Ukraine, the formation of growth processes and the productivity of plant organisms after moisture is most affected by the nutrition regime, which is created by the correct rotation of crops in crop rotation and the use of an optimal fertilisation system (Miroshnychenko *et al.*, 2018).

In modern agriculture, the role of mineral fertilisers has considerably increased due to the insufficient use of organic fertilisers, the increase in the share of row crops in crop rotation, in particular the oversaturation of sunflowers, as well as the spread of erosion processes. To form stable harvests and obtain a full-fledged, according to the main quality indicators, grain of winter wheat, it is necessary to create optimal plant nutrition, and foremost, in terms of macroelements (Havryliuk, 2019). One of the important conditions for the effective use of fertilisers is to determine the plants' need for them, for the desired yield level, considering the content of mobile NPK compounds in the soil (Yan *et al.*, 2021).

Increasing the grain yield of winter wheat is directly related to various elements of the crop structure, which mainly consist of three parts: the productive amount of straw per unit area, the number of grains in an ear and the weight of a thousand grains. To study the role of various productivity factors in the formation of wheat grain yield, the determination of this indicator depends on 50% of productive straw, 25% on the number of grains in an ear, and 25% on the weight of 1,000 grains (Olkhovskiy *et al.*, 2019).

In the conditions of the Southern Steppe of Ukraine, farmers should firstly pay attention to the accumulation and preservation of moisture in the soil, ensuring the maximum use of water by plants, which is the most principal factor affecting the level of yield of agricultural crops, including winter cereals. All life processes are determined by the movement of water in plant organs. In addition, soil moisture not only determines the level of vital activity of plants, but also determines the level of vital activity of microbes, ensuring the intensity of many physico-chemical processes. Due to climate change and global warming, moisture has become a major key factor influencing crop yields. Research by O. Tsyliuryk established that most of the moisture in the soil accumulates in black steam, but recently this precursor of winter wheat is used less and less due to the excessive cost of caring for it (Tsiliryuk, 2019).

Many researchers have established that the grain yield of winter wheat depends on the nutritional background of the previous crop, but to a greater extent on the weather conditions in the year of sowing – the supply of water to plants during wintering and growing season (Korkhova & Mykolaichuk, 2022; Panfilova *et al.*, 2020; Andriichenko & Kachanova, 2018).

Increasing the yield of winter wheat grain with reducing resource inputs and reducing the chemical

load on the soil is a priority area of agricultural development, success in which can be achieved by greening crop production (Raneesha Madushanki *et al.*, 2019; Soto-Gómez & Pérez-Rodríguez, 2022). Due to the introduction of excessive amounts of fertilisers, environmental pollution increases, quality decreases, and the energy intensity of the produced products increases (Kulkarni & Goswami, 2019).

Recently, there has been an increase in the interest of domestic agricultural producers in biological preparations, which is associated with the increase in the price of mineral fertilisers, the contamination of agricultural land with chemicals, and the expansion of acreage for organic farming (Kulkarni & Goswami, 2019). Biopreparations stimulate the growth and development of agricultural crops, increase resistance to stress, diseases, and balance nutrition. This effect is achieved since living bacteria convert insoluble compounds into available forms, provide nitrogen nutrition and protect plants from bacterial and fungal diseases (Krutyakova, 2020; Panfilova & Mohylnytska, 2019).

The purpose of the research was to determine the productivity of winter wheat of the Duma Odeska variety depending on the predecessor, doses of mineral fertilisers and foliar fertilisation with biological preparations.

LITERATURE REVIEW

In agricultural production, crop rotation is always one of the main agrotechnical measures that contribute to increasing the yield of agricultural crops. It follows from scientific literature that farms use a high proportion of cereals in crop rotations, which leads to a decrease in winter wheat grain yield (Kvasnitska & Voitova, 2021; Woźniak, 2019; Alemu *et al.*, 2014).

In the South of Ukraine, many scientists were engaged in the research of predecessors for winter wheat. For example, A.O. Lytovchenko *et al.* (2017), A.I. Kryvenko and S.I. Burykina (2018) determined that black steam forms higher grain yield and better indicators of its quality in winter wheat plants.

R. Oripov and A. Buriev (2021) claim that for sustainable wheat production in the Republic of Uzbekistan, peas, as a precursor to winter wheat, are better compared to repeated crops.

Long-term research carried out in the Northern Steppe of Ukraine determined that the highest productivity of winter wheat is formed when it is grown after black steam and corn for silage, in years with the termination of autumn vegetation in the 3rd decade of November, and the lowest – in the 1st decade of November (Mostipan *et al.*, 2019).

The studies of V. Hanhur and Y.O. Kotliar (2021) prove that it is necessary to place winter wheat on a black pair only in dry years, while in years favourable for moistening, there is a decrease in productivity due to the lodging of crops.

In a long-term (1996-2009) field experiment conducted by S.I. Kudria at the experimental field of the Kharkiv National Agrarian University named after V.V. Dokuchaev, it was determined that in crop rotation with leguminous precursors (peas and soybeans) of winter wheat, the content of available forms of nitrogen nutrients was higher (116-120 mg/kg of soil) than with pure steam (111-114 mg/kg of soil) and corn for silage (110-113 mg/kg of soil) (Kudria, 2020).

As can be seen from the conducted research, the soil and climatic zone of cultivation, varieties, feeding conditions and weather conditions during the years of research have a significant impact on determining the best and good predecessors for winter wheat.

The analysis of the results of 14-year research (2007-2020) conducted by S. Burykina *et al.* (2021) on the topic: "Effectiveness of winter wheat fertilisation systems in the Southern Steppe of Ukraine" showed that the application of fertilisers in a dose of $N_{180}P_{60}K_{60}$ increased grain yield by 2.24 t/ha, or by 40.3% compared to the control variant (without fertilisers) (Burykina *et al.*, 2021).

Research conducted by O.V. Sidiyakina and V.F. Dvoretzky (2020) determined that as a result of foliar feeding with complex fertilisers, 0.62-0.96 t/ha of grain was additionally formed.

Pekarskas J. *et al.* (2017) prove that the use of biological preparation Fertenat increased the yield of spring wheat by 0.05-0.30 t/ha or by 2.29-13.76%.

Research by D. Jodaugiene *et al.* (2022) determined that the use of biological preparations did not have a significant effect on seed germination, but contributed to tillering, an increase in the number of productive stems and the leaf surface area of winter wheat plants, the weight of 1,000 grains, the number of grains in an ear, the weight of grain in an ear, and increased grain yield compared to control.

Therefore, both Ukrainian and foreign scientists paid considerable attention to the research of predecessors and optimisation of nutrition for soft winter wheat, but in connection with climate change, the introduction of significant areas into crop rotation for sunflower, mustard, with the appearance of new varieties, changes in fertility soil, there is a need to investigate this issue in more detail.

MATERIALS AND METHODS

Experimental research was conducted during 2019-2021 at the research field of the Educational-Scientific-Practical Centre of the Mykolaiv National University, which belongs to the Southern Steppe zone of Ukraine.

The research material was the winter wheat variety Duma Odeska, the owner of which is the Breeding and Genetic Institute – National Centre for Seed Science and Varietal Research (BGI – NCSSVR), which was registered in the State Register of Plant Varieties Suitable for Distribution in Ukraine in 2017 (State register of plant varieties..., 2022).

The agricultural technique of conducting the experiments was generally accepted for the current zonal recommendations for the conditions of the Southern Steppe zone of Ukraine, except for the factors that were taken for study. Sowing of winter wheat was carried out on October 1 with a sowing rate of 5 million units/ha.

The soil type is southern chernozem with a humus content of 3.3% in the arable layer, a neutral reaction of the soil solution (pH – 6.8-7.2) and an average availability of mobile forms of nitrogen, phosphorus, and potassium. The area of the sowing area was 50 m², and the accounting area was 26 m², it was repeated 4 times. Experimental plots were placed by the method of incomplete randomisation.

The scheme of the experiment included the following options: Factor A – precursors: black steam, legumes (peas), cruciferous vegetables (mustard of the spring); Factor B – doses of mineral fertilisers: without fertilisers (control), application of $N_{32}P_{32}K_{32}$, application of $N_{64}P_{64}K_{64}$; Factor C – bacterial preparations: control (water treatment), Biocomplex-BTU-r, Organic Balance.

The influence of biopreparations Biocomplex-BTU-r and Organic Balance was studied on the studied winter wheat variety. Biocomplex-BTU-r – has a complex effect, as it contains a mixture of different microbial strains. Organic Balance – a concentrated mixture of living and inactivated microorganisms and their active metabolites, living bacteria: nitrogen fixation – provides plants with nitrogen; phosphorus and potassium mobilisation – transforms insoluble compounds into forms available to plants; has microorganisms with bactericidal properties – protect plants from bacterial and fungal diseases, components of the nutrient medium (macro-, micro-, and organic food sources). The preparations are used for foliar feeding of plants during the spring-summer vegetation period at the rate of 1.0 and 0.3 l/ha, respectively.

Planting density calculations were determined on test plots with an area of 1 m² twice per growing season, located diagonally across the plot area. The first time is calculated at the stage of full seedlings, and the second time – before harvesting.

The mass of 1,000 grains was determined according to GOST 10842-89. The average number of grains in an ear is calculated according to the ratio, where the numerator is the total number of grains after threshing 25 ears, and the denominator is the sum of the average weight of the studied sample (25 ears), and the weight of grain from 1 ear is the weight of grain from the sheaf divided by the number of productive stalks, obtained in the bundle sample.

Harvesting of winter wheat was carried out with a SAMPO-500 harvester from each repetition. After threshing each plot, the threshing machine of the combine was turned off, the harvested grain was weighed separately and transferred to standard humidity (14%) and purity (100%).

The obtained research results in the form of analytical digital material were subjected to statistical and

mathematical processing, performed by the method of dispersion and correlation analyses thanks to computer programs Microsoft Excel and "Agrostat" by the method of variation, correlation, and dispersion analyses.

RESULTS AND DISCUSSION

A mandatory technique for obtaining high-yielding winter wheat grain is to provide plants with nutrients during

the growing season. Therefore, fertilisation systems should be based on the specific features of the soil and climatic conditions of the region, predecessors, and varieties of winter wheat (Panfilova *et al.*, 2019).

The conducted study shows that the highest yield of winter wheat grain can be obtained by placing it in a black pair, both in individual years of sowing, and on average during the three years of the study (Fig. 1).

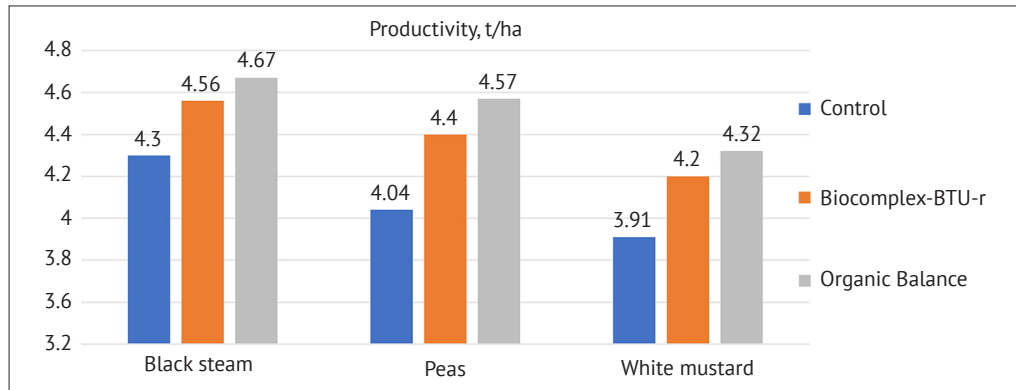


Figure 1. Yield of winter wheat grain depending on the predecessor for cultivation in unfertilised control with feeding with bacterial preparations (average for 2019-2021), t/ha

Source: developed by the authors of this study

After peas or white mustard, when grown without the use of mineral fertilisers, it was 3.9-8.6% lower, and with their application in a dose of $N_{64}P_{64}K_{64}$ – by

16.0-17.6% lower compared to the predecessor of black steam, on average by a factor treatment with biological preparations (Table 1).

Table 1. Yield of winter wheat depending on the predecessor, doses of mineral fertilisers and foliar fertilisation with bacterial preparations, (average for 2019-2021), t/ha

Treatment with biological preparations (factor C)	Precursor (factor A)			Mean	± To control	
	Black steam	Peas	White mustard		t/ha	%
Without the use of mineral fertilisers (factor B)						
Control (water treatment)	4.30	4.04	3.91	4.08	–	–
Biocomplex-BTU-r	4.56	4.40	4.20	4.39	0.30	7.43
Organic Balance	4.67	4.57	4.32	4.52	0.44	10.69
Mean for factor A	4.51	4.34	4.14	4.33	0.25	6.04
Mineral fertiliser $N_{32}P_{32}K_{32}$ (factor B)						
Control (water treatment)	4.66	4.54	4.44	4.55	–	–
Biocomplex-BTU-r	4.94	4.80	4.64	4.79	0.25	5.43
Organic Balance	5.01	4.85	4.74	4.87	0.32	7.04
Mean for factor A	4.87	4.73	4.61	4.74	0.19	4.15
Mineral fertiliser $N_{64}P_{64}K_{64}$ (factor B)						
Control (water treatment)	5.48	4.70	4.67	4.95	–	–
Biocomplex-BTU-r	5.73	4.94	4.84	5.17	0.22	4.44
Organic Balance	5.79	5.03	4.94	5.25	0.30	6.13
Mean for factor A	5.67	4.89	4.82	5.12	0.17	3.52
LSD ₀₅ by factor A	0.17	0.11	0.10			
LSD ₀₅ by factor B	0.22	0.14	0.11			
LSD ₀₅ by factor C	0.23	0.15	0.13			

Source: developed by the authors of this study

The conducted research also determined that under the influence of weather conditions of the growing year, and especially the supply of moisture during the growing season, the grain yield of winter wheat changes (Table 2). Notably, from the years of conducting research, the lowest yield was formed in 2020 due to unfavourable overwintering conditions, which led to a significant decrease in the number of winter wheat plants during the period of their full maturity, i.e., before harvesting

the grain crop. In this growing year, the advantage of the black pair over other predecessors was most evident. In addition, the lowest grain productivity in the specified year was formed when the crop was grown after black steam against the background of applying a high dose of mineral fertiliser $N_{64}P_{64}K_{64}$ with treatment with the biological preparation Organic Balance and amounted to 3.46 t/ha, which is 0.61 t/ha or 21.4% exceeded the predecessor white mustard in a similar version of fertiliser.

Table 2. The yield of winter wheat grain (t/ha) under the influence of the studied factors (average for 2019-2021)

Treatment with biological preparations (factor C)	Precursor (factor A)									Mean
	Black steam			Peas			White mustard			
	2019	2020	2021	2019	2020	2021	2019	2020	2021	
Without the use of mineral fertilisers (factor B)										
Control (water treatment)	5.36	3.74	5.52	5.11	3.25	5.31	4.94	3.12	5.14	4.61
Biocomplex-BTU-r	5.57	4.18	5.76	5.34	4.03	5.60	5.26	3.47	5.48	
Organic Balance	5.66	4.33	5.86	5.48	4.27	5.77	5.41	3.59	5.61	
Average by years	5.53	4.08	5.71	5.31	3.85	5.56	5.20	3.39	5.41	
Mineral fertiliser $N_{32}P_{32}K_{32}$ (factor B)										
Control (water treatment)	5.85	4.21	5.93	5.63	4.15	5.78	5.48	4.01	5.69	
Biocomplex-BTU-r	6.18	4.48	6.21	5.96	4.46	5.99	5.66	4.38	5.81	
Organic Balance	6.22	4.55	6.31	5.98	4.53	6.07	5.75	4.42	5.96	
Average by years	6.08	4.41	6.15	5.86	4.38	5.95	5.63	4.27	5.82	
Mineral fertiliser $N_{64}P_{64}K_{64}$ (factor B)										
Control (water treatment)	6.72	4.18	6.90	5.89	4.22	6.02	5.84	4.22	5.98	
Biocomplex-BTU-r	6.88	4.63	7.11	6.15	4.51	6.27	5.99	4.46	6.11	
Organic Balance	6.93	4.89	7.19	6.28	4.58	6.35	6.07	4.59	6.26	
Average by years	6.84	4.57	7.07	6.11	4.44	6.21	5.97	4.42	6.12	

Source: developed by the authors of this study

Despite the investigated factors, favourable weather conditions during the growing seasons of 2019 and 2021 ensured a significantly higher yield of winter wheat. Thus, judging by the average indicators of predecessors, foliar feeding, and mineral fertilisers, 5.84 t/ha was formed in 2019, and 6.0 t/ha in 2021, which exceeds the level of 2020, which was less favourable, on 2.96 and 3.12 t/ha or by 102.8 and 108.3% relative to years.

In all years of research, the positive effect of applying mineral fertilisers is clearly visible. More substantial increases in grain yield, optimisation of nutrition of winter wheat plants, is ensured by growing the crop according to non-paired (more impoverished in nutrients) predecessors. At the same time, it is important to pay attention to the fact that with the improvement of the nutritional regime of winter wheat plants, even in the unfavourable year 2020, the yield for cultivation after peas and white mustard was not so significantly reduced compared to black steam. With the optimisation of plant nutrition, the value of the precursor is reduced,

and the yield from applied mineral fertilisers increases on soils more depleted of nutrients.

The productivity of winter wheat is significantly determined and varies under the influence of the weather conditions of the growing season, the availability of plant nutrients and foliar fertilisation with bacterial preparations. Of the studied bacterial preparations, the largest yield increases are provided through the bacterial preparation Organic Balance, and the lowest – Biocomplex-BTU-r. Of the predecessors, regardless of the weather conditions of the year of growing winter wheat, black steam provides the highest grain yield. The level of grain yield increases significantly when mineral fertilisers are applied to the crop. To a greater extent, this can be traced to the cultivation of impoverished predecessors – peas and white mustard.

The growth and development of plants during the growing season and the yield they produce when sowing grain crops are determined by the structural elements of productivity. These are mainly: the density of

the plant stand (the number of productive stems per 1 m²), the number of grains in the ear and the weight of 1,000 seeds. The three components listed above directly determine the level of productivity. The formation of structural elements of the crop is influenced by many factors: the weather conditions of the year, biological features of the variety, crop care, including agrotechnical measures, namely mineral nutrition of plants (Panfilova *et al.*, 2020).

The interaction of productivity factors contributed to the formation of winter wheat grain yield, mainly the number of productive straws formed, the weight of 1,000 grains, the size, and weight of the grain in the ear (Tsvey *et al.*, 2021). Studies of the main indicators for determining the structure of winter wheat crops show that under the influence of mineral fertilisers, the number of productive stems increases (Table 3).

Table 3. The influence of the investigated factors on the number of plants before harvesting and the number of productive stems (average for 2019-2021), pcs/m²

Treatment with biological preparations (factor C)	Doses of mineral fertilisers (factor B)		
	Without fertiliser (control)	N ₃₂ P ₃₂ K ₃₂	N ₆₄ P ₆₄ K ₆₄
Black steam (factor A)			
Control (water treatment)	344	352	354
	442	455	488
Biocomplex-BTU-r	353	366	370
	448	467	496
Organic Balance	361	368	371
	453	471	500
Peas (factor A)			
Control (water treatment)	327	330	332
	425	443	450
Biocomplex-BTU-r	339	351	356
	438	460	462
Organic Balance	346	359	362
	443	460	470
White mustard (factor A)			
Control (water treatment)	321	322	330
	421	436	450
Biocomplex-BTU-r	334	340	343
	433	455	463
Organic Balance	342	346	347
	442	457	470

Note: in the numerator – the number of plants before harvesting; in the denominator – the number of productive stems

Source: developed by the authors of this study

Of the predecessors studied, the highest density of productive stems was formed by winter wheat plants according to the steam precursor – 469 pcs/m², and after peas and white mustard, they were formed somewhat less – 450 and 447 pcs/m². The most productive stalks of winter wheat are formed against the background of applying a dose of mineral fertilisers N₆₄P₆₄K₆₄ and foliar fertilisation of the crop with the bacterial preparation Biocomplex-BTU-r and Organic Balance at the main stages of plant growth. Thus, in these variants of the winter wheat plant placed after the steam predecessor, 496 and 500 pcs/m² of productive stems were formed, respectively, and after white mustard – 463 and 470 pcs/m². Against the background of the introduction of mineral fertilisers in the dose

of N₃₂P₃₂K₃₂, a slightly lower density of the productive stem was formed. During the years of research, 461 pcs/m² of productive stems were formed on 1 m² for fertilising with Biocomplex-BTU-r and 463 pcs/m² – Organic Balance in the section of predecessors.

The choice of feeding option also influenced to some extent the amount of grain formed in the ears of winter wheat (Table 4). Thus, if in the control without fertilising, on average over the years of the study, there are 26.9 grains in the ear of winter wheat after placement on the background of the steam precursor, 26.4 pcs – after peas, 25.9 pcs – white mustard, the application of mineral fertilisers in doses of N₃₂P₃₂K₃₂ and N₆₄P₆₄K₆₄ increased these indicators by 0.6-2.9; 1.3-1.5 and 1.8-1.9 grains, respectively.

Table 4. The number of grains from 1 ear and their weight depending on the precursor, fertiliser and biological preparations (average for 2019-2021)

Treatment with biological preparations (factor C)	Doses of mineral fertilisers (factor B)		
	Without fertiliser (control)	N ₃₂ P ₃₂ K ₃₂	N ₆₄ P ₆₄ K ₆₄
Black steam (factor A)			
Control (water treatment)	26.9 0.97	27.5 1.02	29.8 1.12
Biocomplex-BTU-r	27.7 1.02	27.8 1.06	30.0 1.16
Organic Balance	27.8 1.03	27.9 1.06	29.9 1.16
Peas (factor A)			
Control (water treatment)	26.4 0.95	27.7 1.02	27.9 1.04
Biocomplex-BTU-r	25.5 1.00	27.7 1.04	28.3 1.07
Organic Balance	28.0 1.03	27.8 1.05	28.2 1.07
White mustard (factor A)			
Control (water treatment)	25.9 0.93	27.7 1.02	27.8 1.04
Biocomplex-BTU-r	26.8 0.97	27.6 1.02	27.8 1.05
Organic Balance	26.7 0.98	28.0 1.04	27.9 1.05

Note: in the numerator – the number of grains from 1 ear, pc.; in the denominator – the mass of grains from 1 ear, g

Source: developed by the authors of this study

In all years of research, the number of grains in the ear was the largest in winter wheat plants placed after the steam precursor with the use of mineral fertilisers in the dose of N₆₄ P₆₄ K₆₄ and foliar fertilisation with the bacterial preparation Biocomplex-BTU-r, which is 3.1 pcs or by 10.3% more compared to the control option.

During the years of research, it was determined that precursors, mineral fertilisers, and treatment of plant sowing with biological preparations had an effect on the mass of grain from one ear (Table 3). Thus, when a low dose of mineral fertiliser N₃₂ P₃₂ K₃₂ was applied to winter wheat after the steam precursor, the mass of grain from the ear, compared to the unfertilised control, increased by 4.9%, after peas – by 6.9%, and after

white mustard – by 8.8%. Foliar fertilising with bacterial preparations Biocomplex-BTU-r and Organic Balance increased the specified indicator of crop structure, respectively: by 8.5% – after black steam, by 9.1% – after peas and by 9.7% – after white mustard.

The conducted studies showed that there are certain differences in the influence of precursors and feeding conditions during the growth of winter wheat on the formation of grains of varied sizes by plants. The weight of 1,000 grains, depending on the precursor, treatment with biological preparations and the use of mineral fertilisers, varied widely and amounted to 36.2-38.7 g for the steam precursor, for peas – 36.0-37.9 g, and after white mustard – 35.9-37.7 g (Fig. 2).

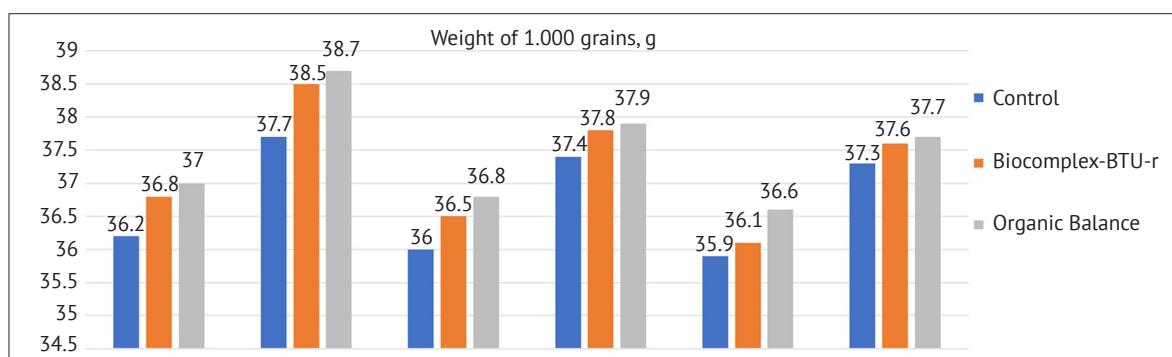


Figure 1. The influence of the precursor, mineral fertilisers and biological preparations on the weight of 1,000 grains of winter wheat (average for 2019-2021), g

Source: developed by the authors of this study

Foliar feeding of a winter wheat plant with organic balance organic preparation over the years of research in the section of predecessors against the background of a high dose of mineral fertilisers ($N_{64}P_{64}K_{64}$) increased the mass of 1,000 grains to 38.1 g, which exceeds this indicator compared to the control variant by 2.1 g or 5.8%.

Thus, on average, over the previous years and during the years of research, the use of mineral fertilisers increased the mass by 1,000 grains. In particular, the application of mineral fertilisers in a dose of $N_{32}P_{32}K_{32}$ showed an increase in the yield structure indicator compared to the control by 1.0 g or by 2.8%, and with biological preparations (provided this dose of mineral fertilisers is applied) increased by 1.5-01.7 g or 4.2-4.7%. At the same time, it should be noted that among the options for growing winter wheat plants with fertilisation of the crop with the bacterial preparation Organic Balance, the weight of 1,000 grains was the highest – 37.7-38.7 g, depending on the predecessor, with the use of mineral fertilisers in the dose of $N_{64}P_{64}K_{64}$.

CONCLUSIONS

Research conducted in the South of Ukraine in 2019-2021 shows that the yield of winter wheat grain largely depends on and varies under the influence of weather conditions during the growing season, the supply of plant nutrients and foliar fertilisation with bacterial preparations.

Of the studied bacterial preparations, the largest increase in yield was provided using the bacterial preparation Organic Balance, the smallest – Biocomplex-BTU-r. Among the predecessors, black steam significantly increased the yield of winter wheat, regardless of weather conditions during the growing years. When mineral fertilisers are applied to crops, the level of grain yield increases significantly, and this applies even more to cultivation after depleted predecessors – peas and white mustard.

The use of biological preparations has a significant effect on winter wheat productivity. Comparing the values between the years of the study, it can be noted that the highest yields were obtained in a more favourable year for growing (2021) on the option for growing the crop on black steam against the background of applying a high dose of mineral fertiliser $N_{64}P_{64}K_{64}$ with treatment with the biological preparation Organic Balance and amounted to 7.19 t/ha, which is more compared to the control variant by 1.67 t/ha or by 30.3%.

Of the studied bacterial preparations, the greatest increase in yield is provided by feeding with the bacterial preparation Organic Balance, and the lowest by Biocomplex-BTU-r. Regardless of the weather conditions of the growing year, a significantly higher yield of winter wheat grain is formed by black steam. The level of grain yield increases significantly with the introduction of mineral fertilisers to the culture, and to a greater extent due to the impoverished predecessors – peas and white mustard.

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Формування продуктивності пшениці озимої залежно від попередника, доз мінеральних добрив та біопрепаратів

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Анотація. Пшениця є основною сільськогосподарською культурою в багатьох країнах світу, а також основною продовольчою – у степовій зоні, тому система агротехнічних заходів повинна бути спрямована на створення сприятливих умов для отримання високої врожайності. Питання інтенсифікації виробництва зерна невіддільні від виробництва та використання нових біогенних ефективних препаратів, які позитивно впливають на ріст і розвиток культурних рослин. Метою роботи було встановити вплив позакореневого підживлення бактеріальними препаратами, попередників та доз мінеральних добрив на урожайність зерна та елементи продуктивності пшениці озимої. У статті наведено дані про результати дослідження пшениці озимої сорту Дума одеська в умовах Навчально-практичного центру Миколаївського НАУ у 2019–2021 рр. У ході проведення дослідження використовувалися загальноприйняті методи: монографічний, системний підхід і системний аналіз, аналіз і синтез, польовий та статистичний. Було проаналізовано вплив попередника, позакореневого підживлення бактеріальними сучасними біопрепаратами та застосування різних доз мінеральних добрив на елементи структури врожаю та врожайність зерна пшениці озимої. Встановлено, що рівень урожаю залежав і змінювався від попередника, взятого для позакореневого підживлення бактеріального препарату, рівня мінерального живлення і значною мірою за впливу погодних умов року вирощування. За роки досліджень, попередники, мінеральні добрива та обробка посіву рослин біопрепаратами вплинули на кількість продуктивних стебел, кількість зерен з колосу, масу зерна з одного колосу та масу 1000 зерен пшениці озимої. Проведеними дослідженнями підтверджено доцільність позакореневих підживлень в основні періоди вегетації біопрепаратами для оптимізації живлення рослин пшениці озимої з метою формування сталої врожайності зерна. Отримані наукові результати досліджень сприятимуть широкому застосуванню біопрепаратів, які забезпечать швидкий та повноцінний ріст і розвиток рослин пшениці озимої, що в подальшому сприятиме підвищенню врожайності та валових зборів зерна

Ключові слова: урожайність зерна, підживлення, продуктивні стебла, кількість зерен з 1 колосу, маса 1000 зерен



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Biochemical Composition of Sweet Cherry Leaves Depending on the Method of Soil Maintenance in an Organic Garden

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Abstract. Conducting sustainable agriculture involves not only increasing the productivity of crops and increasing the volume of crop production, but also preserving ecosystems. Mulching the soil in orchards is one of the ways to preserve the natural balance of agricultural landscapes. But the effect of competition with grasses on the biochemical composition of fruit tree tissues has not yet been definitively elucidated. The purpose of this study was to determine the influence of soil retention under mulching (compared to pure steam) on the biochemical composition of cherry leaf tissues. The research was conducted in an organic cherry orchard (*Prunus avium* L./ *Prunus mahaleb*) during 2017-2019 in the conditions of the Southern Steppe of Ukraine. A significant decrease in the content of ascorbate, glutathione, sugars, total reducing activity and activity of antioxidant enzymes was established under conditions of prolonged drought and an increase in the content of titrated acids. The total reducing activity under mulching conditions tended to increase. A gradual increase in the content of titrated acids, ascorbate, sugars, phenolic substances, and glutathione was recorded in the leaves of cherry trees from the flowering phase to November. In the autumn phase, a significant increase in sugars and phenolic substances was established in cherry leaves under the conditions of mulching in 2017, and in 2018 – phenolic substances; in 2019 – phenolic substances and ascorbate. An increase in the content of malondialdehyde (MDA) and the activity of antioxidant enzymes was found during the growing season of cherries in both variants of the experiment. In the November phase only in 2019, the MDA content was significantly higher by 14% under the condition of mulching. Under mulching conditions, a significant increase in ascorbate peroxidase (by 28-30%) and polyphenol oxidase (by 45-46%) was determined. In 2018 and 2019, a 2.4-fold increase in peroxidase activity in cherry leaves was determined. Research results help to understand the mechanisms of adaptation of fruit plants to stress factors (drought, competition with natural grasses) and can be used as an argument in favour of mulching in organic cherry orchards

Keywords: mulching, vitamin C, glutathione, titrated acids, catalase, ascorbate peroxidase, polyphenol oxidase



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INTRODUCTION

The development of sustainable agricultural production requires the creation of a suitable scientific base to have a clear idea of the consequences of innovative and “green” technologies for plant physiology. Maintaining garden soil under mulching has numerous positive ecological effects: it contributes to the preservation of agroecological relationships (Yao *et al.*, 2005), ensures optimal soil temperature and humidity (Gerasko *et al.*, 2021), attracts beneficial insects-entomophages and pollinators (Mateos-Fierro *et al.*, 2021), promotes the development of symbiotic mycorrhizae (Balestrini *et al.*, 2018) and beneficial microorganisms in the soil, the number of which increases due to the well-developed rhizosphere of grasses (Yao *et al.*, 2005). However, at present, the question of the effect of soil mulching of fruit plantations on biochemical processes in tree tissues has not been fully investigated.

One of the most popular fruit crops is the sweet cherry (*Prunus avium* L.), which is valued by consumers for its attractive appearance, high fruit taste, and nutritional value (Szpadzik *et al.*, 2019; Pereira *et al.*, 2020; Ivanova *et al.*, 2021). Many scientists investigate the biochemical composition of sweet cherry fruits depending on the genetic characteristics of varieties, weather factors and conditions of the growing region (Picariello *et al.*, 2016; Ivanova *et al.*, 2020; Ivanova *et al.*, 2022). Recently, there has been increasing attention to the content of biologically active substances (BAS) in the vegetative organs of fruit trees, namely sweet cherries (Prvulović *et al.*, 2011; Bastos *et al.*, 2015; Jesus *et al.*, 2019), by-products of fruit growing (Yüksekkaya *et al.*, 2009; Djilas *et al.*, 2011; Afonso *et al.*, 2019), and in the leaves of fruit trees (Dziadek *et al.*, 2018; Dziadek *et al.*, 2019; Uysal *et al.*, 2020). This is explained by the fact that, firstly, leaves and by-products of fruit growing can be used for therapeutic and illness prevention purposes in the human diet, and, secondly, the content of these substances can indicate the physiological state of fruit trees (Polonskaya *et al.*, 2007; Grebennikova *et al.*, 2011; Bonyanpour *et al.*, 2020). The course of oxidation-reduction processes in the leaves of fruit trees during the growing season also deserves attention.

In the conditions of the Southern Steppe of Ukraine, plants face various stresses, including drought, extreme temperatures, and excessive light intensity. Mulching can create additional stressful conditions for fruit trees as a result of competition with them for the most important ecological factors, such as nutrients and light (Atucha *et al.*, 2011). In response to stressful conditions, reactive oxygen species (ROS) are produced in excess, which cause oxidative damage to cell membranes (lipid peroxidation, LP), proteins, and nucleic acids (Sharma *et al.*, 2012). One of the products of lipid peroxidation is malondialdehyde, the accumulation of which can be used to judge the intensity of LP in plant tissues (Gill *et al.*, 2013). To normalize the level of ROS

in plants, the antioxidant defence system (ADS), which contains non-enzymatic and enzymatic antioxidants, works (Atucha *et al.*, 2011; Sharma *et al.*, 2012; Gill *et al.*, 2013). Information on the content of biologically active substances, malondialdehyde and the activity of antioxidant enzymes in sweet cherry leaves will help find out how mulching affects the level of stress in the tissues of sweet cherry leaves in the conditions of the Southern Steppe of Ukraine.

The purpose of this study was to determine the content of biologically active substances, malondialdehyde, and the activity of antioxidant enzymes in sweet cherry leaves under mulching conditions in an organic garden in the South of Ukraine.

MATERIALS AND METHODS

The research was carried out during 2017-2019 in the conditions of the Scientific Research Garden of the Tavria State Agricultural Technological University (Zelene village, Melitopol district, Zaporizhzhia Oblast: 46°46'N, 35°17'E). The soil of the experimental plots is chestnut, with a sandy granulometric composition. Despite the insufficient provision of nutrients, low humus content, the soils of the study region are suitable for growing cherries. The weather conditions of the research years were warmer in terms of the average annual air temperature by 1.2-1.6°C than the long-term indicators, but in 2017 and 2019 they were inferior in terms of the average annual amount of precipitation.

Thus, the amount of precipitation in these years was 11 and 8% less, respectively, than the average multi-year data. In 2017, April was cold (the average monthly air temperature was below 10°C) and rich in precipitation (76% more than the long-term norm). May 2017 was cool and very dry. The drought continued in June 2017 as well. July 2017 was relatively satisfactory in terms of precipitation and less hot, compared to long-term data. The amount of precipitation in August-September 2017 was considerably higher than the long-term average, but the average monthly temperature in August was 3.2°C higher than the long-term norm. September and October 2017 were relatively satisfactory in terms of moisture supply. In 2018, the drought lasted from April to the end of June. July 2018 was satisfactory in terms of precipitation, but August this year was the driest in all the years of the study (precipitation was 82% below the multi-year average). Abundant precipitation in September 2018 was replaced by a drought in October (the amount of precipitation was 44% less than the average long-term norm). April and May 2019 were satisfactory in terms of moisture supply (the amount of precipitation was, respectively, 44% and 107% more than the average multi-year norm). But June 2019 was unusually hot and dry. The drought continued in July 2019 as well. August 2019 was relatively satisfactory in terms of average monthly temperature and amount

of precipitation. In September 2019, there was a severe drought that continued into October this year. As a summary regarding the weather conditions for the development of sweet cherry leaves, it can be stated that in the months of April and May, which are most important for the formation of the leaf plate, in 2017 the conditions were satisfactory in terms of moisture supply, but cold in April and cold and dry in May; in 2018, both April and May are dry and hot; in 2019, it is warm and satisfactory in terms of moisture supply in April and May.

The research was conducted in sweet cherry (*Prunus avium* L.) fruit plantations of Dilema variety on Antipka (*Prunus mahaleb*) rootstock. Tree planting scheme in 2011 – 7×5 m. The mid-early variety Dilema was obtained as a result of crossing two varieties, Drohana Zhovta and Valerii Chkalov. Strong-growing trees of the variety form sprawling, slightly drooping, dense crowns. The shape of the fruits is convex-heart-shaped with a dark red skin and pulp. The fruits are characterized by an excellent sweet-sour, refreshing taste. Fruit ripening in the conditions of the region is observed in the first decade of June. Fruits are mainly used fresh.

The experiment was laid out as a randomized complete block with three replications. There are 10 control trees in each repetition. The scheme of soil retention in the experimental areas is as follows:

Option 1. Pure steam (weeding was carried out to a depth of 15 cm, manual weeding);

Option 2. Covering the soil with natural grasses or “living mulch” (natural grasses were mowed, biomass was left on the soil surface).

Plant care measures were identical in each version of the experiment. Synthetic pesticides and mineral fertilizers were not used in the sweet cherry growing technology. During the growing season (from April to November), leaves were collected annually for analysis. Leaf collection was carried out 4 times per growing season in the phases of flowering (BBCH 61-65), ripening of fruits (BBCH 87-89), completion of shoot growth (BBCH 91) and November (BBCH 93-97). For biochemical analyses, 100 intact leaves were selected in three replicates from each variant of the experiment.

The main elements of records and observations: the content of malondialdehyde (MDA, nmol/g), the activity of antioxidant enzymes – catalase (CAT, $\mu\text{mol H}_2\text{O}_2/\text{g}\cdot\text{min}$), ascorbate peroxidase (APO, mg oxidized ascorbic acid/g), polyphenol oxidase (PPO, c.u./g·min), peroxidases (PO, mcat/g); the content of sugars (S, %), titrated acids (TA, %), phenolic substances (Phen, mg GA/100 g), ascorbic acid (As, mg/100 g), glutathione (Glu, mg/100 g) in sweet cherry leaves.

The intensity of lipid peroxidation (LP) was determined by the accumulation of the secondary LP product – MDA. The method is based on the fact that at 95°C in an acidic environment, MDA reacts with TBA, forming a pink trimethyl complex with an absorption maximum

at 535 nm (Costa et al., 2002). For the analysis, 250 mg of plant material was taken, homogenized with 4 ml of 20% trichloroacetic acid (TCA). 4 ml of 0.5% TBA dissolved in 20% TCA was added to 1 ml of filtrate and boiled at 95°C in a water bath for 30 minutes, followed by cooling. Optical density was measured at wavelengths of 532 nm and 600 nm. Then the MDA content was calculated according to formula 1:

$$C = \frac{(E_{635} - E_{600})}{E}, \quad (1)$$

where C is the concentration of MDA; E_{532} and E_{600} are the optical density at wavelengths of 532 nm and 600 nm, respectively; E is the molar extinction coefficient of the trimethyl complex for a beam path length of 1 cm ($E=1.55 \times 10^5 \text{ M}^{-1} \text{ cm}^{-1}$). The result of MDA content calculations was displayed in nM per gram of plant material weight.

The activity of catalase (CAT, EC 1.11.1.6) was determined by the spectrophotometric method according to the degree of decomposition of hydrogen peroxide by catalase, the residue of which was determined by reaction with ammonium molybdate, expressed in $\mu\text{mol H}_2\text{O}_2/\text{g}\cdot\text{min}$.

The activity of ascorbate peroxidase (APO, EC 1.11.1.11) was determined by titrating the remaining unoxidized ascorbic acid with 0.001 solution of Tillmans reagent (2,6-dichlorophenolindophenol) until a light pink colouration that did not disappear within 30 s (Gorodniy et al., 2006). In the control, APO was deactivated with metaphosphoric acid. APO activity was determined according to formula 2:

$$X = \frac{(a-b) \times T \times V_1}{H \times V_2}, \quad (2)$$

where X is APO activity (mg of oxidized ascorbic acid per 1 g of raw mass); a is the amount of 0.001 Tillmans reagent used for the titration of the control sample, ml; b is the amount of 0.001 Tillmans reagent used for titration of the test sample, ml; T is the reagent titre (amount of ascorbic acid corresponding to 1 ml of paint), mg; V_1 is the total volume of the extract, ml; H is the weight of plant material, g; V_2 is the volume of extract taken for titration, ml.

Determination of the activity of polyphenol oxidase (PPO, EC 1.10.3.1) was carried out by the spectrophotometric method, which is based on the measurement of the optical density of the reaction products formed during the oxidation of pyrocatechin over a certain period. The optical density was measured at 420 nm. The activity of polyphenol oxidase was expressed in conventional units per 1 g of raw tissue in 1 min.

Determination of peroxidase activity (PO, EC 1.11.1.7) was carried out by oxidation of indigo carmine with oxygen released during the decomposition of hydrogen peroxide under the influence of peroxidase (Frew

et al., 1983): upon oxidation, indigo carmine changes its colour from blue-green to yellow-pink. 1 g of plant tissue was homogenized with 6 ml of acetate buffer with pH=4.9. 2 ml of indigo carmine was added. 1 ml of homogenate was taken, and 0.5 ml of 0.03 M hydrogen peroxide solution was added. After 2 minutes, 20% sulphuric acid was added to stop the reaction. Photometry was performed at a wavelength of 610 nm against distilled water in a cuvette with a working length of 1 cm. In parallel, a control sample was prepared, where instead of hydrogen peroxide, 0.5 ml of distilled water was added. PO activity was expressed in mcat/g of plant material weight.

The content of sugars (%) in plant tissues was determined by the photometric method based on the ability of monosaccharides to reduce picric acid (2, 4, 6-trinitrophenol) to picramic acid. The final product of the reaction acquires an intense red colour. The content of titrated acids in the studied samples was determined by the generally accepted method (Methods of ...). The total content of phenolic substances was determined photometrically using the Folin-Chocalteau reagent and calculated in mg of gallic acid (GA) per 100 g of

raw material (Waterhouse, 2002). The content of ascorbic acid, glutathione and total reducing activity of plant tissues was determined according to well-known methods (Gorodniy *et al.*, 2006).

All studied analyses were performed in triplicate. The obtained experimental data were compared by Tukey's mean separation test at a significance level of $P \leq 0.05$ and were processed using the Pearson correlation analysis method using Minitab 19 software (Minitab Inc., State College, PA).

RESULTS AND DISCUSSION

As a result of the research, it was established that the total reducing activity in sweet cherry leaves varied between 8.5-18.7 ml of $KJO_3/100$ g of raw material for keeping the soil in the garden under pure steam and from 9.3 to 20.2 ml of $KJO_3/100$ g of raw material when covering the soil with natural herbs (Tables 1-3). Total reducing activity tended to increase under mulching conditions, but this indicator was statistically significantly greater under mulching conditions only in the flowering phase in 2018 (9% more, compared to pure steam conditions).

Table 1. Phytochemical composition of sweet cherry leaves of the *Dilema* variety depending on soil maintenance in the garden (2017), $M \pm m$

Variant	Sugars, %	Titrated acids, %	Phenolic substances, mg GA/100 g	Ascorbate, mg/100 g	Glutathione, mg/100 g	Total reducing activity, ml of $KJO_3/100$ g
Flowering						
Pure steam	3.2±0.23	1.1±0.06	7.9±0.60	8.4±0.61	30.7±2.09	10.1±0.63
Mulching	3.8±0.24*	1.4±0.08*	10.2±0.65*	9.7±0.64	32.2±2.11	10.5±0.69
Fruit ripening						
Pure steam	3.4±0.25	1.1±0.08	43.2±3.04 ^a	9.1±0.73	33.8±2.25	11.2±0.68
Mulching	4.1±0.27*	1.5±0.08*	50.4±3.76 ^{a*}	10.6±0.75	36.8±2.29	12.1±0.76
Completion of shoot growth						
Pure steam	3.8±0.29	1.3±0.09 ^a	136.5±10.25 ^a	10.7±0.79	38.4±2.59	12.5±0.78
Mulching	4.5±0.32*	1.5±0.10*	175.1±10.69 ^{a*}	12.4±0.83	39.9±2.66	13.3±0.83
Defoliation						
Pure steam	4.2±0.34	1.6±0.10 ^a	155.0±13.61 ^a	11.1±0.85	41.4±2.84	13.5±0.88
Mulching	4.8±0.28*	1.8±0.12 ^a	228.5±15.65 ^{a*}	12.3±0.89	42.9±2.99	14.6±0.93

Note: *the difference between options is significant at $P \leq 0.05$; and the difference compared to the previous stage of organogenesis is significant at $P \leq 0.05$

Table 2. Phytochemical composition of sweet cherry leaves of the *Dilema* variety depending on soil maintenance in the garden (2018), $M \pm m$

Variant	Sugars, %	Titrated acids, %	Phenolic substances, mg GA/100 g	Ascorbate, mg/100 g	Glutathione, mg/100 g	Total reducing activity, ml of $KJO_3/100$ g
Flowering						
Pure steam	2.8±0.20	0.9±0.06	8.8±0.56	7.0±0.29	26.1±1.58	8.5±0.49
Mulching	3.4±0.21*	1.1±0.06	13.8±0.61*	7.5±0.31	27.9±1.71	9.3±0.52*

Table 1, Continued

Variant	Sugars, %	Titrated acids, %	Phenolic substances, mg GA/100 g	Ascorbate, mg/100 g	Glutathione, mg/100 g	Total reducing activity, ml of KJO ₃ /100 g
Fruit ripening						
Pure steam	3.0±0.22	1.0±0.07	48.6±2.62a	7.9±0.33a	29.2±1.85	9.5±0.59a
Mulching	3.7±0.22*	1.2±0.07	68.7±2.81*a	8.4±0.35a	30.7±1.89	10.1±0.63
Completion of shoot growth						
Pure steam	3.4±0.25	1.1±0.08	153.5±10.90a	8.8±0.41a	32.2±1.91	10.5±0.69
Mulching	4.1±0.26*	1.3±0.09	197.2±11.82*a	9.2±0.53a	35.3±2.19	11.5±0.74
Defoliation						
Pure steam	3.8±0.27	1.4±0.09 ^a	174.5±13.32 ^a	9.7±0.61 ^a	36.8±2.54 ^a	12.1±0.91 ^a
Mulching	4.3±0.28	1.6±0.10 ^a	257.1±15.11* ^a	10.1±0.70 ^a	39.9±2.72 ^a	13.4±0.89 ^a

Note: *the difference between options is significant at $P \leq 0.05$; and the difference compared to the previous stage of organogenesis is significant at $P \leq 0.05$

Table 3. Phytochemical composition of sweet cherry leaves of the *Dilema* variety depending on soil maintenance in the garden (2019), $M \pm m$

Variant	Sugars, %	Titrated acids, %	Phenolic substances, mg GA/100 g	Ascorbate, mg/100 g	Glutathione, mg/100 g	Total reducing activity, ml of KJO ₃ /100 g
Flowering						
Pure steam	2.9±0.11	1.0±0.06	11.2±0.75	9.5±0.27	46.1±2.14	14.8±0.51
Mulching	3.5±0.18*	1.2±0.07	17.5±0.80*	10.6±0.39*	47.6±2.19	15.5±0.57
Fruit ripening						
Pure steam	3.1±0.21	1.1±0.07	61.2±2.62a	11.4±0.51a	49.1±2.29	15.9±0.65
Mulching	3.6±0.22*	1.3±0.07*	87.2±2.82*a	13.2±0.67*a	52.1±3.20	17.1±0.49
Completion of shoot growth						
Pure steam	3.5±0.20	1.2±0.08	195.5±12.16a	12.3±0.65	55.3±3.51	17.8±0.87a
Mulching	4.2±0.22*	1.4±0.09*	250.4±15.28*a	14.1±0.67	56.8±3.49	18.5±0.83
Defoliation						
Pure steam	3.9±0.24	1.3±0.09	242.3±15.65a	13.2±0.71	58.3±3.91	18.7±0.95
Mulching	4.5±0.26	1.5±0.09	298.1±16.98*a	15.5±0.79*	61.4±3.99	20.2±0.99

Note: *the difference between options is significant at $P \leq 0.05$; and the difference compared to the previous stage of organogenesis is significant at $P \leq 0.05$

The content of ascorbate in sweet cherry leaves varied between 7.0-13.2 mg/100 g of raw material under conditions of pure steam and 7.5-15.5 mg/100 g of raw material when the soil was covered with natural grasses. In 2017 and 2018, there was no significant difference in the content of ascorbate in the leaves. In the experiment, the highest accumulation of ascorbate in leaves was noted in the November phase in the year 2019, which was relatively satisfactory in terms of moisture supply. Moreover, under the conditions of mulching, ascorbate accumulated substantially more in the leaves, compared to the conditions of pure steam:

in the flowering and leaf phases, respectively, by 12 and 17%. Ascorbate is a widespread and effective antioxidant associated with photosynthetic reactions, which accumulates in high concentrations in both photosynthetic and non-photosynthetic organs and tissues and has many functions in plants, the main ones being the protection of the glutathione pool and the proper functioning of some enzymes (Gest *et al.*, 2012).

Under the conditions of keeping the soil under black steam, the content of glutathione in sweet cherry leaves was in the range of 26.1-58.3 mg/100 g of raw material. When the soil was covered with natural grasses,

the studied indicator varied from 27.9 to 61.4 mg/100 g of raw material. It should be noted that over the years of research, no significant difference between the variants of the experiment has been established. The tripeptide glutathione (GSH, γ -glutamyl-cysteinyl-glycine) is one of the main components of the ascorbate-glutathione (AsA-GSH) pathway and plays a significant role in protecting cells from oxidative stress and the accumulation of harmful LP products in plant tissues (Anjum *et al.*, 2010; Walker *et al.*, 2018).

Notably, in 2018, when the weather conditions were unfavourable, the total reducing activity in sweet cherry leaves tended to decrease in both versions of the experiment. Thus, the studied indicator decreased by 14% when the soil was kept under black steam and by 12% when covered with natural grasses. This was probably due to a decrease in the content of ascorbate and glutathione in leaves in 2018 compared to 2017. Thus, the content of ascorbate in sweet cherry leaves in 2018 decreased by 15% when the soil was kept under clean steam and by 22% when mulched compared to since 2017. The content of glutathione in sweet cherry leaves decreased in 2018 by 14% when the soil was kept under clean steam and by 12% when mulched compared to 2017. Similar trends have already been described in the scientific literature: under the stress of progressive drought in apple trees the initial response was a slight oxidation of glutathione with a subsequent increase in glutathione concentration, but as drought stress continued to increase, glutathione concentration decreased substantially (Polonskaya *et al.*, 2007). In 2019 (with sufficient moisture supply), the total reducing activity significantly increased, compared to 2018, in both variants of the experiment: under conditions of pure steam by 66%, under conditions of mulching – by 62%. The content of ascorbate in leaves in 2019 under conditions of pure steam increased by 41% compared to 2018, under conditions of mulching – by 51%. The same trend was observed regarding the content of glutathione in leaves: in 2019, under the conditions of mulching, this indicator was 64% more, compared to 2018, under the conditions of pure steam – by 69%. If one compares the total reducing activity in sweet cherry leaves in the favourable year of 2019 with the average year in terms of climatic conditions in 2017, then this indicator was 42% higher in both versions of the experiment. Likewise, the content of ascorbate in 2019 was higher compared to 2017: under the conditions of pure steam by 20%, under the conditions of mulching – by 18%. The content of glutathione in the leaves also increased in 2019, compared to 2017: under the conditions of mulching – by 44%, under the conditions of pure steam – by 45%. From the above, it can be concluded that with sufficient moisture supply, the content of ascorbate, glutathione, and general reducing activity in sweet cherry leaves increases. Ascorbate consumption occurred under drought conditions, while

under mulching conditions it was consumed more, but also produced more. This is confirmed by the absence of a significant difference in the investigated indicator between the variants of the experiment. Glutathione content and total reducing activity under drought conditions decreased in the same way, both under mulching conditions and under clean steam conditions, no substantial difference in these parameters between the experimental variants was noted during all three years of research. The content of ascorbate, glutathione, and total reducing activity in sweet cherry leaves gradually increased from the flowering phase to November and had maximum values in the November phase. A decrease found in the content of ascorbate, glutathione, and total reducing activity in leaves under drought conditions indicates stress exhaustion of sweet cherry trees, when a high level of stress leads to a decrease in the production of protective antioxidants (Anjum *et al.*, 2010).

In the flowering phase (BBCH 61-65), the sugar content in the leaves was 2.8-3.2% when the soil was kept under pure steam and 3.4-3.8% when covered with natural grasses. In the fruit ripening phase (BBCH 87-89), the sugar content in the leaves increased. Thus, on pure steam, the sugar content in leaves was 3.0-3.4%, and on mulching – 3.6-4.1%. In the phase of completion of shoot growth, a difference between the experimental variants was also observed. The content of sugars in the leaves was higher under the condition of soil mulching (4.1-4.5%) compared to pure steam (3.4-3.8%). However, in the defoliation phase (BBCH 91), the difference between the test options was statistically significant (by 14%) only in 2017. In general, the highest content of sugars in the leaves was accumulated before the defoliation phase and was 4.3-4.8% in the conditions of mulching and 3.8-4.2% in the conditions of pure steam. The content of sugars decreased under unfavourable weather conditions in 2018 almost equally in both versions of the experiment – by 10-11%.

Organic acids in plant tissues perform several essential functions, e.g., they help to change the turgor pressure in the stomata, which provokes their movement (Richter, 2021). During the growing season, the content of titrated acids in sweet cherry leaves increased from 0.9 to 1.6% under the condition of pure steam and from 1.1 to 1.8% under the condition of mulching. The content of titrated acids in sweet cherry leaves under the condition of being covered with natural grasses was significantly higher compared to pure steam: in 2017, by 27, 36 and 15% in the phases of flowering, ripening of fruits and completion of shoot growth, respectively; in 2019, by 18 and 17% in the phases of fruit ripening and the completion of shoot growth, respectively. In 2018, there was no substantial difference between the experimental variants in the content of titrated acids in the leaves. Under unfavourable weather conditions in 2018 (compared to 2017), the content of titrated acids in the leaves of sweet cherry trees decreased: under clean

steam conditions by 14%, under mulching conditions by 16%. However, in the year 2019, which was more favourable in terms of moisture supply, the acid content increased insubstantially compared to 2018 (only by 3% under clean steam conditions and by 2% under mulching conditions). Thus, in 2017, the content of titrated acids in sweet cherry leaves was the highest in three years of research. This can be explained by the cold conditions of April and May 2017, which contributed to the shift of leaf metabolism towards the accumulation of acids.

Total phenolic concentration in plant leaves is a major component of stress tolerance (Cheynier *et al.*, 2013). The total content of phenolic substances in sweet cherry leaves was 7.9-242.3 mg of GA/100 g of raw material when the soil was kept under pure steam. Under the condition of covering the soil with natural grasses, the studied indicator increased significantly and ranged from 10.2 to 298.1 mg GA/100 g of raw material. There was a substantial difference between the variants of the experiment in terms of the content of phenolic substances throughout all years of research. Thus, the content of phenolic substances in sweet cherry leaves was 16-56% higher compared to pure steam. Under adverse weather conditions in 2018, the content of phenolic substances (in contrast to ascorbate, glutathione, sugars and titrated acids) increased by 12% when the soil was kept under pure steam and by 24% when covered with natural

grasses. In 2019, the content of phenols increased by 30% compared to 2018 when kept under pure steam and by 24% when covered with natural grasses. The total content of phenolic substances in sweet cherry leaves, established by our research in the fruit ripening phase, is consistent with the data of Turkish scientists (Uysal *et al.*, 2020). As a result of the research, a gradual increase in the content of the following biologically active substances was recorded in sweet cherry leaves from the flowering phase (BBCH 61-65) to the defoliation phase (BBCH 91): ascorbate, glutathione, sugars, titrated acids and phenolic substances. In the defoliation phase, sugars and phenolic substances were substantially more in the leaves of sweet cherry trees under mulching conditions in 2017, phenolic substances in 2018, and phenolic substances and ascorbate in 2019 compared to the conditions of pure steam.

Correlation analysis confirms a strong direct positive correlation between BAS content and total reducing activity (Table 4). At the same time, the total reducing activity in sweet cherry leaves was most closely correlated with the content of glutathione and phenolic substances. The accumulation of biologically active substances occurred in a close correlation (Table 5). The closest correlation was noted between the content of phenolic substances and glutathione, sugars and titrated acids, ascorbate, and glutathione.

Table 4. Correlation coefficients (r^2) of general reducing activity (GRA) with the content of biologically active substances (BAS) in sweet cherry leaves

Year of research	Sugars	Titrated acids	Phenolic substances	Ascorbate	Glutathione
2017	0.81	0.71	0.93	0.85	0.98
2018	0.82	0.94	0.92	0.96	0.99
2019	0.85	0.82	0.95	0.91	0.99

Table 5. Correlation coefficients (r^2) between the content of biologically active substances (BAS) in sweet cherry leaves

Year	Sugars and				Titrated acids and			Ascorbate and		Phenolic substances and glutathione
	Titrated acids	Ascorbate	Phenolic substances	Glutathione	Ascorbate	Phenolic substances	Glutathione	Phenolic substances	Glutathione	
2017	0.90	0.92	0.74	0.78	0.75	0.60	0.69	0.82	0.84	0.93
2018	0.89	0.77	0.76	0.81	0.90	0.76	0.91	0.93	0.98	0.94
2019	0.96	0.86	0.77	0.81	0.89	0.69	0.76	0.80	0.86	0.97

Similar trends have already been noted in the studies of A.K. Polonskaya, V.N. Yezhov, and O.A. Grebennikova (Polonskaya *et al.*, 2007; Grebennikova *et al.*, 2011). The content of biologically active substances in plum leaves increased during the growing season and was the largest in the defoliation phase, and there was a close correlation between antioxidant activity and the content of biologically active substances. Comparative

chemical analysis of fruits and leaves of apricot, plum, nectarine showed that the leaves of these crops are a valuable source of biologically active substances: the ascorbate content in the leaves of these crops was 12.4-21.3 g/100 g of raw material, organic acids – 1.0-2.1 g/100 g; carbohydrates – 8.0-14.8 g/100 g. Dry apricot leaves collected during defoliation contained up to 56.8 mg/100 g of ascorbate (Polonskaya *et al.*, 2007).

Malondialdehyde (MDA) is one of the end products of the peroxidation of unsaturated fatty acids in phospholipids and is responsible for cell membrane damage (Sharma *et al.*, 2012). Under the conditions of mulching, the

content of MDA in the tissues of sweet cherry leaves in 2017 was substantially higher in the phases of flowering (by 58%) and the completion of shoot growth (by 36%), compared to the leaves of sweet cherry trees on pure steam (Table 6).

Table 6. The content of malondialdehyde (MDA) and the activity of ADS enzymes in the sweet cherry leaves of Dilema variety depending on the content of the soil (2017), $\bar{M} \pm m$

Variant	MDA, nmol/g	CAT, $\mu\text{mol H}_2\text{O}_2/\text{g}\cdot\text{min}$	APO, mg of oxidized ascorbic acid/g	PPO, c.u./g·min	PO, mcat/g
Flowering					
Pure steam	35.1±1.44	5.5±0.39	5.4±0.44	7.4±0.45	3.5±0.29
Mulching	55.5±5.25*	5.5±0.43	6.3±0.54	10.7±0.49*	5.4±0.33*
Fruit ripening					
Pure steam	104.3±9.81 ^a	6.54±0.53 ^a	7.2±0.69 ^a	14.2±0.57 ^a	5.9±0.45 ^a
Mulching	115.6±10.43 ^a	7.62±0.69 ^a	8.3±0.71 ^a	16.9±0.55 ^{*a}	15.3±0.47 ^{*a}
Completion of shoot growth					
Pure steam	219.7±17.91 ^a	10.3±0.55	15.9±0.99 ^a	30.9±0.79 ^a	25.6±0.85 ^a
Mulching	297.8±20.93 ^{*a}	12.4±0.92 ^{*a}	17.3±0.75 ^a	35.6±0.81 ^{*a}	33.1±0.88 ^{*a}
Defoliation					
Pure steam	265.5±25.34	9.1±0.73 ^a	20.1±0.85 ^a	35.4±0.88 ^a	43.5±0.89 ^a
Mulching	288.5±16.55	9.3±0.82 ^a	25.8±0.79 ^{*a}	45.8±0.85 ^{*a}	45.9±0.96 ^a

Note: *the difference between options is significant at $P \leq 0.05$; and the difference compared to the previous stage of organogenesis is significant at $P \leq 0.05$

In the phases of fruit ripening and defoliation, there was a tendency to increase the content of MDA in leaves under the conditions of mulching, but the difference between the variants of the experiment was statistically

insignificant. In 2018, the content of MDA in leaves was substantially lower under the conditions of mulching in the phases of flowering (by 34%), ripening of fruits (by 40%) and the completion of shoot growth – by 28% (Table 7).

Table 7. The content of malondialdehyde (MDA) and the activity of ADS enzymes in the sweet cherry leaves of Dilema variety depending on the content of the soil (2018), $\bar{M} \pm m$

Variant	MDA, nmol/g	CAT, $\mu\text{mol H}_2\text{O}_2/\text{g}\cdot\text{min}$	APO, mg of oxidized ascorbic acid/g	PPO, c.u./g·min	PO, mcat/g
Flowering					
Pure steam	15.1±3.35	3.8±0.23	4.1±0.34	5.6±0.35	2.7±0.19
Mulching	10.0±1.15*	4.5±0.20*	4.9±0.41	8.2±0.39*	4.1±0.24*
Fruit ripening					
Pure steam	59.5±14.57	7.2±0.25 ^a	5.5±0.43 ^a	10.7±0.44 ^a	4.4±0.35 ^a
Mulching	35.8±8.35*	7.6±0.19 ^a	6.3±0.51 ^a	13.0±0.46 ^{*a}	11.6±0.49 ^{*a}
Completion of shoot growth					
Pure steam	191.3±18.47 ^a	12.2±0.32 ^a	12.1±0.76 ^a	23.4±0.74 ^a	11.8±0.54 ^a
Mulching	138.5±12.53 ^{*a}	17.3±0.34 ^{*a}	13.3±0.79 ^a	27.4±0.75 ^{*a}	25.4±0.75 ^{*a}
Defoliation					
Pure steam	255.4±20.15 ^a	10.0±0.30 ^a	15.2±0.99 ^a	26.9±0.81 ^a	10.2±0.78
Mulching	223.8±20.17 ^a	9.4±0.32 ^a	19.8±0.95 ^{*a}	35.2±0.87 ^{*a}	35.3±0.99 ^{*a}

Note: *the difference between options is significant at $P \leq 0.05$; and the difference compared to the previous stage of organogenesis is significant at $P \leq 0.05$

The tendency to decrease the content of MDA in the leaves on the mulching remained in the defoliation phase, but the difference between the variants was insignificant here. In general, the content of MDA in the sweet cherry leaves on the mulching decreased in 2018 by 57% compared to 2017. In 2019, a tendency to increase the content of MDA in the leaves on the mulching was

noted, and in the phases of flowering, fruit ripening and defoliation, the MDA content was substantially larger in the leaves of sweet cherry trees grown on mulching (Table 8). The general trend for both variants of the experiment was a gradual increase in the content of MDA in leaf tissues during the growing season and the maximum accumulation of MDA in the defoliation phase.

Table 8. The content of malondialdehyde (MDA) and the activity of ADS enzymes in the sweet cherry leaves of Dilema variety depending on the content of the soil (2019), $\bar{M} \pm m$

Variant	MDA, nmol/g	CAT, $\mu\text{mol H}_2\text{O}_2/\text{g}\cdot\text{min}$	APO, mg of oxidized ascorbic acid/g	PPO, c.u./g·min	PO mcat/g
Flowering					
Pure steam	13.5±2.67	12.2±0.35	6.0±0.43	8.3±0.23	3.9±0.25
Mulching	35.4±2.75*	17.9±0.30*	7.1±0.45*	12.1±0.29*	6.1±0.29*
Fruit ripening					
Pure steam	138.0±10.44 ^a	19.0±0.25 ^a	8.1±0.57 ^a	15.9±0.35 ^a	6.6±0.33 ^a
Mulching	155.5±13.45* ^a	19.1±0.29 ^a	9.4±0.60* ^a	19.7±0.37* ^a	17.2±0.37* ^a
Completion of shoot growth					
Pure steam	236.2±21.18 ^a	19.3±0.63 ^a	17.8±0.88 ^a	34.6±0.67 ^a	17.4±0.74 ^a
Mulching	234.5±19.25 ^a	26.6±0.54* ^a	19.5±0.85 ^a	40.2±0.75* ^a	37.4±9.78* ^a
Defoliation					
Pure steam	255.6±11.28	27.2±0.33 ^a	22.5±0.90 ^a	39.8±0.99 ^a	15.1±0.89
Mulching	290.5±11.55* ^a	27.3±0.25 ^a	29.2±0.93* ^a	51.7±0.84* ^a	51.8±0.85* ^a

Note: *the difference between options is significant at $P \leq 0.05$; and the difference compared to the previous stage of organogenesis is significant at $P \leq 0.05$

Considering the extremely dry conditions of the formation of the leaf plate in 2018, sweet cherry trees suffered less from oxidative stress in the conditions of mulching. However, during the 2018 growing season, the MDA content also decreased in the leaves of sweet cherry trees under pure steam conditions (by 29% on average) compared to 2017. An increase in the MDA content in sweet cherry leaves under the conditions of mulching indicates a higher level of lipid peroxidation and is an indicator of oxidative damage to cell membranes. The presented data are fully consistent with the previously described general trends inherent in the non-specific response of plants to stress: a decrease in the activity of metabolic processes, which is accompanied by the induction of the formation of compounds necessary for the preservation of the integral structure of cells and the life potential of the plant as a whole (Polonskaya et al., 2007). In 2019, the content of MDA in sweet cherry leaves increased substantially, compared to 2018, especially in the phase of fruit ripening: under conditions of pure steam by 2.3 times, under conditions of mulching – by 4.3 times. In general, the content of

MDA in sweet cherry leaves from both variants of the experiment in 2019 was more, compared to the similar phases of 2018, by an average of 2 times.

In 2017, the content of MDA in sweet cherry leaves was strongly correlated with the activity of antioxidant enzymes and the content of biologically active substances (Table 9). The correlation of MDA content with PPO activity and the content of phenolic substances, glutathione, and total reducing activity was the strongest in 2017. In 2018, the correlations of MDA content with the activity of antioxidant enzymes and the content of biologically active substances were much weaker, compared to 2017. The highest correlation of MDA content in leaves in 2018 was noted with the activity of APO, PPO, and the content of ascorbate and phenolic substances. In 2019 (under conditions of satisfactory moisture supply during the formation of the leaf blade), the content of MDA was strongly correlated with the activity of antioxidant enzymes and the content of BAS in sweet cherry leaves, most strongly with the activity of PPO and the content of glutathione, phenolic substances and general reducing activity.

Table 9. Correlation coefficients (r^2) of MDA content with general reducing activity (GRA), ADS enzyme activity and the content of BAS in sweet cherry leaves

Year of research	Correlation coefficients of MDA content with									
	CAT	APO	PPO	PO	Sugars	Titrated acids	Phenolic substances	Ascorbate	Glutathione	GRA
2017	0.83	0.88	0.95	0.90	0.68	0.50	0.95	0.90	0.91	0.91
2018	0.37	0.86	0.83	0.36	0.41	0.57	0.80	0.82	0.79	0.79
2019	0.76	0.82	0.90	0.58	0.63	0.62	0.91	0.81	0.93	0.93

The activity of catalase in both versions of the experiment in 2017 and 2018 increased until the phase of shoot growth completion and further decreased until the defoliation phase. In 2019, catalase activity continued to increase until the defoliation phase. Under the conditions of mulching during all three years of research, a tendency to increase catalase activity in the tissues of sweet cherry leaves was observed, but a statistically significant difference between the experimental variants was only in the phase of the end of shoot growth in 2017 (by 20%), in the phases of flowering and end of shoot growth in 2018 (by 18% and 42%, respectively) and in the phases of flowering and the end of shoot growth in 2019 (by 47% and 38%, respectively). Catalase activity in sweet cherry leaves in 2018 in the flowering phase was significantly lower, compared to the same period in 2017: under mulching conditions by 18%, under pure steam conditions – by 31%. But in the future, the activity of catalase in sweet cherry leaves increased, and in the phase of fruit ripening it was 40% more in the conditions of mulching, and 10% more in the conditions of pure steam, compared to the same period in 2017. In general, it can be stated that during the entire vegetation period of 2018, the activity of catalase did not significantly differ from the level of 2017, showing an increase of 4%. In 2019, catalase activity also increased insignificantly compared to 2018 – by an average of 2.6% in both variants of the experiment. But, if we compare with 2017, in 2019, the activity of catalase in leaves increased by 171% under the conditions of mulching, and under the conditions of pure steam – by 150%. Stresses have been reported to cause either enhancement or depletion of CAT activity in plants, depending on the intensity, duration, and type of stress. Depletion of CAT activity is observed when the intensity of protein turnover decreases under stress (Sharma *et al.*, 2012; Gill *et al.*, 2013; Cai *et al.*, 2019).

The activity of ascorbate peroxidase in leaves increased throughout the growing season and reached maximum values in the defoliation phase. Moreover, under the conditions of mulching, APO activity in sweet cherry leaves was significantly higher, compared to the conditions of pure steam: in the defoliation phase of 2017 by 28%, in the defoliation phase of 2018 by 30%,

in the flowering, fruit ripening and defoliation phases of 2019, respectively, by 10%, 16%, and 29%. In 2018, APO activity in leaves decreased by 23% under mulching conditions and by 24% under clean steam conditions compared to 2017. In 2019, APO activity in sweet cherry leaves increased by 47% under mulching conditions and by 50% under clean steam conditions couple compared to 2018. But, if one compares the data of 2019 with the data of 2017, the activity of APO showed a tendency to decrease (on average, by 6% for both variants of the experiment).

The activity of polyphenol oxidase in sweet cherry leaves increased continuously during the growing season, reaching a maximum in the defoliation phase. At the same time, under the conditions of mulching, the activity of polyphenol oxidase in sweet cherry leaves was consistently higher, compared to the conditions of pure steam: in the flowering phase by 45%, 46%, and 45% (in 2017, 2018, and 2019, respectively). In the fruit ripening phase – by 19.21% and 24%; in the phase of completion of shoot growth – by 15%, 17%, and 16%; in the defoliation phase – by 29%, 30%, and 29%. In 2018, the activity of PPO in the leaves of both variants of the experiment decreased, on average, by 24%. In 2019, compared to 2018, PPO activity increased, on average, by 48% for both variants of the experiment. But, if compared with 2017, PPO activity increased in sweet cherry leaves in 2019 by only 12% under pure steam conditions and by 14% under mulching conditions.

Notably, PPO activity in sweet cherry leaves was strongly and stably correlated with the content of phenolic substances during all years of research ($r^2=0.99$, $p=0.0001$). APO activity in leaves was highly correlated with ascorbate content ($r^2=0.96$ in 2017 and 2018 and $r^2=0.76$ in 2019, $p=0.0001$).

The activity of peroxidase in leaves was significantly higher under the conditions of mulching, compared to the conditions of pure steam: in 2017, in the flowering phase by 54%, in the fruit ripening phase by 159%, in the phase of the completion of shoot growth – by 29%; in 2018, in the flowering phase by 51%, in the fruit ripening phase by 164%, in the phase of shoot completion by 115%, in the defoliation phase by 246%; in 2019, in the flowering phase by 56%, in

the fruit ripening phase by 160%, in the phase of shoot completion by 114%, in the defoliation phase by 243%. But the dynamics of peroxidase activity differed over the years of research. Thus, in 2017, peroxidase activity increased throughout the growing season in both variants of the experiment, reaching a maximum in the defoliation phase. In 2018 and 2019, an increase in peroxidase activity was observed in both variants before the phase of shoot growth completion. Later, until the defoliation phase, peroxidase activity in the leaves of sweet cherry trees in pure steam slightly decreased (statistically insubstantial), and under mulching conditions it continued to increase, reaching a maximum in the defoliation phase.

In 2018, peroxidase activity decreased in leaves by 24% under mulching conditions and by 45% under pure steam conditions compared to 2017. In 2019, PO activity in leaves increased by 48% under mulching conditions and by 47% under pure steam conditions compared to 2018. If we compare the data of 2019 with the data of 2017, the activity of PO in sweet cherry leaves under the conditions of pure steam decreased by 19%, and under the conditions of mulching, it increased by 13%.

The dynamics of APO and PPO activity in sweet cherry leaves did not coincide with the dynamics of CAT activity after the phase of shoot growth completion in 2017 and 2018 and with the dynamics of PO activity after the phase of shoot growth completion in 2018 and 2019: APO and PPO activity after the completion of shoot growth continued to increase to the defoliation phase, while CAT activity significantly decreased and PO activity showed a decreasing trend. Similar trends have already been described by B. Cai: opposite trends in the activity of CAT, PO, and APO were noted in the flower buds of cherries when the resting period was disturbed. Regarding the range of fluctuations in enzymatic activity, our data are similar to fluctuations in the activity of antioxidant enzymes under the action of exogenous treatment of sweet cherry trees with gibberellins (Cai *et al.*, 2019). This suggests that phytohormones, which are produced in leaf tissues under mulching conditions, are involved in increasing the activity of antioxidant enzymes in leaves under mulching conditions. We can assume that the reason here is the activity of soil microorganisms that exist in the rhizosphere of trees and natural grasses, primarily plant growth-stimulating rhizobacteria and mycorrhizal fungi, which can provide trees with moisture, nutrients, hormones, enzymes and increase the tolerance of fruit trees to abiotic stresses. (Esitken, 2011; Turrini *et al.*, 2017). Mulching provides better conditions for the existence of soil microorganisms (Yao *et al.*, 2005, Balestrini *et al.*, 2018). Therefore, the greater number and activity of soil microorganisms may be the reason for the increase in the activity of antioxidant enzymes in sweet cherry leaves under mulching conditions (compared to standard mechanical treatment).

The BAR content in the leaves of fruit crops is often higher than in the fruits (Tabart *et al.*, 2006; Teleszko *et al.*, 2015, Oszmiański *et al.*, 2016). Organic practices in horticulture contribute to the accumulation of biologically active substances and antioxidants not only in fruits, but also in plant leaves (Hallmann & Sabała, 2020). In the study presented here, both variants of sweet cherry trees were grown using organic technology, so they contained a sufficiently large amount of biologically active substances and antioxidants in the leaf tissues. But trees under mulching conditions experienced added stress due to competition with grasses, which led to increased accumulation of protective anti-stress substances. Thus, it can be stated that the leaves of sweet cherry trees grown under mulching conditions are a powerful source of biologically active substances and antioxidants and can be used as a dietary supplement and medicinal raw material.

CONCLUSIONS

1. Prolonged drought contributed to a substantial decrease in the content of ascorbate, glutathione, sugars, total reducing activity and activity of antioxidant enzymes in the tissues of sweet cherry leaves, while the content of titrated acids increased substantially in both variants of the experiment.

2. The content of biologically active substances (ascorbate, glutathione, sugars, titrated acids and phenolic substances) in the leaves of sweet cherry trees gradually increased from the flowering phase to the defoliation phase. In the defoliation phase, the leaves of sweet cherry trees under mulching conditions had substantially more sugars (by 14%) in 2017 and ascorbate (by 17%) in 2019 compared to pure steam conditions. Over the years of research, under the condition of mulching, the total content of phenolic substances in sweet cherry leaves was 16-56% higher compared to the conditions of pure steam.

3. The content of malondialdehyde tended to increase under the conditions of mulching, and substantially increased in both variants of the experiment during the growing season. In the defoliation phase, a statistically substantial difference between the options was noted only in 2019, when the MDA content under mulching conditions was 14% higher compared to keeping the soil under pure steam.

4. The activity of antioxidant enzymes increased during the growing season in both versions of the experiment. Mulching increased the activity of antioxidant enzymes, but statistically significant differences compared to the conditions of pure steam were only for ascorbate peroxidase (by 28-30%) and polyphenol oxidase (by 45-46%) during all three years of research. During 2018 and 2019, the activity of peroxidase in sweet cherry leaves was substantially 2.4 times higher under the conditions of mulching with natural grasses compared to the conditions of pure steam.

5. The established regularities can be explained by the formation of stressful conditions of competition with natural herbs that activate the synthesis of anti-stress BASs.

6. The leaves of sweet cherry trees under the conditions of mulching are a powerful source of biologically active substances and antioxidants and can be used as a dietary supplement and medicinal raw material.

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Біохімічний склад листків черешні залежно від способу утримання ґрунту в органічному саду

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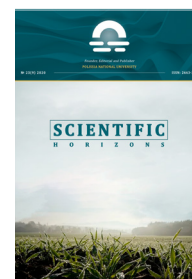
Анотація. Ведення сталого сільського господарства передбачає не лише підвищення продуктивності культур і збільшення обсягів виробництва рослинницької продукції, але й збереження екосистем. Задерніння ґрунту у плодкових садах є одним із шляхів збереження природної рівноваги агроландшафтів. Але вплив конкуренції з травами на біохімічний склад тканин плодкових дерев наразі остаточно не з'ясований. Метою досліджень було встановити вплив утримання ґрунту під задернінням (порівняно з чистим паром) на біохімічний склад тканин листків черешні. Дослідження проводили у органічному саду черешні (*Prunus avium* L./*Prunus mahaleb*) впродовж 2017–2019 рр. в умовах Південного Степу України. Встановлено істотне зменшення умісту аскорбату, глутатіону, цукрів, загальної редуруючої активності та активності антиоксидантних ферментів за умов тривалої посухи та збільшення умісту титрованих кислот. Загальна редуруюча активність за умов задерніння мала тенденцію до збільшення. У листках дерев черешні від фази цвітіння до листопаду зафіксовано поступове збільшення умісту титрованих кислот, аскорбату, цукрів, фенольних речовини і глутатіону. У фазі листопаду у листках черешні за умов задерніння встановлено достовірне збільшення у 2017 р. цукрів і фенольних речовин, у 2018 р. – фенольних речовин; у 2019 р. – фенольних речовин і аскорбату. Упродовж вегетації черешні на обох варіантах дослідів встановлено збільшення умісту малонового діальдегіду (МДА) та активності антиоксидантних ферментів. У фазі листопаду лише у 2019 р. вміст МДА був достовірно більшим на 14 % за умови задерніння. За умов задерніння визначено достовірне збільшення аскорбатпероксидази (на 28–30 %) і поліфенолоксидази (на 45–46 %) у 2018 і 2019 р. встановлено збільшення у 2,4 рази активності пероксидази у листках черешні. Результати досліджень допомагають зрозуміти механізми адаптації плодкових рослин до стресових факторів (посухи, конкуренції з природними травами) і можуть бути використані як аргумент на користь задерніння у органічних садах черешні

Ключові слова: задерніння, вітамін С, глутатіон, титровані кислоти, каталаза, аскорбатпероксидаза, поліфенолоксидази

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Agricultural Service Cooperatives in Ukraine: Institutional Development Drivers

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Abstract. The development of agricultural cooperation in Ukraine is one of the main vectors for rapid recovery of agricultural production after the Russian-Ukrainian war, increasing its competitiveness, ensuring sustainable development of rural areas, increasing employment and welfare of rural population. However, agricultural service cooperatives are not developed in Ukraine. The purpose of this study was to find the main drivers of agricultural service cooperatives' development in Ukraine, to outline on this basis promising directions for development of agricultural policy in terms of stimulating their development as a counterweight to the dominance of agricultural holdings. It is proven that the main restraining factor in the development of agricultural service cooperatives in Ukraine is institutional memory of a peasant, which was formed during collectivization in Soviet times and which in modern conditions is associated with the concept of "cooperative". This creates opposition from agricultural producers towards the national policy on the development of agricultural cooperatives, which meet international cooperative principles, and which have proven their advantages in increasing competitiveness of farmers on the example of developed countries of the world. It is emphasized that before changing formal institutions through legislation, it is necessary to form proper informal institutions that will strengthen, and not oppose, the introduction of formal ones. This paper is of practical importance for scientists and representatives of public administration in the field of forming strategic state and regional programs for agricultural development. Compliance of national policy measures according to the identified drivers of agricultural service cooperation' development, requires further research

Keywords: national socio-cultural code, agricultural policy, institutionalism, informal institutions



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INTRODUCTION

Russia's full-scale invasion of Ukraine in 2022 resulted in the damage and mining of an agricultural land, destruction or damage of agricultural machinery, blockade of Ukrainian ports, and the impossibility of exporting food to countries that desperately need it. Ukraine ranked second in grain exports in 2021 and is a powerful guarantor of food security in many countries around the world. Therefore, recovery and further development of agriculture in Ukraine and support of the least protected farming is a vital global issue. Experience of the USA, EU countries, Canada, etc., shows that this can be achieved by the development of an agricultural service cooperation. Such international organizations as FAO, IFAD and WFP note that "Agricultural cooperatives pave the way to food security and rural development. They facilitate the access of small producers to natural resources (land, water), information, communications and knowledge, as well as to markets, food and productive assets, provide an opportunity to make their own decisions and participate in the formation of policies" (Agricultural cooperatives..., 2012). If A. Batziou *et al.* (2021) consider only economic benefits for agricultural producers from activities through agricultural service cooperatives (hereinafter – ASC) and improvement of product quality standards, then J. Parrilla-González and D. Ortega-Alonso (2021) entrust the ASC with the mission to implement social innovations, create jobs, and develop rural areas sustainably.

For more than 150 years, developed countries have been showing powerful potential of agricultural cooperation in terms of entry of small farmers into world markets. ASC turn them into large, competitive, and sustainable agribusiness entities. A third of the largest cooperatives in the world by turnover are agricultural and agro-food cooperatives (Exploring the cooperative economy, 2021). The turnover of ASC in Europe is the largest among all types of cooperatives and amounts to more than 39%, or 347 billion euros (The power of cooperation, 2016). They account for 40-60% of all agricultural trade. In Scandinavia, 80% of agricultural products are sold through ASC, more than 90% in China and Japan, and 82% of processed milk in the USA (Ajates, 2020). 70% of olive oil in Spain is produced by ASC (Parrilla-González & Ortega-Alonso, 2021). ASC has prospered in the EU, the USA, Canada, Korea, and China.

While in the fruit and vegetable sector in EU countries, national cooperatives are successfully operating within the framework of transnational cooperation, increasing competitiveness of farmers and their cooperatives (e.g., European Fruit Cooperation), Ukrainian farmers in 2021, due to a large harvest of apples, destroyed their products because of extremely low purchase prices and lack of own processing plants and storage facilities (Bezus *et al.*, 2019). If in Europe there are almost 180,000 cooperatives with an annual trade turnover of

almost 1 trillion US dollars, where more than 4.5 million workers work, then in Ukraine cooperatives create less than 1% of the country's agricultural GDP (FAO, 2020).

Despite the development of cooperatives in most developed countries and their presence on international markets, scientists continue to use complex mathematical calculations to prove the benefits of membership in a cooperative for small agricultural producers. In particular, K. Olagunju *et al.* (2021) see these advantages in higher technical efficiency; T. Wossen *et al.* (2017) – in the implementation and access to new technologies, unhindered access to loans, high-quality consulting and joint services, increasing the level of well-being; R. Ajates (2020) – in savings from wholesale, collective purchase of raw materials and payment for expensive infrastructure, in access to training and obtaining greater market power in the "farmer-consumer" supply chain; J. Bijman & A. Saris (2012) consider ASC as a tool to consolidate market position. And if the scientists investigating the cooperative movement in agricultural sector of developing countries' economies and countries of the post-Soviet system are sure that its development is the only way to build a competitive small and medium-sized business, as well as a sustainable development in rural areas, then scientists studying the behaviour and results of the activities of ASC in developed countries of the world, where they are producing the most part in the turnover of agricultural sector, – have doubts about preservation of cooperative principles and values in the conditions of fierce competition with large corporations. They argue that to survive in the "dominant capitalist system" and to be successful while still being true to their values and principles, agricultural cooperatives try to be "deviant" and at the same time continue to portray the "prefigurative policy" that the broad public would like to see from them (Ajates, 2020).

Having studied the latest publications of Ukrainian scientists on the strategy of agricultural sector development, it can be said that most of them do not consider important mission of ASC in development of farming, and their proposals lack measures to stimulate development of those (Pronina *et al.*, 2021; Haidai *et al.*, 2019). At the same time, while highlighting the problems and risks that only medium and small producers of agricultural sector have (but not agricultural holdings), scientists propose general measures that should be applied to all subjects of agricultural sector (Pronina *et al.*, 2021). Given the strong influence and lobbying interests of agricultural holdings, with such an approach to the mechanism of agricultural sector development, it can only lead to the development of agricultural holdings and complete destruction of small and medium-sized enterprises in agriculture. I. Ostapchuk *et al.* have no doubt that agricultural holdings will acquire

farms. Their publications examine which farms will be acquired first: unprofitable or profitable (Ostapchuk *et al.*, 2020).

Since ASC in Ukraine have not become powerful competitors to developed and powerful agricultural holdings, the negative consequences of whose activities are sufficiently covered in the scientific space, we consider it necessary to deepen the study of factors that inhibit ASC development.

The purpose of this study was to find the main drivers of ASC development in Ukraine, to outline on this basis the promising vectors for development of agricultural policy in terms of stimulating ASC development as a counterweight to agricultural holdings' dominance.

MATERIALS AND METHODS

In this study, not all types of agricultural cooperation that exist in rural areas were studied, only the ASC, which are a continuation of the food chain in agricultural production (processing, storage, sale of products, etc.), and also deal with the purchase of means of production and provision of technical and information services to its members. Agricultural production cooperation is not the subject of the current study as such, effectiveness of which is not confirmed either by the world or by rich Ukrainian experience of the Soviet economic period.

When choosing the research methodology, the authors rejected the methodology popular among economists, which is based on arbitrary mathematical assumptions, based on which economic models are created (Olah, 2018). Because the limited reliability of the inputs of such models, reinforced by the errors of systematic multiplication of fragmentary assumptions, irrelevant conclusions and results will be obtained, regardless of the quality of economic and mathematical tools used.

When the optimal legal form of conducting agribusiness – ASC, that maximize profit of their members, does not develop, atypical behaviour of agribusiness subjects occurs from the standpoint of mainstream economics and its inability to explain the extremely low level of inclination of small agricultural producers to cooperate in Ukraine. Comparative analysis of the differences in effectiveness of identical government stimulation tools of ASC development in different countries with variable institutional environments indicates the dominance of institutional factors in their development. That is why institutional approach was chosen as the methodological framework of this study. The research was concluded in the following stages:

1. Study of the current state of ASC in Ukraine and justification of reducing of their cooperative nature. Statistical and graphic research methods were used to analyse development of ASC in Ukraine. The data of the State Statistics Service of Ukraine served as the information base for this. The legislative framework of the Verkhovna Rada of Ukraine and the international

cooperative principles of the International Cooperative Alliance, which have already proven their viability and effectiveness, were used for a comparative study of the regulatory and legal support for development of ASC in Ukraine and economically developed countries of the world. Using content analysis of the types and results of individual ASC activities in Ukraine, according to the open database "Opendatabot" (n.d.), numerous violations of the current legislation on cooperation were found;

2. Using analysis and synthesis, the main factors inhibiting development of ASC in Ukraine were determined, individual drivers of their development were selected and ranked, and their influence on the cooperative movement in historical perspective was traced. In the study of informal institutions that were formed under the influence of historical development of Ukraine as part of the Soviet Union and whose role was determined to be decisive, the study acquired an interdisciplinary character, and to highlight the sociocultural aspect of the problem, the results of sociological studies by G. Hofstede (Hofstede, 2011) on the peculiarities of national business cultures in different countries were used;

3. Systematization of institutional drivers of ASC development and their visualization in a schematic form. The systematization is based on institutions of their coordination. At the same time, normative approach was used, that focuses not on current disposition of the subjects of coordination, but rather on the position that will ensure the meeting of set goals of ASC development and, as a result, an increase in competitiveness of agriculture in the country as a whole;

4. Outline of the main directions of agricultural policy for the formation of informal institutions, which should contribute to ASC development in Ukraine. Considering the information nature of modern society, informational methods of forming informal institutions were chosen, primarily advocacy.

The authors of this paper chose the period of 2009-2021 for the study, since the awareness of unrealized potential of ASC and purposeful stimulation of their development by the Ukrainian government began with the adoption in 2009 of the first state targeted economic program for their support.

RESULTS AND DISCUSSION

Despite the government reports and research findings of some Ukrainian scientists who insist on the increase in the number of ASC over the past 10 years (Bezus *et al.*, 2019; Petrova *et al.*, 2020; State Statistics Service of Ukraine, n.d.), Figure 1 shows only a slight growth, the decrease in the number of production cooperatives and the growth of service providers. And one may get the impression that ASC are really developing in Ukraine. But if one analyses the quality of these processes, conclusions will be opposite.

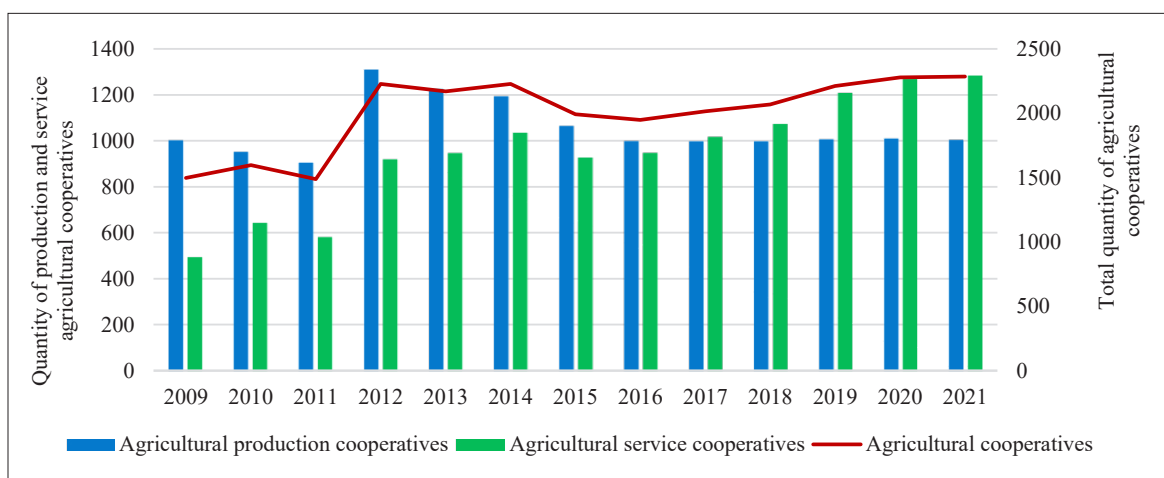


Figure 1. Dynamics of cooperatives' development in Ukraine

Source: compiled according to the data of the State Statistics Service of Ukraine (n.d.)

Almost half of the registered ASC in Ukraine are not active. For example, in 2019, only 60% of the registered cooperatives were active (State Statistics Service of Ukraine, n.d.). At the same time, most of the active agricultural structures, which are registered as ASC, in reality are not service cooperatives. In 2020, when the Law of Ukraine "On Agricultural Cooperation" (1997) was still in force and it defined ASC as non-profit organizations and those that cannot be engaged in the production of agricultural products, but only in providing services to producers (sales, processing, preservation of products, etc.), the cooperative association ASC "FAYNI GAZDY" still earned 16,300 UAH in net profit, ASC "Yagidny Lan Shumshchyny" – 96,600 UAH (Opendatobot, n.d.), and ASC "Ratai", which unites 250 farmers and personal peasant households, has been engaged in production activities, which it should not have, – in particular, growing grain crops since 1997 (YouControl, n.d.). And such violations are not unique throughout Ukraine. Authors agree with V. Zinovchuk that in Ukraine "one part functions with significant violations of cooperative principles (pseudo-cooperatives), and the other part only formally belongs to cooperatives (quasi-cooperatives)" (Zinovchuk, 2007).

An essential indicator of success and competitiveness of ASC is turnover and the number of members. The more members there are in a cooperative, the larger the share of sales market it will have, or the larger the wholesale batch of means of production it will be able to buy at the wholesale price. Unfortunately, such statistics are not kept in Ukraine at all, but analysis of the income of cooperatives showed that these are small cooperatives that are incapable of benefitting from the scale and showing the farmers who do not work as ASC its advantages, and such cooperatives cannot compete with powerful agricultural holdings. That is why the proposals of Ukrainian scientists to create agricultural cooperatives of the second and third levels in Ukraine (Bezus et al, 2020), when they are still far from creating

an extensive and sustainable network of agricultural cooperatives of the primary level, seem inappropriate.

As practices of economically developed countries of the world have shown, the only way for farming to resist the dominance of agricultural holdings is their activity through ASC. Since ASC are not developing in Ukraine, the development of farming has also stopped – the main guarantor of the country's internal food security, especially in the conditions of Russia's armed aggression, providing the population with a variety of healthy food, preserving ecosystem, creating jobs, and effectively restoring and ensuring sustainable development of rural areas. During the period of 2012-2019, the number of farms in Ukraine increased by 5%. They cultivate about 24% of agricultural land and produce less than 12% of all agricultural products, and these indicators practically stay constant (growth during the studied period by 3-4% cannot be interpreted as development), which shows the lack of development of farming in Ukraine (State Statistics Service of Ukraine, n.d.). For comparison, in the USA, family farms make up 96% of all farms, which cultivate 87% of agricultural land and their specific weight in the value of all agricultural products sold is 82% (US Department of Agriculture, 2017).

In authors' opinion, despite many scientific publications about the advantages of non-profit ASC, agricultural cooperation in Ukraine has not been properly developing for more than 20 years, as Yu. Lupenko *et al.* (2021) believe, but it has no signs of development whatsoever, despite the existence of legislation that, until 2020, corresponded to the best European models and the recommendations of neoliberal Western experts. The question arises: why in Ukraine, where the relevant legislation was created and the state with various foreign projects financially and informationally supported creation of ASC, these measures did not stimulate their rapid development, as in the EU countries and the USA?

According to the traditional economics, the main driver of any business is profit maximization, because

a business entity will not be able to withstand competition if it does not use all possible ways to reduce the cost of production and increase price. That is why competition among farmers in developed countries has become a powerful driver for ASC development.

A powerful driver in the developed countries of the world has been the national financial support for ASC. Even many foreign grant programs for the development of ASC in Ukraine were unsuccessful. To receive financial support, peasants registered ASC, which were not actually functioning. Therefore, the authors of this paper cannot agree with those researchers who believe that insufficient national financial support for agricultural producers slows down the development of ASC, that “development of ASC in Ukraine can take place at a rapid pace due to combination of state support with the implementation of grant projects of international technical assistance” (Prylipko, 2006). This approach will only increase the number of registered cooperatives, i.e., increase their number “on paper” to receive financial support, but the number of active, and even more so – effectively active, cooperatives may not change at all.

Another powerful driver in developed countries of the world is high-quality regulatory and legal support for the effective functioning of ASC. Authors agree with the statement that the Law of Ukraine “On Agricultural Cooperation” of 1997 is imperfect (Petrova et al, 2020; Lupenko et al, 2021), although compared to the legislation of other countries of the post-Soviet space, it is the closest to the cooperative principles declared by the International Cooperative Alliance (ICA), the viability and effectiveness of which have been verified by cooperative movement in various countries of the world. At the same time, this Law was not coordinated with other legislative acts of Ukraine. For example, inconsistency with the Tax Code of Ukraine resulted in the collection of taxes from these entities, as tax service officials did not understand the category of “non-profitability” regarding to the cooperative. As a result, farmers had to pay taxes twice, which nullified positive effects of ASC operation and formed a negative attitude of agricultural producers towards it.

However, instead of eliminating these legal conflicts and creating favourable regulatory support for ASC development, despite strong opposition from stakeholders (Association of Farmers and Private Landowners of Ukraine, Union of Agricultural Cooperatives of Ukraine, National Association of Agricultural Advisory Services of Ukraine, etc.), as well as leading Ukrainian scientists from the Institute of Agrarian Economics and the Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine, long-term lobbying by Ukrainian agricultural holdings ended with the adoption of the new corporatized Law of Ukraine “On Agricultural Cooperation” (2020) (Lupenko et al., 2021), which was optimistically called by European Bank for Reconstruction and Development and the Food and Agriculture Organization a promising law that will “pave

the way for modern agricultural cooperation in the country.” They believe that “the law harmonizes the national legal framework on agricultural cooperation with international principles of economic cooperation” (FAO, 2020).

The Law of Ukraine “On Agricultural Cooperation” of 2020 is ambiguously perceived by Ukrainian scientists. If N. Rudik (2020) believes that with its help “at the legislative level, the principles of the creation and operation of agricultural cooperatives, which correspond to the generally recognized principles of cooperation of the International Cooperative Alliance, will be consolidated”, then Yu. Lupenko et al. (2021), whose opinion we share, believe that its provisions largely do not correspond to generally accepted cooperative principles and values, create legal conflicts, in particular with the Law of Ukraine “On Cooperation” and bring agricultural cooperative closer to a limited liability company, organizational structure of the corporate type (Hryhorieva, 2020). For example, in clause 13 of Art. 16 of the new Law it is stated that: “The charter of an agricultural cooperative may provide that its members, when making decisions at the general meeting of such a cooperative on entire or a part of the issues referred to their competence..., have an additional number of votes proportional to their participation in the economic activities of such a cooperative” (Law of Ukraine, 2020). This contradicts the second cooperative principle of the International Cooperative Alliance on democratic member control: in primary cooperatives, members have equal voting rights “one member – one vote” (Bylaws, 2013). After the adoption of the Law of Ukraine “On Agricultural Cooperation” (2020), some leading scientists of the National Academy of Agrarian Sciences of Ukraine, who study the problems of development of rural areas, no longer rely on ASC as subjects of social infrastructure’s development in rural areas. For instance, if in the publication of 2016 V. Ryabokon & N.L. Novikova (2016), attributes a vital role to agricultural cooperation in this direction, then in 2021 this driver of rural development is not mentioned (Riabokon, 2021).

The authors of this paper, as well as the majority of leading Ukrainian scientists investigating the cooperative movement in Ukraine (Lupenko et al., 2021), believe that such a change in legislation will lead to the liberalization of almost every cooperative principle, which will nullify its special status compared to any other organization (enterprise), which operates in a market economy, and non-cooperative structures with some features of a cooperative or, in general, a limited liability company called a “cooperative” (to obtain various privileges from the state and foreign grants), will develop, i.e. “pseudo- and quasi-cooperatives”, using the categories of V. Zinovchuk (2012). Moreover, we believe that the new Law will destroy the sprouts of ASC in Ukraine.

But, in authors’ opinion, the above drivers are not the main ones in ASC development in Ukraine. Improvement of the legal framework and targeted financial

aid, which the government of Ukraine has used over the past decade, has yielded no results. The main reason for inhibition of the cooperative movement can be found in the history of the country's agricultural development. Historically, Ukraine had experience in the development of agricultural cooperation, when peasants themselves understood the advantages of cooperation and initiated creation of such structures, but under the Soviet government this idea was distorted by the collectivization. In contrast to the voluntary cooperation, which harmoniously combined individual interests of private property owners and collective interests of cooperative members, forced collectivization carried out by the Soviet authorities involved unification of peasant farms into large collective farms, elimination of private ownership of land and means of production. Peasants who refused to join collective farms were sent to Siberia, their land and property nationalized.

Thus, as stated on the FAO (2020) website, there is a negative attitude towards cooperatives in Ukraine,

which are identified with collectivization and collective farms, but this fact has its roots not in imperfection of the Law of Ukraine "On Agricultural Cooperation" of 1997, but in institutional memory of peasants about collective farms and the lack of knowledge about the essence and advantages of real cooperation, and ASC in particular.

After the collapse of the Soviet Union, the governance of Ukraine was dominated by the psychology of unconscious copying and imitation of the Western way of formation and development of ASC. And until now, the mentality and institutional memory of the post-Soviet peasantry is not considered in the formation of legislation and strategic programs for ASC development, which plays a decisive role in the effectiveness of these measures. The long-lasting, almost age-old, joint economic system of the Soviet period formed national business cultures with similar characteristics, which are fundamentally different from the countries of the EU and the USA and even from post-socialist countries (Fig. 2).

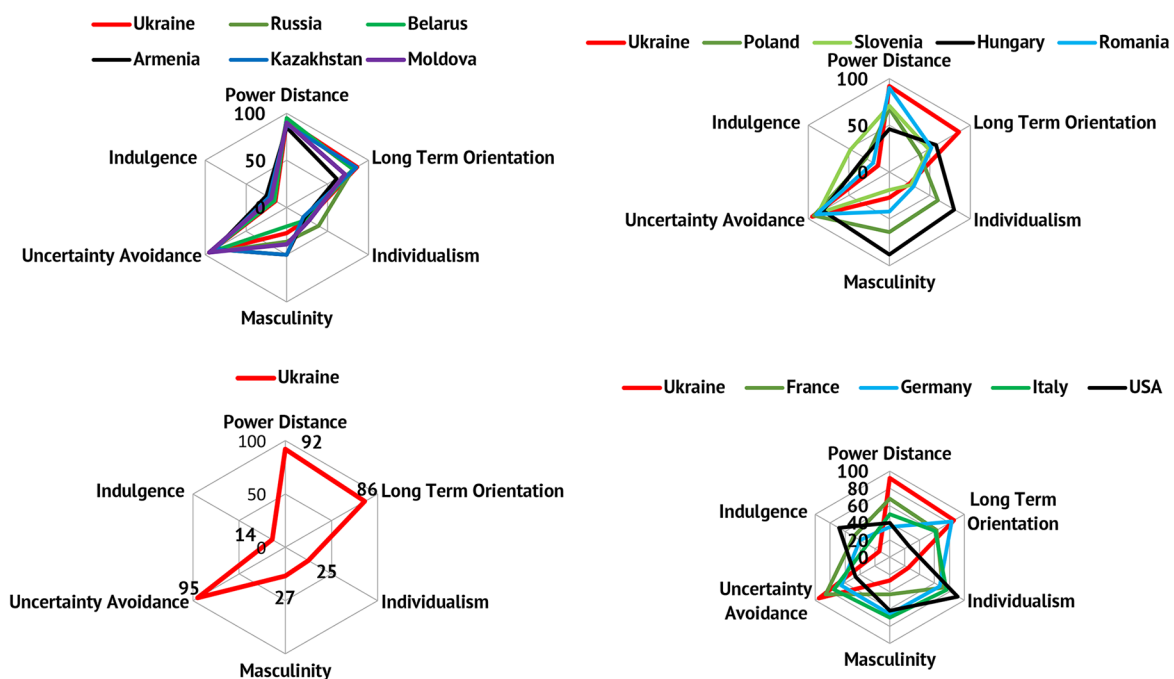


Figure 2. Comparative characteristics of cross-cultural characteristics of national business cultures of Ukraine, some countries of the post-Soviet space, post-socialist countries and developed countries of the world
Source: compiled by the authors based on (Hofstede Insights, n.d.)

Implementation of cooperative idea, which had such an immense potential in developed countries of the world, could not yield the same results in Ukraine due to the absence of new informal institutions that could stimulate development of real ASC, as well as because of specifics of national business' cross-cultural features in the country that were unaccounted for. As for the EU countries, this figure shows the low cultural gap in Western European countries, which contributes to the further development of ASC in these countries,

their entry into new international markets, creation of international cooperative associations and international cooperation between ASC (Bijman & Saris, 2012).

Authors see a problem in the fact that politicians overestimate the role of formal institutions and underestimate informal ones in Ukraine (Pylypenko *et al.*, 2019), which can play a decisive role in the economic behaviour of business entities, and, accordingly, in the effectiveness of politics. Since formal institutions created by the authorities can contradict with informal ones,

that were formed historically, its traditions, habits, institutional memory, which causes public opposition to the formal institutions created by the state. And thus, the measures of the state, which were aimed at increasing well-being, are doomed to failure.

Authors agree with Yu. Pylypenko *et al.* (2019), who believe that "... any institutional changes can be effective only when new formal rules are adapted to existing informal norms within the limits of permissible possibilities determined by social and cultural factors". Formation of formal institutions should be based on the existing informal institutions in a country, which will strengthen, and not counteract, the formal ones. Adaptation of formal rules to existing informal norms is necessary but insufficient condition for the formation of an effective institutional environment. If any institutional changes contradict the existing informal institutions, they should begin with formation of new ideology, value orientations, culture, mentality, etc. The study of factors stimulating entrepreneurial activity by M-T. Méndez-Picazo *et al.* (2021) has proved that the socio-cultural factor, rather than the economic one, has a greater stimulating effect.

Thus, an important driver of ASC development in Ukraine is the socio-cultural code, which consists of a set of socio-cultural programs holding value and worldview orientations, stereotypes of behaviour, communication methods, etc., formed under the influence of generations' experience. At the same time, the impact of changes taking place in Ukrainian society during its resistance to Russian armed aggression on socio-cultural code should not be underestimated. The latter became a factor in effective destruction of rudimentary informal institutions of the Soviet model due to conscious need

of Ukrainians to dissociate from the soviet ideals, which are cultivated in Russian Federation. Authors have already observed the tendency to evolutionary distancing of Ukrainian society from other post-soviet societies due to adulating of new generation not coloured by soviet stereotypes. The black swan of the war becomes the catalyst of approaching to bifurcation point of change of set of informal social institutes. It is the line with the model of path dependency and critical junctures, developed by Arthur (1994), Dunning (2017), Zurn (2018) and others.

There is a need for state to consider the institutional change to approach regulatory framework to the current or even future (acting proactively) set of informal institutions. It was a mistake of the Ukrainian parliament, which, instead of creating informal institutions of agricultural cooperation, changed the Law of Ukraine "On Agricultural Cooperation", thereby legitimizing pseudo- and quasi-cooperatives, nullifying the last hope for development of both agricultural cooperation and farming, and therefore sustainable development of rural areas of the country.

Institutional drivers of ASC development, which are the basis for formation of formal and informal institutions of agricultural cooperation, can be structured as shown in Figure 3. At the same time, for Ukraine, competition and national financial support are not the main drivers of ASC development, as they are in most of developed countries of the world. The first step in this direction is to form proper informal institutions for ASC support. And although there is no proper institutional coordination of the relevant informal institutions by the government, this is the right vector to stimulate ASC development in Ukraine today.

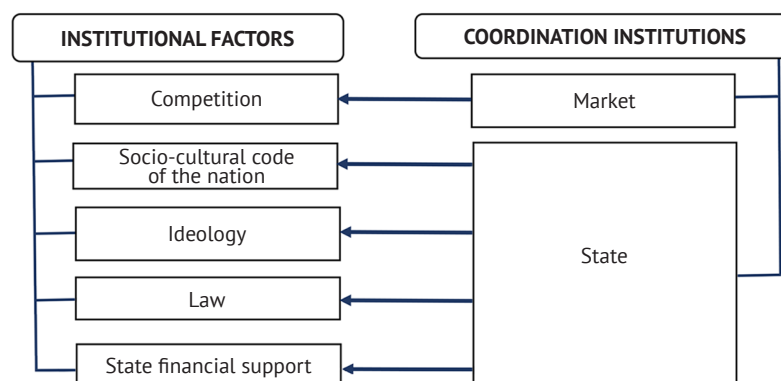


Figure 1. Institutional drivers of ASC development

Source: compiled by the authors

Many Ukrainian researchers consider the imperfection of legislation (Trutenko, 2020), problems with registration of non-profit organizations, insufficient state support and problems of access to information and consulting services (Petrova, 2020) to be the barriers holding back ASC development in Ukraine. The following

main barriers to ASC development in Ukraine can be highlighted:

- persistent post-Soviet stereotypes (Zinovchuk, 2019) – the Soviet legacy of collective farming (Wolz, 2020), that deforms consciousness of an agricultural producer and preserves the gene of negative experience

in collective farming, through which the concept of “ASC” is perceived. This causes not just a passive attitude, but a strong opposition of farmers to participation in the ASC (Wolz, 2020). Effectiveness of ASC activity, first of all, depends on the desire of its members to work in the cooperative, understanding its advantages, conscious adherence to cooperative principles (Zinovchuk, 2007), which cannot be achieved only with the help of state financial incentives;

- economic and political power of agricultural holdings, which lobby for legislation that inhibits ASC development and with whom it is difficult for newly created cooperatives to compete. At the same time, it is the cause for concern that some scientists (Lukianova & Hurska, 2018) and the newspaper of the Cabinet of Ministers of Ukraine form a positive attitude of society, and farmers, towards agricultural holdings, which help create and develop ASC (Shot, 2018). At the same time, ASC are not considered as a potential powerful competitor of agricultural holdings, in the development of which agricultural holdings are not interested;

- lack of political will, real interest of the authorities in development of real cooperation in agriculture, which is manifested in a) lack of an appropriate regulatory and legal framework that can contribute to ASC development; b) lack of statistical, especially reliable, data on turnover, financial results, which would allow scientists to identify real processes taking place in the created ASC (Zinovchuk, 2007), and this, in turn, distorts the results of their research, which the authorities then rely on when formulating the policy for ASC development; c) the absence of a controlling executive authority, that would detect non-compliance of activities of ASC with cooperative principles and monitor ASC development at the national level (Zinovchuk, 2007); d) lack of large-scale advocacy of ASC among peasants;

- lack of understanding of the true classic nature of cooperatives, their non-profit status and mission both by scientists and (and this is very important!) by representatives of the legislative and executive authorities, as a result of which structures are developed that de jure are named as “ASC”, and de-facto have nothing to do with the cooperative structure.

The authors believe that the formation of ardent supporters of cooperative movement in rural areas among the youth to be a crucial factor in ASC development. Currently, according to sociological survey conducted by R. Korints & Ya. Rybak (2014), only 53.2% of surveyed youth in Ukraine evaluate their knowledge of cooperative awareness as “good”, and a fifth of respondents, including youth and students, “does not know the real state and real problems of agricultural cooperation or does not see the need to be interested in this field of activity”. And this is natural, because currently in Ukrainian higher education institutions, the disciplines that explain the essence and advantages of agricultural cooperation are selective.

When forming agricultural policy and the strategy for rural areas development, a significant role in formation

of a positive attitude of a farmer towards ASC could be played by the use of positive narratives about these structures, which should become “viral” among Ukrainian farmers. It takes at least 40 years to change the mentality of a certain community, but the Russian-Ukrainian war radically changes Ukrainian nation and forms a new socio-cultural code, which is based on the desire for cohesion and trust of each member of society in each other. Damaged or destroyed material and technical base of agricultural production, mined agricultural lands and the great desire of Ukrainian peasants for the rapid recovery of agriculture after the war creates a powerful impetus for a broad cooperation between agricultural producers and ASC development.

CONCLUSIONS

There was an attempt to develop a formal institution of agricultural cooperation according to international cooperative principles and values in Ukraine, but it was made without consideration of the existing informal institutions, historically formed institutional memory of the negative consequences of collectivization during the Soviet era, which was identified among agricultural producers with the concept of “cooperative”. As a result of the contradiction between formal and informal institutions of agricultural cooperation, Ukrainian agriculture fell into an institutional trap that blocked ASC development and created favourable conditions for the rapid development of agricultural holdings.

It is necessary to create new informal institutions first that would stimulate implementation of cooperative legislation, to form an effective regulatory and legal field for ASC development. The Russian-Ukrainian war united the Ukrainian nation, increased the level of trust in society, and revolutionized the socio-cultural code of Ukrainians, reducing cultural gap with Western European countries and increasing the distance with the countries of post-Soviet bloc. This gives confidence, that in the conditions of post-war recovery of agriculture in Ukraine, there will be a need not only for the government, but first, for agricultural producers to cooperate, which creates a powerful impetus for ASC development.

The study showed that there are many deviations from cooperative values and principles in the activities of integrated structures that position themselves ASC in Ukraine, which distorts the essence of a cooperative idea and adversely affects the image and mission of a cooperative movement. Therefore, we see the need for further research in identifying the heterogeneity of actors, their true aspirations and intentions regarding creation of pseudo- and quasi-cooperatives, the causes and consequences of these processes. In this context, the consequences of competition between agricultural holdings and farmers, which has recently started to reveal itself in Ukraine, requires further research. In addition, further in-depth research of the national policy vectors outlined in this paper regarding ASC development according to the identified drivers is needed.

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Сільськогосподарська обслуговуюча кооперація в Україні: інституційні драйвери розвитку

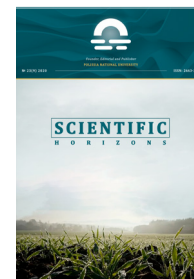
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Анотація. Розвиток сільськогосподарської кооперації в Україні є одним з головних напрямів швидкого відновлення фермерського виробництва після російсько-української війни, підвищення його конкурентоспроможності, забезпечення сталого розвитку сільських територій, зростання зайнятості і добробуту сільського населення. Проте в Україні сільськогосподарські обслуговуючі кооперативи не отримали свого розвитку. Метою статті є визначення основних драйверів розвитку сільськогосподарських обслуговуючих кооперативів в Україні, окреслення на цій основі перспективних напрямів розвитку аграрної політики в частині стимулювання їх розвитку як протидії домінуванню агрохолдингів. Доведено, що головним стримуючим чинником розвитку сільськогосподарських обслуговуючих кооперативів в Україні є інституційна пам'ять селянина, що сформувалася під час колективізації за радянських часів, і, яка в сучасних умовах асоціюється з поняттям «кооператив». Це створює супротив сільськогосподарських виробників політиці держави щодо розвитку сільськогосподарських кооперативів, які відповідають міжнародним кооперативним принципам і, які довели на прикладі розвинених країн світу свої переваги у підвищенні конкурентоспроможності фермерів. Наголошено на тому, що перед зміною формальних інститутів через законотворення, необхідно сформувати відповідні неформальні інститути, які будуть посилювати, а не протидіяти, впровадженню формальних. Стаття має практичне значення для науковців та представників публічного управління у сфері формування стратегічних державних та регіональних програм розвитку як сільського господарства в цілому. Подальших досліджень потребує деталізація заходів державної політики відповідно до визначених драйверів розвитку сільськогосподарської обслуговуючої кооперації

Ключові слова: соціокультурний код нації, аграрна політика, інституціоналізм, неформальні інститути



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Optimization of Small Agricultural Producer's Taxation by Creating Innovative-Integrated Structures

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Abstract. Issues of tax optimisation of business entities have always been in the centre of attention of taxpayers. Solving this issue requires strong human, technical, and other types of support. There are substantial features of the functioning of small-scale agricultural producers, which make it difficult to optimise their taxation. Presently, it is possible to solve this issue by creating innovative and integrated structures. The purpose of this study was to substantiate the feasibility of creating innovative and integrated structures in the agro-industrial complex, which should lead to optimisation of taxation of Ukrainian small-scale agricultural producers. Both general scientific and special research methods were used in the preparation of this study, namely: logical generalisation – for theoretical justification of the need to create innovative and integrated structures to optimise the functioning of small-scale agricultural producers; mathematical and system analysis – to justify the feasibility of creating integrated structures to optimise the taxation of small-scale agricultural producers, etc. The study of the theoretical foundations and practices of taxation of Ukrainian small-scale agricultural producers allowed substantiating the feasibility of creating innovative and integrated structures in the agricultural sector of the economy. It was found that in the structure of agricultural enterprises, the largest share belongs to small enterprises that, according to the specifics of their activities, are geographically remote from the centres of civilisation (labour market, tax services, internet resources, etc.) and do not have the opportunity to have highly qualified employees in their staff. It was proved that it is possible to optimise the taxation of small-scale agricultural producers by creating innovative and integrated structures. It is proposed to create integration structures by involving small-scale agricultural producers and employees of advisory services in accounting and analytical work. Delegating complex and variable tasks to a highly qualified specialist would substantially optimise the tax policy of an agricultural enterprise. Further research should be carried out towards developing a mechanism for optimising the functioning of agricultural producers in the context of the development of digital technologies

Keywords: consulting, digital technologies, agricultural advisory services, agro-industrial complex



INTRODUCTION

The current stage of economic development is characterised by the processes of creating innovative and integrated structures that comprise interrelated objects that perform various functions. An objective prerequisite for the development of these structures in the agro-industrial complex is a balanced system of financial and industrial relations, both between all participants of innovative and integrated structures and with external entities. Among external entities, a special place is occupied by the state tax service bodies.

Creating integrated structures is a global trend. Developed countries are currently undergoing processes of agro-industrial cooperation and integration, which allows these countries to ensure high socio-economic development.

Agro-industrial integration unites agricultural producers, processing, trade, and service entities, as well as financial, insurance, and other organisations (Hrosul *et al.*, 2021). The main purpose of combining these objects is to achieve a positive synergistic effect, to form an optimal system of socio-economic relations. However, when creating innovative and integrated structures in the agro-industrial complex, it is necessary to consider the uneven conditions for the development of interrelated industries and the disparity in the distribution of added product between them. Furthermore, in the context of the development of digital technologies, there is a transformation of industries (Bentley, 2019), including agricultural ones.

The evolution of humanity is always a wave-like development, where “waves” are associated with technological leaps (Toffler, 1980). In agriculture, development is also mainly driven by technological revolutions, the introduction of achievements of which allowed considerably increasing the level of production efficiency. Presently, humanity is on the brink of the Fourth Industrial (digital) revolution, the achievement of which will substantially increase the profitability of agriculture, optimise management, ensure the functioning of the system in real time, achieve full control over processes, etc. The main goal of introducing digital innovations in agriculture is to increase productivity and quality of labour, to increase economic efficiency. Even today, digitalisation is actively penetrating all areas of agriculture (especially those that are easily automated), including accounting and monetary (Schwab, 2017). However, digitalisation requires considerable financial investment and strong human resources, which leads to the active implementation of digital solutions mainly by large holdings.

The existence of any business entity is associated with the payment of taxes during its entire life cycle. Therewith, business entities strive to minimise (optimise) the amount of these deductions. Digitalisation is transforming tax processes. The issues of tax optimisation with digital technologies are so significant that they have aroused the interest of the “Big Four” companies (PwC, KPMG, E&Y, Deloitte). Deloitte’s team of consulting

companies deals with tax technologies. They consider tax transformation as a holistic, closely intertwined system of evolution of business operations and strategies based on the use of digital technologies. The employees of consulting companies include professionals with extensive experience in both tax and digital technologies. This allows developing and implementing an individual tax strategy, considering the specific features of the taxpayer’s activities. Specialists of consulting companies provide advice on tax legislation and obligations on real-time tax reporting; assessment of tax policy and strategy, etc. Global shifts towards digital transformation and cloud applications provide unprecedented opportunities for tax optimisation (Deloitte, N.d.; Ernst & Young, n.d.). However, digitalisation affects several subjects: taxpayers and tax authorities. The transformation of a typical average tax service into a modern high-tech one requires a certain time and considerable effort. The introduction of technologies that are really significant involves the application of strategic changes that lead to time savings, costs, increased efficiency, etc. Therewith, digital technologies is merely one (albeit mandatory) component of tax service transformation (KPMG, 2018). Digital technologies are constantly developing, which leads to constant transformations in all spheres of life, including in the tax process. Furthermore, COVID-19 forced people to work on-line, which led to an acceleration in the development and introduction of digital technologies (Spotlight: robotic process..., 2017).

There are certain features of optimising the taxation of agricultural producers, which is primarily associated with elevated risks of agricultural activities (due to dependence on natural and climatic conditions, with the specifics of the use of biological assets), the variety of biological objects, the complexity of technological processes, the distribution of controlled parameters over a large area. The digital revolution affects the optimisation of the tax process. Small-scale agricultural producers, apart from the above-mentioned problems, also face problems of limited human, financial, and other resources. The problem is compounded by the fact that the current system of taxation of agriculture in Ukraine is mainly focused on large businesses. The issues of taxation of small businesses are not given due attention, and therefore the procedure for their taxation is still undeveloped, which complicates its implementation. Under these conditions, it is possible to ensure efficient production and optimal tax burden for small-scale agricultural producers by creating innovatively integrated structures. It is these circumstances that determine the relevance of research on tax optimisation of Ukrainian small-scale agricultural producers by creating innovative and integrated structures.

The purpose of this study was to develop a mechanism for optimising taxation of Ukrainian small-scale agricultural producers by creating innovative and integrated structures.

LITERATURE REVIEW

Issues of optimising the tax burden are constantly at the centre of scientific research. Thus, A.G. Karantounias (2018) studies optimal fiscal policy with recursive preferences. The study found that optimal policies require more active use of debt obligations as a fiscal absorber. D. Bentley (2019) investigates the process of adapting taxation to the conditions of using digital technologies. Bentley concludes that digital transformation leads to changes in the tax procedure, which was developed for the conditions of previous centuries.

S.M. Chaudhry *et al.* (2015) studies the issues of tax optimisation of banking activities. Chaudhry's study proved that the tax on financial transactions is economically inefficient and potentially costly for the economy and cannot protect taxpayers; the bank fee, which is used to finance deposit guarantees and banking resolution mechanisms, is potentially useful for financial stability, but poses a risk of double taxation. The authors support the abolition of value-added tax (VAT) for financial services. A. Hansford & J. Hasseldine (2012) investigated issues related to taxation of small and medium-sized businesses. These scientists have proved the need to reform the taxation system of small and medium-sized businesses due to its excessive burdensome nature.

S. Eichfelder & F. Hechtner (2016) investigate the costs of tax collection procedures. As a result of their study, it was found that the cost of compliance with tax collection procedures is too high for private entrepreneurs.

N. Shalimova (2019) investigated regional development priorities in taxation of agricultural producers. Her paper proves the need to expand the powers of local self-government bodies, local authorities, and territorial communities to establish local taxes and fees, develop a mechanism for tax incentives that would contribute to the activation of innovation activities and the development of agriculture. The paper also notes the need to correct the procedure for allocating budget funds for national support to agricultural producers.

V.M. Savchenko *et al.* (2018) studies the impact of the quality of information support on tax efficiency. Savchenko's study found that the effectiveness of tax management primarily depends on the quality of its information support.

N.G. Mankiw *et al.* (2009) considered theoretical and practical aspects of tax optimisation. In this paper, the authors define how the main taxes should be formed. N.N. Stern (1986) investigated models of optimal income taxation. This scientist calculated the rate of optimal income taxation. A. Maksymenko & V. Kozak (2021) researched the issues of tax asymmetry of multinational corporations in the context of uneven economic development. As a result of their study, these authors found that in underdeveloped countries, the tax system encourages business activity to a lesser extent.

O. Sarapina & O. Yeremian (2015) studied the specific features and issues of taxation in the agricultural sector. In this paper, the authors, based on the analysis of the advantages and disadvantages of applying a single tax of Group IV, developed vectors for optimising the taxation mechanism of agricultural enterprises.

Nesterenko *et al.* (2021) studied general issues of development and functioning of the Ukrainian tax system. The authors define the features of the evolution of the tax system of Ukraine at the present stage. These researchers focused on the necessity of adapting progressive international practices to Ukrainian realities and the expediency of continuing tax reforms towards their liberalisation.

The scientific developments of S.M. Homovij *et al.* (2018) are aimed at research and improvement of organisational and managerial aspects of taxation of agricultural enterprises. As a result of the conducted research, scientists based on the DEA analysis carried out formed the main articles that allow optimising the indicator of the tax burden of an agricultural enterprise.

Recently, many researchers have been concerned about the creation and functioning of integrated structures. Thus, V. Hrosul *et al.* (2021) considered the processes of integration of enterprises in the field of nutrition. These scientists have established that in the future there may be further integration of food enterprises in the context of the regions of Ukraine. Furthermore, it was concluded that the priority of creating a cluster based on agricultural enterprises (or enterprises where agriculture is the main type of economic activity) is given.

A. Sumets *et al.* (2021) investigated the development of agricultural clusters. They have developed methodological approaches to choosing options for ensuring the competitiveness of agricultural enterprises during their integration. During their study, the authors found that the problem of choosing the best option should be reduced to finding the distribution of investment resources that is the most optimal.

O. Popelo *et al.* (2021) focus on the formation and development of innovatively integrated agro-industrial structures. Researchers have developed a conceptual model for their creation and development. This model is based on structural modernisation of the economic space, solving issues of ensuring sustainable development based on the effective use of available spatial resources.

Z. Rakhmetulina *et al.* (2020) investigated the issues related to optimising the structure of an innovation cluster. Therewith, scientists paid considerable attention to competitive principles. As a result of their study, the authors constructed a simulation model of the optimal cluster (the model is focused on choosing the rational composition of cluster participants, its structure and activity goals).

V. Khmurova *et al.* (2021) researched the development of public-private partnerships. As a result of their

study, researchers have established a general trend towards the decentralisation of power. This trend leads to the transfer of more powers to local self-government bodies.

MATERIALS AND METHODS

When preparing this paper, both general scientific and special research methods were employed, namely: logical generalisation – for theoretical justification of the need to create innovative integrated structures to optimise the functioning of small-commodity agricultural producers; mathematical and system analysis – to justify the feasibility of creating integrated structures to optimise the taxation of small-commodity agricultural producers. The initial basis of this study included the regulatory documents of the Ministry of Labour and

Social Policy (2003), data from the State Statistics Service of Ukraine (2020).

Upon calculating the effectiveness of integration of small-scale agricultural producers and advisory services, the authors of this paper used the standards for calculating the number of accountants and the norms of their working time at Ukrainian enterprises, which are governed by intersectoral standards for the number of accounting employees, approved by Order No. 269 of the Ministry of Labour and Social Policy of Ukraine (2003) of September 26, 2003. According to this document, the time standards planned for an accountant of a small-scale agricultural producer at the stage of accounting and working on methodology and calculations with the budget are presented in Table 1.

Table 1. Planned working hours of an accountant of a small-scale agricultural producer at the stage of drafting accounting records and working on methodology and calculations with the budget

Item No.	Name of the type of accounting work	Units of measurement	Time standards, hours
1	2	3	4
1.	Analytical accounting of settlements with tax payments and fees and verification of these settlements by regulatory authorities (State Tax Service)	Statement	0.2
2.	Keeping a Purchase and Sale Book	Book	0.1
3.	Study of accounting (methodological support provision)	Consultation	0.25
4.	Conducting financial and legal analysis of accounting policies applied at the enterprise	Event	12.0
5.	Formation of methodological documentation on accounting issues based on scientific and methodological sources	Letter (A4 format)	2.00
6.	Visiting institutions and organisations (Tax Service, bank, State Treasury, etc.)	Visit	1.3
Total			15.85

Source: grouped based on Order No. 269 of the Ministry of Labour and Social Policy of Ukraine “Intersectoral standards for the number of accounting employees” dated 26.09.2003 (2003)

According to the current intersectoral standards for the number of accounting employees, the norms of an accountant’s working time at the stage of working on methodology and calculations with the budget do not depend on the number of structural divisions of the enterprise and on the number of employees in it (unlike other norms of this document). Thus, upon delegating these procedures to an agricultural adviser on accounting and taxation issues, most of these items will not formally save time. However, the authors of this paper believe that in reality there will still be time savings.

Items 3 “Study of accounting (methodological support provision)” and 6 “Visit to institutions and organisations (Tax Service, bank, State Treasury, etc.)” under the conditions of delegation of authority will allow the adviser to considerably reduce the time spent on the formation and submission of tax reporting. Therewith, it is possible to extrapolate the amount of time savings from attracting an agricultural adviser on accounting and taxation from approaches to calculating equivalent income

from public use (in most cases, it is estimated within 30% for each subject) (Kisil, 2007). Therefore, under these conditions, the following correlation is correct (1):

$$\sum_{i=m}^n OPDST_i * 0.3 \leq \sum_{i=m}^n OPSGOO_i \quad (1)$$

where $\sum_{i=m}^n OPDST_i$ is the amount of labour costs for an employee of the accounting department of small-scale agricultural producers; $\sum_{i=m}^n OPSGOO_i$ is the amount of payment for the services of an agricultural adviser on accounting and taxation issues; m is the lower limit of summation; n is the number of farms.

Thus, the effectiveness of cooperation in the system of small-scale agricultural producers and the advisory service in this case will be determined according to the following formula (2):

$$E = \sum_{i=m}^n OPSGOO_i - \sum_{i=m}^n OPDST_i * 0.3 \quad (2)$$

where E is the economic effects of cooperation in the system.

RESULTS AND DISCUSSION

In the structure of innovative and integrated systems of the agro-industrial complex, agricultural producers occupy the key position. Research by a group of scientists led by V. Hrosul (2021) proves that “the most promising for

the formation of clusters is the creation of an integrated structure based on enterprises whose main economic activity is agriculture.” In Ukraine, agricultural producers are mainly represented by small business entities (Table 2, Fig. 1).

Table 2. Dynamics of the share of agricultural, forestry and fisheries enterprises depending on the size for 2015-2020 (%)

No. seq.	Size of the business entity	2015	2016	2017	2018	2019	2020
1	2	3	4	5	6	7	8
1	Large	0.0	0.0	0.0	0.0	0.1	0.1
2	Average	3.2	3.4	3.1	3.0	3.0	2.9
3	Small	96.8	96.6	96.9	97.0	96.9	97

Source: grouped based on information from the State Statistics Service of Ukraine (2020)

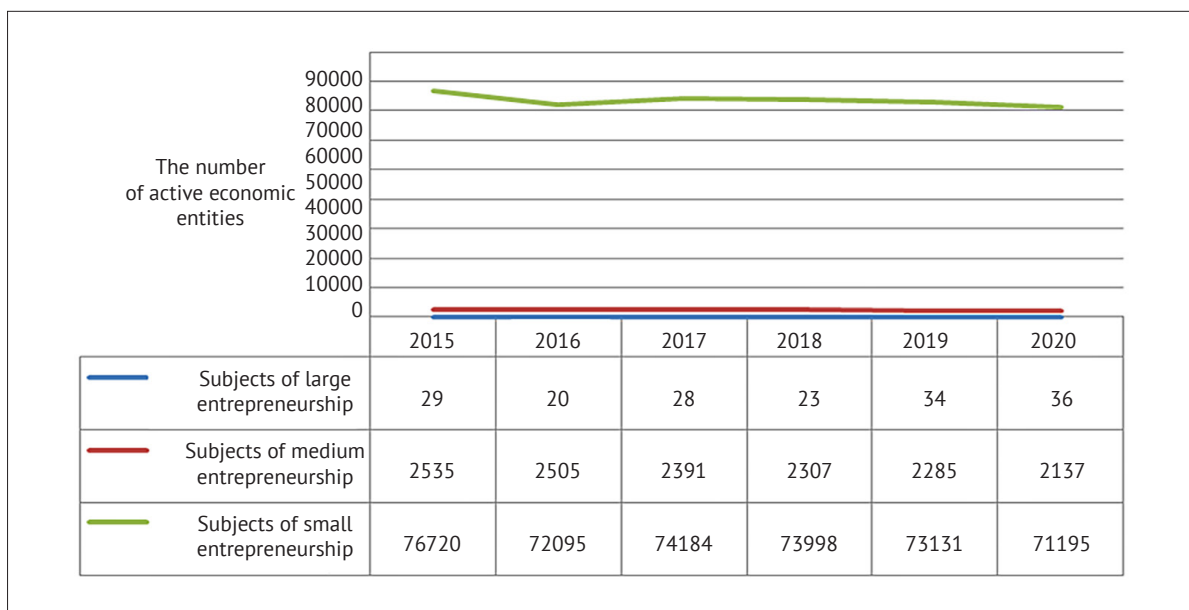


Figure 1. Dynamics of the number of agricultural, forestry and fishing enterprises depending on their size for 2015-2020
Source: built by the authors based on information from the State Statistics Service of Ukraine (2020)

The information presented in Table 2 illustrates the fact that from 2015 to 2020, the share of small enterprises in agriculture, forestry, and fisheries exceeded 95%. Figure 1 clearly shows that the dynamics of the number of agricultural, forestry, and fisheries enterprises depending on the size for 2015-2020 is not observed. Unlike large agricultural formations, the Ukrainian small-scale agricultural producer is focused on the domestic market, which means that it is at the present stage that ensures the country's food security and raises living standards in rural areas. However, it is these producers who have substantial problems with material and technical support, personnel support, elevated production costs, lack of sales markets, etc.

In Ukraine, in the component of the system of support for agricultural producers, a large share belongs

to the tax system (through the mechanism of tax incentives). However, in relation to small-scale agricultural producers, this mechanism is currently quite undeveloped. Thus, O. Sarapina and O. Yeremian (2021) note in their study that “the system of taxation of agricultural enterprises necessitates reformation to equalise the competitive environment, eliminate imbalances in the structure of the agricultural sector of the economy in favour of small and medium-sized socially oriented agricultural businesses, increase the competitiveness of small forms of management...” (Sarapina, & Yeremian, 2021).

As of 01/01/2022, agricultural producers had the right to independently choose whether to apply the simplified taxation system in the form of a single Group IV tax or pay taxes under the general system (Table 3).

Table 3. List of basic taxes to be paid by agricultural producers as of 01/01/2022

No. seq.	Tax name	Rate (%)	Added taxation terms	
1	2	3	4	
1.	Land plots	Land tax		
		The standard monetary valuation of which has been carried out	Up to 0.1% (of the standard monetary valuation of land)	Forest lands
	From 0.3% to 1% (of the standard monetary valuation of land)		Agricultural lands	
	Up to 1% (of the standard monetary valuation of land)		Public land	
	Up to 3% (of the standard monetary valuation of land)		-	
	Up to 12% (of the standard monetary valuation of land)		Land plots permanently used by business entities (except for state and municipal property entities)	
	The standard monetary valuation of which has not been carried out	Up to 0.1% (of the standard monetary valuation of land established in the region)	Forest lands	
		From 0.3% to 5% (of the standard monetary valuation of arable land established in the region)	Agricultural lands	
		Up to 5% (of the standard monetary valuation of land established in the region)	Land located within or outside localities	
	2.	Single tax	10% (of the subsistence level)	Group I
20% (of the minimum wage)			Group II	
3% (of income)			In case of payment of value-added tax (VAT)	Group III
5% (of income)			If VAT is included in the single tax	
0.95% (to the standard monetary valuation of land)			Hayfields, pastures, and arable land	Group IV
0.57% (to the standard monetary valuation of land)			Hayfields, pastures, and arable land located in the Polissia territories and in mountainous areas	
			Perennial plantings	
0.19% (to the standard monetary valuation of land)			Perennial plantings located in Polissia territories and mountainous areas	
2.43% (to the standard monetary valuation of land)			Water fund lands	
6.33% (to the standard monetary valuation of land)			Agricultural land used in closed ground conditions	
3.	Income tax	18%	-	
4.	VAT	20%	-	
		14%	Certain types of agricultural products	
		0%	Export	

Source: summarised by the authors based on (Tax Code of Ukraine, 2010)

An agricultural producer can choose the optimal tax policy only based on complex calculations. This requires the involvement of a highly qualified specialist,

which not all farms can afford. Thus, for a small-scale producer, the procedure and choice of the optimal tax system (as well as the tax procedure itself) are quite

complex issues. Presently, the Ukrainian tax policy is focused on performing control functions. In its reports, the State Tax Service of Ukraine notes the increase in the number of control inspections with the increase in the use of punitive (financial) sanctions as a positive fact. Thus, the report of the State Tax Service of Ukraine for 2020 indicates that the tax audit units of Ukraine conducted 16.6 thousand factual inspections, and UAH 565.0 million in fine (financial) sanctions were applied to violators. Accordingly, the report of the State Tax Service of Ukraine for 2021 indicates that the number of factual inspections increased by 62% and amounted to 26.8 thousand inspections. Accordingly, in 2021, "fine (financial) sanctions in the amount of UAH 878 million were applied to business entities, which is 55% (or UAH 313 million) more than in 2020" (Tax Service of Ukraine, 2022). In other words, the growth rate of the number of inspections is higher than the growth rate of the application of punitive (financial) sanctions. However, the amount of paid fines (financial) sanctions, in percentage terms, is ahead of the increase in the number of factual inspections carried out. Thus, in 2021, according to the materials of factual inspections, 203 million UAH were received, which is 88% or 95 million UAH more than in the same period of 2020 (Tax Service of Ukraine, 2022). Global trends in the formation of tax policy and tax administration indicate that factors that allow transforming the tax process into a public service are becoming increasingly important. With such approach, certain economic incentives start working, the work of tax authorities becomes optimised, and the tax culture changes. However, as James Alm (2012) noted, some unresolved issues stay regarding the measurement, explanation, and control of tax evasion. As for the system of Ukrainian taxation (including agricultural producers), it is advisable to apply foreign practices, namely: simplify the tax system (number of taxes, rates, reporting, and payment procedures); introduce a mechanism to help the taxpayer in filing declarations and paying taxes; create media campaigns that link taxes with public services and motivate ethical behaviour (tax culture) (Alm, 2012). All this can be achieved by creating innovative and integrated structures with the involvement of consulting (advisory) services.

Due to the relatively small amount of tax revenues to the budget, the issues of taxation of small enterprises at the present stage in Ukraine are not given the necessary attention. The economic operations of a small-scale agricultural producer are diverse and cover the entire production cycle, which causes the complexity and multidimensional nature of accounting and analytical work (albeit small in volume). In this regard, the issues of calculating and paying tax payments are handled by an accountant (who, as a rule, is alone and works as the chief) or directly by the director (owner), who does not have the physical (and sometimes qualification and

practical) opportunity to thoroughly study the features of taxation of their farm, monitor changes in legislation, and choose the best tax system at the given stage. The authors of this paper support the opinions expressed by O. Kilnitska, et al regarding unsatisfactory staffing in the agricultural sector. Thus, these scientists note that agricultural enterprises generally have a "shortage of labour resources and a prominent level of personnel danger" (Kilnitska *et al.*, 2020). Furthermore, according to the reports of the State Tax Service of Ukraine, the mechanism of appealed tax notifications-decisions is currently working effectively. Thus, in 2021, the share of appeals against monetary obligations that were cancelled does not exceed 17% (Tax Service of Ukraine, 2022). Therefore, "the main reasons for cancellations are as follows:

- ambiguous interpretation of tax legislation – 35.6%;
- provision of added documents by the payer during the administrative appeal procedure – 31.8%;
- incorrect determination of the amount and application of the amount of punitive (financial) sanctions – 17.7%;
- poor-quality inspection and failure to prove established violations – 11.0%;
- other – 3.9% (Tax Service of Ukraine, 2022).

However, the implementation of the mechanism of appealed tax notices-decisions of the State Tax Service of Ukraine also requires the presence of highly qualified employees of the corresponding speciality.

Starting from 2021, the procedure for taxation of small-scale agricultural producers was complicated by the fact that taxpayers could use a single account to pay monetary obligations or tax debt on taxes and fees and other payments. Therewith, the taxpayer must submit an electronic notice about the use of a single account and receive a receipt for the Register of Payers Using a Single Account (Tax Service of Ukraine, 2022).

For VAT payers, the State Tax Service of Ukraine has implemented opportunities for accepting and processing tax invoices and calculating adjustments to cost and quantitative indicators for tax invoices. These invoices are drafted according to new forms, which make provision for the application of a rate of 14%, which directly affects agricultural producers. In addition, in 2021, the information and technological support (ITS) "Tax block" of the State Tax Service of Ukraine implemented the entry of data on persons related to the agricultural commodity producer to the Register of recipients of budget subsidies based on the application form No. 1-ROBD (Tax Service of Ukraine, 2022). All these innovations were designed to optimise cooperation between taxpayers and the tax service. However, their implementation requires some support (technical, qualification-related). Small-scale agricultural producers generally do not have access to high-quality Internet, to the services of IT specialists, etc. The most problematic situation has developed with small businesses, as evidenced by the data presented in Table 4.

Table 4. Level and dynamics of the share of enterprises that used digital technologies depending on the number of employees (individuals) in 2018-2020 (%)

No. seq.	Size of the business entity depending on the number of employees, individuals	had access to the Internet			have hired specialists in the field of ICT		
		2018	2019	2020	2018	2019	2020
1	2	3	4	5	6	7	8
1	10-49	86.3	84.4	84.5	15.1	14.5	14.2
2	50-249	93.5	93.0	93.8	40.1	39.1	42.0
3	over 250	95.9	94.8	94.5	75.1	73.9	74.1

Source: compiled by the authors based on the data from the State Statistics Service of Ukraine (2020)

Modern society is characterised by digitalisation processes that cover all spheres of human life, including agricultural production. Presently, ecosystems of market participants have begun to be created in Ukraine, and new types of partnerships are emerging (Khmurova et al., 2021). Therewith, there is an integration of digital platforms of many market participants. These processes are available to large agricultural producers (classical holdings, etc.), while small-scale agricultural producers face many issues. Furthermore, the Fourth Industrial Revolution (like any other) is not smooth and gradual, but wave-like (Toffler, 1980). This necessitates swift assimilation of new knowledge and technologies, adaptation to permanently improving technologies. There is a need for a specialist capable of correctly and quickly adapting new digital solutions, solve tasks, and understand modern digital equipment. In general, digitalisation is considerably influenced by the human factor. Thus, the average age of the rural population of Ukraine as of January 01, 2022 was 41.5 years. This, to some extent, causes some resistance and concerns about the transition to digital solutions.

Notably, the regulatory framework leaves such a category of agricultural producers as households out

of the legal field. They are not taxpayers, but they do not have the opportunity to use national support programmes and count on social protection.

Currently, in most countries of the world, small agricultural enterprises widely exercise the support of agricultural advisory services (“extension”). Employees of advisory services provide advice on analysing and resolving issues by providing the necessary information, take actions to encourage innovation, etc. In modern conditions in developed countries, advisory services place a substantial emphasis on ensuring long-term well-being (Bloody, 2017). Substantial differences between advisory services and other consulting services are that: first, they give advice on a fairly wide range of issues, and secondly, for the most part, these consultations are free for the client. The staffing of these services comprises highly qualified employees in various fields. Therefore, the authors of this study consider it appropriate to cooperate with regional advisory services to optimise accounting work (including tax optimisation). Therewith, it is advisable to create an active-adaptive model of the company’s accounting service with two-way information communication channels (Fig. 2).

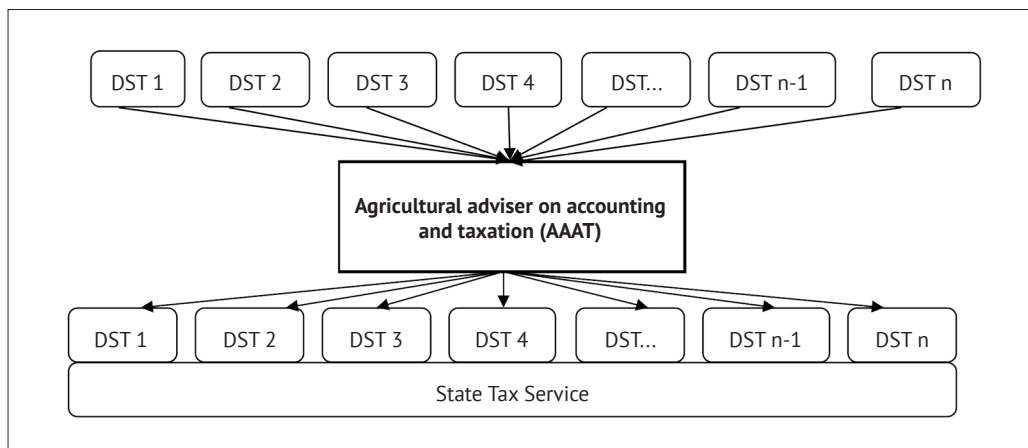


Figure 2. Structure of relationships between small-scale agricultural producers – advisory service – State Tax Service

Note: DST is an accounting and analytical service (accountant) of a small-scale agricultural producer

Source: compiled by the authors

Delegating complex and variable tasks will allow the specialist to substantially optimise the tax policy of an agricultural enterprise. One of the areas of tax optimisation at the level of a business entity is tax planning, which is part of corporate planning. Tax planning involves the use of tax incentives, digital technologies, planning forms of contractual relations, pricing policies, agreements, etc. Furthermore, ways to optimise the tax burden include creating a simulated financial model, developing effective tax control, etc. (Olikhovskiy, 2018). In any case, optimisation of the tax burden involves the development of an active-adaptive model that considers permanent changes in tax legislation and responds accordingly to them.

The implementation of the specified model requires powerful personnel, information and technological support, the implementation of which, for a small-scale agricultural producer, is possible with the involvement of an agricultural consultant. The current stage of development is characterised by the active introduction of digital technologies in all spheres of life, including in tax payment administration (Schwab, 2017). This creates opportunities to optimise collecting and analysing tax information, building a model for assessing tax risks, improving tax planning, more efficient formation and submission of tax reports, etc.

The use of digital technologies in corporate taxation processes ensures the efficiency and transparency of these processes. However, in Ukraine, the state of digitalisation of the tax sector considerably falls behind the developed countries of the world. As for small-scale agricultural producers, the situation is much worse than generally in the country. This once again underlines the expediency of attracting an agricultural adviser on accounting and taxation by small-scale agricultural producers, which would efficiently organise a tax planning system, reduce the cost of paying tax payments, and consider the specifics of the activities of each small-scale agricultural producer.

CONCLUSIONS

Agricultural enterprises occupy a key position in the structure of innovative and integrated systems of the agro-industrial complex. Among these enterprises in Ukraine, the small-scale manufacturer prevails, which in its functioning faces many problems due to the specifics of its activity, size, and location. In modern conditions, such a business entity needs certain support. In the component of the system of this support, the largest share belongs to the tax system. However, currently the mechanism of this system for small-scale agricultural producers needs to be finalised. The declared possibility of choosing the optimal tax system for a particular enterprise requires the involvement of a highly qualified specialist, who cannot always afford the farm. Moreover, the current tax legal framework is ambiguous and unstable, and the processes of implementing digital technologies increase the requirements for the qualification of employees.

Under any circumstances, the primary task in optimising the taxation of small-scale agricultural producers (as well as any other) has been compliance with the norms of tax legislation. Therewith, a highly qualified specialist in accounting and taxation can take advantage of gaps in the current legislation. Furthermore, one of the key factors in preventing errors in calculating tax payments is the use of modern digital technologies. The use of a single software integrated into the software of fiscal authorities allows automatically and remotely checking the correctness and timeliness of calculating and paying tax payments. To optimise the taxation of small agricultural producers, especially in the context of transformations caused by the Fourth Industrial Revolution, it is necessary to use fundamentally new approaches by creating innovative and integrated structures with the involvement of an agricultural adviser on accounting and taxation. Delegating complex and variable tasks to the adviser will substantially optimise the tax policy of an agricultural enterprise, improve work with fiscal authorities, make better use of the capabilities of digital technologies and yield a positive synergistic effect.

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Оптимізація оподаткування дрібнотоварного сільськогосподарського виробника шляхом створення інноваційно-інтегрованих структур

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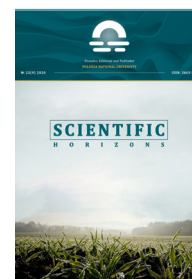
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Анотація. Питання оптимізації оподаткування суб'єктів господарювання завжди знаходились у центрі уваги платників податків. Вирішення цього питання потребує потужного кадрового, технічного та інших видів забезпечення. Існують суттєві особливості функціонування дрібнотоварних сільськогосподарських виробників, які зумовлюють складність оптимізації їх оподаткування. Вирішити це питання на сьогодні можливо шляхом створення інноваційно-інтегрованих структур. Метою проведеного дослідження є обґрунтування доцільності створення інноваційно-інтегрованих структур у агропромисловому комплексі, що повинно привести до оптимізації оподаткування українських дрібнотоварних сільськогосподарських виробників. При підготовці статті було використано як загальнонаукові так і спеціальні методи дослідження, а саме: логічного узагальнення – для теоретичного обґрунтування необхідності створення інноваційно – інтегрованих структур з метою оптимізації функціонування дрібнотоварних сільськогосподарських виробників; математичні та системного аналізу – для обґрунтування доцільності створення інтегрованих структур з метою оптимізації оподаткування дрібнотоварних сільськогосподарських виробників тощо. Дослідження теоретичних засад та практичного досвіду оподаткування українських дрібнотоварних сільськогосподарських виробників дало змогу обґрунтувати доцільність створення інноваційно-інтегрованих структур в аграрному секторі економіки. Визначено, що у структурі сільськогосподарських підприємств найбільша питома вага належить малим підприємствам, які за специфікою своєї діяльності територіально віддалені від центрів цивілізації (ринку праці, податкових служб, інтернет-ресурсів тощо) та не мають можливості мати у своєму штаті висококваліфікованих працівників. Обґрунтовано, що оптимізувати оподаткування дрібнотоварних сільськогосподарських виробників можливо шляхом створення інноваційно-інтегрованих структур. Запропоновано створення інтеграційних структур шляхом залучення до обліково-аналітичної роботи дрібнотоварних сільськогосподарських виробників, працівників Дорадчих служб. Делегування складних і варіативних завдань висококваліфікованому спеціалісту дозволить суттєво оптимізувати податкову політику сільськогосподарського підприємства. Подальші дослідження доцільно проводити у напрямку розробки механізму оптимізації функціонування сільськогосподарських товаровиробників в умовах розвитку digital-технологій

Ключові слова: консультування, digital-технології, сільськогосподарські дорадчі служби, агропромисловий комплекс

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Architectural Design of Universities for Green Campus in Guangdong-Hong Kong-Macao Greater Bay Area and Singapore: A Comparative Aspect

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Abstract. College campuses need the most attention to build. This article is relevant, as the design of green campus buildings is one of the essential forms of the good ecological development concept that can best reflect the sustainable development of university campuses. The total energy consumption of school buildings is second only to that of all kinds of office buildings and accounts for a considerable proportion of the total. The purpose of this study is to investigate the typical campus buildings in Singapore with mature development of green campus buildings to provide a reference for the study of architectural development in the Guangdong-Hong Kong-Macao Greater Bay Area with similar climate adaptability. This paper uses Ladybug Tools to conduct quantitative analysis and compares the Greater Bay Area with Singapore, which has similar conditions, to try to summarize the universal design strategies and models suitable for it. It was found that the university campuses in the Greater Bay Area have a better development in the greening of building courtyards and building roofs, while in the greening of building platforms and building walls, it still needs to carry out more technical practice. It was established that among all kinds of designs on the green campus of the Singapore universities, the energy-saving-oriented design has the highest proportion. It was concluded that only by absorbing more mature design experience and strategies can the development of green campus buildings in the Greater Bay Area go further. The findings of the paper will further provide more powerful data support for the development of the Greater Bay Area and Singapore, and simply put forward feasible and universal design patterns and strategies to a certain extent

Keywords: green building, visualization, Grasshopper, Ladybug, campus building, quantitative relationship



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INTRODUCTION

The development of the Greater Bay Area (GBA) is inseparable from the construction of universities and personnel training. In 2008, the Ministry of Education and the Ministry of Housing and Urban-Rural Development jointly launched the “Opinions on Further Strengthening the Work of Energy-Saving and Water-Saving in Colleges and Universities to Promote the Construction of Energy-Saving Campuses” and the “Guidelines for the Management and Technology of Conservative Campus Construction in Colleges and Universities (Trial)” (Guangdong-Hong Kong-Macao Greater..., 2019). Since then, major colleges and universities across the country have extensively carried out the construction of green universities, campuses, and energy-saving campuses. With the continuous advancement of urbanization, the upsurge in building university towns in China continues to rise (Liu & Wang, 2022).

However, the extensive university development, planning and construction in recent years have not been environmentally friendly and have also brought a series of problems, such as waste of land resources and large energy consumption. According to Q. Lijuan (2018) and Ya. Ibrahim et al. (2021), faced with these problems, the development of university campuses has taken a new direction. The construction of university campuses is increasingly inclined to adapt to local conditions and to the intensive development mode guided by the inner needs of college students. Therefore, utilization of land resources and the construction of energy-saving, and green campuses have become major trends in the current planning and construction of colleges and universities (Abdelkhalik & Azmy, 2022; Kelly & Iqbal, 2021).

According to the opinion of W. Jianhua et al. (2018), the three-dimensional greening of buildings at the university campus of the Greater Bay Area is still restricted by realistic conditions to a considerable extent. For example, due to the high degree of urbanization and the shortage of land, Hong Kong and Macao have always been inclined to vertical greening in the development of green campus buildings and are relatively mature in terms of building roof greening and sky garden greening. However, T. Chen (2021) considers that the green campus buildings in Guangzhou and Shenzhen are inclined to ground and courtyard greening, but there is a lack of architectural three-dimensional greening designs with high greening efficiency. Overall, the greening rate of three-dimensional greening in the campus buildings of the Greater Bay Area is not high, and the green area is small.

Singapore has a small land area, most of which is hills and plains (Jing & Tuo, 2019). The overall climate is hot and humid year-round, with rain and typhoons (Gholami et al., 2020). According to B. Zhu et al. (2020), the green building evaluation system guides the entire process of green campus construction during the development of university campuses in Singapore. Therefore,

in the preliminary design of campus buildings, more consideration is given to the green building design strategy and the introduction of green space, which can help achieve the coordination and unity of the green space from the whole to parts. Unlike Singapore, which has limited development space, the Guangdong-Hong Kong-Macao Greater Bay Area has a vast land area. X. Linji (2018) believed that these large-area resources are still undeveloped, suggesting considerable development space. Therefore, there is still a considerable gap between greening in the campus buildings of the Greater Bay Area and that in Singapore, another research object of this paper. So, it is necessary to carry out visual quantitative relationship analysis on climate characteristics, energy consumption, solar radiation, and other aspects to deeply investigate the universal strategy for greening design of campus buildings.

The purpose of this paper is to study the campus architecture with mature development of green campus buildings in the Guangdong-Hong Kong-Macao Greater Bay Area and Singapore.

MATERIALS AND METHODS

Singapore and the Greater Bay Area share hot and humid climates. Singapore has always attached foremost importance to the exploration and development of green buildings as a major strategy to relieve domestic resource shortages and environmental pressure. Universities in Singapore use Green Mark, a green building evaluation system (Green Mark Certification Scheme, 2021), to guide the construction of the Green campus, which provides inspiration and reference for the update and revision of the “Green Campus Evaluation Standard” (2019) in China in terms of evaluation objects, evaluation grading, category setting and provision integration.

The Green Mark evaluation standard system is based on the core concepts of environmental friendliness and sustainable development in the whole life cycle of buildings and is positioned as “a green certification system for evaluating the environmental impact and performance of tropical and subtropical buildings”. This standard fully reflects the characteristics of a hot and humid climate, thus being widely used in Singapore and has been promoted internationally. Singapore is located in a tropical coastal area with a typical tropical climate of high temperature and humidity. The Green Mark evaluation standard starts from the innovative perspective of climate adaptation, considering indoor and outdoor light and heat, environmental comfort, etc., and comprehensively considers coping strategies from scales of single buildings, blocks and cities. Furthermore, this system covers the comprehensive utilization of water resources, materials, and waste and accounts for a large proportion of the entire evaluation system. In terms of indoor environmental quality, it establishes a more systematic and effective feedback

mechanism through intelligent technology to achieve precise indoor environmental control to carry out the concept of healthy buildings.

To fulfil the main purpose of this study, the following scientific methods were used:

– Visual quantitative analysis: Visual quantitative analysis is based on the plug-in Ladybug Tool of grasshopper, a commonly used analysis software. It provides a multidimensional comparative quantitative analysis based on meteorological data, including a comparative analysis of sunshine time, annual monthly average temperature, wind direction, wind speed, the relationship between solar trajectory and thermal radiation, etc., between the Guangdong-Hong Kong-Macao Greater Bay Area and Singapore. It establishes a quantitative relationship of a single variable, thereby conducting research through reliable quantitative data support.

– Literature research: First, the issues and papers on current green buildings were selected through CITE Space software. Then, by reading many studies, the authors conducted in-depth research and analysis of the relevant theories. The literature relevant to the subject

under study was selected according to the criteria of originality and relevance to the green building design of university campuses.

– Comparative study: The comparative study was based on the high degree of similarity between the green buildings of Singapore University campuses and those in the Guangdong-Hong Kong-Macao Greater Bay Area in terms of geography and climate.

RESULTS AND DISCUSSION

A quantitative analysis and comparison of climatic factors between the Greater Bay Area and Singapore

The most representative universities in Singapore have high greening rates overall, rich, and diverse ways of building greening, and a general multilevel building greening space (Fig. 1). These typical campuses have the common feature that they all make full use of indoor and outdoor green space to form a unique architectural form. In addition, the platform green space is the main green space of these buildings, dominated by the building veranda and the semi-outdoor space on the ground floor.

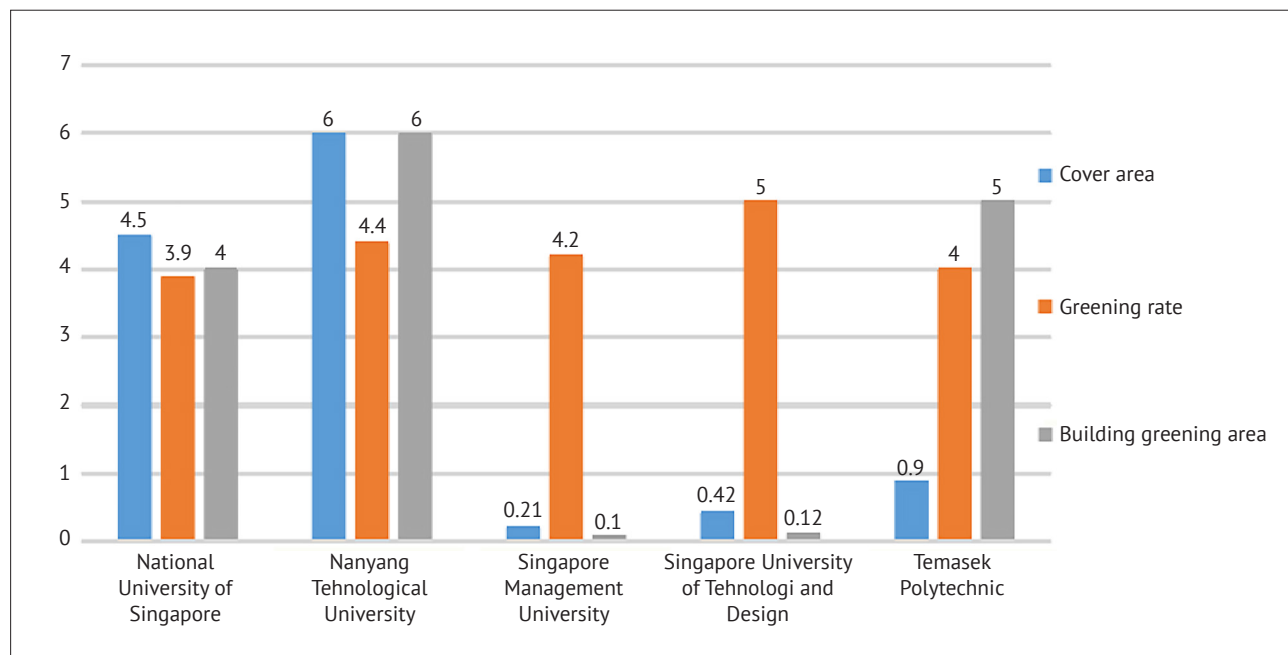


Figure 1. Horizontal comparison table of greening data of typical universities of green buildings in Singapore

Figure 2 is completed by Ladybug Tool sun Path and sunlight Analysis. Based on the meteorological data of the four representative areas of Guangdong-Hong Kong-Macao Greater Bay Area and Singapore, according to the single variable method, the solar trajectory, wind

speed and annual sunshine time from 9:00-15:00 of June 15th every year of the same building area are analysed and then made into quantitative visualization charts. The authors chose this time, because it was necessary to investigate the level of illumination, specifically in daylight.

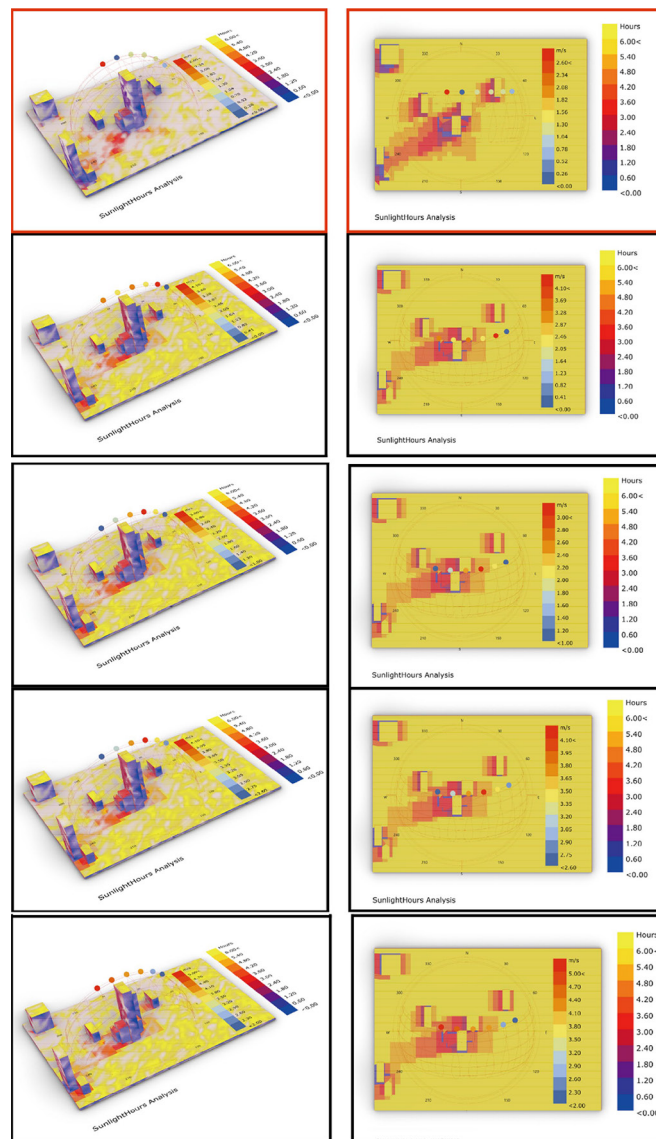


Figure 2. Comparison charts of solar trajectory and wind speed and thermal radiation and sunshine time in Singapore and the Guangdong-Hong Kong-Macao Greater Bay Area

There are slight differences in the annual sunshine duration in Shenzhen, Guangzhou, Macao, Hong Kong, and Singapore, but they are all within the range of 1.2 h–6 h, and the annual average sunshine duration of these five places is higher than the average level of other regions in China. The differences in wind speed variation in 6 hours of the same day in these five places were also slight, and the maximum wind speeds were all in the range of 5.00 m/s–<1.00 m/s. However, with the movement of the solar track, there were significant differences in wind speed in these five places at the same time. The solar radiation range of the same building area in these five places is the same.

In Shenzhen, Guangzhou, Macao, and Hong Kong, the sunshine duration of the same building in the same area is the same. In comparison, the sunshine duration in Singapore is longer, exceeding the average duration of the above four places by approximately 0.6–1 h. In Shenzhen, Guangzhou, Macao and Hong Kong, the wind speed

in one day reaches the maximum value at noon, and in the morning and afternoon it shows a gradually decreasing trend, while the trend of wind speed in Singapore in one day gradually increases from morning to night.

The Greater Bay Area and Singapore enjoy sufficient average sunshine duration and light conditions, with abundant solar energy being available, which is one of the important conditions for the green campus buildings. Although the Greater Bay Area and Singapore have some differences in daily wind speed and direction, they both have sufficient wind energy to be considered as a means of developing energy efficient design. The Greater Bay Area and Singapore share the same annual sunshine duration and radiation range. Therefore, for the green campus buildings in the Greater Bay Area, the energy-saving (solar, wind energy) design models and strategies of Singapore's buildings can be a good reference. This induction produces design patterns and

strategies of general applicability. On this basis, general design patterns and strategies can be inducted and summarized.

Figure 3 is done by Ladybug Windrose. Based on the meteorological data of the four representative regions of Guangdong-Hong Kong-Macao Greater Bay Area and Singapore, the paper employs a single variable, that is, wind speed and direction in the abovementioned five places from January 1st 1:00 to December 31st 24:00 during the full year to conduct analysis and then make a quantitative visualization chart.

The differences in wind direction among the five places are slight: north winds prevail in Singapore and Guangzhou, while northeast winds prevail in Shenzhen and Macao, and east winds prevail in Hong Kong. These five places all belong to a typical subtropical climate.

Among them, the Guangdong-Hong Kong-Macao Greater Bay Area shows more features of the subtropical monsoon maritime climate, with warm winters and hot summers. Its wind speed in summer is smaller than that in winter, with unstable wind directions in spring and autumn. Among the areas, the wind speed in Hong Kong is lower than that in the other three places, which is related to its unique urban density. Wind speed in Singapore varies within a small range. Therefore, its wind energy is more stable than that in the Greater Bay Area and is thus easier to use. Nevertheless, changes in wind direction and speed in the Greater Bay Area are complicated and related to urban buildings, so the use of wind energy is not as convenient as that in Singapore. Therefore, the use of wind energy should be considered according to local conditions.

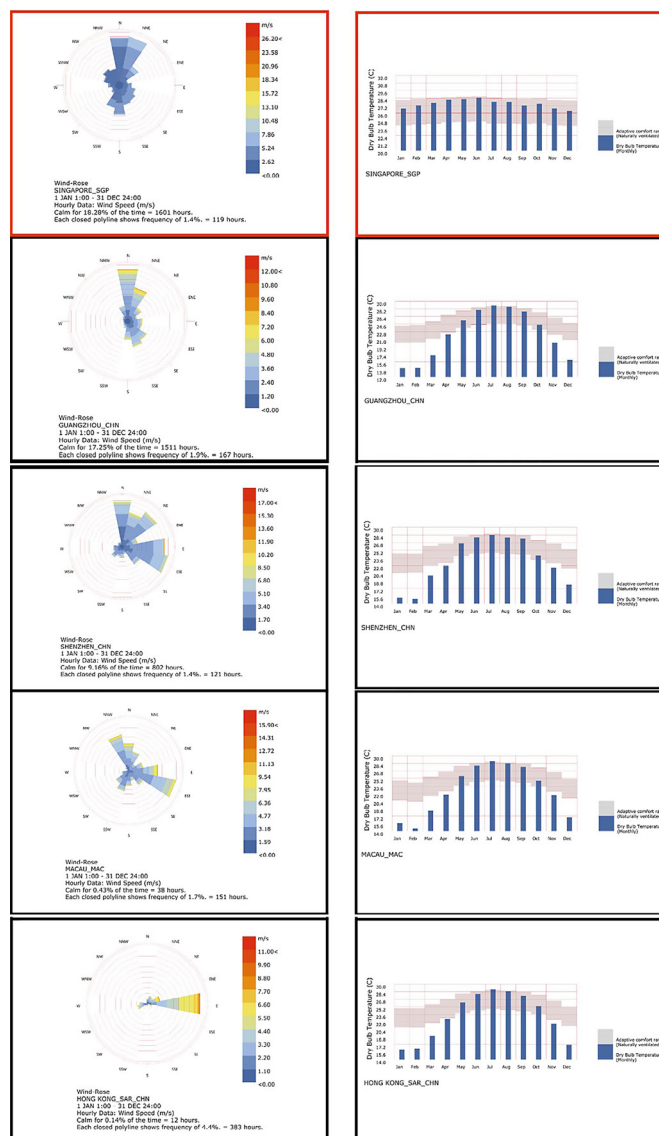


Figure 3. Comparison charts of the wind roses and the annual monthly average dry bulb temperature and annual thermal comfort temperature

Figure 3 is partially completed with the help of the Ladybug Monthly Bar Chart. According to the meteorological data of four representative regions of the Greater Bay Area and Singapore, the monthly average dry bulb temperature and comfort temperature of the five regions based on the single variable, thermal comfort of level 2 (naturally ventilated), are analysed in this paper and further embodied in a quantitative visualization chart. The highest temperature in the five places is the same, approximately 28.4°C, and their highest temperature month is July every year (that is, the summer season). The five places are warm throughout the year, and their lowest temperatures are >13.8°C. It can be clearly seen from the annual monthly average temperature changes that the Greater Bay Area has four distinct seasons throughout the year, with significant seasonal temperature changes and a maximum temperature difference of approximately 12°C between summer and winter, while Singapore experiences little change in temperature throughout the year, with a maximum temperature difference of approximately 4°C between summer and winter.

The temperatures of the five places are the same throughout the year, and they all belong to a typical subtropical climate. The climate of Singapore is hotter than that of the Greater Bay Area, which is affected by factors such as wind direction and wind speed. Under the same thermal comfort level, the suitable temperature ranges of the five places are similar. Therefore, the indoor and outdoor energy saving design modes and strategies of Singapore are a good reference for the Greater Bay Area.

Quantitative analysis of energy consumption data in the Guangdong-Hong Kong-Macao Greater Bay Area

According to the analysis of online data from 2000 to 2017, the total energy consumption of public buildings

and diverse types of energy consumption in four major cities in the Greater Bay Area is shown in terms of energy consumption. As early as 2000, the total energy consumption of Hong Kong was as high as 3.5 Mtce, which is much higher than the other three cities in the Greater Bay Area, while the energy consumption of Macao, which is sparsely populated, is less than 0.5 Mtce year-round, ranking last in the Greater Bay Area.

South China University of Technology International Campus is the third campus of South China University of Technology in Guangzhou. The first two are the old Wushan campus and the new campus of Guangzhou Panyu University Town. The International Campus is also located in Panyu District, Guangzhou, facing the University Campus across the bank. Adhering to the construction concept of integrating Chinese and Western education concepts, tradition and modernity, the International Campus adopts high standard planning and stands at a high starting point. It is committed to creating an innovative green campus. The community building takes the green space in the centre of the campus as the core of the landscape, thus extending to the north and south, and then forms the multifunctional campus space through important spatial nodes.

In terms of campus planning and zoning, it adopts a horizontal and vertical pattern, with 7 sequences of horizontal A-G and vertical 1-7, dividing the campus into different blocks. Moreover, each block uses the same label and then sets a/b/c/d and other sublevel labels for buildings. The C2-C3 group architectures (Table 1) are connected by outdoor corridors on the second floor, and vertical stairwells are used to organize space nodes. The design of the platform corridor on the second floor also adopts various forms with a sense of design.

Table 1. The C2-C3 building cluster analysis table of South China University of Technology international campus

Basic building information	Gross floor area	61300 m	Green rate	26
	Land area	15200 m	Building green rate	3952
	Floor area ratio	4.0	Building stories	6F

Cooling requirements for building spaces are kept low through the design of campus building orientations, shading between blocks and corridors. In addition, the balance between daylight quality and shading is achieved using solar analysis and daylight simulation tools to maximally reduce window heat gain (Fig. 4). In the water management section, Stormwater Management encourages

the treatment of stormwater before it enters public drains, while the campus design incorporates protections against stormwater runoff. Landscape water saving requires "drought-resistant plants to be selected in the design to reduce water demand. Therefore, in landscape design, local landscape species with low water consumption are universally used (Fig. 5).



Figure 4. Planning Zoning Map of International Campus of South China University of Technology (Image source: South China University of Technology)

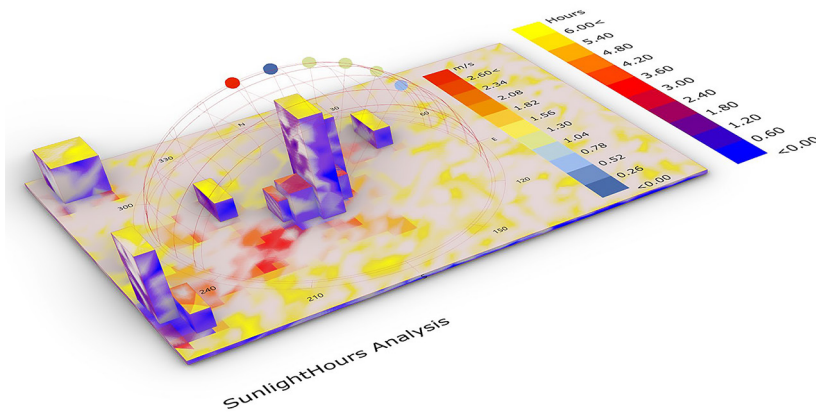


Figure 5. Singapore Sunlight Hours Analysis

Green Building encourages the use of green building practices in the design, construction, and renovation of buildings in the area. This campus consists of several enclosed buildings designed with natural ventilation principles, cooling technology, covered walkways, louvered curtain walls, open spaces, indoor sunlight, and water treatment equipment. Its buildings have obtained platinum-ranking certification from the Singapore Green Label. Green mobility requires compact and walkable zoning patterns in the master plan with walking distances within 500 m of the main building entrance and with shelters and connections. The campus buildings are completely open and highly connected. In addition,

the introduction of diagonal viewing corridors and various vertical and horizontal connections can help create an open campus walkway. The geometry of the building allows for a perfect ventilation path for outdoor gathering spaces such as the inner courtyard. Shaded sidewalks also serve as external circulation routes, helping to create a walkable, low-carbon campus.

In Singapore, the development of green campuses has always employed the green building evaluation system as the guideline during the entire construction process. Therefore, in the preliminary design of campus buildings, more consideration is given to the green building design strategy and the introduction of green

space, which can help achieve the coordination and unity of the green space from the whole to parts (Table 2).

Since the popularization of higher education in Singapore in the 1990s, the construction of university campuses in Singapore has paid increasing attention to campus green space. They all enjoy a higher average greening rate and larger average greening area than universities in the Guangdong-Hong Kong-Macao Greater Bay Area in China. In the design process of green space, universities in Singapore focus on the integration of buildings and the overall environment of the campus and integrate the design of green space into the cultural spirit of the campus to achieve a campus cultural atmosphere that is free and natural. The specific campus building greening space design is not limited to the traditional ground type and integrated greening landscape design but a combination of various greening space design methods, which is conducive to improving the overall

greening environment of the campus and creating better learning and communication space for students. All of these have constructed a pleasant university campus for students to study and travel and truly achieved the reinforcement of a pleasant environment and academic governance, which is worth learning from.

Furthermore, it shows the comprehensive application of the latest building greening technology on the campus of Singapore University, especially the application and practice of building platform greening and building wall greening technology, which is an excellent example for our reference. The Greater Bay Area needs to give full play to the unique advantages of the university's combination of production, education, and research, pay attention to the trial and use of green innovative technologies first on campus, and provide comprehensive feedback on the application and effects, thus laying a solid foundation for the promotion of the whole society.

Table 2. Comparison of green building indicators for green campus buildings in Singapore and the Guangdong-Hong Kong-Macao Greater Bay Area

Project	Singapore	Nine cities of Guangdong	Hong Kong and Macao
Land area(km ²)	719.1	54954	1137
Population (10000 people)	564	6150.6	814.8
GDP (trillion yuan)	239	8.10	2.88
GDP per capita (ten thousand yuan)	42.3	13.2	35.3
Number of universities	56	139	31
University density (university/km ²)	0.078	0.0025	0.027
Number of universities per 10,000 people	0.099	0.023	0.038
Average university greening rate	62%	25%	51%
Average green area of university buildings (university/10 km ²)	0.0858	0.0018	0.728
Representative universities	National University of Singapore, Singapore University of Technology and Design, Nanyang Technological University	Sun Yat-sen University, South China Normal University, Jinan University, Shenzhen University, Southern University of Science and Technology	Chinese University of Hong Kong, Hong Kong University of Science and Technology, Hong Kong Polytechnic University, University of Macao, Macao University of Science and Technology, Macao Polytechnic Institute, City University of Macao

According to H. Jun et al. (2020), the microclimate optimization in the environmental planning section calls for validation of the optimized design through simulation of major climate data and field measurements before and after development to improve microclimate, for example, the use of natural planting and water optimization. M.A. Alim et al. (2022) convinced that small plants on the campus can be planted along corridors, hanging gardens

and green roofs from the external area to the building space to regulate the microclimate. J. Ren et al. (2022) considered that the overall campus design integrates with natural environment through facade plantings, green roof terraces and hanging gardens, as well as extensive planting of small native trees and flower-watching plants.

Site planning and building orientation calls for minimizing heat gain or loss using passive solar strategies

to reduce energy demand (Bakhshoodeh et al., 2022). According to J.A. Puppim de Oliveira et al. (2022), cooling requirements for building spaces are kept low through the design of campus building orientations, shading between blocks and corridors. In addition, the balance between daylight quality and shading is achieved using solar analysis and daylight simulation tools to maximize the reduction window heat gain. This statement is consistent with the results of our study.

In the water management section, Stormwater Management encourages the treatment of stormwater before it enters public drains, while the campus design incorporates protections against stormwater runoff (Bin & Zhongkai, 2017). According to these researchers, landscape water saving requires drought-resistant plants to be selected in the design to reduce water demand. We agree with this opinion, because also discovered that in landscape design, local landscape species with low water consumption are universally used.

According to N. Fezzioui & M. Benaichata (2021), the microclimate optimization in the environmental planning section calls for validation of the optimized design through simulation of major climate data and field measurements before and after development to improve the microclimate, for example, the use of natural planting and water optimization. Small plants on the campus can be planted along corridors, hanging gardens and green roofs from the external area to the building space to regulate the microclimate. In this way, the overall campus design integrates with natural environment through facade plantings, green roof terraces and hanging gardens, as well as extensive planting of small native trees and flower-watching plants.

CONCLUSIONS

The findings of this paper revealed that the collaborative social architecture adopted by the campus makes connectivity, collaboration, and sociability the core elements of the new campus design. It was shown that green universities will play a role in cultivating talent, which is also called “environmental education”, including the role of microclimate regulation played by green campus landscapes and the advanced benchmarking role of eco-city construction. In addition, it was found that the university campuses in the Greater Bay Area have a better development in the greening of building courtyards and building roofs, while in the greening of building platforms and building walls, it still needs to carry out more technical practice.

Based on the analysis of the characteristics of campuses in Singapore, the recommendations for Chinese campuses were provided as follows: active response to the unique geographical climate of the Greater Bay Area; sustainability, which helps improve the entire life cycle of buildings and greening; full integration with the architectural form; integration with traffic space; combination with the shared communication space on campus; the maximized use of roof space; integration of indoor and outdoor campus landscape; and rational use of planting devices.

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Архітектурне проектування університетів для зеленого кампусу в районі Великої затоки Гуандун-Гонконг-Макао та Сінгапурі: порівняльний аспект

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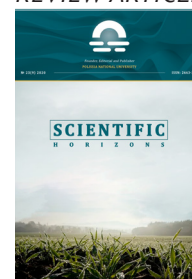
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Анотація. Студентські містечка потребують найбільшої уваги при будівництві. Дана стаття є актуальною, оскільки проектування зелених будівель кампусів є однією з основних форм концепції доброго екологічного розвитку, яка може найкращим чином відображати сталий розвиток університетських кампусів. Загальне енергоспоживання університетських будівель поступається лише енергоспоживанню всіх видів офісних будівель і становить значну частку від загального обсягу. Метою цього дослідження є вивчення типових будівель кампусу в Сінгапурі зі сформованим розвитком зелених будівель кампусу, щоб забезпечити основу для вивчення архітектурного розвитку в районі Великої затоки Гуандун-Гонконг-Макао зі схожою адаптивністю до клімату. У цій роботі використовуються інструменти Ladybug Tools для проведення кількісного аналізу та порівняння району Великої затоки з Сінгапуром, який має схожі умови, щоб спробувати узагальнити універсальні стратегії та моделі дизайну, які підходять для нього. Було виявлено, що університетські кампуси в районі Великої затоки мають кращий розвиток в озелененні внутрішніх дворів будівель та дахів будівель, тоді як в озелененні будівельних платформ та стін будівель все ще потрібно проводити більше технічної практики. Встановлено, що серед усіх видів дизайну зелених кампусів сінгапурських університетів найбільшу питому вагу має енергозберігаючий дизайн, орієнтований на енергозбереження. Зроблено висновок, що тільки шляхом засвоєння більш зрілого досвіду та стратегій проектування можна досягти подальшого розвитку будівель зелених кампусів у районі Великої затоки. Висновки статті надалі забезпечать більш ефективну інформаційну підтримку розвитку району Великої затоки та Сінгапуру, а також запропонують універсальні моделі та стратегії проектування

Ключові слова: зелена будівля, візуалізація, Grasshopper, Ladybug, будівля кампусу, кількісне співвідношення



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The State and Trends of Agricultural Development in the Structure of the National Economy of Ukraine

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Abstract. In the conditions of active socio-economic changes and reintegration of the economic development of Ukraine, determining the place of agriculture in this process is relevant. Based on this, the purpose of this study is to establish the current state and role of agriculture in the national economy of Ukraine. Various scientific and methodological tools were used to fulfil this purpose. The concepts of "agriculture" and "national economy" were distinguished by the method of analysis and their features were established; connections between these concepts were investigated by the method of synthesis; the dependence of the development of the agrarian sector on the national economy was found by the method of comparison; the method of generalization was used for detailed analysis of results and drawing conclusions. In the conditions of the dynamic development of the national economy, the existing state, and promising vectors of the development of the agricultural sector were found. Priority was given to the approach that lies in the implementation of bio- and nanotechnologies and diverse types of genetic developments. The essence of the structural changes implemented in the national economy was found. It was established that the main structural changes are related to the increase of Ukraine's investment potential. The priority vectors for the further development of agriculture were investigated. The authors found that such vectors are the introduction of European principles of regulation and organization of the agrarian sector into the Ukrainian environment. The practical value of this study lies in the fact that it can be used as a source in the creation of appropriate plans and programs aimed at the development of the national economy

Keywords: agricultural sector, forms of management, land market, economic potential



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INTRODUCTION

An analysis of current socio-economic conditions of Ukraine's national economy shows that they are extremely dynamic, which in turn requires constant changes in the approaches used for economic development. Therewith, the state, as an institution of power, governs this issue and implements proper structuring of the national economy (Lindholm-Dahlstrand *et al.*, 2019; Parsons *et al.*, 2019). This is conditioned upon the fact that this entity is empowered to implement operational, and most importantly, structural reforms, which should be aimed at increasing the economic growth, greening of the state and socio-economic improvement (Garibaldi & Pérez-Méndez, 2019). All these aspects are necessary to establish and ensure an appropriate level of economic development that meets the interests and needs of all citizens (Onegina & Vitkovskiy, 2020; Pryshchepa *et al.*, 2020).

Based on this, the targeted area of the system's structural changes of the national economy of the country is to increase the level of economic development in the long term. C. Elleby *et al.* (2020) interpreted this concept as a systemic process consisting of several quantitative and qualitative changes introduced into the structure of the national economy. According to O. Kravchenko *et al.* (2020), the result of such process is expected to be a transition to a better form of organisation and control of economic relations, and the implementation of established economic growth rates, which should be accompanied by an increase in production potential. J.E. Amorós *et al.* (2019) believed that this procedure is closely related to economic growth, since the latter implies the material wealth of citizens. As a result of such changes, both the current and future needs of society in the context of goods and services are expected to be met (Szafranska *et al.*, 2020; Yaky-mchuk *et al.*, 2021). Thus, the changes currently taking place in the system of the national economy pursuing the idea of the correlation in their structure of both macro-level economic elements and stable structural ties, for the proper establishment and implementation of favourable conditions under which all subjects of socio-economic relations can develop effectively. This condition is mandatory since the quality and success of the national economic system depend on the possibility of endowing its citizens with the most profitable and necessary socio-economic means (Farooq *et al.*, 2020; Nicola *et al.*, 2020; Dema *et al.*, 2019).

As for the agricultural sector, it certainly occupies one of the leading places in the structural changes that are actively being introduced in Ukraine's national economy. This factor is absolutely justified since Ukraine is one of the most developed agricultural countries. According to P. Gai & S. Kapadia (2019), this property is determined by such economic characteristics as a share of agricultural sector in the structure of exports, share in employment, investment attractiveness, gross value

added, and the share in taxes paid to the state budget. These parameters in the context of agriculture are certainly positive since this sector of the economy has the largest share in the system of Ukrainian exports, in particular – almost 42% (Attri *et al.*, 2020). Furthermore, about 33% of foreign exchange earnings were obtained through agriculture (Berezyuk *et al.*, 2019). Therewith, approximately 12% of GDP is concentrated in this sector of the economy (Kaletnik *et al.*, 2020). Moreover, the agricultural sector is the only sphere that has never been characterised by a negative foreign economic balance of payments (Lemishko, 2018; Reznik *et al.*, 2018).

Based on this, the prospects for investigating and developing latest trends for improving and increasing efficiency of agricultural sector are, admittedly, extremely high. For that reason, in the current programmes for implementation of national economy of Ukraine, the issue of modernisation of the above-mentioned sector, increasing its adaptability and flexibility to dynamic climatic and socio-economic conditions in society, is actively raised. To a greater extent, this development concerns technologies and innovations, which is a well-founded aspect, since currently one of the main areas of national policy in all sectors is their digitalisation.

Therefore, *the purpose of this study* is to investigate the current state and promising areas of agriculture in the national economy of Ukraine.

MATERIALS AND METHODS

To analyse the essence of the issue under study, it should be established that the said issue is quite broad, which indicates the complexity of its investigation. Moreover, it includes several elements that require individual consideration to acquire a reading object of this study based on the properties and foundations obtained. It is important to pay attention to functional and systematic methodological approaches. Their role is extremely important since they are used during the study of the structural part. Based on the functional approach, a plan for conducting the analysis was defined, and the purpose and tasks of the study were established. For the study to have an integral structure and the elements under consideration to be interrelated, a systematic approach was applied. It ensured unity in the use of all other methodological tools.

Moreover, the study used analysis and synthesis, which to a greater extent played the role of theoretical elements. Thus, based on the analysis method, several concepts were identified that should be considered separately, while their specific features should be established. Such concepts include agriculture, and national economy. The synthesis method allowed combining the separated concepts into a single general question, investigating the connections between them, and analysing the relationship between these categories. A prominent place in this study is occupied by the comparison method

since it allowed qualitatively finding the dependence of the agricultural sector on the national economy. In addition, on its basis, various trends in this process were compared and their priority for the future economic development of Ukraine was proved.

The method of deduction was used so that the study has a perfect logical structure. The study developed in the following area: from general to specific. In the theoretical part of the study, the essence and properties of the main general concepts related to the issue under study were found. In the practical part, this analysis was narrowed down to particular concepts and a certain context in which they need to be considered. Further, a generalisation method was used to examine the results in detail and draw conclusions based on them. Furthermore, on its basis, a priority area was established for the continuation of the investigation of this issue. The study was conducted in three stages:

1) at the first stage, the basic organisational foundations that concern this study were established. A theoretical analysis of the issue under study was also initiated;

2) at the second stage, the specific features and areas in which agriculture is developing in Ukraine during the implementation of the national economy were investigated;

3) at the third stage, the essence of the main results obtained was found and conclusions were drawn on their basis.

RESULTS AND DISCUSSION

Presently, the characteristic factors for the development of the world economy are deep structural and integration reforms, which provoke a change in the areas of the national economy of different states, including Ukraine. Consideration of such global conditions is a mandatory factor in determining and consolidating the national foundations of the functioning of the economy. During the development of a full-fledged algorithm for improving various sectors of the national economy, it is important to consider the features caused by both the social and economic needs of a particular society. Admittedly, for the qualitative and rapid economic growth of the state, it is necessary to find its starting economic sectors characterised by high profitability and academic performance, since this approach allows implementing an effective national policy characterised by high results, particularly in the sphere of the national economy.

When investigating the features of the agricultural sector, it should be agreed that they are formed based on the dynamics of evolutionary changes, including the qualitative parameters of resource elements, i.e., land, specific species of plants or animals. Their development and order of priority were established according to the level of implementation of the country's innovative path, which consists in mastering production technologies, tools, and mechanisms necessary for the organisation of labour in the agriculture. Admittedly, Ukraine

adheres to this approach in its development. Thus, currently, an innovative development model prevails in the field of agriculture, which allows it to effectively affect the overall system of the national economy. For current programmes and plans, it is inherent to attract modernised approaches based on the use of digital tools, which allows increasing the level of attractiveness of this sector of the national economy.

As for statistical data, respectively, in 2021, the share of the agricultural sector in Ukraine's GDP amounted to more than 12%, which, admittedly, is the highest among other developed sectors of the national economy. Therewith, agriculture is characterised by the highest increase in production over the past year, which amounts to 15.4%. Furthermore, this trend is growing, since the results of last year show that production at agricultural enterprises increased by 19.2%. The agriculture sector is extremely important for the national economy of Ukraine in the context of exports as well, since it accounts for the largest share of it, almost 42% per year (Ukrinform, 2022). Therewith, the data on the success of indicators of the agricultural sector showed that in 2021 the largest crop of early grains and legumes was obtained – 46.4 million tonnes. This indicates that Ukraine is developing effectively in the agriculture, in particular, this is reflected in revenues to the state budget.

Ukraine is on the way to obtaining the status of one of the largest guarantors of world food security, which also confirms the effectiveness of the chosen state innovation area for the development of this industry. To confirm this statement, there is an example that during the 2000s Ukraine supplied grain resources to 40 million people around the world. Therewith, Ukraine currently sells its agricultural resources to about 400 million people, excluding the share of Ukrainian citizens (Kanmani et al., 2020).

Furthermore, attention should be paid to such factor as a sharp increase in the investment attractiveness of this industry. Admittedly, this is conditioned by introduction of and market in the context of agrarian reform on July 1, 2021. Thus, by the end of 2021, 27.3 thousand contracts for the purchase and sale of agricultural land were implemented on the territory of Ukraine (Shkola et al., 2021). Attention should be focused on the fact that all these buyers are private individuals, that is, citizens of Ukraine. Presently, the legislation makes provision for the operation of the land market without the involvement of both commercial organisations and foreigners in it. Therewith, the maximum limit for the purchase of agricultural land by one person is 100 hectares. Nevertheless, starting from January 1, 2024, it is expected to expand the boundaries of this limit up to 10 thousand hectares for one person and grant the right to buy land to legal entities with the condition that foreign citizens do not belong to the list of its owners (Kharchenko, 2021).

The land market is one of the characteristic advantages, which testifies to the successful process of European integration of Ukraine. Due to its functioning, it becomes possible to introduce European principles of regulation and organisation of the agrarian sector into the Ukrainian environment. In addition, because of such actions, an even greater increase in Ukraine's investment potential is expected, including in the international arena. These changes can have a positive impact on ordinary citizens, including those who own shares, since the cost of land is projected to increase, which is proportional to the increase in rent.

This fact is confirmed by the successful involvement of the latest mechanisms and approaches to this sector, which usually occurs in the context of general digitalisation. Thus, it is important to continue to analyse social conditions and, accordingly, consider all factors that affect the results of agricultural activities of entities of Ukraine. This condition is necessary because the socio-economic parameters of society are quite dynamic, which obliges business entities to consider all possible external and internal factors.

The destruction of the economic system occurred because of the collapse of the USSR and, accordingly, the collapse of the planned economy. Similar processes took place in all post-Soviet countries, as showed by inflation in Ukraine in 1993-1995, which exceeded 10,000%. Based on this, it can be established that as a result of choosing the wrong approaches and areas for economic development, there was a deep and sharp decline, which was certainly reflected in a number of other social relations. Nevertheless, the number of obstacles and problems created in economic development of Ukraine shows that more time is needed for the development of high-quality market, non-market institutions, and other tools to accelerate this process. In 2000, the first wave of economic revival became visible in Ukraine, characterised by an increase in potential and volume of the business climate. In addition, incomes of citizens increased along with incomes of various organisations, activities of which concerned the

leading sectors of the national economy, including agriculture, which to a certain extent allowed Ukraine to consistently enter the international market. Nevertheless, the global budgetary crisis of 2008-2009 played a significant role in the national economy. Thus, the indicators of GDP growth rates typical for this period were 7.5% (Pronko *et al.*, 2020).

A considerable role in the development of the national economy of Ukraine was played by the armed aggression of the Russian Federation in 2014, which continues to this day. Precisely because of the dramatic change in socio-political conditions, both the humanitarian and economic potential of the country was considerably reduced. Based on this, over the next seven years, this factor continues to be clearly reflected in the state of economic development and programmes for its improvement. The coronavirus crisis caused a sharp drop in entire economic system of the world and certainly affected the state of Ukraine. Economic processes in Ukraine in 2019-2021 were to a certain extent more positive in contrast to several European countries, including Great Britain, Germany, and France. Therewith, one of the main drawbacks in this process was that, due to the establishment of quarantine restrictions by the state authorities, there were no effective mechanisms in Ukraine that would allow continuously providing citizens with wages, controlling the incomes of the population, and implementing measures to support business.

Thus, it is necessary to consider the ability to fulfil relative economic advantages in international markets to implement qualitative and effective economic changes. In this context, attention should be paid to the agricultural sector, which in turn is intricately linked to the food production industry. The share of agricultural products in Ukrainian exports is growing dynamically. In 2000, it was up to 20.1%, and in 2021 – 42% (DLF Attorneys-at-Law Ukraine, 2020). Notably, structurally this indicator is divided between such agricultural products as sunflower oil (5.5 tonnes), corn (21.5 tonnes), barley (3.6 tonnes), wheat (16.4 tonnes), soya beans (2.2 tonnes), sunflower meal (4.5 tonnes) (Fig. 1).

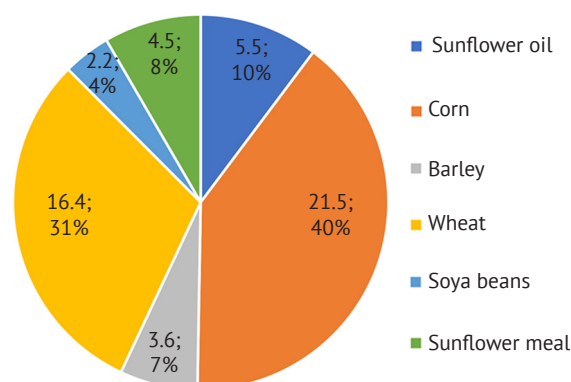


Figure 1. Agricultural exports from Ukraine

Source: DLF Attorneys-at-Law Ukraine (2020)

In current structural changes in the national economy, particularly the development of new mechanisms in the agricultural sector, more and more attention is paid to two areas, namely increasing the investment potential for this industry and increasing the share of extracted resources for their implementation on international market. It is necessary to support and improve agriculture to continue ensuring a rational and effective national policy in the sphere of economy. Such choice not only develops a certain industry but, admittedly, improves the quality and accelerates overall economic growth of Ukraine.

Currently, the free trade zone between Ukraine and the European Union plays an essential part since such condition causes an increase in the orientation of producers towards European markets. This approach allows stabilising both internal and external production, which affects quality and efficiency of the development of Ukraine's export capacity. This is evidenced by statistical data, namely the fact that in 2020 export of agricultural resources to 28 EU countries amounted to \$21.7 billion, which exceeded the data for 2013 by 25% (Hryhoruk *et al.*, 2020). In general, the percentage of exports of goods to European countries increased from 24.5% in 2013 to 53.5% in 2021. However, one of the key roles in these indicators is played by agricultural raw materials, which indicates the prospects for their further development and improvement.

Presently, society is undergoing dynamic information changes. They are caused by digitalisation, which is global since it concerns each of the developed countries. Thus, to implement the structure of the national economy, it is necessary to involve several information and digital means. As for the current state of digital development of agriculture in Ukraine, it is at the initial stage and is characterised by a slow pace and low prospects. This is conditioned upon the discrepancy between the approaches and mechanisms used to implement this process. Computers and software are used to perform tasks such as economic management, collection of analytical information, and provision of financial and statistical reporting, which certainly does not correspond to the practical foundations of the activity of this sector. Moreover, for current information support, presence of the necessary set of structural technical functions needed for its prompt updating is not inherent. Nevertheless, one of the most acute problems is the low level of provision of agricultural sector with modern computing equipment of various classes. This factor plays vital role since the functioning and qualitative improvement of agricultural enterprises take place on its basis, including their management. Moreover, possession of reliable and updated information allows business entities to quickly establish contact and track changes that occur during production. In this context, the digitalisation of the agricultural sector is a mechanism through which it is possible not only to monitor

the management process but also to manage risks and other features that arise during the interaction of producers and consumers.

In this way, it is possible to simplify several processes that are quite important and complex for the sale of agricultural resources and to influence their economic growth. For that reason, digitalisation takes a prominent place in programmes and plans aimed at national economy, since modern technologies on its basis are used to obtain effective and operational results due to the introduction of specific changes. As a result, a dynamic increase in the competitiveness of a particular industry is expected not only at the national but also at the international level. Nevertheless, without the introduction and development of digital tools and innovative programmes, it is impossible to integrate the agricultural sector into the high-tech industry.

According to O. Grishnova *et al.* (2019), one of the most successful sectors of Ukrainian national economy is agriculture. A.J. Abdulloev (2020) emphasised that it is a source capable of providing food resources, namely raw materials, to society and other sectors of the economy. Moreover, agriculture can ensure the development of such category as food security systems (Ostrovskaya *et al.*, 2020). Based on this, agriculture is being improved during the development of the national economy since it is a priority area for Ukraine. The active development of this branch of the economy in recent years allows clearly determining its state and trends. As a result, there is a full-fledged understanding of the specific processes and mechanisms operating in its structure. Thus, the analysis of such structural elements enables qualitative influence and development in the necessary areas (Latinin & Kharchenko, 2021; Cioffi *et al.*, 2022).

O. Khodakivska & O. Mohylnyi (2018) believed that the agricultural sector certainly occupies a key place in the national economy. In this context, it directly concerns the land issue, namely the category of private ownership of land, the purchase and sale of agricultural land (Onegina *et al.*, 2020). Admittedly, according to T. Shtets *et al.* (2020), this is conditioned upon the fact that this area is one of the most relevant and promising for the development of the economy at the expense of agriculture. The above refers to the land market built in 2021, which has been mentioned in the study by H. Zelinska *et al.* (2020). Currently, most experts state that this tool can quite quickly and, most importantly, qualitatively change some processes in economic relations concerning the agricultural sector, namely agriculture (Yang *et al.*, 2021; Shpak *et al.*, 2020; Bardash & Osadcha, 2020; Saher *et al.*, 2020).

Furthermore, special attention is focused on these sectors of the national economy because a considerable part of the country's labour resources is concentrated in them (Gadzalo *et al.*, 2021). Thus, the major structural changes are related to increasing the investment potential of Ukraine. This is conditioned upon the fact that this approach enables a considerable development of

production volumes, which affects the export indicators of agricultural resources. Moreover, it is expected that the wages and incomes of citizens working in this sector of the national economy will increase.

CONCLUSIONS

This study determined the priority of the agricultural sector for the entire economy of the state and its development in the international arena. The main stages that contributed to both the economic development and the decline of Ukraine were considered. It was found that the current state of digital development of agriculture in Ukraine is at the initial stage and is characterized by a slow pace. Main structural changes that were introduced in the system of the national economy of Ukraine were found, and their effectiveness was analysed. The study established that the increase in investment potential enables a considerable development of production

volumes, which affects the export performance of agricultural resources.

The study examined the priority areas of development of the agricultural sector. It was found that currently Ukraine is on the path towards European integration, which positively changes the approaches and tools chosen by the state authorities for the national economic development. It was found that agricultural activity is more oriented towards the international market, which is also an advantage for Ukraine, as this factor affects its competitiveness among other states. It was also found that the development of agriculture in the context of the national economy takes place in three vectors: increasing the investment potential, digitalization, and entering the international market. Future studies should expand research of the impact of digitalization on the development of the national economic system of Ukraine.

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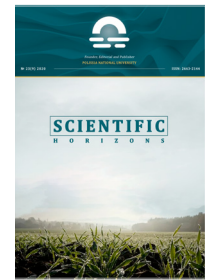
Стан і тенденції розвитку сільського господарства в структурі національної економіки України

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Анотація. В умовах активних соціально-економічних змін та реінтеграції економічного розвитку України актуальним є визначення місця сільського господарства в цьому процесі. Виходячи з цього, метою даного дослідження є встановлення сучасного стану та ролі сільського господарства в національній економіці України. Для досягнення поставленої мети було використано різноманітний науково-методичний інструментарій. Методом аналізу розмежовано поняття «сільське господарство» і «національна економіка» та встановлено їх ознаки; методом синтезу досліджено зв'язки між цими поняттями; методом порівняння виявлено залежність розвитку аграрного сектору від національної економіки; метод узагальнення використано для детального аналізу результатів і формулювання висновків. В умовах динамічного розвитку національної економіки виявлено існуючий стан та перспективні вектори розвитку аграрного сектору. Пріоритет надано підходу, який полягає у впровадженні біо- і нанотехнологій та різноманітних видів генетичних розробок. Розкрито сутність структурних зрушень, що здійснюються в національній економіці. Встановлено, що основні структурні зрушення пов'язані з підвищенням інвестиційного потенціалу України. Досліджено пріоритетні вектори подальшого розвитку сільського господарства. Встановлено, що такими векторами є впровадження в українське середовище європейських принципів регулювання та організації аграрного сектору. Практична цінність даного дослідження полягає в тому, що воно може бути використане як джерело при створенні відповідних планів і програм, спрямованих на розвиток національної економіки

Ключові слова: аграрний сектор, форми господарювання, ринок землі, економічний потенціал



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Smart Fertilizers as a Solution for the Biodiversity and Food Security During the War in Ukraine

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Abstract. The ongoing war between Russia and Ukraine has resulted in widespread damages and loss of lives in highly populated cities, advanced to rural settings as well as sparked massive displacement amongst the population. The two nations are the key exporters of agronomic goods, and they play a huge role in supplying international markets with food products and fertilizers and the ongoing war has led to shortage of supply of these products. The purpose of this study is to present the current aspects related to the use of smart fertilizers as an opportunity to ensure food security and biodiversity. To fulfil this purpose, scientific publications were analysed, and the following groups of methods were employed: dialectical method of scientific cognition, general scientific and special methods. To summarise the scientific and methodological nature, an abstract-logical method of approach to examining the possibilities of using smart fertilizers in agriculture and drawing conclusions was used. Furthermore, the method of logical observation and analysis was used, and based on input data and correlations, conclusions were made that correspond to the object of the study. The generalization method was used to summarise the results of the study. As a result of the study, it was found that the use of smart fertilizers leads to less absorption of resources by agricultural crops, lesser losses in the form of leaching, run-off and denitrification, and a favourable impact on the surrounding natural environment. Moreover, their use is a necessary approach to increase the production of foods, which is necessary to make provision for the population and support economic development. The findings of the current study show that smart fertilizers can serve as a solution for the biodiversity and food security during the Russian invasion in Ukraine

Keywords: russian invasion, innovation, sustainable agriculture, nanotechnology, international markets



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INTRODUCTION

The Russian invasion in Ukraine has subjected the international markets to more vulnerabilities due to shocks and be more volatile. On average, both nations account for 19%, 14%, and 4% respectively, of worldwide production of wheat, barley, and maize for 2016-2020. In terms of oilseed production, their output globally was significant for sunflower oil, in which half of the global production originated from two nations (Astrov, 2022; Blinnikov, 2021). In 2021, both Russia and Ukraine were among the world's top three producers of corn, wheat, sunflower oil, seeds, and rapeseed, while Russia ranked the world's top three for nitrogen fertilizer supplier, potassium fertilizer export, and phosphorus fertilizer supplier, respectively (Boincean & Dent, 2019; Mbah & Wasum, 2022). The ongoing invasion in Ukraine has therefore subjected global markets to shock since food markets are striving because of increasing prices and other constraints faced globally due to the COVID-19 pandemic. Several nations that highly depend on Russia and Ukraine for importation of food products and fertilizers including less developed countries are currently facing serious deficits since they had the challenges of soaring prices globally of foodstuffs and fertilizers as well as dealing with the COVID-19 pandemic (Butzen, 2013; Calabi-Floody *et al.*, 2012).

Further, the invasion in Ukraine has led to persistence in insecurity and eventually the disruption of local and state supply chain which has resulted to individuals falling into more hunger and increased cases of malnutrition (Nagarjuna, 2022; Nevzorova, 2020). Particularly, the war has disrupted winter harvest and spring planting and has also led to agricultural labour accessibility due to massive displacement that has taken place. This invasion has also led to limited access to agricultural inputs including fuel, seedlings, fertilizers as well as insecticides and eventually disrupted logistics and every aspect of food supply chain. The military activities in Ukraine have also damaged food crops and destructed agri-food systems and infrastructure (Calabi-Floody *et al.*, 2018; Dobermann *et al.*, 2020).

According to M. Ranjith and S. Surapaneni (2021), world population growth will increase, as will the pressure on global food systems and agriculture. Therefore, it will be extremely necessary to use modern technologies in agroecosystems to ensure adequate nutrition and minimise the adverse environmental impact caused by chemical fertilizers and inadequate processing of agricultural waste. A. Dobermann *et al.* (2020) noted that the next 10-20 years will be crucial for the transition to a global food system wherein mineral nutrients in agriculture must be used in a more holistic way, and achieving this requires highly efficient use of all available organic and inorganic nutrient sources substances adapted to the specific features of food systems and agroecosystems in different regions of the world.

Continuous application of fertilizers is essential to support and increase food production. However, there

are problems associated with the use of mineral fertilizers due to the low uptake of nutrients by crops in productive systems (Hunt *et al.*, 2021). To provide solutions for current and future issues in agriculture and the possibilities of solving them, the optimal combination of biotechnologies and nanotechnologies has great potential. According to foreign studies by M.Y. Naz and S.A. Sulaimann (2016) – the development and use of intelligent fertilizers with controlled release of nutrients together with biopreparations based on bacteria or enzymes is essential for the revolution in agricultural systems.

M. Calabi-Floody *et al.* (2018) conducted research to provide a critical understanding of current food security challenges and the role of smart fertilizer development in future food production. The authors also focused on advances in the development of biofertilizers and the use of crop residues as coating and carrier materials. Furthermore, R.K. Sastry *et al.* (2021) have argued in their paper "Smart Fertilizers as a Strategy for Sustainable Agriculture" that new types of smart fertilizers with controlled nutrient release are needed to improve nutrient use efficiency. The development of such fertilizers can be based on the use of microorganisms (biofertilizers) and/or nanomaterials (nanofertilizers). In this context, nanotechnology is a promising and rapidly developing field of interdisciplinary research that can revolutionise food systems. Nanotechnology involves the development, synthesis, and use of materials at the nanoscale level from 1 to 100 nm. In this aspect, the properties of materials are fundamentally different from the properties of individual atoms, molecules, or mass of matter (Mammadov, 2022). The ability to manipulate matter at the nanoscale can lead to a better understanding of biological, physical, and chemical processes and to the creation of improved materials, structures, devices, and systems that can be used in agroecosystems (Jeločnik *et al.*, 2020; Qian & Hinestroza, 2004).

The purpose of this study is to present the modern aspects related to the use of smart fertilizers as an opportunity to ensure food security. Since there is a great interest in the development of new innovative fertilizers to increase the efficiency of growing agricultural crops, this is of particular relevance to the research.

MATERIALS AND METHODS

The current study used a systematic review method to analyse existing literature on the topic under study. The theoretical framework of this study included the main provisions and results of the studies carried out by many researchers, which relate to the use of smart fertilizers in the technologies of growing agricultural crops to overcome the issue of ensuring food security.

Scientific literature was analysed through a series of searches refined by journal type, year of publication, subject area, and specific keywords. The procedure that was followed involves first identifying the articles, then

screening them and including only those publications that are relevant to the current topic under study. Information gathered was analysed by use of the Farm Economics and Solvency Projector model while assuming that the fertilizers utilised in farming were procured in 2022.

Since the purpose of this study was to identify modern aspects of the use of smart fertilizers as an opportunity to ensure food security and biodiversity, it was important to analyse the world practices of using smart fertilizers and their impact on the environment. Furthermore, an essential aspect was also to find the future perspective of the use of smart fertilizers and the possibility of their introduction in Ukraine, especially against the background of the risk of military aggression and the growing food crisis.

In the article, the following methods were used: dialectical method of scientific cognition, general scientific and special methods. To summarise the scientific and methodological nature, an abstract-logical method of approach to studying the possibilities of using smart fertilizers in agriculture and drawing conclusions was used. In addition, the method of logical observation and analysis was used in the study, based on input data and correlations, conclusions were made that correspond to the object under study. To conclude the results of the study, the generalisation method was used.

The presented study was carried out in three main stages.

1. Theoretical analysis was used to identify the available methodological approaches dedicated to the issue of ensuring food security, especially as a result of military aggression; the problem, purpose, and methods of study were identified, and a plan of scientific research was drawn up.

2. An analysis of the results of the use of smart fertilizers was carried out; scientific research, analysis, and formation of the results obtained during the study.

3. Based on the obtained results, the final conclusions of this study were formulated; the main aspects of the possibilities of using smart fertilizers to ensure food security and biodiversity were analysed; the obtained results were summarised and systematised.

The provisions and proposals formulated and substantiated in this paper constitute a strong basis for solving the research-to-practice foundations concerning the organisational and economic justification of developing opportunities for solving the global food crisis through the rational use of smart fertilizers.

RESULTS

The Russian invasion of Ukraine will affect the global food security and biodiversity because the world community is so interconnected that a crisis at any point is felt everywhere. The war in Ukraine has an impact on losses that lead to critical disruptions in the supply

chain, food production, access to fertilizers, energy carriers, which were already barely organised due to the global pandemic. Furthermore, the cost of food products and basic niche agricultural products is rising rapidly. As a result, more people are at risk of becoming vulnerable to famine. The very issue of preventing a food crisis has become serious, especially against the background of Russia's war against Ukraine.

The significant role played by Russia and Ukraine in the agricultural arena globally is clear as seen in the global trade viewpoint. The two nations are the biggest suppliers of agricultural goods globally. For instance, Russia is the net exporter of wheat globally since in 2021, it shipped 32.9 million tonnes of wheat which translates to 18% of worldwide shipment. In addition, Ukraine ranked sixth amongst the top wheat exporters in 2021, supplying 20 million tonnes of wheat which stands for 10% worldwide market share (Jorquera *et al.*, 2021). Russia and Ukraine are also both prominent in the international trade arena since they are the largest exporters of maize, barley, and rapeseed as well as sunflower oil in which they hold a market share of approximately 80% from the year 2018 to 2021 (Kirilenko & Dronin, 2022). Apart from exporting food products, these two countries also important in the export of fertilizers with Russia being the lead exporter of fertilizer. In 2021, the Russia was ranked as the leading supplier of nitrogen (N) fertilizers, came in second position of supplying potassium (K) fertilizers and in third position in exporting phosphorous (P) fertilizers (Korovkin & Makarin, 2021). Both Russia and Ukraine are the biggest exporters to several nations that entirely depend imported agricultural products and fertilizers. Many of these nations fall under the group of the less-developed nations while others are characterised by low-income economies. For instance, a country like Eritrea entirely sourced its wheat products in 2021 from Russia 53% and Ukraine 47%. Additionally, several nations located in North, West, and Central Africa entirely depend on supplies from Russia and Ukraine (Kumar *et al.*, 2007; Lang & McKee, 2022).

The actual level of application of smart fertilizers in different countries of the world is quite high. First of all, the highest indicator is observed in the Netherlands, where on average 258 kg of fertilizers are used for agricultural production per 1 ha of available land, in Great Britain – 247 kg, Israel – 240 kg, Germany – 202 kg, Poland – 176 kg, France – 169 kg, the Czech Republic – 153 kg, the USA – 137 kg, Italy – 129 kg, Hungary – 118 kg, Turkey – 107 kg (Gutiérrez-Moya *et al.*, 2021). During 2021-2022, the total amount of smart fertilizers applied in agricultural enterprises of Ukraine with a land use area of more than 1 ha increased from 98 kg to 123 kg (Hosseini, 2022). However, the current level of use of smart fertilizers in Ukrainian agriculture, despite the positive trends of recent years, is still quite low.

According to preliminary data, the average yield of wheat in the territories controlled by Ukraine in 2022 is 4.14 t/ha (Lang & McKee, 2022). Odesa region becomes the main “wheat region of Ukraine” in the war-time agricultural season. Here, in the part controlled by

Ukraine, 18.1 million tons of wheat grain were collected. The application of smart fertilizers positively affected the growth and development of wheat and at the same time increased the yield in the final result (Fig. 1).

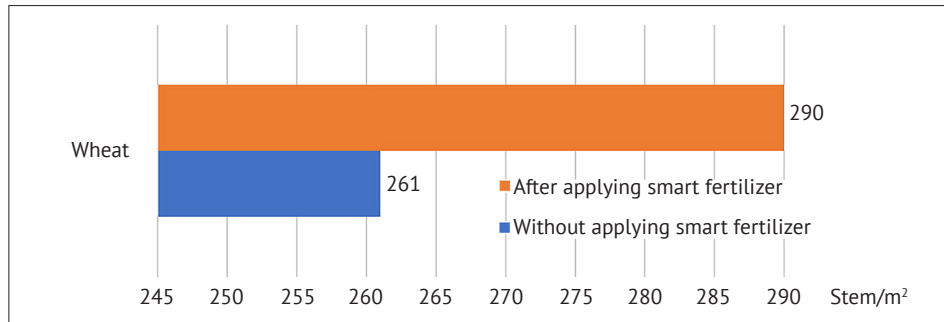


Figure 1. The number of productive stalks of wheat, depending on the application of reasonable fertilizers

Source: compiled by the author

Canada is Ukraine's closest competitor on the world wheat market (Fig. 2). Analysts of Agriculture and Agri-Food Canada (2022) in the May report increased the forecast of wheat production in Canada in 2022-2023 by 0.4 million tons to the previous indicator (31.6 million

tons). It will also significantly exceed the grain harvest collected in the previous season (21.7 million tons). In turn, USDA experts left unchanged the wheat production forecast for Ukraine for 2022-2023, which amounted to 19.5 million tons (World Agricultural Supply..., 2022).

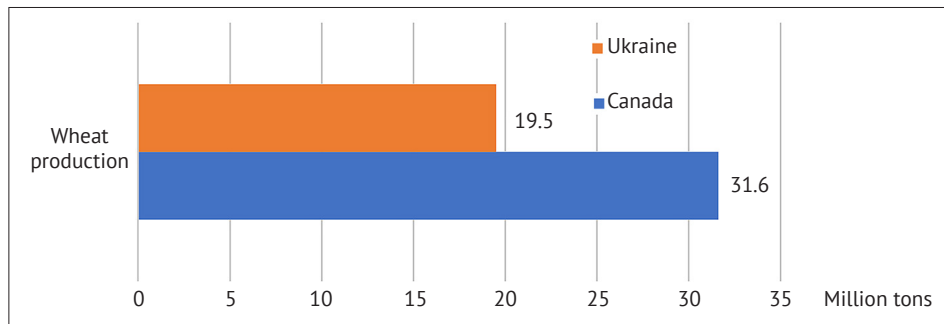


Figure 2. Wheat production forecast for Ukraine and Canada for 2022-2023

Source: compiled by the author

Experts (Astrov *et al.*, 2022) warn that Russia's military actions on the territory of Ukraine will negatively affect the functioning of food systems and even lead to serious threats to global food security. Considering the exceedingly difficult conditions in which Ukrainian farmers have to work, it is necessary to take a very rational approach to all production processes, as well as to the selection of fertilizers. Mineral fertilizers help farmers get high yields and feed the population, however, they still harm nature. In turn, smart fertilizers are in special “capsules”, they enter the soil more slowly, which allows plants to absorb them more than once. The capsules can be set to release doses of fertilizer at specific intervals, depending on the nuances of the soil, temperature, acidity, and humidity. This allows saving on costs and improve the condition of local ecosystems. When using smart, high-quality fertilizers, farmers can reduce the rate of sowing, shorten the time of sowing, and reduce the use of added nutrition.

The outcome of the invasion in Ukraine implies that nations that entirely depend on Russia and Ukraine for essential foodstuffs and fertilizers ought to produce other approaches including the use of smart fertilizers as a solution for the biodiversity and food security during this war period in Ukraine. The invasion has resulted in limited supply of food products and fertilizers to the international food system resulting to food insecurity. As a result of the looming food shortage across the globe, it is imperative that nations that initially depended on Russia and Ukraine for foodstuffs and fertilizers adopt innovative technology with the aim of producing enough food and agricultural inputs to curb food insecurity. This can be achieved through combining biotechnology and nanotechnology to transform the agricultural system and offer a solution to the present and imminent challenges associated with food insecurity. Innovative technology that can be adopted include the adoption of smart fertilizers while controlling nutrients released as well as the use of

bioformulations composed of bacteria and enzymes. Fertilizers can only be classified as smart if, on application to the soil surface, it can allow control over the amount, time, and period of nutrient release. Therefore, smart fertilizers can be defined as a single or composition of (sub) nanomaterials, multi-components as well as bioformulations which contain various nutrients that can physically, chemically or biologically adapt the timing of releasing nutrients to the plants as per their demand and enhance the agricultural output as well as be able to reduce the environmental effect at sustainable expenses in comparison to traditional fertilizers (Gutiérrez-Moya *et al.*, 2021; Hartmann *et al.*, 2010).

To ensure global food security, sustainable methods of agriculture are needed, which today faces several urgent and complex challenges that require innovative solutions. The three most significant are population growth, escalating consumer demand, and the introduction of innovative technology. Farming systems in the world involve the intensive use of substantial amounts of fertilizers and plant protection products to achieve higher productivity per unit of arable land to support and increase food production. However, there are problems associated with the use of mineral fertilizers, such as soil, water, air pollution, low efficiency of their use, development of resistance to diseases, pests and weeds, soil degradation, etc., which leads to increased doses of fertilizers. Unfortunately, more fertilizers do not guarantee increased crop yields, and nutrient utilisation efficiency is still extremely low due to many loss pathways, such as leaching, denitrification, microbial immobilisation, fixation.

Scientists have proposed several strategies to increase the efficiency of fertilizer use, such as precision fertilizer application, split or localised application, fertigation, and the use of nanofertilizers. Nanofertilizers

are nanoparticle-based fertilizers where nutrients are provided to maximise plant growth, have higher utilisation efficiency by recycling plant-unavailable nutrients in the rhizosphere, and can be delivered to the rhizosphere in real-time or through foliar spray (Hosseini, 2022). The small size, high surface area and reactivity of nanofertilizers increase the solubility, diffusion, and availability of plant nutrients and increase the productivity of crops. Biopreparations are microbial preparations containing specific beneficial microorganisms that can fix, solubilise, or mobilise plant nutrients to promote plant growth and yield. Smart fertilizers are a better choice for farmers to increase crop yields with low inputs in an environmentally friendly way without degrading the natural environment.

The review of existing literature showed that nano fertilizer which is a form of smart fertilizers has the capability of increasing the use of nutrients in an efficient manner and subsequently minimise negative environmental impact as opposed to the use of traditional fertilizers (Manjunatha *et al.*, 2016; Ramona *et al.*, 2020). A study by L. Mastronardi *et al.* (2015) showed three different forms of nano fertilizers: nanoscale fertilizers, nanoscale additives and nanoscale coated fertilizers (Table 1). Nano fertilizers and nano composites that are slowly released are proper substitutes to solvent fertilizers. The release of nutrients takes place slowly when crops are growing which reduces losses. To ensure that nutrients are released slowly to the environment, there is need to use zeolites or natural clay, which plays the role of reserving nutrients (Shahini *et al.*, 2022). That nutrients which the plants for growth can be compressed in the nano materials including nano tubes as well as nanoporous constituents, covered with a slight shielding polymer coat or nano scale elements (Lun *et al.*, 2021).

Table 1. Changes in price of organic fertilizers

Price of organic fertilizers	Year 2020	Year 2021	Year 2022
Nitrogen Fertilizer	-3.22	7.29	9.94
Potassium Fertilizer	-0.79	5.87	13.61
Phosphate Fertilizer	-6.05	4.78	7.67

Source: compiled by the author

According to the application method, it is likely to utilise artificial as well as natural nano particles acquired through different means such as plants, soil surface as well as microbes. Nano clays, which by nature are found on the soil surface are incredibly significant in today's agricultural activities since they hold physicochemical properties elements. Nano clays play a key role in terms of stabilising enzymes and in that way enhance their catalytic action for various biotechnology related functions (Hosseini, 2022). According to the works of some scientists (Jorquera *et al.*, 2011), the impact of synthetic allophane which is composed of artificial iron-covered

allophanes as well as naturally occurring solid montmorillonite functions as support of phytases. This study further showed that immobilisation pattern within diverse pH values highly depend on enzymes and support features. Additionally, montmorillonite is seen as suitable immobility support for *Escherichia coli* phytase, while it inhibits *Aspergillus Niger* phytase action. M. Calabi-Floody *et al.* (2012) did another study aimed at evaluating and implementing the utilisation of natural clay and nano clay acquired from montmorillonite as well as allophonic clay as supporting elements for Acid Phosphatase in nano clay-cow manure-AP components.

The study established the existence of an obvious stabilisation of Acid Phosphate by the components through the process of encapsulation. It was further established an upsurge of both precise action at 48% and V_{max} at 38% of the enzymes. Acid Phosphate was also found to immobilise on allophonic nano clay which enhances the process of releasing inorganic P from cow manure in comparison with free Acid Phosphate (Kirilenko and Dronin, 2022).

Advances in the application of biotechnology and nanotechnology have the potential to improve the management and efficiency of nutrient use in agroecosystems, including in Ukraine. Slow/controlled release smart fertilizers increase crop yields, improve soil productivity, and provide less nutrient loss compared to conventional fertilizers. Thus, as a result of this study, it was established that the use of smart fertilizers optimises the absorption and use of resources by agricultural crops, ensures lower losses in the form of leaching, run-off, denitrification, and a favourable impact on the natural environment. Furthermore, the use of smart fertilizers is a necessary approach to increase food production, which is incumbent to support the world's population in overcoming the food crisis and supporting economic development.

DISCUSSION

The modern agricultural system faces several challenges, the most important of which is the ability to supply food for a growing world population and mitigate climate change. To ensure food security for a growing world population, sustainable agricultural practices are required. The production of foods is usually associated with a high supply of nutrients in the form of mineral fertilizers, which are not always fully used by the plant itself. Since the beginning of agriculture, this practice has led to soil degradation and the release of environmental pollutants. In this context, increasing the effectiveness of fertilizers while reducing their cost and impact on the environment is one of the most critical tasks. Scientists and researchers have made many efforts to develop innovative fertilizers, defined as "smart fertilizers".

In the coming decades, pressure on global food systems will increase, and agriculture will face the challenge of ensuring food security for a growing world population without affecting environmental security. It will be necessary to use modern technologies in agroecosystems to ensure sufficient food and reduce the adverse environmental impact caused by chemical fertilizers and inadequate disposal or reuse of agricultural waste.

As for today, the issue of the ability of current crop improvement methods to ensure food security in the future still is uncertain. The demand for agricultural products will be further impacted by such factors as the reduction of the workforce in rural areas, climate change, moisture deficit, etc., which can have a massive impact on the quantity and quality of food products (FAO..., 2020). New types of smart fertilizers with con-

trolled nutrient release are required to improve nutrient use efficiency. The development of modern fertilizers can be based on the use of microorganisms (biofertilizers) and/or nanomaterials (nanofertilizers).

In this context, nanotechnology constitutes a promising and rapidly developing area, as nanotechnology has many potential benefits, ranging from improving the quality and safety of food products to reducing the costs of agricultural production (Veronica *et al.*, 2015).

The combination of biotechnology and nanotechnology has the potential to revolutionise agricultural systems and provide solutions to current and future challenges. These include the development and use of smart fertilizers with a controlled release of nutrients together with biologics based on bacteria or enzymes. Smart fertilizers can also be a solution to increase food production and environmental quality.

Polymers are also smart fertilizer formulations that can serve as a solution for biodiversity and food security. Polymers are to a considerable extent utilised in agriculture particularly for the development of fertilizers. Smart polymeric components are applicable to smart delivery mechanisms of various agrochemicals (Puoci *et al.*, 2008; Jeločnik *et al.*, 2020). Different type of artificial components including polymers based on petroleum are useful in the encapsulation of solvent fertilizers. The key components that are presently utilised in coating include Polysulfide, polyacrylonitrile, polyvinyl chloride, polyurethane, as well as polystyrene (Sindhvani *et al.*, 2022). A study was carried out by A. Jarosiewicz and M. Tomaszewska (2003) with the aim of comparing the usage of the artificial polymers; polysulfide and polyacrylonitrile together with the recyclable cellulose acetate to develop a fertilizer that can be gradually released. The study established that physical features of the coating are capable of influencing the macronutrients including N, P, and K are released which are mainly found in the centre of the fertilizers with a coating. In addition, artificial nondegradable components have a gradual releasing rate as opposed materials with cellulose acetate. Another study by Y. Tao *et al.* (2011) was done to determine the utility of triple polymer fertilizers in encapsulating and enhancing the functional features of urea. The data obtained showed that the use of polyethylene, acrylic acrylamide, and butyl methacrylate as the third layers improved the controlled production of urea. Additionally, incorporating triple polymer fertilizers into the soil surface improves its ability to hold water which enhances the intake of nutrients and crop produce. However, replacing sulphur with dicyclopentadiene to enhance coating features, humidity as well as abrasion resistance and mechanical ability enhances the gradual release of fertilizers. The mechanical ability of the covering is associated with the dicyclopentadiene component, which is released efficiently by ameliorated nutrients (Blinnikov, 2021; Boincean and Dent, 2019).

Biodegradable polymers have also been widely utilised as alternatives of other polymers in farming. It was found that biodegradable polymers can be utilised for the gradual release of N and K fertilizer. A study by J. Zhang *et al.* (2016) showed polymer-covered N fertilizer can be developed by use of biobased polyurethane acquired through liquifying grasshopper sawdust as coating element. This study proved that the fertilizer showed high efficiency in releasing N to maize plants as opposed to traditional form of urea. Biodegradable polymers can therefore be utilised in bioformulations where they act as bacterial carriers. The carriers safeguard bacterial inoculants from distinct types of stress and extend their survival (Hartmann *et al.*, 2010; Kumar *et al.*, 2007). For instance, calcium alginate gel can protect bacterial cells as well contribute to increased duration of survival. In addition, Sodium alginates are to a great extent utilised for bioformulations, particularly microbial fertilizers together with insecticides. Despite being highly affordable and environmentally friendly, it is significant to blend biodegradable polymers with artificial materials to enhance their performance (Shahini *et al.*, 2022; Richardson *et al.*, 2016).

The research of M. Mora *et al.* (2021) serves as a confirmation of the results of this study, according to which, since the beginning of the development of agriculture, the practice of mindless application of fertilizers has led to soil degradation and the release of environmental pollutants, and therefore it is essential to focus on innovations in the production of organic and inorganic fertilizers and the development of smart fertilizers, including biological preparations with mineral particles, nanomaterials, and microorganisms that promote plant growth.

Furthermore, this study correlates with scientific claims (Veronica *et al.*, 2015; Butzen, 2013) that nanobiotechnologies can improve the understanding of the nature and genetics of various agricultural crops and thus potentially increase the yield or quality of products. As nutrient leaching causes environmental and water pollution, and excess nutrients promote the wide spread of pests and weeds, the rationalisation and optimisation of resources is a pressing issue and increasing the efficiency of plant nutrition without compromising productivity and economic sustainability will be imperative. Moreover, there is an opportunity to develop and improve systems to monitor environmental conditions and improve the ability of plants to absorb nutrients or respond to pesticides. Advances in the application of biotechnology and nanotechnology have the potential to improve nutrient management and utilisation and overall efficiency in agroecosystems.

The results of this study especially demonstrate the conclusions of many researchers, who claim that smart fertilizers due to their availability of nutrients are considered a new and effective way to achieve sustainable existence, the main thing is to develop the correct concept of using smart fertilizers.

Although knowledge of the balance between benefits and potential risk is in the initial stages of development, nanotechnology has the potential to improve agricultural productivity and contribute to food security. And among the latest lines of technological innovation, nanotechnology occupies a prominent place in the transformation of agriculture and food production. The development of nanodevices and nanomaterials can open new areas of application in plant biotechnology and agriculture. Therefore, smart fertilizers due to the availability of nutrients are considered a new and effective way to achieve sustainable management in agriculture.

CONCLUSIONS

The Russian invasion on Ukraine has led to various negative impacts on food security in the domestic and international arena. In the domestic setting, the invasion has constrained the nation's agricultural production which in turn will lead to food shortage in the whole country. In the global arena, the invasion has resulted to limited supply of food products as well as fertilizers to other countries which entirely depend on Russia and Ukraine for agricultural inputs and food stuffs.

Global challenges are changing rapidly, and with a growing population, limited resources and climate change, the complex challenge of providing the world with food is emerging. Increasing global food production sustainably can only be achieved thanks to balanced and rational use of fertilizers and organic agriculture because global food security is clearly impossible without fertilizers. The scientific research performed was undertaken to provide a critical review of information related to current food security issues and the role of smart fertilizer development in future food production.

Smart fertilizers such as slow and controlled release fertilizers, nanofertilizers, and biofertilizers are emerging technologies to improve nutrient use efficiency by increasing crop yields sustainably. The use of slow and controlled release fertilizers increases the efficiency of nutrient use and minimises the risks of water and environmental pollution.

Thanks to nanotechnology, many unresolved issues in the field of agriculture can be solved. The authors of this study expect that more focused research on energy, environment, crop improvement, disease control, and resource efficiency is needed to increase productivity and profit without harming the natural ecosystem. Future research should continue to evaluate the composition, production, agronomic, and environmental performance of different smart fertilizers.

It is recommended that the trade in food stuffs and fertilizer products is kept open through prevention of the invasion from having an impact on production and trade to make it possible to supply these products locally and internationally. It is also recommended that nations relying on Russia and Ukraine for food stuffs and fertilizers produce modern and diverse sources for these products.

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Розумні добрива як рішення для біорізноманіття та продовольчої безпеки під час війни в Україні

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Анотація. Триваюча війна між Росією та Україною призвела до широкомасштабних руйнувань та загибелі людей у густонаселених містах, у сільській місцевості, а також до величезного переміщення населення. Ці дві країни є ключовими експортерами сільськогосподарської продукції і відіграють величезну роль у постачанні міжнародних ринків продуктами харчування та добривами, а війна, що триває, призвела до дефіциту поставок цих товарів. Мета цього дослідження – представити сучасні аспекти, пов'язані з використанням розумних добрив як можливості забезпечення продовольчої безпеки та біорізноманіття. Для досягнення цієї мети було проаналізовано наукові публікації, а також використано такі групи методів: діалектичний метод наукового пізнання, загальнонаукові та спеціальні методи. Для узагальнення науково-методичного характеру було використано абстрактно-логічний метод підходи до вивчення можливостей використання розумних добрив у сільському господарстві та формулювання висновків. Крім того, використовувався метод логічного спостереження та аналізу, на основі вихідних даних та кореляцій були зроблені висновки, що відповідають об'єкту дослідження. Для узагальнення результатів дослідження використали метод узагальнення. В результаті дослідження було встановлено, що використання інтелектуальних добрив призводить до меншого поглинання ресурсів сільськогосподарськими культурами, менших втрат у вигляді вилуговання, стоку та денітрифікації, а також сприятливого впливу на навколишнє природне середовище. Крім того, їх використання є необхідним підходом до збільшення виробництва продуктів харчування, що необхідно для забезпечення населення та підтримки економічного розвитку. Результати цього дослідження показують, що розумні добрива можуть бути вирішенням проблеми біорізноманіття та продовольчої безпеки під час російського вторгнення в Україну

Ключові слова: російське вторгнення, інновації, стійке сільське господарство, нанотехнології, міжнародні ринки

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