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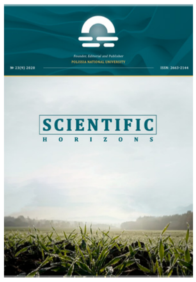

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Pharmacological effects of the use of enzyme and probiotic feed additive for dry cows

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Abstract. The scientific research conducted worldwide on the use of probiotics in animal husbandry demonstrates only a positive effect on the functioning of the macroorganism, but questions persist about the various pharmacological effects of multicomponent microbial preparations in combination with enzymes important in the digestion of certain types of productive animals, which makes it important for veterinary medicine and farmers to obtain environmentally friendly and high-quality products. The purpose of this study was to investigate the effect of a multicomponent

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enzyme and probiotic supplement on the duration of calving stages, prevention of postpartum complications in cows and some haematological parameters. Clinical, haematological, and statistical research methods were employed in this study. The research was conducted in a private dairy farm with 195 cows. The housing conditions and diet of the animals in the control group (n=6) and the experimental group (n = 17) were analogous, and the enzyme and probiotic supplement "ProActivo" (containing enzymes, Bacillus subtilis strain AX20, B. licheniformis strain EA22, and Enterococcus faecium) was added to the diet of the experimental cows at the rate of 10-14 g/animal, once a day, for 21-30 days before calving. A positive effect on the body of pregnant cows was found – elimination of diarrhoea symptoms in 4 days in 100% of diseased animals, and no changes in the control group. The study proved that the prenatal course of probiotic therapy of cows provided 95% prevention of afterbirth retention, a significant ($P \leqslant 0.001$) reduction in the duration of the stage of afterbirth separation in cows of the experimental group (253.9 ± 3.6 min) compared to the control group (326.8 ± 8.9 min). A significant ($P \leqslant 0.01$) increase in the count of lymphocytes by 3.25 ± 0.2 G/l, monocytes by 0.43 ± 0.03 G/l, neutrophils ($P \leqslant 0.001$) by 1.6 ± 0.28 G/l in cows treated with an enzyme-protein supplement was recorded, which is associated with the optimisation of the functioning of the primary immune system and the pharmacosynergistic effect of the multicomponent supplement. The findings obtained are valuable for veterinarians and dairy herd keepers, as the addition of an enzyme and probiotic supplement to the diet of dry cows will facilitate the calving stages and prevent afterbirth retention

Keywords: probiotic; cows; afterbirth retention; calving; immunity

INTRODUCTION

Cattle breeding is a strategic industry in agrarian countries around the world, as it provides jobs, organic fertilisers, food, and raw materials for the dairy and meat industries. Therefore, the application of technological innovations to increase the profitability of this livestock sector is relevant for the sustainable development and economic stability of the country. Considering that animals on farms are under constant antigenic load, the use of environmental agents (containing beneficial microorganisms) that increase the state of resistance – non-specific immunity factors – is important for the stable development of livestock farming and increasing its profitability. K. Nalla *et al*. (2022) notes that probiotics optimise and maintain microbial homeostasis in the digestive tube, which prevents the development of pathogens in it. That is, probiotic feed additives or preparations are important in the formation of proper animal health, which ensures the epizootic well-being of the herd.

S. Fernández-Ciganda *et al*. (2021) have conducted a significant amount of research on the feasibility of using probiotics in animal husbandry. N. Zhang *et al*. (2020) note the proven benefits of feeding animals with *Bacillus* feed additives. Specifically, the inclusion of *Bacillus amyloliquefaciens* fszns-06 and *Bacillus pumilus* fsznc-09 in the diet of goats promoted the development of rumen papillae and villi of the small intestine, which increases the absorption of nutrients. According to Zh. Rybachuk *et al*. (2022), a significant ($P \leqslant 0.05$) increase in the content of immunoglobulins and improvement of the functioning of the digestive system was found in calves.

Y. Guo *et al*. (2022) reported that the use of probiotics of different composition in dairy calves led to an increase in average daily weight gain, and with an increase in the dose (2 g, 4 g, 6 g per day for a calf) of a multistrain biological product, the weight gain increased proportionally. Therewith, milk lactobacilli further improved the microbial composition of faeces, and the inclusion of feed additives with a multistrain probiotic (containing the bacteria *Bifidobacterium Animalis, Lactobacillus Casei, Streptococcus faecalis, and Bacillus cerevisiae*) in the calves' diet prevented diarrhoea.

According to O. Maamouri and B. Salem (2021), feeding live Saharomices cerevisiae yeast to calves additionally stabilised the rumen pH at around 6, which helped prevent the development of acidosis. It is becoming clear that microbial symbioses have an antiseptic effect. Thus, R. Steinberg *et al*. (2022) consider the use of lactic acid bacteria isolated from the breast for the treatment of mastitis to be promising. This is conditioned by the fact that beneficial bacteria show antagonism to *Staphylococcus aureus* and *Escherichia coli* due to the synthesis of H_2O_2. Apart from direct antagonism to pathogens, there is an indirect and direct effect on the immune system of animals. C. Mazziotta *et al*. (2023) note that probiotic bacteria can interact with and stimulate gut immune cells and the commensal microflora, modulating specific immune responses and immune homeostasis. This is due to a complex system of interaction between the immune system and the microbiota, which maintain a balance between immune tolerance and immunogenicity.

Scientific research on the pharmacodynamics and polyvectoriality of the pharmacological effects of feeding probiotics to animals of different ages has given rise to an increase in the use of this group of biological products in the livestock industry. They are used to optimise fermentation processes in the rumen, and thus increase milk production, reduce the negative impact of stress and increase efficiency in calf rearing. That is why the purpose of this study was to investigate the feasibility of including a multistrain enzyme and probiotic supplement in the diet of dry cows to ensure optimised delivery and prevention of postpartum complications.

LITERATURE REVIEW

The body of animals is constantly under antigenic pressure, which induces the formation of artificial active immunity or the development of an infectious process with the manifestation of corresponding symptoms of homeostasis disorders. That is why livestock farms with external herd recruitment record an increase in morbidity and mortality due to infectious diseases. Natural immunity factors play a significant role in the protection of the animal body, and the gastrointestinal microbiome is of particular importance.

An optimised digestive tract microbiota ensures immune homeostasis and an enhanced immunological response. The presence of beneficial microbiota in the rumen improves fibre breakdown, volatile fatty acid production and nitrogen, which improves milk composition (Nalla *et al.*, 2022). Scientists are investigating the optimised species-specific microbiome of the gastrointestinal tract or the impact of individual bacterial strains on the animal body. P. Shridhar *et al.* (2022), using genetic sequencing, studied the strains of *Enterococcus faecium* isolated from pigs (n = 9) and cows (n = 13) and found that 7 out of 9 strains and 13 strains, respectively, were *Enterococcus lactis*. Furthermore, all 22 isolated strains lacked virulence genes and most contained adhesion genes, which facilitates intestinal colonisation. The data obtained provide a substantiation for the use of *Enterococcus faecium* in the composition of probiotics for animals.

Bacillus subtilis is a representative of symbiotic bacteria that are included in probiotics for animals due to their specific physiological features. *Bacillus subtilis* are thermostable and can withstand the pH of the stomach and bile acids, which allows the species to be included in food supplements. The concept that these bacteria are soil microorganisms is erroneous and they are considered as intestinal commensals. Therefore, it is advisable to use *Bacillus* species as probiotics. X. Guo *et al.* (2022) reported that *Bacillus subtilis* strain MA139 showed 100% resistance to pH 2, bile acid salts of 0.3%, and the best antimicrobial activity. The researchers note the expediency of using this strain with an activity of 2.2×105 CFU/g in the diet of fattening pigs, since in faecal samples of piglets receiving bacteria in the diet and increased the count of *Lactobacilli* (P = 0.02) and decreased the count of *E. Coli* (P = 0.05). The performance of the experimental animals was analogous to the group of animals treated with the antibiotic.

The findings of scientific research by N. Nakamura *et al.* (2023) report that they recorded an improvement in the growth performance of fattening pigs when Bacillus subtilis *C-3102 was* added to their diet and this improvement was conditioned by the symbiosis of the gut microbiota. Bacillus *strains* are also used in bioremediation and can reduce nitrogen waste, which helps to improve environmental conditions and water quality. Feeding piglets with the feed additive "PROPIGplv" containing *Lactobacillus plantarum* CCM 7102 increased milk production of sows by 26.5-25.8%, and multiplicity increased by 12.3% in the groups receiving the preparation at 4 g and 6 g/animal/day compared to the control group (without feed additive) (Blyda, 2019).

In addition to bacillary microorganisms, the addition of enzymatic extracts of *Aspergillus oryzae* at 5 g/cow of Holstein breed was also used, which resulted in an increase in milk yield, milk protein, and lactose concentration, but did not change fat content. Such extracts do not affect the structure of rumen VFAs, pH, ammonia, and protein production by microbial cells, but reduce the % of lipopolysaccharides and lactate concentrations. Therewith, they increase the pH of faeces and the content of propionate, isovalerate, and valerate. Enzymatic extract of *Aspergillus oryzae* affects the overall composition of the rumen bacterial population, increases the relative amount of *Ruminococcaceae* UCG-010 and unclassified *Clostridiales* vadinBB60 group and decreasing the *Christensenellaceae* R-7 group and the unclassified *Muribaculaceae, Prevotellaceae* UCG-001, and *Romboutsia* (Zhang *et al.*, 2022).

J. Shen *et al.* (2020) conducted a metagenomic analysis of microbial and carbohydrate-active enzymes in the rumen of dairy goats and found that the rumen microbial composition changes with the intake of different amounts of dietary starches that are broken down in the rumen. The study showed that young goats fed a high content of dietary starch had a reduced amount of carbohydrate-active enzymes, which encode enzymes designed to break down cellulose and starch in dairy goats. This is proof of the significance of microbial symbiosis in the optimised physiological functioning of the ruminant digestive system. Many scientists report the positive effects of probiotics on the body and the advisability of using them in the treatment of diseases of not only the gastrointestinal tract, but also the respiratory and nervous systems, and to reduce the negative effects of stress.

Probiotics can influence the intestinal epithelium to synthesise antimicrobial peptides and cytokines IL-12, IFN-γ, IL-10, and TNF-α. Controlled studies have proved that the presence of probiotics in the diet of pigs and poultry activates the phosphorylation of the cytoskeletons of their protein structures and stimulates the secretion of mucus and chlorides by these cells, which generally improves the barrier functions of the intestinal mucosa. R. Fuller (1989) noted that not all probiotics interact with the macroorganism in the same specific way. Genetic studies revealed the presence of resistomes (antibiotic resistance genes (ARGs) in intestinal commensals) that can be transmitted horizontally to pathogens and contribute to the development of drug resistance. According to the researchers, this phenomenon can occur between distantly related microbial species. Such studies explain the negative effects of simultaneous inclusion of antibiotics and probiotics in treatment regimens (Radovanovic *et al.*, 2023).

Thus, probiotic feed additives have been scientifically proven to be highly effective in various livestock sectors, but their composition varies, which necessitates a detailed investigation of each bacterial association of commensals to accumulate an evidence base for their use. Thus, for the organic development of dairy cattle breeding in Ukraine, it is promising to investigate the effect of probiotic preparations to reduce the risks of postpartum complications.

MATERIALS AND METHODS

The study was conducted over a 3-month period in one of the private dairy farms in the Zhytomyr region, where 195 cows are kept. To conduct the study, experimental (n = 17) and control (n = 6) groups of dry cows were formed 17-21 days before calving. The animals of the experimental group received a multistrain enzyme and probiotic feed additive, while the control group received a diet without an enzyme and probiotic additive (EPA). No other medications were used before delivery. The enzyme and probiotic supplement ProActivo (manufactured by Kronos Agro) contains beneficial bacteria (*Bacillus subtilis* strain AX20, *B. licheniformis* strain EA22, *Enterococcus faecium*) and enzymes (amylase, xylanase, protease, cellulose, beta-gluconase).

The dairy farm has a technological process that involves dividing dairy cows into different groups based on their physiological state. Accordingly, the cows are divided into early dry cows (kept in pens in the yard for the first 30 days of calving) and late dry cows (transferred to the maternity ward for the next 30-35 days before calving). The basis of the diet is silage, which was harvested using probiotic preparations. Feeding is carried out from the floor, three times a day. The cattle kept on the farm were immunised with the Skowgard 4 KS vaccine (made in the USA).

The cows were fed a complete ration that met the needs of the physiological group (a mixture of silage, chopped alfalfa hay, and groats). During the dry period, the cows are kept untethered in a room with access to free range near the barn. The diet and housing conditions of the animals in all groups were identical throughout the experiment. The cows of the experimental group were daily fed with the enzyme and probiotic supplement "ProActivo" at the rate of 10-14 g/animal/day. To investigate the effect of EPA on the body of cows in both groups, the clinical condition (change in appetite, diarrhoea, body temperature, during calving – the course of calving, and after calving: afterbirth retention, endometritis) was recorded and blood was taken 1-3 days after calving from the *Vena subcaudialis* using a needle holder, disposable venipuncture needles, and EximLab vacutainers with K3 EDTA. Blood tests were performed within 4 hours after sampling, using the device "Analyser haematological VS-5000 vet", made in China.

There are three stages of labour: 1 – preparatory or opening and dilatation of the cervix; 2 – delivery of the foetus (birth of a calf); 3 – afterbirth or expulsion of the membranes and residues around the foetal fluids. The onset of cervical dilatation in cows was recorded by anxiety, stepping from limb to limb, and the degree of cervical dilatation was determined after vaginal examination. The end of the stage is when the newborn calf's body parts are wedged into the cervix. Subsequently, the countdown to the beginning of the second stage of labour – delivery of the foetus – was recorded. The end of which is the time of the calf's birth. The time of the afterbirth (third) stage began immediately after the calf was born, and the end time was the hour of discharge around the membranes from the cow's genital slit. The calving stage was recorded following the methodology for determining the stages of labour outlined in the order of the Ministry of Health No. 310 "On Approval of Clinical Protocols for Obstetric and Gynaecological Care" dated 8 May 2014.

The analysis of changes in cellular immunity was carried out by analysing granulocytes and agranulocytes in the blood of cows of the experimental and control groups after haematological studies using a haematological analyser "VS-5000 vet". The material of the study was stabilised blood of cows during the dry period, which were kept in the dairy farm of the above mentioned farm. The methods of the study included are clinical, haematological, and statistical. The study was conducted following the ethical standards of animal treatment (not causing distress and pain) according to Directive 2010/63/EU (2010) on the protection of animals used for scientific purposes.

RESULTS AND DISCUSSION

Notably, 4 cows of the experimental group (23.5%) did not consume EPA well, while the other 13 (76.5%) tried to consume their dose and the next available dose. Before the start of feeding the probiotic-enzymatic feed additive, the chewing behaviour of animals in both groups was moderate, sometimes on the verge of laziness. After 4 days, the cows in the experimental group ate silage better, and after 8 days, significantly better, compared to the cows in the control group. However, according to K.A. Beauchemin (2018), the length of the chewing period is influenced by the length of the feed parts, dietary components, and feeding frequency. The duration of the chewing period during the day was not measured due to the complexity of the accounting methodology. The accounting of diarrhoea symptoms in cows of both groups of the experiment is presented in Table 1.

Table 1. Symptoms of diarrhoea in cows when feeding EPA

Indicator 1 day		Experimental group, n = 17			Control group n = 6			Reference values
		1 day	After 4 days	After 8 days	1 day	After 4 days	After 8 days	
Presence of diarrhoea	Number of animals	8	0	0	3	3	3	0 (none)
	%	47	0	0	50	50	50	

Source: *developed by the authors of this study*

Table 1 shows that before the start of supplementation, half of the cows in both groups had diarrhoea of varying intensity. After 4 days of the experiment, the absence of digestive disorders in cows treated with the enzyme-probiotic supplement and the persistence of diarrhoea symptoms in control animals were recorded. We believe that the data obtained are related to the pharmacological effect of the components of the tested drug in the body. After all, digestive disorders can develop due to a decrease in the amount of beneficial and symbiotic microbiota, which leads to the growth of pathogenic microorganisms. According to Q. Wang *et al.* (2022), after entering the gastrointestinal tract, *Bac. subtilis*, despite its transient properties, together with *Bac. lichineformis* produce secondary metabolites that create unfavourable conditions for the pathogenic intestinal microflora, which leads to optimisation of the digestive system function. According to Zh. Rybachuk *et al.* (2020), the use of a preparation with Bac. subtilis and Bac. lichineformis reduces the toxic effect on the liver of dogs due to antagonistic properties against pathogens of the digestive system

In cows, there are different stages of calving (cervical dilatation, parturition, and afterbirth). During the study of pharmacological effects of EPA, the calving periods in the experimental and control groups were analysed. The problem of afterbirth retention in cows of a dairy farm was relevant at the beginning of the study. It is understood that afterbirth retention develops due to the formation of inflammatory adhesions between the chorion and cotyledon. Considering the pharmacological effect of probiotic microbes in the animal body, the course of calving stages was investigated using EPA. It was found that the duration of the preparatory, delivery, and afterbirth separation periods differed significantly ($P \leq 0.001$) in the groups (Table 2).

Table 2. Effect of the additive on calving in cows

Indicators	Experiment, n=17	Control, n=6
Duration of the preparatory stage of calving, min	172.23 ± 6.7**	274.83 ± 9.71
Duration of foetal delivery, min	31.47 ± 1.2**	65.8 ± 6.2
Duration of afterbirth separation, min	253.9 ± 3.6**	326.8 ± 8.9
Afterbirth retention, animals/(%)	1/5.9	3/50
Udder swelling, %	0.41 ± 0.12	0.5 ± 0.22

Note: *I** – $P \leq 0.001$*
Source: *developed by the authors of this study*

After the stage of foetal delivery in cows of the experimental group, the duration of afterbirth separation was significantly ($P \leq 0.001$) shorter compared to animals of the control group. In general, it lasted 4-4.5 hours. In cows treated with an enzyme and probiotic additive, 20-30 cm of amniotic membranes hung from the genital slit after the foetus was removed. After licking the calf, the female ate feed, drank water, but after 240-260 minutes she lay down and within 10-20 minutes a rapid afterbirth separation was recorded. No postpartum complications were recorded. We believe that the absence of afterbirth retention in such cows may be due to the pharmacodynamics of the components of the EPA containing *Bacillus subtilis* strain AX20 and *B. licheniformis* strain EA22, *Enterococcus faecium* (as representatives of the endogenous microflora). The colonisation of cows' forestomachs and large intestines by the above microorganisms causes the release of lactic acid (as a result of the hydrolysis of complex carbohydrates), the release of antibacterial, antiviral, and antifungal substances, which create unfavourable conditions for the development of pathogenic microflora. And by forming ligand bindings with pathogens, they make it impossible for them to attach and multiply in the body of animals. The synergistic pharmacological effect of the bacterial component of the feed additive on bacterial translocation significantly reduces the antigenic intake of pathogenic microorganisms from the gastrointestinal tract into the bloodstream. Furthermore, it is possible to stimulate the production of antimicrobial peptides and cytokines IL-12, IFN-γ, IL-10, and TNF-α. The multivectorial mechanism of action of the multi-strain enzyme and probiotic supplement in the digestive tract is manifested, and the immune system is activated, which neutralises pathogenic microflora in other tissues of the body. All this leads to a pharmacological effect – the absence of afterbirth retention due to the absence of inflammation in the chorion-cotyledon system. Accordingly, the mucins contained in uterine mucus have a more active bactericidal effect, which prevents the development of endometritis and metritis and reduces the duration of uterine involution.

In other words, feeding an enzyme and probiotic supplement significantly reduces the retention of manure in cows, as beneficial microorganisms spread in the gastrointestinal tract and increase the amount of the above-mentioned transient microflora in faeces, contaminating environmental objects, which reduces the amount of pathogenic microflora. To explain the clinical effects obtained by feeding a complex feed additive, changes in cellular immunity were analysed. With a constant antigenic load of cows, which occurs when animals are kept in commercial dairy farms, the functioning of the immune system is aimed at inactivating and eliminating pathogens. Therewith, post-infectious or post-vaccination immunity (in the case of vaccinations) is additionally formed. The strength of the immune system depends on many factors. The key factor here is the intensity of the above load (bacteria and viruses), which depends on sanitary and hygienic conditions, feed quality, and the presence of stress factors.

Pregnancy and calving is the period of maximum functioning of the cow's body systems, including the immune system. Therefore, in farms, inflammation of the mammary gland parenchyma is often recorded immediately after calving, as a result of which such animals develop endometritis or metritis (can be caused by delayed afterbirth or develop as an independent disease due to uterine atony; this study does not consider unskilled obstetric care). No significant difference in the general haematological parameters of the experimental and control groups was recorded as a result of the inclusion of the supplement in the diet. However, the indicators reflecting the functioning of the immune system, and specifically cellular immunity, indicate a positive effect of the enzyme and probiotic supplement on the body of cows (Table 3).

***Table 3**. Indicators of cellular immunity with the use of EPA*

Indicators	Experimental group, n=17	Control group, n=6	Reference indicators
Total number of leukocytes G/l****.	14 ± 0.53*	7.64 ± 1.1	4-12
Lymphocytes**, G/l**	8.4 ± 0.4*	5.15 ± 0.6	2.5-7.5
Monocytes, **G/l**	1.19 ± 0.07*	0.76 ± 0.1	0-0.84
Neutrophils, **G/l**	3.8 ± 0.14**	2.2 ± 0.42	0.6-6.7
Eosinophils, **G/l**	0.26 ± 0.01	0.51 ± 0.28	0.1-1

Note: ** – P ≤ 0.01; ** – P ≤ 0.001*
Source: *developed by the authors of this stud*

The findings of scientific studies (Table 3) confirm a significant activation of cellular immunity in cows of the experimental group. A significant (P ≤ 0.01) increase in the total leukocyte count by 6.36 G/l was recorded compared to the control group, and the value exceeded the upper physiological limit by 2 G/l. Notably, the animals were healthy in terms of leukaemia, and the farm is safe from this infectious disease. Leukocytosis is an intensified defence of the body against pathogens, and therefore it should be considered as a full-fledged functional increase in the absolute number of immune cells, considering the epizootic situation on the dairy farm. Leukocytosis in cows of the experimental group can be rationally explained by characterising the groups of leukocytes: lymphocytes, monocytes, and granulocytes. The specific feature of lymphocytes is their ability to recirculate between lymphoid organs with the blood and lymph flow, while the pool of circulating cells is predominantly T-lymphocytes with a life expectancy of 100-200 days. In the body of cows receiving daily enzyme-multistrain probiotic supplementation, due to the prevention or reduction of bacterial translocation, there should be a decrease in the antigenic load on the cellular and humoral immune system, but the data obtained suggest the opposite phenomenon. We assume that this may be caused by improved monitoring of cow tissues or cells by naïve lymphocytes during recirculation, detection of viral pathogens, and activation of the immune response. Exceeding the upper physiological limit by 12% indicates the formation of antiviral protection of the animal body. At the same time, the number of lymphocytes in cows that did not receive an EPA was average, suggesting the presence of bacterial translocation, which is confirmed by data from L.Z. Shu *et al*. (2023).

T-lymphocyte receptors recognise antigenic peptides in combination with histocompatibility molecules of classes 1 and 2. They are specific to peptides of pathogens and, accordingly, antibodies, which indicates the formation of intense immunity; we assume post-infectious, because cows of both groups (experimental and control) were kept in identical conditions. That is, the recorded significant (P ≤ 0.01) increase in lymphocytes in cows that consumed EPA indicates the optimised (qualitative recognition of infectious pathogens, and, accordingly, the release of cytokines and the synthesis of appropriate antibodies) functioning of the primary immune system.

Monocytes, as a group of leukocytes, play an auxiliary role in the formation of a specific immune response and have a unique ability to adhere to various substrates, which ensures phagocytosis. It is known that monocytes use a range of lectin receptors and receptors for the C3b component of complement and Fc fragments of antibodies to recognise foreign agents. Considering a significant ($P \leqslant 0.01$) increase (by 0.43 kl/l) in monocytes in cows compared to the control group in the post-hospital period, and by 40% with the maximum permissible reference value (0.84 kl/l), active phagocytosis is taking place in the body of cows of the experimental group.

This is also confirmed by a significant ($P \leqslant 0.001$) increase by 72% in the count of neutrophils in the experimental group, which, together with monocytes, provide peripheral protection of the macroorganism. Unlike other groups of leukocytes, the count of microphages was within physiological limits, which confirms the concept of activation of cellular immunity in animals fed a feed supplement with probiotic bacterial strains (*Bacillus subtilis* strain AX20 and *B. licheniformis* strain EA22, *Enterococcus faecium*). In addition, there is a decrease in the range of neutrophils count in cows of the experimental groups from 3.2 G/l to 4.7 G/l compared to the control group – from 1.4 G/l to 3.1 G/l, which suggests almost the same level of antibacterial protection.

The use of multi-strain EPA in the diet blocks bacterial translocation, which helps to optimise the function of the cellular immune system against pathogens that enter the body through other routes (other than oral). Since the epizootic chain for some viral infections is functioning in the herd, inflammation does not develop in the cotyledon-chorion system. This is conditioned by the optimised functioning of the immune system, which restrains the development of inflammatory processes in the reproductive system of cows in the early postpartum period and the birth of viable calves with an Apgar score of 9-10. Thus, the indices of cellular immunity in cows of the experimental group compared to those of the control group suggest a positive effect of the EPA components (enzymes, hepatoprotectors, *Bacillus subtilis* strain AX20, and *B. licheniformis* strain EA22, *Enterococcus faecium*) on the body of pregnant cows, since the level of phagocytosis activity in all experimental cows was at the same level, with different levels in cows of the control group.

The results of the study on the use of probiotics in various livestock sectors prove a positive impact on the functioning of the digestive system. Therefore, the cure of diarrhoea in pregnant cows after 4-day daily feeding of a multistrain enzyme and probiotic supplement is confirmed by the publications of T. Maake *et al.* (2021) on maintaining the homeostasis of the gastrointestinal microbiome with the use of probiotics. Considering that the microbial component of the feed additive used contains *Bacillus subtilis* strain AX20 and *B. licheniformis* strain EA22, *Enterococcus faecium*, which provides antagonism to the pathogenic microflora of the digestive tract of animals of the experimental group. This is confirmed by the recent publications of A. Kovács (2019), who reported that *Bac. subtilis* and *Bac. lichineformis* are transient bacteria, but during their passage through the gastrointestinal tract, they produce secondary metabolites that inhibit or prevent the development of pathogenic microflora in its lumen, which optimises the microbiota. Furthermore, other components of the EPA – enzymes that improve feed digestibility – also contribute to improved digestion. The positive effect of the multi-strain enzyme and probiotic supplement on the body is confirmed by a significant ($P \leqslant 0.001$) reduction in the duration of the stages of labour and 94.1% prevention of afterbirth retention in cows of the experimental group compared to the control group (without feed supplement). We believe that this is due to a decrease in bacterial translocation and, as a result, a decrease in disseminated inflammation in the body of the experimental group cows. This concept is confirmed by the published data by S. Vovk *et al.* (2021), when probiotic-containing preparations stimulate the production of antimicrobial substances and cytokines. Additionally, scientists have partially clarified certain aspects of the mechanism of action of probiotics in the macro body. It was proved that probiotics containing *Lactobacillus casei*GG, inhibit the translocation of bacteria into the intestinal epithelium by increasing the amount of mucin, which is a physical barrier against pathogens. It is believed that probiotics compete with pathogens for nutrients and attachment sites and indirectly exert antagonistic effects against pathogens.

An additional confirmation of the activation of the immune system function in the body of cows of the experimental group as a result of a decrease in bacterial translocation is a significant ($P \leqslant 0.01$) increase in the count of leukocytes (by 6.36 G/l), monocytes (by 0.43 G/l), and neutrophils (by 1.6 G/l) – $P \leqslant 0.001$ compared to the average data of the control group. The data obtained are confirmed by S. Ruiz Sella *et al.* (2021), who showed in experiments the antimicrobial, enzymatic, antioxidant, and anti-inflammatory effects of microorganisms. V. Yaderets *et al.* (2023) found antagonism of *Bac. subtilis* RBT-7/32 and Bac. licheniformis RBT-11/17 against Escherichia coli and Staphylococcus aureus, amylolytic activity and resistance to some veterinary antibiotics. Additionally, P. Shridhar *et al.* (2022) report that Enterococcus faecium lacks pathogenicity genes and a considerable proportion contains adhesion genes, which causes colonisation of the digestive tract in animals. Thus, these bacterial strains necessitate their use in the composition of probiotics for animals. That is, the use of a multi-strain enzyme and probiotic additive has a positive effect on the body of pregnant cows.

CONCLUSIONS

Daily feeding of the enzyme and probiotic supplement in the diet at the rate of 10-14 g/animal for 4-8 days helps to improve digestion, eliminates diarrhoea symptoms, and stimulates the intensity of feed intake, due to the pharmacological effect of enzymes (amylase, xylanase, protease, cellulose, and beta-gluconase) and symbiotic bacteria (*Bacillus subtilis* strain AX20, *B. licheniformis* strain EA22, *Enterococcus faecium*). The inclusion of a multistrain feed additive in the diet of cows 21-30 days before calving contributed to a significant ($P \leqslant 0.001$) decrease in the duration of the preparatory stage of calving (from 274.83 ± 9.71 min to 172.23 ± 6.7 min in the experiment), foetal delivery (from 65.8 ± 6.2 min to 31.47 ± 1.2 min in the experiment), duration of afterbirth separation 326.8 ± 8.9 min (control) to 253.9 ± 3.6 min in the experiment), and prevented 94.1% of afterbirth retention in cows of the experimental group, which allows recommending it as a general stimulant.

Feeding the additive to cows for 21-30 days before calving, compared to the control group ($P \leqslant 0.01$), contributed to the development of leukocytosis by 6.36 G/l, lymphocytosis by 6.25 G/l, an increase of 0.43 G/l of monocytes, and a significant ($P \leqslant 0.01$) increase in neutrophils count by 1.6 G/l from 2.2 ± 0.42 G/l in the control compared to 3.8 ± 0.14 G/l in the experiment.0.14 G/l in the experiment, due to a decrease in bacterial translocation in the digestive tube with a simultaneous increase in the activity of tissue monitoring by naive lymphocytes and phagocytosis by monocytes and neutrophils, indicating an optimisation of the functioning of the primary immune system. The prospect of further research is to investigate changes in blood biochemical parameters, which are diagnostic markers of the functional state of internal organs involved in immunogenesis and digestion in pregnant cows, using a multicomponent feed additive.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Фармакологічні ефекти використання ферментно-пробіотичної кормової добавки сухостійним коровам

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Анотація. Проведені наукові дослідження в світі щодо використання пробіотиків у тваринництві демонструють тільки позитивний вплив на функціонування макроорганізму, але залишаються відкритими питання щодо різних фармакологічних ефектів мультикомпонентних мікробних препаратів в поєднанні із ферментами, важливими у процесі травлення певних видів продуктивних тварин, що обумовлює актуальність для ветеринарної медицини та фермерів у отриманні екологічної та якісної продукції. Мета роботи - вивчити вплив полікомпонентної ферментно-пробіотичної добавки щодо тривалості стадій отелення, профілактики післяпологових ускладнень у корів та деяких гематологічних показників. При проведенні наукових досліджень були використані клінічні, гематологічні та статистичні методи дослідження. Дослідження були проведені в одній із приватних молочно-товарній фермі де утримується 195 корів. Умови утримання та раціон тварин групи контролю (n = 6) та дослідної (n = 17) були аналогічними, а в раціон корів експерименту додавали ферментно-пробіотичну добавку «ПроАктиво» (містить ферменти, Bacillus subtilis штаму AX20, B. licheniformis штаму EA22 і Enterococcus faecium) із розрахунку 10-14 грам/тварину, 1 раз на добу, протягом 21-30 діб до отелення. Було встановлено позитивний вплив на організм тільних корів – усунення симптомів діареї через 4 доби у 100 % хворих тварин, а у групі контролю без змін. Дослідженням було доведено, що передпологовий курс пробіотикотерпії корів забезпечив 95 % профілактику затримки посліду, достовірне ($P \leq 0{,}001$) зменшення тривалості стадії відділення посліду у корів дослідної групи (253,9 ± 3,6 хв) відносно контрольної (326,8 ± 8,9 хв). Зареєстровано достовірне ($P \leq 0{,}01$) збільшення кількості лімфоцитів на 3,25 ± 0,2 Г/л, моноцитів 0,43 ± 0,03 Г/л, нейтрофілів ($P \leq 0{,}001$) 1,6 ± 0,28 Г/л у корів, які отримували ферментно-пробіотичну добавку, що пов'язуємо із оптимізацією функціонування первинної ланки імунітету і фармакосинергічній дії полікомпонентної добавки. Отримані результати є цінними для ветеринарних лікарів, утримувачів дійного стада, бо додавання до раціону сухостійних корів ферментно-пробіотичної добавки полегшить перебіг стадій отелення та профілактує затримку посліду

Ключові слова: пробіотик; корови; затримка посліду; отел; імунітет

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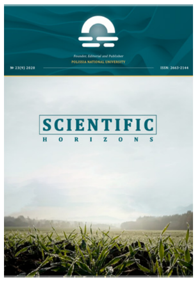

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Efficiency of using levamisole-based anthelmintics

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Abstract. Animal parasitic diseases cause major losses to the livestock industry and require constant monitoring and control. The purpose of this study was to monitor the livestock (calves, goats, sheep, pigs, dogs, chickens) for the presence of helminthic pathogens, to determine the therapeutic efficacy of levamisole-based preparations and the general toxicity of meat of experimental animals using the *Colpoda steinii* test culture. In 2020-2022, a considerable spread of invasive animal diseases was

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detected in the Kharkiv region of Ukraine. In a study of 3,500 calves, 1,000 (28.6%) were found to be persistently infected with nematodes with an intensity of 25.0-150.0 worm eggs per 1 g of faeces. In goats, the intensity of endoparasite infection ranged within 10.0-15.0 worm eggs per 1 g of faeces, while in sheep this figure reached 25.0 worm eggs per 1 g of faeces. In the study of faeces from pigs, 800 (34.8%) samples revealed the presence of helminth eggs, while mono-infestation was detected in 300 samples (37.5%). In the study of canine faeces, 10 (66.7%) positive samples were found. When examining the manure from chickens, 200 (44.4%) positive samples revealed the presence of helminth eggs. The use of levamisole dosage forms can reduce the extent of infection in animals by 50% as early as on Day 5. No worm eggs were detected in the faeces of animals from Day 14 to Day 30 of observation, and therefore the extensional efficacy of the studied products under modern conditions is 100%. Meat obtained from farm animals (pigs, calves, sheep) treated with levamisole-based preparations shows signs of general toxicity within 5-9 days after the use of the products: 5 days for pigs and 9 days for calves and sheep. At the same time, meat obtained from poultry (chickens) treated with levamisole-based preparations shows signs of general toxicity within 2 days after the end of the treatment course

Keywords: levamisole; endoparasites; helminth eggs; antiparasitic agent; extensive and intensive invasion; meat; toxicity

INTRODUCTION

Tens of thousands of species on the planet have adapted to a parasitic lifestyle. It is difficult to name a species of animal that does not have helminths. Helminthiasis is one of the most common diseases of cattle, pigs, poultry, and exotic poultry, and domestic animals (Paliy *et al.*, 2019; Galat *et al.*, 2019; Bohach *et al.*, 2023). According to J.W. Lewis (2016), the effect of parasites on the host depends on the intensity of infection, age, host resistance, conditions of housing, feeding, and a series of environmental factors. M. Rashid *et al.* (2019) and S. Ola-Fadunsin *et al.* (2020) show a decrease in the productivity and quality of livestock products and large economic losses caused by parasitic animal diseases worldwide.

S.A. Nixon *et al.* (2020) note that the type of infectious agent and the number of eggs and larvae found in animal excrement are of significant importance. Prevention and control of animal diseases has always been one of the principal and crucial areas of work for any veterinarian. According to R.W. Avramenko *et al.* (2017), the effectiveness of antiparasitic measures directly depends on the availability of highly effective veterinary medicines. H.R. Vineer *et al.* (2020) and J. Charlier *et al.* (2023) note that the issue of parasite resistance to anthelmintics is becoming a major issue in veterinary medicine and poses a serious threat to animal welfare. In veterinary medicine, C. Chartier *et al.* (2020) are testing anthelmintics with different ratios of active ingredients, but the number of infected animals is constantly growing.

Residual content of veterinary preparations in animal products can have a negative impact on human health. According to J.T. Campillo *et al.* (2022), levamisole contributes to the development of vasculitis, neuropathy, agranulocytosis, and leukoencephalopathy in humans. It was because of the elevated risk of these side effects that levamisole was withdrawn from the US and Canadian human medication markets in 2000 and 2003, respectively. Although the probability of acute human intoxication from levamisole residues and its metabolites in meat products has been proven to be low, due to the widespread use of the preparation in animal treatment, concerns about their content persist. To ensure the safety of slaughter products for human consumption, monitoring protocols have been developed for veterinary preparations, including anthelmintics, which include the establishment of maximum residue limits (MRLs).

The purpose of this study was to determine the endoparasite prevalence in animals in the Kharkiv region (Ukraine), to determine the effectiveness of helminthic infections treatment with preparations containing levamisole and the general toxicity of meat by biotesting obtained from animals treated with levamisole.

MATERIALS AND METHODS

The study was conducted within the framework of the state scientific theme of the National Research Centre "Institute of Experimental and Clinical Veterinary Medicine" 34.01.02.02 F "Investigation of the role of arthropods in the spread of pathogens of parasitic and infectious diseases and development of a strategy to combat them" No. DR 0121U108356 (2020–2022) and the initiative research work of Odesa State Agrarian University "Ensuring animal welfare, food safety, and quality in the context of European integration" No. 0123U103523 (2023-2028).

Two preparations from different manufacturers containing the active ingredient levamisole were used in the trials: preparation No. 1, Levamisole Plus 10% (solution for injection); preparation No. 2, Levamisole 10%. The preparations were administered individually, orally, subcutaneously, or intramuscularly in the following doses: cattle, small cattle, pigs – 0.75 ml per

10 kg of body weight; dogs – 0.75 ml per 10 kg of body weight, once, orally; poultry – 1.0 ml per 250 ml of drinking water for three consecutive days orally.

The experiments were carried out in the laboratory of veterinary sanitation and parasitology of the National Scientific Centre "Institute of Experimental and Clinical Veterinary Medicine", the Multidisciplinary Laboratory of Veterinary Medicine of Odesa State Agrarian University and in livestock farms of various forms of ownership in the Kharkiv Oblast of Ukraine in 2020-2023. Clinical trials of preparations on animals to investigate their therapeutic effect were conducted according to the following scheme:

1) clinical examination of animals, preliminary diagnosis, faecal sampling for laboratory testing, and ongoing clinical monitoring of the physiological state of experimental animals;

2) microscopic examination of samples to determine the pathogens of helminthic diseases in the biological material, their identification, and determination of the extent of infections in animals;

3) administration of preparations, individually, keeping animals, taking faecal samples for laboratory testing 5, 10, 15, and 30 days after the last preparation administration; determination of the preparation efficacy.

Total number of animals studied: black-and-white dairy calves aged 4-12 months (n = 3,500), goats (n = 200) and sheep (n = 300) aged 1-5 years, pigs (n = 2,300: 50 sows, 10 boars, and 1,700 piglets aged 3-4 months), non-pedigree dogs (n = 15) aged 6 months to 7 years, chickens (n = 450) of the Leghorn breed.

Experimental group I – animals treated with preparation No. 1 "LEVAMISOL-plus 10% (solution for injection)": calves (n = 500), goats (n =м60), sheep (n = 50), pigs (n = 400), dogs (n = 5), chickens (n = 100);

Experimental group II – animals treated with preparation No. 2 "Levamisole 10%": calves (n = 500), goats (n = 60), sheep (n = 50), pigs (n = 400), dogs (n = 5), chickens (n = 100).

Experimental group III (control) – clinically healthy animals without the use of levamisole-based preparations: calves (n = 2,500), goats (n = 80), sheep (n = 200), pigs (n = 1,500), dogs (n = 5), chickens (n = 250).

Experimental animals treated: calves (n = 1,000), goats (n = 120), sheep (n = 100), pigs (n = 800), dogs (n = 10), chickens (n = 200). According to the objectives, the study was conducted using visual and microscopic methods (Robinson & Dalton, 2009; Collender *et al.*, 2015). The study carried out in vivo diagnostics of helminth infections and determined the number of helminth eggs. The intensity of infection was determined by counting the number of worm eggs per 1 g of faeces.

At 5, 10, 15, and 30 days after treatment, the results of the study were recorded based on examinations of treated animals, detection of worm eggs in faecal samples, determination of the extent of invasion after treatment and the extensefficacy of the preparation. Faecal samples were examined for the presence of helminth eggs using the native smear method, the Füllleborn flotation method, and the Berman method (Bahur & Zgozinska, 2015; Dakhno, 2023) using a light microscope at a magnification of ×100. The detected worm eggs and larvae were examined under magnification (×400) for identification. The extent of the infestation was determined according to the following formula:

$$IE = \frac{x}{y} \times 100, \tag{1}$$

where *IE* is the invasion extensiveness; *x* is the number of faecal samples in which worm eggs were detected; *y* is the total number of faecal samples; 100 is the conversion factor to percentage.

The general toxicity of meat of animals treated with levamisole was studied by the author's biological express method using the infusoria *Colpoda steinii* as a test object (The method of determining the toxicity of the meat of slaughtered animals: Patent No. 149685, Ukraine, 2022; Gorobey *et al.*, 2022)

The total number of meat samples from the experimental animals: calves (n = 54), sheep (n = 54), pigs (n = 45), chickens (n = 45).

Experimental group I – meat of animals treated with preparation No. 1 "LEVAMIZOL-plus 10% (solution for injection)": calves (n = 18), sheep (n = 18), pigs (n = 15), chickens (n = 15);

Experimental group II – meat of animals for the treatment of helminthiasis where preparation No. 2 "Levamisole 10%" was used: calves (n = 18), sheep (n = 18), pigs (n = 15), chickens (n = 15).

Experimental group III (control) – meat of clinically healthy animals without the use of levamisol-based preparations: calves (n = 18), sheep (n = 18), pigs (n = 15), chickens (n = 15).

The general toxicity study was conducted for 11 days with an interval of 1 day. To determine the toxicity, a test culture of *Colpoda steinii* was prepared by adding 2 cm^3 of culture medium to a vial of dry culture and placing it in a thermostat for 24 hours at +26…+28°C. A sample of meat weighing 10 g was taken, the sample was extracted with aqueous acetone in a volume of 10 cm^3, shaken for 20 minutes, and filtered. 0.5 cm^3 of filtrate was collected and 60 cm^3 of Lozin-Lozinsky solution was added. Subsequently, 2 cm^3 of the obtained acetone extract solution was added to a vial with the prepared test culture of *Colpoda steinii* infusoria, placed in a thermostat for 1 hour at +26…+28°C. After thermostatting, the working mixture was examined under a microscope at a magnification of x80-120 to determine the condition and behaviour of the test culture and to count the percentage of live and dead infusoria (Table 1).

***Table 1**. Criteria for the assessment of general toxicity*				
Condition and behaviour of the test culture of the infusoria *Colpoda steinii*	**Degree of toxicity**			
	Non-toxic	**Slightly toxic**	**Toxic**	**Highly toxic**
Live (active/motile) infusoria, %	90-100	80-85	5-10	0
Unnatural movements, %	0-2	3-5	3-5	0
Growth inhibition, %	0-2	3-5	3-5	0
Pathological forms, %	0-2	3-5	3-5	0
Dead infusoria, %	0-5	5-10	70-90	100

***Source:** developed and patented by the authors of this study (The method of determining the toxicity of the meat of slaughtered animals: Patent No. 149685, Ukraine, 2022)*

The experiments conducted on animals follow the requirements of DSTU ISO/IEC 17025:2005 (2006), the Regulation on the Procedure for Conducting Experiments and Experiments on Animals by Scientific Institutions (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (European convention…, 1986) and international bioethical standards (materials of the IV European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Purposes (Council Directive 86/609/EEC, 1986).

RESULTS AND DISCUSSION

Determination of the extent of animal endoparasite infestation. As a result of the clinical examination of calves, animals were found to be underweight, emaciated, with dull, tousled hair, signs of digestive disorders – bloating, discharge of liquid faeces.As a result of coprological examination of faeces from calves, eggs of various helminths were found (Table 2).

In the study of 3,500 calves, 1,000 (28.6%) of them were found to be persistently infested with endoparasites of different species composition. In calves, mono-infestations with nematodes were observed with an intensity of 25.0-150.0 worm eggs per 1 g of faeces.

During the examination of small cattle (sheep, goats), clinical signs of digestive disorders were found – abdominal distention, unformed faeces. Faeces from small cattle (sheep, goats) were examined and worm eggs were found (Table 3).

***Table 2**. Infestation of calves with helminths (M ± m, n = 3,500)*

Type of parasite	**Samples, pcs.**	**Invasion extensiveness, %**	**Invasion intensity**
Haemonchus spp.	400	11.4	150.0 ± 13.5
Nematodirus spp.	200	5.8	25.0 ± 5.5
Ostertagia spp.	400	11.4	25.0 ± 1.5

***Source:** developed by the authors of this study*

***Table 3**. Infestation of goats (M ± m, n = 200) and sheep (M ± m, n = 300) with helminths*

Type of parasite	**Samples, pcs.**	**Invasion extensiveness, %**	**Invasion intensity**
goats			
Trichostrongylus spp.	40	20	15.0 ± 1.5
Nematodirus spp.	40	20	15.0 ± 1.5
Cooperia spp.	40	20	10.0 ± 0.5
sheep			
Haemonchus spp.	40	13.3	15.0 ± 0.5
Nematodirus spp.	20	6.7	10.0 ± 1.5
Ostertagia spp.	40	13.3	25.0 ± 1.5

***Source:** developed by the authors of this study*

At the time of the survey, the extent of infection among goats was higher than in sheep, at 60% and 33.3%, respectively. Mono-invasions were detected in animals with varying intensity. Thus, in goats, the intensity of endoparasite infection ranged within 10.0-15.0 helminth eggs per 1 g of faeces, while in sheep this figure reached 25.0 helminth eggs per 1 g of faeces. During the examination of pigs with clinical manifestations of digestive disorders (liquid faeces), nematode eggs were found in faeces (Table 4).

Table 4. Infection of pigs with helminths ($M \pm m$, $n = 2{,}300$)			
Type of parasite	**Samples, pcs.**	**Invasion extensiveness, %**	**Invasion intensity**
Ascaris suum	400	17.4	35.0±5.5
Oesophagostomum spp.	200	8.7	15.0±1.5
Strongyloides ransomi	400	17.4	45.0±3.5

Source: *developed by the authors of this study*

In the study of faeces from pigs, 800 (34.8%) samples revealed the presence of helminth eggs, while mono-infestation was detected in 300 samples, which is 37.5%. Twenty sows were found to be infected with *Ascaris suum*, and boars – with *Oesophagostomum* spp. The presence of a mixed invasion was detected in piglets – 62.5%. Dogs with clinical manifestations of digestive disorders (distorted appetite, liquid faeces) were also examined. Faecal samples were collected from the animals for parasitological studies (Table 5).

Table 5. Infection of dogs with helminths ($M \pm m$, $n = 15$)			
Type of parasite	**Samples, pcs.**	**Invasion extensiveness, %**	**Invasion intensity**
Toxocara canis	4	26.7	35.0±3.5
Toxascaris leonina	6	26.7	15.0±1.5
Ancylostoma spp.	2	13.3	25.0±3.5
Uncinaria spp.	2	13.3	15.0±1.5

Source: *developed by the authors of this study*

The study revealed 10 (66.7%) positive samples, with monoinvasion detected in 8 samples, which is 80%. Eggs of *Toxocara canis* were detected in two dogs aged 4 years, and Toxascaris leonina was indicated in six animals aged 3-5 years. Two dogs were also found to be infected with parasites *Toxocara canis, Ancylostoma* spp., and *Uncinaria* spp. According to the results of the studies, the highest intensity of *Toxocara canis* infection was 35.0 worm eggs per 1 g of faeces, and the lowest was *Toxascaris leonina* and *Uncinaria* spp. – 15.0 worm eggs per 1 g of faeces each. In the study of chicken manure, in 200 (44.4%) positive samples, monoinfestation of *Ascaridia galli* was detected in 100 (50%) chickens, monoinfestation of *Heterakis gallinarium* – in 50 chickens (25%), and *Capillaria* spp. – in 50 (25%) chickens. The intensity of infection was highest for *Ascaridia galli* (45 eggs per 1 g of faeces), and lowest – for *Capillaria* spp. (10 eggs per 1 g of faeces) (Table 6).

Table 6. Helminth infestation in chickens ($M \pm m$, $n = 450$)			
Type of parasite	**Samples, pcs.**	**Invasion extensiveness, %**	**Invasion intensity**
Ascaridia galli	100	22.2	45.0±1.5
Heterakis gallinarium	50	11.1	15.0±1.5
Capillaria spp.	50	11.1	10.0±3.5

Source: *developed by the authors of this study*

Determination of the effectiveness of treatment of helminth infections in animals with preparations containing levamisole. After identifying animals infected with various types of helminths, they were given experimental levamisole preparations for therapeutic purposes. At the first stage, the therapeutic efficacy of the preparations in nematode infections in ruminants was determined (Table 7).

Table 7. Study of the therapeutic efficacy of levamisole preparations in ruminants										
Type of helminths	**Before treatment**		**After treatment**							
	IE, %	**II, avg**	**Day 5**		**Day 10**		**Day 20**		**Day 30**	
			IE, %	**II**	**IE, %**	**II**	**IE, %**	**II**	**IE, %**	**II**
Calves (n=500), preparation No. 1										
Haemonchus spp.	100	150	50	65	50	5	0	0	0	0
Nematodirus spp.	100	25	0	0	0	0	0	0	0	0
Ostertagia spp.	100	25	50	2	0	0	0	0	0	0

Table 7. Continued

Type of helminths	Before treatment		After treatment							
	IE, %	II, avg	Day 5		Day 10		Day 20		Day 30	
			IE, %	II	IE, %	II	IE, %	II	IE, %	II
Calves (n = 500), preparation No. 2										
Haemonchus spp.	100	132	50	45	50	3	0	0	0	0
Nematodirus spp.	100	30	0	0	0	0	0	0	0	0
Ostertagia spp.	100	23	50	2	0	0	0	0	0	0
Goats (n = 60), preparation No. 1										
Trichostrongylus spp.	100	15	50	7	0	0	0	0	0	0
Nematodirus spp.	100	14	50	8	0	0	0	0	0	0
Cooperia spp.	100	17	50	7	0	0	0	0	0	0
Goats (n = 60), preparation No. 2										
Trichostrongylus spp.	100	17	50	8	0	0	0	0	0	0
Nematodirus spp.	100	16	50	8	0	0	0	0	0	0
Cooperia spp.	100	17	50	8	0	0	0	0	0	0
Sheep (n = 50), preparation No. 1										
Haemonchus spp.	100	15	50	8	0	0	0	0	0	0
Nematodirus spp.	100	10	0	0	0	0	0	0	0	0
Ostertagia spp.	100	25	50	12	0	0	0	0	0	0
Sheep (n = 50), preparation No. 2										
Haemonchus spp.	100	14	50	10	0	0	0	0	0	0
Nematodirus spp.	100	8	0	0	0	0	0	0	0	0
Ostertagia spp.	100	23	50	11	0	0	0	0	0	0

Note: *IE – invasion extensiveness; II – invasion intensity*
Source: *developed by the authors of this study*

After the use of antiparasitic preparations, the presence of *Haemonchus* spp. eggs in the faeces of calves was detected up to 10 days. Therewith, after the administration of the preparations, the extent of *Haemonchus* spp. and *Ostertagia* spp. infestation in calves decreased by 50% as early as on Day 5. The average infestation intensity decreased by 43.3% and 92.0%, respectively, compared to the average infestation intensity before treatment. No worm eggs were found in the faeces of animals from Day 14 to Day 30 of observation, and therefore the extensional effectiveness of the products is 100%. After the administration of the preparations in goats and sheep, the extent of worm infection decreased by 50% on Day 5. The passage of mature worms was observed up to Day 3. No worm eggs were found in the faeces of animals from Day 10 to Day 30 of observation, and therefore the extensefficacy of the preparations is 100%. After the use of antiparasitic preparations in ruminants, no increased individual sensitivity was observed. Levamisole was administered individually to infested pigs (Table 8).

Table 8*. Study of the therapeutic efficacy of levamisole preparations in pigs (n = 800)*

Type of helminths	Before treatment		After treatment							
	IE, %	II, avg	Day 5		Day 10		Day 20		Day 30	
			IE, %	II	IE, %	II	IE, %	II	IE, %	II
Preparation No. 1 (n = 400)										
Ascaris suum	100	32	50	45	50	5	0	0	0	0
Oesophagostomum spp.	100	12	0	0	0	0	0	0	0	0
Strongyloides ransomi	100	40	50	48	0	0	0	0	0	0
Preparation No. 2 (n = 400)										
Ascaris suum	100	30	50	43	50	6	0	0	0	0
Oesophagostomum spp.	100	14	0	0	0	0	0	0	0	0
Strongyloides ransomi	100	43	50	49	0	0	0	0	0	0

Note: *IE – invasion extensiveness; II – invasion intensity*
Source: *developed by the authors of this study*

No individual hypersensitivity was observed in pigs after administration of levamisole preparations. Only *Ascaris suum* eggs were detected *in* the faeces of pigs up to Day 10, and an increase in the egg count in the faeces was observed on Day 5. After the administration of the preparations, the extent of worm infection in pigs decreased by 50% on Day 5. No worm eggs were found in the faeces of animals from Day 14 to Day 30 of observation, and therefore the extensional effectiveness of the products is 100%. At the next stage, the infected dogs were treated with levamisole (Table 9).

Table 9*. Study of the therapeutic efficacy of levamisole preparations in dogs (n = 10)*

Type of helminths	Before treatment		After treatment							
	IE, %	II, avg	Day 5		Day 10		Day 20		Day 30	
			IE, %	II	IE, %	II	IE, %	II	IE, %	II
Preparation No. 1 (n = 5)										
Toxocara canis	100	35	50	45	50	5	0	0	0	0
Toxascaris leonina	100	16	0	0	0	0	0	0	0	0
Ancylostoma spp.	100	25	0	0	0	0	0	0	0	0
Uncinaria spp.	100	15	0	0	0	0	0	0	0	0
Preparation No. 2 (n = 5)										
Toxocara canis	100	37	50	43	50	6	0	0	0	0
Toxascaris leonina	100	14	0	0	0	0	0	0	0	0
Ancylostoma spp.	100	23	0	0	0	0	0	0	0	0
Uncinaria spp.	100	15	0	0	0	0	0	0	0	0

Note: *IE – invasion extensiveness; II – invasion intensity*
Source: *developed by the authors of this study*

No hypersensitivity was observed in dogs after individual oral administration of levamisole preparations. Passage of mature worms in faeces was observed up to Day 3. Until Day 10, only *Toxocara canis* eggs were detected in the faeces of dogs, and an increase in the number of eggs of this helminth species in the faeces was observed on Day 5. After the administration of the preparations, the extent of worm infection in dogs decreased by 50% on Day 5. No worm eggs were found in the faeces of animals from Day 14 to Day 30 of observation, and therefore the extensional effectiveness of the products is 100%. The efficacy of levamisole preparations was also determined on infected chickens (Table 10).

Table 10*. Study of the therapeutic efficacy of levamisole preparations in chickens (n = 200)*

Type of helminths	Before treatment		After treatment							
	IE, %	II, avg	Day 5		Day 10		Day 20		Day 30	
			IE, %	II	IE, %	II	IE, %	II	IE, %	II
Preparation No. 1 (n=100)										
Ascaridia galli	100	44	50	45	0	0	0	0	0	0
Heterakis gallinarium	100	16	0	0	0	0	0	0	0	0
Capillaria spp.	100	13	50	8	50	3	0	0	0	0
Preparation No. 2 (n=100)										
Ascaridia galli	100	46	50	43	0	0	0	0	0	0
Heterakis gallinarium	100	14	0	0	0	0	0	0	0	0
Capillaria spp.	100	11	50	8	50	3	0	0	0	0

Note: *IE – invasion extensiveness; II – invasion intensity*
Source: *developed by the authors of this study*

No individual hypersensitivity was observed in chickens after oral administration with water. The passage of mature worms was observed from Day 3 to 5. An increase in the count of *Ascaridia galli* eggs in the litter was observed up to Day 5. *Capillaria* spp. eggs were *detected* in the poultry manure up to Day 10, indicating the need for repeated use of the preparation. After the application of the preparations, the extent of worm infection in chickens decreased by 50% on Day 5. From Day 14 to Day 30 of observation, no worm eggs were detected in the poultry manure, and therefore the extensional effectiveness of the products is 100% with two-time application.

Thus, the use of levamisole dosage forms in farm animals (subcutaneously or intramuscularly), carnivores and poultry (orally) on Day 5 of use reduces the intensity of infection by 50%. The highest extensefficacy (100%) of the preparations under study was recorded on Day 14 of treatment. No increased individual sensitivity to the test preparations was recorded in domestic animals and pets after the use of levamisole-based antiparasitic preparations for 30 days.

Determination of the toxicity of meat, obtained from animals treated with levamisole, using the test culture Colpoda steinii. During the study of the general toxicity of meat of calves and sheep treated with levamisole, on Days 1 and 3 of the study, toxicity of meat of animals of both experimental groups was detected. On Days 5, 7, and 9 after the application of the experimental preparations, mild toxicity of veal and lamb meat was detected, and on Day 11 no signs of toxicity were found in the meat. Toxicity was detected in meat from pigs treated with levamisole on Day 1 of the study in both experimental groups. On Days 3 and 5 of the study, pork meat showed mild toxicity, while on Days 7 and 9 after the use of the test preparations, the meat showed no signs of toxicity. In contrast to pork meat, meat obtained from chickens treated with levamisole showed mild toxicity in both experimental groups on Day 1 of the study, while no signs of toxicity were detected on Days 3 and 5 of the study. The study of the general toxicity of meat revealed the absence of toxicity in the meat of animals of the III experimental group (control) (Table 11).

***Table 11**. Results of the study of the general toxicity of meat of farm animals and poultry treated with levamisole-based preparations*

Type of processing	Degree of toxicity on the corresponding day of the experiment					
	Day 1	Day 3	Day 5	Day 7	Day 9	Day 11
Calves (n = 54)						
Group I	toxic	toxic	slightly toxic	slightly toxic	slightly toxic	non-toxic
Group II	toxic	toxic	slightly toxic	slightly toxic	slightly toxic	non-toxic
Group III	non-toxic	non-toxic	non-toxic	non-toxic	non-toxic	non-toxic
Sheep (n = 54)						
Group I	toxic	toxic	slightly toxic	slightly toxic	non-toxic	non-toxic
Group II	toxic	toxic	slightly toxic	slightly toxic	non-toxic	non-toxic
Group III	non-toxic	non-toxic	non-toxic	non-toxic	non-toxic	non-toxic
Pigs (n = 45)						
Group I	toxic	slightly toxic	slightly toxic	non-toxic	non-toxic	experiment stopped
Group II	toxic	slightly toxic	slightly toxic	non-toxic	non-toxic	experiment stopped
Group III	non-toxic	non-toxic	non-toxic	non-toxic	non-toxic	experiment stopped
Chickens (n = 45)						
Group I	slightly toxic	non-toxic	non-toxic	experiment stopped		
Group II	slightly toxic	non-toxic	non-toxic	experiment stopped		
Group III	non-toxic	non-toxic	non-toxic	experiment stopped		

***Source:** developed by the authors of this study*

Thus, the results of the general toxicity studies indicate the danger of animal meat after treatment with experimental preparations No. 1 and No. 2. Slaughter of animals for meat is possible on Day 11, and poultry – on Day 3 after the use of preparations in experimental therapeutic doses. Modern antiparasitic preparations are used in the veterinary practice of veterinarians in various forms and have different active substances and excipients. However, the issue of acquired resistance of parasites to anthelmintic preparations poses a serious threat to animal welfare and is manifested primarily by a decrease in animal growth and productivity.

According to J. Charlier *et al*. (2023), sheep/goat nematodes are highly resistant to imidazothiazoles (levamisole), providing high therapeutic efficacy. H. Mohseni *et al*. (2019) investigated the therapeutic efficacy of levamisole (7.5 mg/kg) and albendazole (7.5 mg/kg) against gastrointestinal worms in sheep and found an average efficacy of 44% and 46%, respectively. The determined efficacy indices obtained in the study demonstrate low efficiency, specifically, of levamisole, against gastrointestinal worms in sheep. E.D. van Asselt *et al*. (2018), I. Bagulo *et al*. (2023), studying the effectiveness of different groups of anthelmintic preparations (levamisole at a dose of 0.5 ml/20 kg, albendazole 2.5% at a dose of 2 ml/10 kg, ivermectin 1% at a dose of 1 ml/50 kg) against strongyloidiasis in sheep, prove the high efficiency of levamisole – 95.4%, compared to albendazole (86.2%) and ivermectin (89.8%).

The findings of A.V. Potârniche *et al*. (2021) and M. Mickiewicz *et al*. (2021) suggest the spread of anthelmintic resistance of gastrointestinal nematodes of goats in Romania and Poland to benzimidazoles and macrocyclic lactones and prove their sensitivity exclusively to levamisole, which stopped the development of helminth larvae by 87-100%. Investigating the efficacy of treatment of chickens infected with gastrointestinal nematodes, S.A. Soudkolaei *et al*. (2021) used levamisole at a dose of 16 mg/kg and fenbendazole at a dose of 5 mg/kg for 3 days and proved the efficacy of both anthelmintics. However, the findings of the study showed that fenbendazole (83.7%) was a better and more efficacious deworming agent than levamisole (71.8%).

T. Feyera *et al*. (2021) evaluated the anthelmintic efficacy of levamisole (28 mg/kg), piperazine (100 mg/kg), and fenbendazole (10 mg/kg) against a field strain of *A. galli*, recovered after treatment of poultry with levamisole. It was found that the efficacy of oral administration of levamisole was 99.1%, which was higher than that of other anthelmintics (piperazine – 96.3%, fenbendazole – 97.2%). A. Atta *et al*. (2022) found that the therapeutic level of levamisole persists in the body of animals for 6...9 hours.

When studying the residual content of levamisole in the muscle tissues of laying hens using Nilverm 7.5% at a dose of 20 mg/kg, B. Solomun Kolanović *et al*. (2019) found maximum concentrations of 78.0 µg/kg in the pectoralis muscle and 70.7 µg/kg in the thigh muscle on the first day after preparation administration. Subsequently, a gradual decrease in the residual content of levamisole was observed and the half-life was 3.5 and 3.4 days, respectively, while the period of complete elimination was 14.5 and 13.0 days. P. Cascardo *et al*. (2021) investigated the timing of levamisole residues elimination from the tissues of animals treated with levamisole (10% solution per os at a dose of 10 mg/kg body weight for cattle, sheep, goats, and pigs, and 20 mg/kg for chickens) to a safe level. It was found that in poultry after 3 days, in pigs after 7 days, and in cattle, sheep, and goats after 14 days after treatment, the preparation residues in muscle tissues were below the established limit value.

CONCLUSIONS

It was found that nematode infections are quite widespread in livestock farms in the Kharkiv region of Ukraine. The extent, intensity of infection, and species composition of helminths varies depending on the animal species. The highest prevalence of infection among farm animals was found in goats – 60%. In chickens, the extent of infection was 44.4%, in pigs and sheep – 34.8% and 33.3%, respectively. The lowest extent of infection was found in calves – 28.6%.

In goats, *Trichostrongylus* spp., *Nematodirus* spp., *Cooperia* spp. were found to be infected and the intensity of infection was 10.0...50.0 helminth eggs per 1 g of faeces; in chickens – *Ascaridia galli, Heterakis gallinarium, Capillaria* spp. with an intensity of infection of 10.0...45.0; in pigs – *Ascaris suum*, *Oesophagostomum* spp, *Strongyloides ransomi* with an infection rate of 15.0...45.0; in sheep and calves – *Haemonchus* sp., *Nematodirus* spp., *Ostertagia* spp., and an infection rate of 25.0 and 25.0...150.0 helminth eggs per 1 g of faeces, respectively. In dogs, the infection rate of *Toxocara canis, Toxascaris leonina, Ancylostoma* spp. and *Uncinaria* spp. was found; the extensive infection rate was 66.7% and the intensity of infection was 15.0...35.0 worm eggs per 1 g of faeces.

It was found that anthelmintic preparations with the active ingredient levamisole showed a pronounced therapeutic effect in the treatment of nematode infections in animals. The use of levamisole preparations according to the proposed regimens on Day 5 of the study reduced the extent of the infection by 50%, and starting from Day 14, no helminth eggs were detected in the faeces of animals. During the study period, no deterioration in clinical condition or side effects were observed in animals treated with preparations No. 1 and No. 2. It was found that poultry meat on Day 3, pig meat on Day 7, and meat of calves and sheep on Day 11 after treatment with levamisole showed no signs of toxicity and could be sent for processing by meat market operators.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Ефективність використання ангельмінтиків на основі левамізолу

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Анотація. Паразитарні захворювання тварин наносять великі збитки галузі тваринництва та потребують постійного моніторингу та боротьби. Метою роботи було провести моніторинг поголів'я тварин (телят, кіз, овець, свиней, собак, курей) на наявність збудників гельмінтозів, визначити терапевтичну ефективність препаратів на основі левамізолу та загальну токсичність м'яса дослідних тварин за використання тест-культури Colpoda steinii. У період 2020-2022 років виявлено значне поширення інвазійних захворювань тварин в Харківській області України. При дослідженні 3500 голів телят у 1000 (28.6 %) було встановлено стійку інвазованість нематодами з інтенсивністю від 25.0 до 150.0 яєць гельмінтів в 1 г фекалій. У кіз інтенсивність інвазії ендопаразитами складала від 10.0 до 15.0 яєць гельмінтів в 1 г фекалій, тоді як у овець цей показник сягав 25.0 яєць гельмінтів в 1 г фекалій. При дослідженні фекалій від свиней у 800 (34.8 %) пробах виявлено наявність яєць гельмінтів, при цьому моноінвазію виявлено в 300 пробах (37.5 %). При дослідженні фекалій від собак було виявлено 10 (66.7 %) позитивних проб. При дослідженні посліду від курей у 200 (44.4 %) позитивних проб встановлено наявність яєць гельмінтів. Застосування препаративних форм левамізолу дозволяє знизити екстенсивність інвазії у тварин на 50 % вже на 5 добу. Із 14 доби по 30 добу спостереження в фекаліях тварин яєць гельмінтів не виявляли, отже екстенсефективність досліджуваних засобів у сучасних умовах складає 100 %. М'ясо, отримане від сільськогосподарських тварин (свиней, телят, овець) оброблених препаратами на основі левомізолу проявляє ознаки загальної токсичності протягом 5-9 діб після застосування препаратів: 5 діб – для свиней та 9 діб – для телят та овець. У той же час, м'ясо отримате від птиці (курчат) обробленої препаратами на основі левомізолу проявляє ознаки загальної токсичності протягом 2 діб після закінчення курсу лікування

Ключові слова: левамізол; ендопаразити; яйця гельмінтів; протипаразитарний засіб; екстенсивність та інтенсивність інвазії; м'ясо; токсичність

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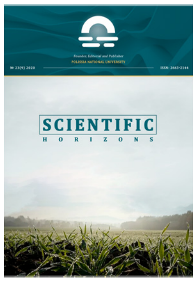

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Ecological plasticity, stability, and nitrogen-fixing capacity of edible bean cultivars in the Forest-Steppe of Ukraine

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Abstract. The purpose of this study was to investigate the influence of climatic conditions of the research years on changes in productivity and environmental plasticity and stability of edible bean cultivars. Furthermore, the study investigated the nitrogen-fixing potential of edible bean cultivars for the biologisation of agriculture. The study was conducted in the conditions of the educational and production department of the Uman National University of Horticulture during 2020-2022, using nine cultivars of edible beans. Standard methods of statistical analysis were used to

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study the parameters of adaptive variability. As a result of the comparative study, the characteristics of various parameters of the adaptive potential of edible bean cultivars were established by the following traits: the onset of the technical ripeness phase: Bianco and Extra Grano Violetto – 78 days. The cultivars Windsor Broad (16.42 t/ha), Bianco (13.73 t/ha), and Svitiaz (11.51 t/ha) stood out in terms of yield and adaptability in the technical ripeness phase, the cultivars Bacchus (1.92 t/ha) and Svitiaz (1.90 t/ha) – in terms of yield and adaptability in the biological ripeness phase; cultivars with high protein content in immature grain: Karmazin (12.77 g/100 g), Windsor Broad (13.51 g/100 g), Bianco (14.30 g/100 g), and Green lowland (14.43 g/100 g); cultivars with high nitrogen-fixing capacity: Ukrainian Sloboda (67.7 kg/ha), Windsor Broad (71.0 kg/ha), and Extra Grano Violetto (75.7 kg/ha). The results of the statistical analysis showed a significant influence of environmental conditions on the formation of productivity indicators of edible bean cultivars and a greater dependence on environmental conditions (CVA = 10.40-82.7%) than on the genetic component (CVG = 5.76-39.7%). The data suggest a tendency for yields to be inversely related to yield stability, with low-yielding cultivars showing stability and high-yielding cultivars showing instability. The presented findings suggest an idea of the change in the productivity parameters of edible beans under contrasting weather conditions, which makes it possible to identify cultivars with high productivity for food purposes and with a higher proportion of high-protein and energy-rich consumer products. Cultivars with increased nitrogen-fixing capacity were identified, which will help reduce the use of synthetic fertilisers

Keywords: yield; adaptability; seeds; nutritional value; protein content

INTRODUCTION

An analysis of the raw material base for food and feed production in Ukraine and variants for its development in the future shows the need to solve the problem of plant protein, primarily by expanding the area under legumes, increasing their protein content, and increasing yields through the selection and zoning of cultivars based on the above parameters. D. Cammarano *et al.* (2023) note that despite the improved functioning of agrocenoses and the benefits to human and livestock health, legumes are currently underutilised in most countries.

According to EUROSTAT (2022), among legume species, bean (*Vicia faba* L.) occupied 21% of the area under legumes in Europe in 2020 and was the main legume grown in, for instance, Denmark, Italy, and the UK. The findings of T. Aybegün (2021), inform that the small area of cereal legumes cultivation in Europe has been unchanged for many decades due to specialisation, market competitiveness, low yield stability, and lack of evidence of the benefits of legumes in the farming system. As a result, Europe imports 70% of its protein, primarily soy, from other regions to meet demand. Beans are a cold-tolerant crop and grow best in cool and moist conditions, making them a very attractive legume for cooler climates where soybeans do not always produce high yields (Duc *et al.,* 2015). Beans show good potential for use in the feed and processing industry due to their higher protein content than other common legumes such as peas (Animal Feed Resources Information System, n.d.).

Studies by W. Nelson *et al.* (2021) and C. Pankou *et al.* (2022) found that the selection and zoning of relevant cultivars substantially affect the productivity of the agrocenosis. According to H. Khazaei and A. Vandenberg (2020), A. Warsame *et al.* (2020) and J. Marshall *et al.* (2021), it is known that edible bean seeds are a rich source of protein, starch, dietary fibre, minerals, and vitamins and are widely grown for food, feed, and green manure worldwide.

H. Khazaei *et al.* (2021) notes that the use of legumes in conventional farming systems forms a symbiosis with nodule-forming bacteria that have nitrogen-fixing capacity, which increases yields and also contributes to agricultural sustainability through soil improvement. R.W. Neugschwandtner *et al.* (2023) point out that compared to other legumes, edible beans are considered an excellent protein crop because of their ability to provide nitrogen in temperate agricultural systems and because of their wide adaptability.

The conclusions drawn by V. Greveniotis *et al.* (2023) indicate that the yields of beans, like most legumes, are considered to be unstable. S.G. Tadesse *et al.* (2023) notes that this volatility is largely explained by the sensitivity of beans to drought and rainfall fluctuations. To make edible beans a more attractive crop for farmers, zoning for cultivars with high seed yields and the desired consistency of high yields is essential. The findings presented by D.N. Chiara *et al.* (2023) make it clear that yield stability can be investigated as the ability of some genotypes to perform consistently in a wide range of environments. S.G. Tadesse *et al.* (2023) report that there are different varieties of beans adapted to grow in a wide range of environments, including areas with cool climates and short growing seasons in the north and subtropical conditions in the south.

E. Sufar *et al.* (2024) noted that the grain yield of beans grown in long-term experiments in the UK, Sweden, and Germany ranged within 2.1-3.0 t/ha, which was on average 50% lower than that of cereals. However, when legume seeds were compared to spring cereals, the differences in performance were less pronounced in terms of yield stability. This should be considered when assessing the productivity of legumes, with the need to fill the existing knowledge gap on the effectiveness of legume productivity management and its impact on the ecosystem. J. Zhao *et al.* (2022) notes that it is necessary to include beans in crop rotations because of their biological nitrogen fixation. This reduces the need for nitrogen fertiliser and increases the overall efficiency of nitrogen fertiliser use in the farming system by potentially increasing the yield of subsequent crops.

The purpose of this study was to investigate the possibility of growing edible beans for green beans and seeds in the Forest-Steppe of Ukraine, the parameters of their adaptive capacity in terms of productivity and nitrogen-fixing capacity for biologisation of the agricultural sector. And replacing some of the soybean imports in European countries with locally produced beans will benefit not only the environment but also the national economy.

MATERIALS AND METHODS

The study was conducted in 2020-2022 at the experimental plots of the Department of Vegetable Growing and the Department of Plant Growing of the Uman National University of Horticulture. Geographical coordinates in Greenwich Mean Time: 48°46' north latitude, 30°14' east longitude and 245 m above sea level. The soil of the experimental plot was podzolised heavy loamy chernozem (World Reference Base, n.d.). The meteorological data base was the Uman weather station. An analysis of the climatic conditions during the study period showed a significantly higher precipitation rate in 2021 compared to long-term data for 2020 and 2022. The analysis of the temperature regime revealed an elevated temperature background in 2021, but there was no significant impact due to sufficient precipitation (Fig. 1).

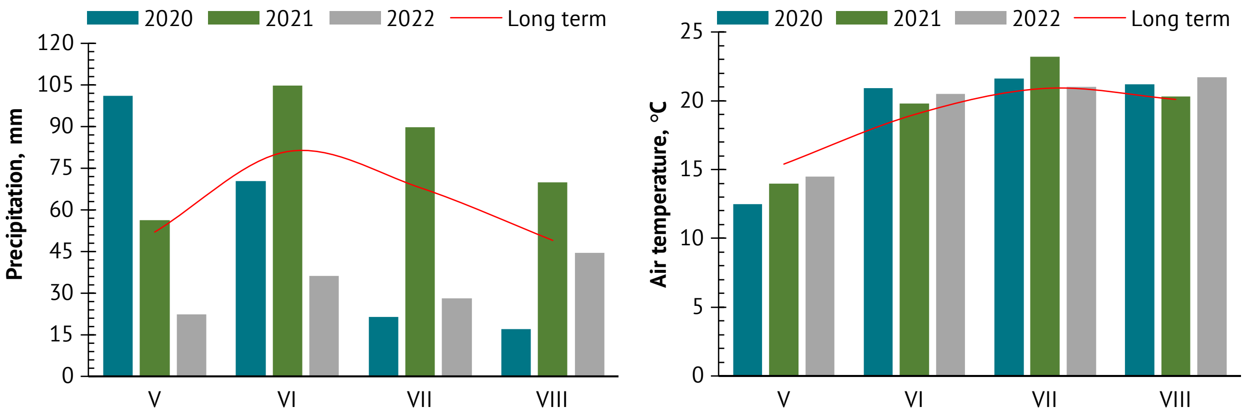


***Figure 1**. Climate map for the research period according to the data of the Uman weather station (2020-2022)*
***Source:** based on data from the Uman weather station*

Growth and development parameters of edible bean cultivars were determined on 100 typical plants. All measurements and studies were performed at the stage of technical maturity of the beans (BBCH 80), and seed yield was determined at the BBCH 99 stage. The study was conducted following the provisions of the Convention on Biological Diversity (1992).

The adaptive and productive potential of edible beans was studied according to a scheme that included nine cultivars of edible bean: Karadag, Ukrainian Sloboda, Bacchus (State register of plant cultivars suitable for dissemination in Ukraine, n.d.), Windsor Broad, Karmazin, Green lowland, Svitiaz, Bianco, Extra Grano Violetto. The Karadag cultivar was taken as the standard (st), as it was the most tested at the time of the study. The cultivation technology was generally accepted for the conditions of the Forest-Steppe. The cultivars were sown using the systemic method, and the repetition of the experiment was fourfold. The area of the experimental plot was 10 m^2. Seeds were sown in the second decade of April according to the scheme of 45×10 cm (222,000 pcs/ha). The predecessor was winter garlic.

Leaf area was determined according to the "notching" method using the formula:

$$S = \frac{K+Y}{P} \cdot B, \quad (1)$$

where S is the leaf surface area, cm^2; K is the number of notches, pcs; Y is the area of one notch, cm^2; P is the weight of notches, g; B is the weight of leaves, g.

Yield accounting was carried out following DSTU ECE LLC FFV-06:2007 (2008), a method of separate weighing during the period of technical ripeness with the division of products into standard and non-standard. The average weight of green beans was determined according to the weight method. The biochemical composition of green beans was determined in the laboratory of mass analysis of the Uman National University of Horticulture:

- dry residue in the beans – by drying at 105°C in a drying oven SNOL58/350A (Ukraine) according to DSTU 7804:2015 (2015);
- protein content – by the Kjeldahl method, according to DSTU ISO 5983-2003 (2004);

- the number and weight of rhizobia on plant roots and the content of legoglobin (leghaemoglobin) were determined according to the method of G.S. Posypanov (1991), the amount of fixed nitrogen – according to M. Unkovich *et al*. (2008). The parameters of total and active symbiotic potential (ASP) were used to determine the symbiotic productivity, which was calculated using the following formula:

$$ASP = M_1 + M_2 \cdot T, \quad (2)$$

where T is the period between two adjacent periods of analysis, days; $M_1 + M_2$ is the average mass of nodules with legoglobin for the period T, kg/ha.

The results were systematised using the rank classification of genotypes by using the ratio of plasticity (bi) and stability $\sigma^2 d$ parameters according to L. Biliavska *et al*. (2021) and S. Eberhart and W. Russell (1966).

Homeostaticity (Hom) was calculated according to the following formula:

$$H_{om} = \frac{\overline{x^2}}{\sigma}, \quad (3)$$

where $\bar{x}$ is the arithmetic mean of the grade; σ is the generalised standard deviation.

The selection value of a genotype was calculated using the following formula:

$$(S_C) = \bar{X} \cdot \frac{\bar{X}_{lim}}{\bar{X}_{opt}}, \quad (4)$$

where $\bar{X}$ is the arithmetic mean of the grade; $\bar{X}_{lim}$ is the limited arithmetic mean; $\bar{X}_{opt}$ – is the optimised arithmetic mean.

The multiplicative coefficient (MC) of the trait was calculated by the following formula:

$$MC = \frac{\bar{X}i + bi \cdot yi}{Xi}, \quad (5)$$

where $\bar{X}i$ is the average value of the studied trait in the i^{th} cultivar; bi is the linear regression coefficient of the i^{th} cultivar; yi is the average value for all averages for all cultivars yi for each j^{th} experiment point.

The environmental plasticity index (EPI) was calculated using the following formula:

$$EPI = \frac{\left(\frac{YV_1}{ATV_1} + \frac{YV_2}{ATV_2} + \dots + \frac{YV_n}{ATV_n}\right)}{n}, \quad (6)$$

where YV_1, YV_2, YV_n are the values of the trait in the cultivar in different years of testing; ATV_1, ATV_2, ATV_n are the average trait values of the cultivars in each of the experimental variants.

The annual adaptability coefficient (AC) was calculated using the following formula:

$$AC = \frac{(Xij) \cdot 100 \cdot X)}{100}, \quad (7)$$

where Xij is the yield of a particular cultivar in the year of testing; X is the average yield of the year.

The absolute average adaptability coefficient (AAC) was calculated for a cultivar using the following formula:

$$AAC = \frac{(XiC) \cdot 100 \cdot Xm)}{100}, \quad (8)$$

where Xic is the average yield of the cultivar over the years of testing; Xm is the multi-year average yield of the cultivar.

Stress resistance and compensatory capacity of cultivars were calculated according to A.A. Rossielle ***and*** J. Hemblin (1981):

$$SR = Y_{min} - Y_{max}; \quad (9)$$

$$CC = \frac{Y_{min} + Y_{max}}{2}, \quad (10)$$

where Y_{min} *and* Y_{max} is the minimum and maximum values of the cultivar trait.

The experiments were conducted to determine the phenotypic, genotypic, and ecological variability of cultivars using the following formulas:

- Genetic variance:

$$\sigma_G^2 = \frac{GM_t - GM_e}{r}, \quad (11)$$

- Environmental variance:

$$\sigma_A^2 = GM_e, \quad (12)$$

- Phenotypic variance:

$$\sigma_F^2 = \sigma_G^2 + \sigma_A^2, \quad (13)$$

- Genotypic variation coefficient:

$$\frac{\sqrt{\sigma_G^2 \cdot 100}}{\bar{X}}, \quad (14)$$

- Phenotypic variation coefficient:

$$\frac{\sqrt{\sigma_F^2 \cdot 100}}{\bar{X}}, \quad (15)$$

- Environmental variation coefficient:

$$\frac{\sqrt{\sigma_A^2 \cdot 100}}{\bar{X}}, \quad (16)$$

where is the generalised root mean square value of the population trait; is the generalised root mean square error; r is the number of repetitions.

Statistical processing of the data was performed using the arithmetic mean (x) and standard deviation (SD) calculated using Microsoft Excel 2019. Correlations were calculated using Statistica 12 software and analysed using the Chaddock scale.

RESULTS AND DISCUSSION

The introduction of high-quality, disease-resistant cultivars allows increasing yields and product quality at no additional cost. However, high productivity is not always possible when using valuable cultivars from other climatic zones. The principal difficulty in expanding the cultivation area of such cultivars is that those created in another zone and showing high productivity there are unsuitable for introduction, and therefore each cultivation region must have its varietal composition adapted to local soil and climatic conditions and resistant to major diseases.

Beans are a plant with a high environmental sensitivity to changes in soil and climatic conditions, which responds to climate, soil, water, and nutrient conditions. In cultivars, the duration of the flowering–technical maturity period is mainly controlled by the genotype, and therefore the duration of this period is considered during selection. In case of the Forest-Steppe zone, due to the climate, addressing the issue of early maturity of bean cultivars is also important. Studies have found that the period from germination to flowering is more constant and characteristic than the period from sowing to full maturity. The optimised length of day for vegetative and reproductive development does not coincide: for the former, the optimised length is 12 hours, for the latter – 18 hours. All forms of beans grown in Ukraine are long-day plants, and therefore their growing season is shortened moving north.

The cultivars under study, according to the classification of C. Francis *et al.* (2000), were divided into two maturity groups: mid-early and mid-ripening. The duration of the period from germination to the onset of technical ripeness in the experiments varied insignificantly depending on the agrometeorological conditions of the year and averaged 78 days for early-ripening forms, 93-94 days for mid-early forms, 97-105 days for mid-ripening forms; the duration of the growing season in the experiments also varied insignificantly and averaged: 93-98 days for early-ripening forms, 113-118 days for mid-early forms, 118-124 days for mid-ripening forms. The majority of the collection under study included samples from the mid-early group – 33% (Svitiaz, Karmazin, Windsor Broad) and from the mid-ripening group – 44% (Green lowland, Bacchus, Ukrainian Sloboda, and Karadag), while the early-ripening cultivars accounted for only 22%, or two cultivars – Bianco and Extra Grano Violetto (Fig. 2).

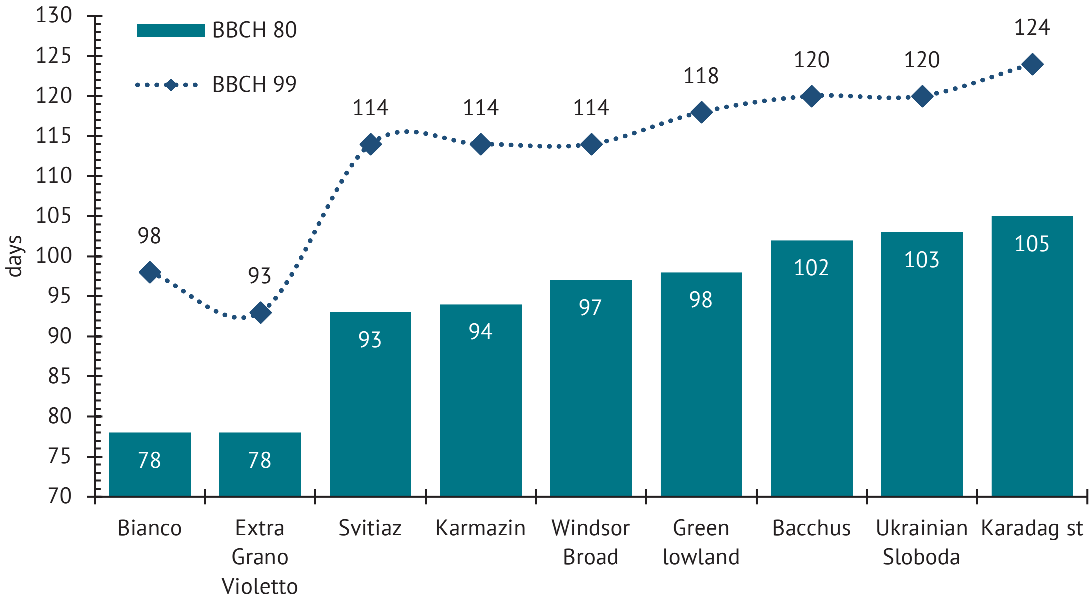


Figure 2. *Duration of periods from germination to technical/biological maturity of edible bean cultivars (2020-2022)*
Note: ** – st – standard*
Source: *obtained as a result of the present study*

Depending on the conditions of the year, most of the individual performance indicators varied greatly. The number of shoots varied from 34-56%, which is explained by the fact that in 2022 the minimum number of shoots was 1 pcs./plant, only in the Bacchus cultivar – 2 pcs./plant, while in 2020 and 2021 their number was at 3-6 pcs./plant. On average, the largest number of shoots was formed by plants of the cultivars Bacchus, Karmazin, Bianco, and Extra Grano Violetto – 3.67 pcs./plant, which is 22.2% more than the standard.

The number of beans per plant is one of the indicators that is influenced by environmental factors and is only 45% determined by varietal characteristics. It is one of the main quantitative traits of pulses that is responsible for their seed yield. Plants of Bacchus and Karmazin cultivars produced a significantly higher number of beans – 10.33 and 9.33 pcs./plant, respectively, which is 34.8% and 21.7% more than the standard. The cultivars Ukrainian Sloboda, Windsor Broad, Green lowland, Bianco, and Extra Grano Violetto formed 6.0-7.3 pcs./plant, which is 4.3-21.7% less than the standard, or 0.33-1.67 pcs. The cultivars Bacchus and Karmazin, selected for this trait, are recommended as sources for breeding to increase the number of beans per plant (Table 1).

***Table 1**. Parameters of individual productivity of different cultivars of edible bean (BBCH 80), (2020-2022), (Lim ± SD)*

Cultivar	Shoots, pcs./plant		Beans, pcs./plant		Seeds, pcs./bean	
	Lim±SD	CV, %	Lim±SD	CV, %	Lim±SD	CV, %
Karadag st	1-5 ± 1.6	54	2-12 ± 4.2	55	2-3 ± 0.5	20
Ukrainian Sloboda	1-5 ± 1.6	54	2-12 ± 4.1	58	2-3 ± 0.5	20
Windsor Broad	1-5 ± 1.7	51	2-12 ± 4.1	56	2-4 ± 0.5	14
Bacchus	1-5 ± 1.2	34	4-15 ± 4.6	45	2-4 ± 0.8	27
Karmazin	1-6 ± 2.1	56	3-13 ± 4.5	48	2-3 ± 0.5	18
Green lowland	1-4 ± 1.2	47	2-10 ± 3.3	54	2-3 ± 0.5	18
Svitiaz	1-4 ± 1.4	47	2-15 ± 5.4	59	4 ± 0	0
Bianco	1-5 ± 1.9	51	2-12 ± 4.1	62	4 ± 0	0
Extra Grano Violetto	1-6 ± 2.1	56	3-10 ± 2.9	42	3-4 ± 0.5	13
$\bar{X}$	3		8		3	
σ^2_G	0.94		5.84		0.07	
σ^2_F	3.89		25.18		0.69	
σ^2_A	2.95		19.34		0.62	
CVG, %	29.39		30.93		8.75	
CVP, %	59.81		64.21		26.73	
CVA, %	52.10		56.27		25.25	
CVG/CVA	0.56		0.55		0.35	

Note: ** – st – standard*
Source: *obtained as a result of the present study*

Analysing the number of seeds in one bean, the Svitiaz and Bianco cultivars were distinguished, where this trait did not change over the years – 4 pcs./bean. Overall, the variation in this trait was 13-27%. The number of seeds per bean was significantly higher than the standard in Windsor Broad – 3.33 pcs., Bacchus – 3.0 pcs., Extra Grano Violetto – 3.67 pcs., and Svitiaz and Bianco – 4 pcs. each, respectively. The selected cultivars Svitiaz and Bianco are recommended as sources for breeding to increase the number of seeds per bean.

Statistical analysis of the formation of individual productivity indicators confirmed a strong dependence on environmental conditions with a significantly higher environmental variation coefficient (CVA) = 25.25-56.27% compared to the genetic variation coefficient (CVG) = 8.75-30.93%. According to the trait "weight of beans per plant", two cultivars were identified on average over three years – Windsor Broad and Bianco, which significantly outperformed the standard. The Karmazin, Svitiaz, and Extra Grano Violetto cultivars produced a less significant weight of beans. The cultivars Ukrainian Sloboda and Bacchus produced a slightly lower mass of beans per plant, while the cultivar Green lowland produced a significantly lower mass than all the cultivars under study.

The genetic-statistical analysis of this trait showed that the most stable (according to the set of indicators σ^2d and MC, Hom) was the Green lowland cultivar (σ^2d – 5.19; MC – 1.82; Hom – 50.1), but the cultivar was characterised by low breeding value (Sc = 79.9). According to the indicators of the ratio of plasticity (bi) and stability σ^2d parameters, all studied Windsor Broad, Svitiaz, and Bianco cultivars had indicators bi > 1, σ^2d > 0 – i.e., they have better results under favourable growing conditions. Cultivars Karadag st, Ukrainian Sloboda, Bacchus, Karmazin, Green lowland, and Extra Grano Violetto had indicators bi < 1, σ^2d > 0, i.e., they have better results under unfavourable conditions, and thus are unstable. According to the environmental plasticity coefficient (bi > 1), Windsor Broad, Svitiaz, and Bianco are highly plastic, and all other cultivars are relatively stable or low plastic (bi < 1).

High selection value (Sc) and compensatory ability (CC) were characterised by the cultivars Windsor Broad and Bianco, which outperformed all other cultivars in these parameters. The most stress-resistant cultivars were Green Lowland and Extra Grano Violetto. The least stress-resistant cultivars were Windsor Broad, Svitiaz, and Bianco. High adaptive capacity for this trait was characterised by cultivars Windsor Broad, Svitiaz, Bianco, in which AAC was greater than 1 (Table 2).

Table 2. Parameters of adaptive capacity and breeding value of edible bean cultivars according to the trait "bean weight", g/plant, (BBCH 80), (2020-2022)

Cultivar	Bean weight, g/plant	σ^2d	bi	Hom	Sc	MC	EPI	SR	CC	AAC
Karadag st	75.12	6.13	0.76	83.3	103.0	1.87	0.90	-87	60	0.88
Ukrainian Sloboda	73.52	5.92	0.68	78.7	100.1	1.80	0.90	-78	56	0.86
Windsor Broad	123.65	9.67	1.94	241.8	175.5	2.29	1.28	-225	130	1.50
Bacchus	72.60	5.79	0.68	75.3	97.9	1.81	0.90	-78	58	0.84
Karmazin	84.40	6.10	0.75	100.1	112.9	1.77	1.06	-86	66	0.97
Green lowland	59.77	5.19	0.56	50.1	79.9	1.82	0.75	-64	49	0.68
Svitiaz	87.33	8.25	1.38	117.9	122.5	2.32	0.92	-160	95	1.05
Bianco	103.57	8.52	1.53	168.3	146.4	2.22	1.10	-177	104	1.25
Extra Grano Violetto	88.73	5.79	0.71	99.2	112.4	1.74	1.20	-45	95	0.96
$\bar{X}$	77.66									
σ_G^2	950.7									
σ_F^2	4126.1									
σ_A^2	3175.4									
CVG, %	39.7									
CVP, %	82.7									
CVA, %	72.6									
CVG/CVA	0.55									

Note: ** – st – standard*
Source: *obtained as a result of the present study*

Structural analysis of the ratio of green bean weight to total bean weight showed that only four cultivars produced green bean weight greater than the weight of bean valves: Windsor Broad (97.62 g/plant or 78.9% of the total bean weight); Bacchus (44.27 g/plant or 61.0% of the total bean weight); Bianco (57.88 g/plant or 55.9% of the total bean weight), and Svitiaz (47.76 g/plant or 54.7% of the total bean weight), all other cultivars under study formed grains weighing less than 50% of the total bean weight (Fig. 3).

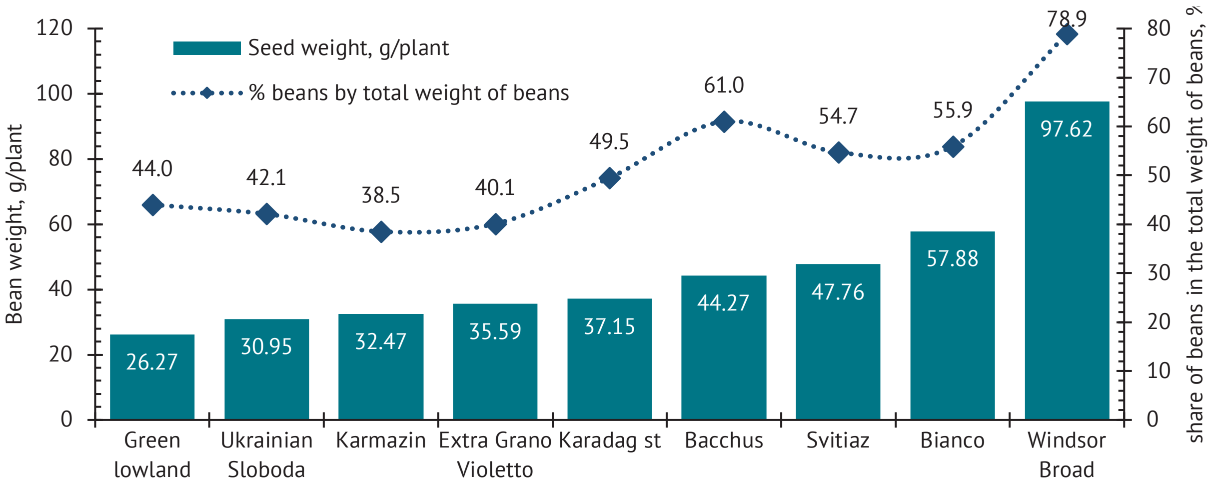


Figure 3*. The ratio of green bean weight (g/plant) to the total weight of edible beans, %, (BBCH 80), (2020-2022)*
Note: ** – st – standard*
Source: *obtained as a result of the present study*

The Ukrainian Sloboda, Karmazin, Green lowland, and Extra Grano Violetto cultivars were characterised by a lower ratio of green bean weight to total bean weight compared to the standard. The generalised weight ratio of green seeds to bean shells showed a 52% advantage for seeds. That is, the so-called "kitchen waste" will account for 48% of the total weight of the edible bean crop on average. The distribution of green bean yields by year showed that the most productive year was 2021, where this indicator varied within 11.20-33.80 t/ha (CV = 42%). Windsor Broad, Svitiaz, and Bianco significantly outperformed the standard, while all other cultivars had yields slightly higher than the standard (Table 3).

***Table 3**. Yield of green beans of edible bean cultivars, t/ha, (BBCH 80), (2020-2022)*

Cultivar	2020	2021	2022	$\bar{X}$	SD	CV, %	K_{sfn}
Karadag st	10.20	12.00	4.37	8.86	3.26	37	2.75
Ukrainian Sloboda	10.46	11.50	4.48	8.81	3.09	35	2.57
Windsor Broad	10.91	33.80	4.56	16.42	12.56	76	7.41
Bacchus	9.62	13.50	4.92	9.35	3.51	38	2.74
Karmazin	11.16	14.70	6.14	10.67	3.51	33	2.39
Green lowland	7.48	11.20	4.37	7.68	2.79	36	2.56
Svitiaz	6.20	24.50	3.84	11.51	9.23	80	6.38
Bianco	10.30	26.80	4.08	13.73	9.59	70	6.57
Extra Grano Violetto	8.20	16.40	7.53	1=0.71	4.03	38	2.18
$\bar{X}$	9.39	18.27	4.92	10.86			
SD	1.61	7.65	1.11	2.59			
CV, %	17	42	23	24			
LSD_{05}	0.53	1.50	0.24				

***Note:** * – st – standard*
***Source:** obtained as a result of the present study*

Hydrothermal conditions in 2020 contributed to yields of 6.20-11.16 t/ha (CV = 17%). In the current year, the Windsor Broad and Karmazin cultivars yielded significantly higher yields of green beans. Weather conditions in 2022 were unfavourable for the bean harvest. This indicator varied greatly (CV = 23%), although the yield was very low – 3.84-7.53 t/ha. A statistically significant difference in yield increase was obtained in the cultivars Karmazin and Extra Grano Violetto. All other cultivars tested produced yields close to the standard and differed only slightly. On average, over the three years, bean yields ranged within 8.81-16.42 t/ha. Windsor Broad and Bianco were distinguished based on this trait. However, regardless of the growing conditions, the most productive cultivar was Windsor Broad, which gave a consistently high yield compared to other cultivars studied.

The analysis of the adaptive capacity parameters made it possible to distinguish Windsor, Svityaz, and Bianco varieties based on the ratio of plasticity (bi) and stability σ^2d parameters, which have better results under favourable growing conditions and have bi > 1, $\sigma^2d > 0$, i.e., highly plastic. The cultivars Karadag st, Ukrainian Sloboda, Bacchus, Karmazin, Green lowland, and Extra Grano Violetto had bi < 1, $\sigma^2d > 0$, i.e., they have better results under unfavourable conditions, are unstable and have low plasticity. High selection value (Sc) and compensatory ability (CC) were characterised by the cultivars Windsor Broad and Bianco, which outperformed all other cultivars in these parameters. The most stress-resistant cultivars were identified as Karadag st, Ukrainian Sloboda, and Green lowland. The least stress-resistant cultivars were Windsor Broad, Svitiaz, and Bianco. High adaptive capacity for this trait was characterised by cultivars Windsor Broad, Svitiaz, Bianco, with AAC greater than 1 (Table 4).

***Table 4**. Parameters of adaptive capacity and breeding value of edible bean cultivars for the trait "green bean yield", t/ha*

Cultivar	$\bar{X}$, t/ha	σ^2d	bi	Hom	Sc	*MC*	EPI	SR	CC	AAC
Karadag st	8.86	1.80	0.52	10.9	13.4	1.64	0.88	-8	8	0.82
Ukrainian Sloboda	8.81	1.76	0.47	10.8	13.3	1.58	0.88	-7	8	0.81
Windsor Broad	16.42	3.54	2.25	37.6	24.8	2.48	1.31	-29	19	1.51
Bacchus	9.35	1.87	0.61	12.2	14.1	1.71	0.92	-9	9	0.86
Karmazin	10.67	1.87	0.61	15.9	16.1	1.62	1.08	-9	10	0.98
Green lowland	7.68	1.67	0.50	8.2	11.6	1.71	0.77	-7	8	0.71
Svitiaz	11.51	3.04	1.62	18.5	17.4	2.53	0.93	-21	14	1.06
Bianco	13.73	3.10	1.72	26.2	20.8	2.36	1.13	-23	15	1.26
Extra Grano Violetto	10.71	2.01	0.70	16.0	16.2	1.71	1.10	-9	12	0.99
$\bar{X}$	10.86									
σ^2_G	15.0									
σ^2_F	66.5									
σ^2_A	51.6									
CVG, %	35.6									

Table 4. Continued

Cultivar	$\bar{X}$, t/ha	$\sigma^2 d$	bi	Hom	Sc	*MC*	EPI	SR	CC	AAC
CVP, %	75.1									
CVA, %	66.1									
CVG/CVA	0.54									

Note: ** – st – standard*
Source: *obtained as a result of the present study*

Seed productivity of plants is determined by a complex of morphological and physiological traits. The main ones include the number of seeds per plant, weight of seeds per plant, and thousand-kernel weight. The cultivars of edible bean under study were characterised by a strong variability of the trait "seed weight per plant", on average over the years CV ranged within 11-18%, while by cultivars over the years this indicator ranged within 27-47%. The most stable cultivars were Karmazin, Svitiaz, and Extra Grano Violetto – 27-29%, while the most volatile cultivars were Ukrainian Sloboda and Karadag – 41 and 47%, respectively. On average, over the years of the study, the most productive cultivars were Svitiaz and Bacchus – 8.33 g/plant and 8.17 g/plant, which is 20.8% and 18.4% more than the standard, respectively. Lower productivity than the standard was observed in the cultivars Ukrainian Sloboda, Green lowland, and Windsor Broad – 5.67-6.83 g/plant.

Statistical analysis of the obtained data on seed productivity of plants showed that the most stable in terms of the complex of indicators ($\sigma^2 d$ and MC, Hom) was the variety Green lowland ($\sigma^2 d$ = 1.30, MC = 1.84, Hom = 12.2) and Extra Grano Violetto ($\sigma^2 d$ = 1.39; MC = 1.76; Hom = 19.5). In terms of the ratio of plasticity (bi) and stability ($\sigma^2 d$) parameters, the cultivars Karadag st, Ukrainian Sloboda, Bacchus, and Svitiaz had a ratio of bi > 1 and $\sigma^2 d$ > 0, i.e., they show better productivity under favourable growing conditions. Cultivars Karmazin, Green Lowlands, Bianco, and Extra Grano Violetto had a ratio of indicators bi < 1, $\sigma^2 d$ > 0, i.e., more productive under unfavourable conditions, unstable. The Windsor Broad cultivar had a ratio of bi = 1, $\sigma^2 d$ > 0 – responds well to improving conditions, unstable. According to the coefficient of environmental plasticity (bi), the Karadag, Bacchus, and Svitiaz cultivars are classified as highly plastic, or intensive, while the Karmazin, Green lowland, Bianco, and Extra Grano Violetto cultivars are classified as low plastic. The statistical data suggest a significant influence of growing conditions on the productivity of edible bean cultivars and a greater dependence on environmental conditions (CVA = 37.2%) than on the genetic component (CVG = 20.4) and a rather high CVG/CVA ratio of 0.55 (Table 5).

Table 5*. Parameters of adaptive capacity and breeding value of edible bean cultivars based on the trait "seed weight", g/plant*

Cultivar	$\bar{X}$, g/plant	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	AAC
Karadag st	6.90	1.81	1.35	18.1	6.7	2.39	0.92	-8	7	0.98
Ukrainian Sloboda	5.93	1.57	1.02	13.4	5.7	2.21	0.82	-6	6	0.84
Windsor Broad	6.83	1.57	1.01	17.7	6.6	2.05	0.96	-6	7	0.97
Bacchus	8.17	1.77	1.28	25.3	7.9	2.11	1.13	-8	8	1.15
Karmazin	7.33	1.45	0.86	20.4	7.1	1.83	1.06	-5	7	1.04
Green lowland	5.67	1.30	0.67	12.2	5.5	1.84	0.83	-4	6	0.80
Svitiaz	8.33	1.70	1.19	26.4	8.0	2.01	1.17	-3	8	1.18
Bianco	7.33	1.43	0.84	20.4	7.1	1.81	1.07	-5	8	1.04
Extra Grano Violetto	7.17	1.39	0.77	19.5	6.9	1.76	1.04	-5	7	1.01
$\bar{X}$	7.07									
σ^2_G	2.08									
σ^2_F	9.01									
σ^2_A	6.93									
CVG, %	20.4									
CVP, %	42.4									
CVA, %	37.2									
CVG/CVA	0.55									

Note: ** – st – standard*
Source: *obtained as a result of the present study*

The Svitiaz and Green lowland cultivars stood out in terms of stress resistance (SR), which suggests their high productivity under optimised growing conditions, as the cultivars with the highest and lowest productivity stood out. In terms of compensatory capacity (CC), the cultivars under study were characterised as quite stable, which allows them to be classified as plastic cultivars. According to the trait "seed weight", the most adaptive cultivars with an adaptation coefficient (AAC) greater than 1 were identified – Bacchus and Svitiaz, cultivars Karmazin, Bianco, and Extra Grano Violetto, which are medium adaptive, and cultivars Karadag, Ukrainian Sloboda, Windsor Broad, and Green lowland, which are classified as low adaptive.

In the conditions of the Right-Bank Forest-Steppe, beans are a rare crop, and there is no data on varietal characteristics of productivity formation. The findings of the study showed an average yield variation of 12%, although the cultivars varied by year within 21-34%. The optimised conditions for the formation of productivity of edible bean cultivars were characterised by 2021, where seed yields ranged within 1.60-2.56 t/ha. The most productive cultivars were Bacchus and Svitiaz, where this indicator was higher than the standard by 16.4% or 0.36 t/ha and 10.0% or 0.22 t/ha, respectively. In 2020, average data on vegetable bean yields were obtained, but the variation was the largest – CV = 16%. In the current year, the cultivars that significantly outperformed the standard were Bacchus and Svitiaz (+0.55 t/ha or 34.4%). Vegetable bean plants were the least productive in 2022, due to dry conditions during the growing season. IN the current year, the yield varied little, with a CV of 9%, but most cultivars were significantly more productive than the standard, with Karmazin (+0.21 t/ha or 23.3%), Svitiaz (+0.23 t/ha or 25.6%), and Extra Grano Violetto (+0.22 t/ha or 24.4%) standing out. The analysis of the average seed yields of edible bean cultivars showed that all cultivars had a comparable variation of data and significantly depended on the weather conditions of the growing season, but this contributed to the selection of more productive cultivars: Bacchus – 1.92 t/ha and Svitiaz – 1.90 t/ha. The Ukrainian Sloboda cultivar had a yield lower than the standard by 11.1%, while all other cultivars tested were slightly higher than the standard.

The optimised conditions for the formation of productivity of edible bean cultivars were characterised by 2021, where seed yields ranged within 1.60-2.56 t/ha. The most productive cultivars were Bacchus and Svitiaz, where this indicator was higher than the standard by 16.4% or 0.36 t/ha and 10.0% or 0.22 t/ha, respectively. In 2020, average data on vegetable bean yields were obtained, but the variation was the largest – CV = 16%. In the current year, the cultivars that significantly outperformed the standard were Bacchus and Svitiaz (+0.55 t/ha or 34.4%). Vegetable bean plants were the least productive in 2022, due to dry conditions during the growing season. IN the current year, the yield varied little, with a CV of 9%, but most cultivars were significantly more productive than the standard, with Karmazin (+0.21 t/ha or 23.3%), Svitiaz (+0.23 t/ha or 25.6%), and Extra Grano Violetto (+0.22 t/ha or 24.4%) standing out. The analysis of the average seed yields of edible bean cultivars showed that all cultivars had a comparable variation of data and significantly depended on the weather conditions of the growing season, but this contributed to the selection of more productive cultivars: Bacchus – 1.92 t/ha and Svitiaz – 1.90 t/ha. The Ukrainian Sloboda cultivar had a yield lower than the standard by 11.1%, while all other cultivars tested were slightly higher than the standard (Table 6).

***Table 6**. Seed yield of edible bean cultivars, t/ha, (BBCH 99), (2020-2022)*

Cultivar	Seed yield, g/plant			$\bar{X}$	SD	CV, %	K_{sfn}
	2020	2021	2022				
Karadag st	1.60	2.20	0.90	1.57	0.53	34	2.44
Ukrainian Sloboda	1.52	1.80	0.86	1.39	0.39	28	2.09
Windsor Broad	1.80	1.84	1.08	1.57	0.35	22	1.70
Bacchus	2.15	2.56	1.06	1.92	0.63	33	2.42
Karmazin	1.91	1.90	1.11	1.64	0.38	23	1.72
Green lowland	1.20	1.60	0.97	1.26	0.26	21	1.65
Svitiaz	2.15	2.42	1.13	1.90	0.56	29	2.14
Bianco	1.67	2.00	1.08	1.58	0.38	24	1.85
Extra Grano Violetto	1.91	1.80	1.12	1.61	0.35	22	1.71
	1.77	2.01	1.03	1.61			
SD	0.29	0.30	0.09	0.20			
CV, %	16	15	9	12			
LSD_{05}	0.09	0.12	0.06				

Note: ** – st – standard*
Source: *obtained as a result of the present study*

Statistical analysis of the obtained data on the yield of edible bean seeds showed that the most stable in terms of the complex of indicators (σ^2d and MC, Hom) was the variety Green lowland (σ^2d = 0.51; MC = 1.72; Hom = 3.3) and the variety Extra Grano Violetto (σ^2d = 0.59; MC = 1.78; Hom = 5.4). According to the indicators of the ratio of plasticity (bi) and stability σ^2d parameters, the cultivars Karadag st, Ukrainian Sloboda, Windsor Broad, Karmazin, Green lowland, and Bianco had a ratio of indicators bi > 1, σ^2d > 0 – i.e., they show better productivity under favourable growing conditions. Cultivars Karadag, Bacchus, and Svitiaz had a ratio of indicators bi < 1, σ^2d > 0, i.e., more productive under unfavourable conditions, unstable. According to the environmental plasticity coefficient (bi), the group of highly plastic or intensive cultivars includes Karadag, Bacchus, and Svitiaz, i.e., these cultivars respond well to improved growing conditions; the group of relatively low plastic cultivars includes Ukrainian Sloboda, Windsor Broad, Karmazin, Green lowland, Bianco, and Extra Grano Violetto. The statistical data suggest a significant influence of growing conditions on the yield of edible bean seed cultivars and a greater dependence on environmental conditions (CVA = 30.1%) than on the genetic component (CVG = 15.8) and a rather high CVG/CVA ratio of 0.53.

According to the stress resistance indicator (SR), the Green lowland cultivar stood out, as this cultivar had a minimum gap between the minimum and maximum yields, indicating a higher resistance to stress and a wider range of its adaptive capabilities. According to the compensatory capacity (CC), two cultivars were distinguished among the cultivars under study – Bacchus and Svitiaz, since the concept of "compensation" is close to "plasticity", this allows them to be classified as plastic cultivars (Table 7).

***Table 7**. Parameters of adaptive capacity and breeding value of edible bean cultivars based on the trait "seed yield", t/ha*

Cultivar	$\bar{X}$, t/ha	σ^2d	bi	Hom	Sc	MC	EPI	SR	CC	AAC
Karadag st	1.57	0.73	1.24	5.1	1.5	2.27	0.96	-1.3	1.6	0.98
Ukrainian Sloboda	1.39	0.63	0.95	4.0	1.4	2.09	0.86	-0.9	1.3	0.87
Windsor Broad	1.57	0.59	0.82	5.1	1.5	1.84	0.99	-0.8	1.5	0.98
Bacchus	1.92	0.80	1.52	7.7	1.9	2.27	1.17	-1.5	1.8	1.20
Karmazin	1.64	0.61	0.87	5.6	1.6	1.85	1.03	-0.8	1.5	1.02
Green lowland	1.26	0.51	0.57	3.3	1.2	1.72	0.80	-0.6	1.3	0.78
Svitiaz	1.90	0.75	1.33	7.5	1.9	2.13	1.17	-1.3	1.8	1.18
Bianco	1.58	0.62	0.91	5.2	1.6	1.92	0.99	-0.9	1.5	0.99
Extra Grano Violetto	1.61	0.59	0.78	5.4	1.6	1.78	1.02	-0.8	1.5	1.00
$\bar{X}$	1.61									
σ^2_G	0.06									
σ^2_F	0.30									
σ^2_A	0.23									
CVG, %	15.8									
CVP, %	34.0									
CVA, %	30.1									
CVG/CVA	0.53									

Note: ** – st – standard*
Source: *obtained as a result of the present study*

According to the trait "seed yield", the most adaptive cultivars with an absolute adaptation coefficient (AAC) greater than 1 were identified – Bacchus and Svitiaz, cultivars Karmazin, Extra Grano Violetto, and Bianco were medium adaptive, and cultivars Karadag, Ukrainian Sloboda, Karadag, Windsor Broad, and Green lowland were classified as low adaptive. For selection practice, seed size is significant. The thousand-kernel weight significantly depends on the varietal characteristics, climatic conditions of cultivation and agricultural practices, and the variability of this trait characterises the plasticity of the genotype.

The findings suggest the presence of a difference in yield and yield stability among the edible bean cultivars evaluated in this study. There is an inverse relationship between yield and yield stability (r = -0.061 at both bean maturity stages), with low yielding cultivars showing the highest stability and high yielding cultivars showing lower stability. This trend in different bean genotypes has been reported previously (Temesgen *et al.*, 2015). According to the thousand-kernel weight (TKW), the cultivars of edible beans under study were conditionally divided into three groups with a low TKW (up to 1,500 g), medium TKW (1,500-2,000 g), and large TKW (over 2,000 g). The first group includes cultivars Karmazin and Ukrainian Sloboda; the second – Karadag, Windsor Broad, Bacchus, and Green lowland; the third group includes Svitiaz, Bianco, and Extra Grano Violetto.

Statistical analysis of the TKW of edible beans showed that the most stable according to the set of indicators (according to σ^2d, and MC, Hom) was the Karmazin cultivar (σ^2d = 3.29, MC = 1.19, Hom = 4,666.9). In terms of the ratio of plasticity (*bi*) and stability (σ^2d) parameters, all varieties Karadag st, Bacchus, Karmazin, Green lowland, Svitiaz, Extra Grano Violetto, and Bianco had a ratio of $bi > 1, \sigma^2d > 0$, i.e., they show better productivity under favourable growing conditions. Ukrainian Sloboda and Windsor Broad cultivars had a ratio of indicators $bi < 1, \sigma^2d > 0$, i.e., they have better results under unfavourable conditions, they are unstable. According to the environmental plasticity coefficient (*bi*), the group of highly plastic or intensive cultivars includes Ukrainian Sloboda, Bacchus, Green lowland, Svitiaz, Bianco, Extra Grano Violetto, i.e., these cultivars respond well to improved growing conditions; the group of relatively low plastic cultivars includes Karmazin, Karadag, and Windsor Broad. The statistical data suggest a strong influence of growing conditions on the TKW of edible bean cultivars and a greater dependence on environmental conditions (CVA = 20.88%) than on the genetic component (CVG = 5.76) and an average CVG/CVA ratio of 0.28.

The Karmazin cultivar stood out in terms of stress resistance (SR), as this cultivar had a minimum gap between the minimum and maximum TKW, indicating a higher resistance of the cultivar to stress and a wider range of its adaptive capabilities, but this cultivar was also characterised by the lowest TKW. According to the compensatory capacity (CC), two cultivars were distinguished among the cultivars under study – Bacchus, Svitiaz, Bianco, and Extra Grano Violetto, since the concept of "compensation" is close to "plasticity", which allows them to be classified as plastic cultivars (Table 8).

***Table 8**. Parameters of adaptive capacity and breeding value of edible bean cultivars by the trait "thousand-kernel weight", g*

Cultivar	$\bar{X}$, r	σ^2d	bi	Hom	Sc	MC	EPI	SR	CC	AAC
Karadag st	1,590	8.56	-0.91	6,723.2	1,602.1	-0.03	0.89	-163	1,561	0.88
Ukrainian Sloboda	1,453	11.92	1.81	5,612.2	1,463.8	3.25	0.80	-304	1,502	0.81
Windsor Broad	1,815	16.40	-3.41	8,760.2	1,828.8	-2.38	1.02	-576	1,723	1.01
Bacchus	1,979	13.84	2.44	10,411.0	1,993.6	3.22	1.10	-410	2,045	1.10
Karmazin	1,325	3.29	0.14	4,666.9	1,334.8	1.19	0.74	-25	1,328	0.74
Green lowland	1,517	10.07	1.30	6,114.8	1,527.9	2.54	0.84	-220	1,550	0.84
Svitiaz	2,059	17.69	3.97	11,266.1	2,073.9	4.47	1.14	-666	2,168	1.14
Bianco	2,126	12.88	2.12	12,011.3	2,141.4	2.80	1.18	-360	2,180	1.18
Extra Grano Violetto	2,354	11.96	1.54	14,734.6	2,371.8	2.18	1.31	-340	2,330	1.31
$\bar{X}$	1,802									
σ^2_G	10,772.44									
σ^2_F	152,285.85									
σ^2_A	141,513.41									
CVG, %	5.76									
CVP, %	21.66									
CVA, %	20.88									
CVG/CVA	0.28									

***Note:** * – st – standard*
***Source:** obtained as a result of the present study*

In terms of seed yield, the most adaptive cultivars with an absolute adaptability coefficient (AAC) greater than 1 were identified – Bacchus, Svitiaz, Bianco, and Extra Grano Violetto, while Karadag, Ukrainian Sloboda, Windsor Broad, and Green lowland cultivars are medium adaptive and Karmazin cultivar is classified as low adaptive. The main indicator of the nutritional value of beans, as well as other legumes, is the protein content. Studies showed that, on average, the protein concentration increased by 12.37% between the technical and biological ripeness phases. Thus, in the phase of technical ripeness, the maximum accumulation of protein in green grain was observed in the cultivars Windsor Broad (13.51 g/100 g), Bianco (14.30 g/100 g), and Green lowland (14.43 g/100 g), where this indicator is 22.5%, 15.7%, and 30.8% higher than the standard, respectively. Overall, only the Bacchus cultivar had a lower protein concentration than the standard – 10.57 g/100 g (-4.2%).

At the stage of biological ripeness, the dynamics of the cultivars changed slightly and became more even. Thus, the maximum protein concentration was obtained in the Green lowland cultivar – 30.57 g/100 g, which is 27.5% higher than the standard. The protein content of Bianco, Bacchus, and Karmazin cultivars was slightly lower than the standard. Significantly higher concentration was observed in the cultivar Windsor Broad, and slightly higher in the cultivars Svitiaz, Extra Grano Violetto, and Ukrainian Sloboda. Statistical analysis shows that in technical ripeness, varietal characteristics, and weather conditions have a greater impact (CVG 8.58%; CVA 18.39%; CVG/CVA 0.47%) on the protein concentration in grain than in biological ripeness (CVG 2.19%; CVA 10.11%; CVG/CVA 0.22%) (Fig. 4).

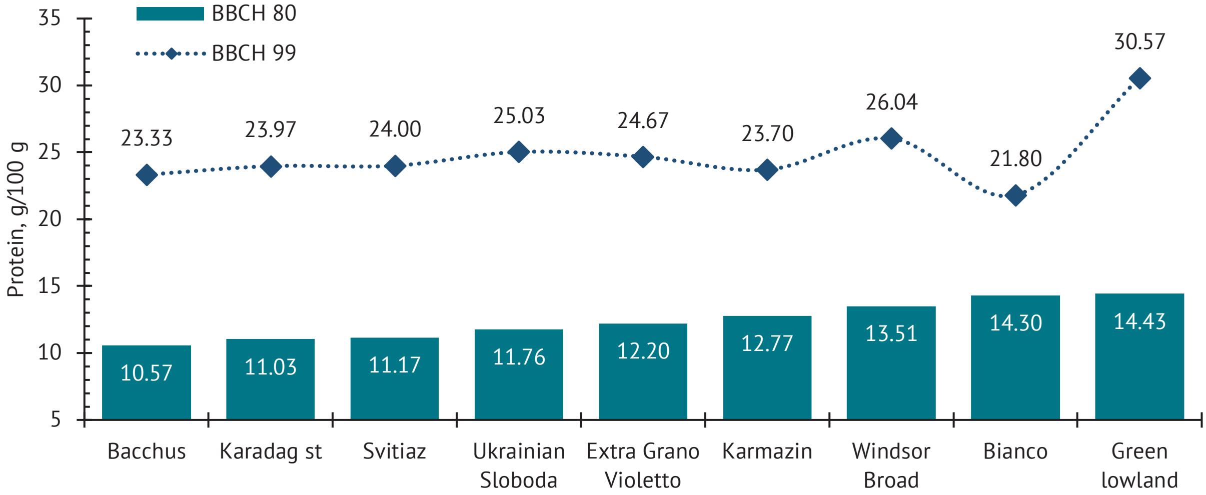


***Figure 4**. Crude protein content at different stages of bean ripeness depending on their cultivar (2020-2022), g/100 g*
Note: ** – st – standard*
Source: *obtained as a result of the present study*

No relationship was found between seed protein content and yield, which is in contrast to the findings of analogous phenotypic correlations in pea (Jha *et al.*, 2012) and chickpea (Frimpong *et al.*, 2009). In a study conducted in Finland by C. Lizarazo *et al.* (2015), the difference in protein content between bean cultivars was significantly dependent on the year (environment)×genotype interaction. According to the above researchers, these differences may be conditioned by genotypic differences in nitrogen metabolism in most cultivars.

Analysing the parameters of biochemical composition, it was found that the lowest yielding cultivar Green lowland had the highest dry matter content – 15.04%, which is 2.24% higher than the standard. Overall, only five cultivars outperformed the standard by this indicator (Green lowland, Ukrainian Sloboda, Windsor Broad, Bianco, and Extra Grano Violetto). The most productive and adaptive cultivars Bacchus and Svitiaz accumulated less dry matter than the standard. Over 50% of carbohydrates by weight of green seeds was recorded in the cultivars Windsor Broad (51%), Green lowland (60%), and Bianco (54%), which is 10.0-18.7% more than the standard. The dynamics of fat concentration in green seeds was comparable. Thus, the highest fat concentration was recorded in the Green lowland (0.84%), Bianco (0.82%), Windsor Broad (0.81%), and Extra Grano Violetto (0.80%) cultivars, which is 0.10-0.14% greater than the standard cultivar. All the above biochemical composition indicators contribute to a comprehensive assessment of edible bean cultivars by calculating the energy value of the products obtained. The results of determining the calorific value of 100 g of raw weight of green beans helped to identify the most valuable ones: Green Lowland (305 kcal), Bianco (242 kcal), and Windsor Broad (266 kcal), whose indicators are 23.6-41.5% or 50.81-89.42 kcal higher than the standard cultivar Karadag (Table 9).

***Table 9**. Nutritional value of green beans of edible bean (BBCH 80), (2020-2022), (X ± SD)*

Cultivar	Dry matter, %	Carbohydrates (g/100 g of wet weight)	Fats (g/100 g of wet weight)	Energy, kcal 100 g of wet weight
Karadag st	12.81±1.80	41±5.3	0.71±0.12	216±26
Ukrainian Sloboda	13.51±1.35	46±2.9	0.79±0.14	239±15
Windsor Broad	14.30±1.20	51±7.4	0.81±0.14	266±34
Bacchus	10.95±1.04	38±4.9	0.71±0.11	202±25
Karmazin	12.75±2.96	49±6.6	0.79±0.14	253±41
Green lowland	15.04±1.50	60±7.8	0.84±0.14	305±39
Svitiaz	11.93±2.91	43±4.6	0.76±0.12	225±29
Bianco	15.02±1.64	54±8.0	0.82±0.14	280±40
Extra Grano Violetto	13.47±1.54	47±6.2	0.80±0.14	242±32
$\bar{X}$	13.31	48	0.78	246
σ_G^2	1.19	12.72	0.004	

Table 9. Continued

Cultivar	Dry matter, %	Carbohydrates	Fats	Energy, kcal 100 g of wet weight
		g/100 g of wet weight		
σ^2_F	6.43	90.38	0.018	
σ^2_A	5.24	77.6	0.014	
CVG, %	8.20	7.47	8.13	
CVP, %	19.05	19.90	17.18	
CVA, %	17.19	18.44	15.13	
CVG/CVA	0.48	0.40	0.54	

Note: ** – st – standard*
Source: *obtained as a result of the present study*

The symbiotic potential of edible beans is significantly greater than that of other legumes. The intensive nitrogen fixation lasts from the budding phase to the full filling of the beans in the upper tiers. On average, during the study period, the total number of nodules varied greatly, ranging within 11-51 pcs./plant (CV = 49%), while the number of active nodules varied significantly less – 6.63-12.76 pcs./plant (CV = 21%). The efficiency of the symbiotic apparatus depends on the number of active nodules. Active nodules are much larger and contain legoglobin. The total mass and mass of active nodules varied greatly (CV = 28% and 37%, respectively). The formation of these indicators was significantly influenced by both varietal characteristics (CVG = 22.62% and 21.90%) and, to an even greater extent, growing conditions (CVA = 48.36% and 53.15%), which is confirmed by the moderate strength of the CVG/CVA ratio, especially when studying active nodules.

The analysis of the data obtained contributed to the selection of cultivars with the best development of the nodulation apparatus, where the highest weight and number of nodules were noted – these are the cultivars Ukrainian Sloboda and Bianco, where the number of nodules was 51 pcs./plant and 39 pcs./plant, while their weight was 0.70 g/plant and 0.80 g/plant. The maximum number of active nodules was observed in the cultivars Svitiaz (12.76 pcs./plant), Ukrainian Sloboda (10.70 pcs./plant), and Bianco (10.40 pcs./plant). The highest percentage of active nodules of the total number was obtained in the cultivar Green lowland – 78.7%, which accounted for 80.6% of their total weight. A large number of nodules, but with a low weight, was obtained in the Extra Grano Violetto cultivar (Table 10).

Table 10*. Development of the nodulation apparatus of edible bean cultivars (BBCH 80), (2020-2022) (X ± SD)*

Collection sample	Nodules, pcs/plant		Bulb weight, g/plant	
	general	active	general	active
Karadag st	23 ± 9.5	6.6 ± 3.6	0.56 ± 0.25	0.28 ± 0.11
Ukrainian Sloboda	51 ± 7.1	10.7 ± 3.3	0.70 ± 0.36	0.41 ± 0.20
Windsor Broad	14 ± 4.5	9.7 ± 3.7	0.71 ± 0.34	0.47 ± 0.21
Bacchus	17 ± 5.3	9.4 ± 3.5	0.58 ± 0.15	0.24 ± 0.05
Karmazin	21 ± 5.7	9.8 ± 3.6	0.51 ± 0.23	0.23 ± 0.10
Green lowland	11 ± 2.5	8.6 ± 2.3	0.33 ± 0.18	0.26 ± 0.14
Svitiaz	18 ± 3.1	12.8 ± 3.2	0.33 ± 0.06	0.22 ± 0.03
Bianco	39 ± 12.3	10.4 ± 4.6	0.80 ± 0.16	0.46 ± 0.10
Extra Grano Violetto	28 ± 4.6	6.1 ± 1.8	0.78 ± 0.18	0.61 ± 0.14
$\bar{X}$	25	9.34	0.59	0.35
σ^2_G	15.16	3.77	0.02	0.01
σ^2_F	204.96	18.76	0.10	0.04
σ^2_A	189.80	14.99	0.08	0.04
CVG, %	15.81	20.78	22.61	21.90
CVP, %	58.13	46.37	53.38	57.49
CVA, %	55.94	41.45	48.36	53.15
CVG/CVA	0.28	0.50	0.47	0.41

Note: ** – st – standard*
Source: *obtained as a result of the present study*

The best development of the nodulation apparatus was found in the cultivars Ukrainian Sloboda, Windsor Broad, Bianco, and Extra Grano Violetto, which had the highest concentration of legoglobin, the highest activity of symbiotic potential and, accordingly, the highest amount of fixed nitrogen. Thus, plants of the Extra

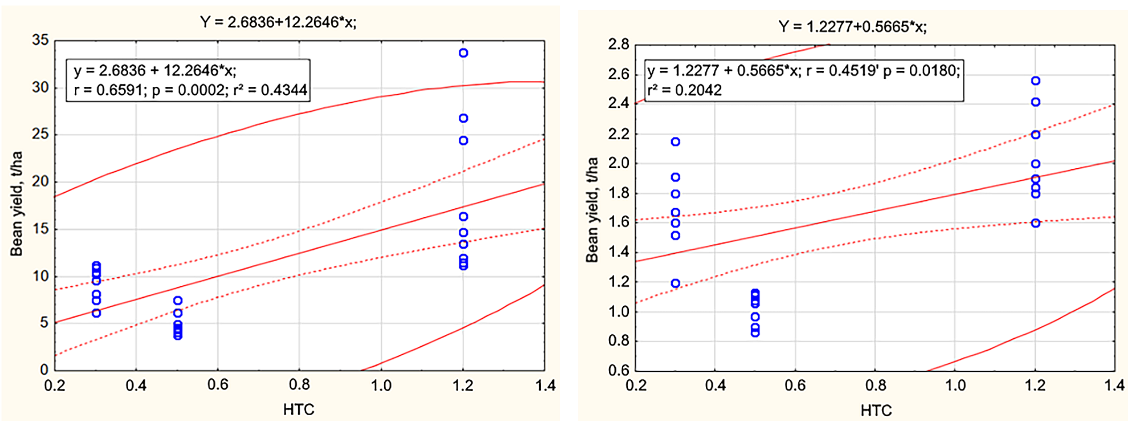
Grano Violetto cultivar had the highest nitrogen fixation among others – 75.7 kg/ha, which is 25.5 kg or 54.0% greater than the standard cultivar. The Ukrainian Sloboda and Windsor Broad cultivars fixed significantly more nitrogen than the standard – 67.7 kg/ha (+37.7% to st) and 71.0 kg/ha (+44.5% to st), respectively, compared to the standard cultivar. Bacchus, Karmazin, and Green lowland cultivars fixed slightly less nitrogen than the standard. Statistical analysis confirmed the noticeable influence of growing conditions on the formation of symbiotic potential productivity. Overall, the influence of environmental conditions was almost twice as strong as the genetic component: CVA = 41.28-53.44%; CVG = 19.26-27.35%, which is confirmed by the CVG/CVA ratio of 0.47-0.53 (Table 11).

***Table 11**. Activity of the symbiotic apparatus of edible bean cultivars (BBCH 80), (2020-2022) (X ± SD)*

Collection sample	Legoglobin content, mg/g	Active symbiotic potential, thsd kg×day/ha	Fixed nitrogen, kg/ha
Karadag st	4.52 ± 1.29	15.7 ± 8.2	49.1 ± 26.7
Ukrainian Sloboda	5.82 ± 1.73	19.3 ± 8.3	67.7 ± 25.2
Windsor Broad	6.45 ± 2.15	22.0 ± 7.9	71.0 ± 27.0
Bacchus	3.34 ± 1.24	11.3 ± 5.6	45.0 ± 20.6
Karmazin	4.16 ± 1.06	13.7 ± 7.4	47.0 ± 20.3
Green lowland	4.46 ± 1.17	12.0 ± 6.5	46.3 ± 22.6
Svitiaz	4.34±1.41	15.7 ± 9.0	50.0 ± 23.0
Bianco	5.15±2.03	17.7 ± 9.7	50.0 ± 30.6
Extra Grano Violetto	7.58±2.56	24.3 ± 8.5	75.7 ± 28.7
$\bar{X}$	16.85	5.09	55.8
σ_G^2	21.24	0.96	211.71
σ_F^2	102.33	5.38	975.96
σ_A^2	81.09	4.42	764.25
CVG, %	27.35	19.26	26.10
CVP, %	60.03	45.55	56.03
CVA, %	53.44	41.28	49.58
CVG/CVA	0.51	0.47	0.53

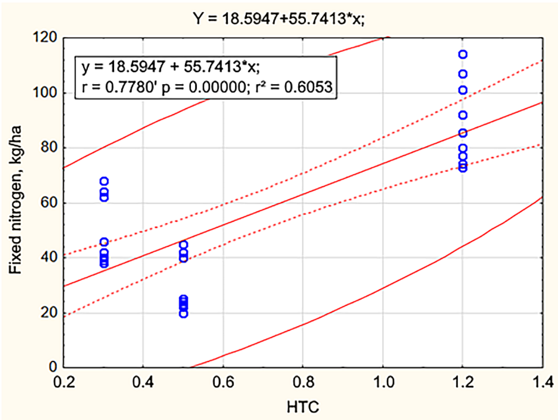
Note: ** – st – standard*
Source: *obtained as a result of the present study*

The statistical analysis revealed a significant relationship on the Chaddock scale – r = 0.6591 between the yield of beans in the phase of technical ripeness and the hydrothermal coefficient (HTC): y = 2.6836 + 12.2646 - x, where x is HTC, g, y is yield, t/ha. A moderate relationship (r = 0.4519) was found between the yield at the stage of biological maturity of seeds and the HTC, which is explained by the regression equation y = 1.2277 - 0.5665 - x, where x is the HTC, y is the yield at biological maturity. Considering the statistical reliability of the equations, the corresponding dependence is presented graphically in Figures 5, 6.



BBCH 80 BBCH 99

***Figure 5**. Correlations between edible bean yields in the phase of technical maturity and HTC and the amount of fixed nitrogen by plants and HTC*
Source: obtained as a result of the present study



BBCH 80

***Figure 6**. Correlations between the volume of fixed nitrogen in plants and the HTC index*

Note: ** – st – standard*

Source: *obtained as a result of the present study*

Statistical studies of the relationship between the volume of fixed nitrogen and the hydrothermal coefficient revealed a strong relationship (r = 0.7780) in edible beans, which is explained by the regression equation y = 18.5947 + 55.7413 - x, where x is the HTC, y is the amount of fixed nitrogen.

Statistical analysis showed significant differences in the interaction of genotypes with the environment in terms of growth and productivity parameters, which affects the difference in yield (both immature grain and seeds) of genotypes; sufficient differences between the environment by years of research to distinguish genotypes. Thus, genotypes did not show analogous development for all years, which is a consequence of unstable climatic conditions (precipitation and temperature). L. Barroso *et al.* (2016) and A. Santos *et al.* (2017) found comparable results for grain yields of cowpea genotypes in multi-environmental analyses in Mato Grosso, Sul, Brazil, showing that edaphoclimatic factors had a significant impact on genotype adaptability and stability, and that additional analyses are needed to identify genotypes that are adapted to multiple environments. The findings of the study conducted in 2020-2023 by S. Barvinchenko *et al.* (2023) showed the variability of quantitative traits of bean plants that are comparable to the ones presented in this study.

C. Grasshoff (1990), F.J. López-Bellido *et al.* (2005) and E. Rezaei *et al.* (2023), with a substantial gap between the years of their studies, note that climatic variables also explain the high variation in cultivar performance, as it was based on three years of data during which the bean cultivars were grown. It is clear that air temperature and precipitation are the limiting factors for the formation of bean productivity, which is confirmed by the data presented in Figure 5. The findings are in line with previous reports that high temperatures and insufficient rainfall are the main factors limiting yields in temperate regions of Europe.

In the current study, the average amount of atmospheric nitrogen fixed by beans was 55.8 kg/ha. This level of biological nitrogen fixation is average, confirming previous reports by G. Ntatsi *et al.* (2018) on the high efficiency of biological nitrogen fixation by beans. In a field study conducted in the British Isles over several consecutive years, M. Maluk *et al.* (2022) observed that pulses can cover almost all of their own nitrogen requirements through biological fixation in a relatively wet and cool climate. E. Jensen *et al.* (2010) reported nitrogen fixation by beans within 73-211 kg/ha. In another study by M. Oliveira *et al.* (2019), it was reported that the average nitrogen fixation for beans was 41 kg, and the findings of S. Klippenstein *et al.* (2021) suggest a significant inter-varietal variance in terms of nitrogen fixation volume, which is analogous to the findings obtained in this study. The values of biological nitrogen fixation estimated in the current study appear to be the result of sufficient soil nitrogen levels.

Thus, the findings of other researchers' studies are largely comparable to the findings presented in this study. However, it was noted that productivity and nitrogen fixation rates vary significantly depending on the genotype, technology, and region of cultivation.

CONCLUSIONS

As a result of the study, the promising cultivars Bianco and Extra Grano Violetto with the shortest period of technical ripeness – 78 days – were identified. Overall, a rather extended period of technical maturity of edible bean cultivars from 78 to 105 days contributes to the production of fresh bean products within 27 days without additional operations. Only one cultivar was identified – Karmazin – which had a significantly higher attachment of the first (lower) bean (which facilitates mechanised harvesting), depending on the year of research, this indicator varied at 11-16 cm. Evaluation of edible bean cultivars by individual productivity parameters showed a significant variation in the number of shoots per plant and the number of beans depending on the year, while the number of seeds per bean varied less significantly. The Svitiaz and Bianco cultivars were stable for this trait – 4.0 pcs./plant, compared to 2-3 and 2-4 pcs./plant for other cultivars. The analysis of the trait "weight of beans per plant" contributed to the selection of two cultivars with a significantly higher value – 123.65 g in the Windsor Broad cultivar and 103.57 g in the Bianco cultivar. The study helped to determine the proportion of immature seeds in the beans – an average of 52%. According to this trait, the cultivars Bacchus, Svitiaz, Bianco, and Windsor Broad were identified, with the share of immature seeds ranging within 54.7-78.9%. These findings will help forecast the conditional harvest of the consumer portion of the crop.

The study of the ecological plasticity and stability of the bean contributed to the selection of the Windsor

Broad, Svitiaz, and Bianco cultivars with a ratio of indicators $bi > 1$, $\sigma^2 d > 0$ – i.e., these cultivars give better results under favourable growing conditions and were characterised by a wide agro-ecological adaptability and belong to the cultivars of intensive type according to the characteristic "yield of green beans". In terms of seed yield, the cultivars under study slightly exceeded the standard, but the Bacchus and Svitiaz cultivars stood out with a maximum of 1.92 t/ha and 1.90 t/ha, which can provide high seed yields, are characterised by high plasticity and respond well to improved growing conditions. Statistical analysis revealed a significant correlation between bean yield at the stage of technical maturity and the HTC index and a moderate correlation between seed yield and HTC. Varieties with high energy value were identified: Green lowland (305 kcal), Bianco (280 kcal), and Windsor Broad (266 kcal). The best development of the nodulation apparatus and increased nitrogen fixation were found in the cultivars Extra Grano Violetto (75.7 kg/ha), Ukrainian Sloboda, and Windsor Broad – 67.7 kg/ha and 71.0 kg/ha, respectively. A strong dependence of the nitrogen-fixing capacity on the hydrothermal coefficient ($r = 0.7780$) was found.

The environmental testing of edible bean cultivars revealed that the conditions of the Ukrainian Forest-Steppe are suitable for growing edible beans for both food and seed purposes. Further research prospects include zoning of the cultivars under study in other zones of Ukraine, investigating changes in nutritional value depending on the methods of storage and processing of immature bean seeds.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Екологічна пластичність, стабільність та азотфіксуюча здатність сортів бобу овочевого у Лісостепу України

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Анотація. Метою досліджень передбачалося дослідження впливу кліматичних умов років досліджень на зміну показників продуктивності й екологічної пластичності й стабільності сортів бобів овочевих. Крім цього, досліджено азотфіксуючий потенціал сортів бобів овочевих для біологізації галузі землеробства. Дослідження проведені в умовах навчально-виробничого відділу Уманського національного університету садівництва впродовж 2020-2022 рр., використано дев'ять сортів бобів овочевих. Для вивчення параметрів адаптивної мінливості використано стандартні методи статистичного аналізу. У результаті порівняльного вивчення дано характеристику різних параметрів адаптивного потенціалу сортів бобів овочевих за ознаками: настання фази технічної стиглості: Б'янко і Екстра Грано Віолетто – 78 діб. За врожайністю й адаптивністю у фазу технічної стиглості виділилися сорти Віндзорські (16,42 т/га), Б'янко (13,73 т/га) і Свитязь (11,51 т/га), за врожайністю й адаптивністю у фазу біологічної стиглості сорти Бахус (1,92 т/га) і Свитязь (1,90 т/га); з підвищеним вмістом протеїну у незрілому зерні сорти Кармазін (12,77 г/100 г), Віндзорські (13,51 г/100 г), Б'янко (14,30 г/100 г), Зелені низинні (14,43 г/100 г); з високою азотфіксуючою здатністю сорти Українські слобідські (67,7 кг/га), Віндзорські (71,0 кг/га) і Екстра Грано Віолетто (75,7 кг/га). Результати статистичного аналізу показали істотний вплив екологічних умов на формування показників продуктивності сортів бобу овочевого і більшу залежність від екологічних умов (CVA = 10,40-82,7 %) аніж від генетичної складової (CVG = 5,76-39,7 %). Отримані дані вказують, що є тенденція зворотного зв'язку між врожайністю і стабільністю врожаю, причому низьковрожайні сорти демонструють стабільність, а високоврожайні сорти – нестабільні. Представлені результати дають уявлення про зміну параметрів продуктивності бобів овочевих за контрастних погодних умов, що дає змогу виділити сорти з високою продуктивністю на продовольчі цілі та з більшою часткою високобілкової й енергетично цінної споживчої продукції. Виділено сорти з підвищеною азотфіксуючою здатністю, що сприятиме зменшенню використання синтетичних добрив

Ключові слова: урожайність; адаптивність; насіння; харчова цінність; вміст протеїну

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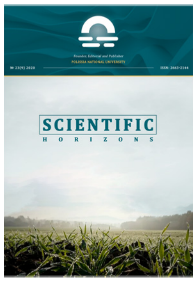

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Influence of weather conditions in Central Polissia, Ukraine, on the expression of quality indicators in potato cultivars of different maturity groups

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Abstract. For Ukrainians, potatoes are a key foodstuff and the most important strategic crop in the vegetable segment, and therefore it is vital to investigate the quality characteristics of potato tubers. The purpose of this study was to investigate the influence of various meteorological factors on the taste and starch content of tubers of different potato cultivars. The study employed laboratory, analytical, mathematical, and statistical methods. Both positive and negative correlation between starch content in tubers, taste, average monthly temperature, and precipitation were found in cultivars of different ripeness groups. For some potato cultivars, the positive effect on the starch content in tubers was due to the synergistic interaction of temperatures in August and precipitation in July, while for other cultivars this effect was determined by temperature and precipitation in August. It was found that an increase in temperature in August

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contributed to the improvement of the taste characteristics of early-ripening cultivars, while for middle early and mid-ripening genotypes, increased temperatures in June and August were key factors, and middle-late cultivars responded to increased precipitation in August. For each of the 19 cultivars studied, periods with a positive effect of average monthly temperature and precipitation on the improvement of taste were identified. The cluster analysis helped to identify potato cultivars with high starch content – Lietana, Opillia, Vzirets, and Oleksandryt, with high taste qualities – Lietana, Mezhyrichka 11, Vzirets, Avanhard, Partner, Oleksandryt, Fanatka, Rostavytsia, and Opillia. The findings of this study can serve as a scientific basis for the formulation of policies aimed at mitigating the effects of climate change and adapting existing cultivars to support sustainable potato production in a particular region and creating new plastic potato genotypes with sustainable quality characteristics

Keywords: *Solanum tuberosum* L.; maturity; temperature; precipitation; starch; taste; cultivar differentiation

INTRODUCTION

Potatoes are a key foodstuff and the most important strategic crop in the agricultural market. It plays a crucial role in ensuring food security and welfare of the population. According to the analysis of operational statistics, as of the end of 2022, potatoes were harvested on an area of 1,204 thsd ha, with a gross harvest of 20,899.2 thsd t and an average yield of 17.35 t/ha. Notably, the structure of potato production by category of farms is as follows: enterprises account for 2.1%, of which farms account for 0.5%, while households account for 97.8% (State Statistics Service of Ukraine, n.d.).

Based on the study conducted by O. Krupa and V. Krupa (2019) the annual consumption of potatoes per person is about 135-140 kg. The researchers suggest that the prominent level of consumption may be an indicator of relative poverty among the population; on the other hand, it is related to deep-rooted traditions in Ukrainian cuisine. In the context of Ukrainian agriculture, potatoes are considered one of the most widespread crops. Therefore, it is crucial to have an in-depth understanding of how growing conditions affect the quantitative and qualitative characteristics of this crop. Changes in climatic conditions significantly affect the growth and development of potatoes through meteorological factors such as temperature, precipitation, and solar radiation. S. A. Jennings *et al.* (2020) and R. Quiroz *et al.* (2018) note that potatoes, as one of the most vulnerable crops in the face of climate change, react negatively to prolonged periods of drought, intense heat, and unexpected frosts. These challenges directly affect yields and pose a threat to food security. In their studies, T. Handayani *et al.* (2019) and T. Adekanmbi *et al.* (2023) note that the development of new innovative cultivars resistant to abiotic stress can ensure effective productivity in conditions that are suboptimal for potato cultivation.

A key indicator of potato quality is the starch content, which classifies it as a “starch product” due to the predominance of carbohydrates in the dry matter content. J. Yu *et al.* (2022) found that starch content affects the taste of potatoes: high starch content leads to dense flesh, while low starch content leads to lack of cooking quality. The starch content determines the types of products that can be made from potatoes. The total starch content of tubers typically ranges within 10-19% of the raw weight for commercial cultivars and is 66-80% of the dry weight (Miller *et al.,* 2022; Akhila *et al.*, 2022).

E. Sim *et al.* (2023) analysed the varietal properties as the predominant factor affecting the starch content in tubers. M. Grudzińska *et al.* (2022) and P. Meise *et al.* (2019) pointed out the significant influence of external factors on starch content, namely weather conditions, soil properties, and fertilisation. Y. Xing *et al.* (2022) note the significant role of harmful microorganisms in this process. Potato varieties, even those of the same species, grown under different conditions, differ in starch structure and function (Koval *et al.*, 2022). This diversity leads to the formation of distinct types of starch with varying culinary, textural, and rheological properties, which are determined by their physicochemical, morphological, and thermal characteristics.

Apart from the carbohydrate content of tubers, according to W. Wadas (2023), a significant aspect of the quality characteristics of potatoes is the assessment of their consumer properties based on sensory parameters such as taste, texture, or colour changes after cooking. It was found that the defining indicator of the variety quality is its taste. The variety of flavour characteristics is related to the content of sugars, amino acids, starch, and proteins. N.S. Kozhushko *et al.* (2020) found that an improvement in taste is noted with an increase in tuber starchiness and starch/protein ratio (13.9-8.8%), while deterioration is observed with an increase in protein and sugar content from 5.9% to 6.8% (from 0.12% to 0.18%). It was noted that in the gastronomic aspect, cultivars with positive qualitative traits that change minimally under external conditions are highly valued (Kravchenko *et al.*, 2021). Consumer assessment of potato varieties is primarily based on the quality characteristics of the tubers. These characteristics depend heavily on the environmental conditions of the region and the duration of the growing season and can undergo considerable changes. Understanding the impact of weather conditions on these parameters allows for the selection of suitable cultivars to obtain a high-quality harvest with the necessary physicochemical properties. The purpose of this study was to investigate the regularities of the influence of average monthly temperatures and precipitation on the formation of starch content and taste during the growing season of potato cultivars of different maturity groups in the central region of Polissia of Ukraine.

MATERIALS AND METHODS

The study was conducted at the Polissia Research Department of the Institute for Potato Research of the National Academy of Agrarian Sciences of Ukraine in the main breeding nurseries during 2018–2023. The soils of the breeding field are represented by soddy-low podzolic and clay-sandy soils, which are formed as a result of sand or clay sand admixture with low natural fertility. Soil characteristics include humus content of 0.77%, pH of 4.7, and concentration of mobile forms in mg/kg of soil: N (NH_4) – 9.9, N (NO_3) – 0.7-1.1, P_2O_5 – 62.3, K_2O – 28.8. The mechanical composition is light (sand content 93–96%, clay content 5-6.4%), not saturated with bases, limited humus reserve and structureless sand mass, which causes unsatisfactory physical characteristics of this soil. The subject of the study was potato cultivars with different maturity periods created in the breeding laboratory of the Polissia Research Department: early ripening – Vzirets, Tyras, Radomysl, Svitlana; middle early – Partner, Mezhyrichka 11, Vyhoda, Opillia, Avanhard, Fanatka, and Sontsedar; mid-ripening – Basaliia, Charunka, Alians, Ivankivska rannia, and Dzhavelina; middle late – Oleksandrit, Rostavitsia, and Lietana. The study employed field, laboratory, selection, and statistical methods.

Potatoes were planted in the first decade of May with a row spacing of 70 cm and at 35 cm between tubers in a row. In the two-row plots, 60 tubers were planted on an area of 44.1 m^2 with a threefold replication. The planting density was 40.8 thsd pcs./ha. Harvesting was carried out at the stage of full ripeness. Mineral fertilisers were applied following the generally accepted technological process in breeding work and the methodology described by A.A. Bondarchuk *et al*. (2019). Plant protection against late blight, the Colorado potato beetle, and weeds was used in the experiments. The analysis of the average starch content and taste characteristics of potato cultivars was based on cumulative data (total sum of replications) for each year separately. To determine the starch content (percentage of starch), undamaged tubers of medium size were selected in two replications. The immersion weighing principle based on specific gravity (Nissen, 1955) was employed. The specific gravity was determined by measuring the underwater weight of the sample at a controlled water temperature of 17.5 °C using the following formula:

$$\text{Specific gravity} = \frac{\text{weight in water x (weight in air} - \text{weight in water)}}{\text{weight in water}}, \tag{1}$$

The total weight of the sample was 5.0 kg. The immersion weighing principle was used in a standardised Reimann-Parov immersion hydrostatic balance scale according to the method by K. Eckert (1975). The evaluation of taste was carried out by analysing 5-10 healthy tubers of average size for each cultivar. Each cultivar was cooked separately until readiness without the use of seasonings or added flavourings. The samples were evaluated on a nine-point scale, where 9 is the highest level of trait expression (Methodology for the examination of potato plant varieties..., 2017; Bondarchuk *et al.,* 2019).

Using a stepwise regression analysis, a study was conducted on the effect of temperature and precipitation in the summer months on the starch content of potato tubers and taste. The dependent variables in the study included maturity group, years, and potato cultivars, while the independent variables were precipitation and average air temperature for individual months: X_1 – temperature in June, X_2 – temperature in July, X_3 – temperature in August, X_4 – precipitation in June, X_5 – precipitation in July, X_6 – precipitation in August. The coefficient of determination was used to assess the model's fit. A mathematical model of the relationship between starch content and taste of potato cultivars of different maturity groups, temperature conditions, and precipitation was developed for the growing seasons of 2018-2023:

$$y_{1,2} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6, \tag{2}$$

where y_1 is the starch content (dependent variable), y_2 is the taste (dependent variable), a_1, a_2, ..., a_6 are the coefficients of the regression equation, starting from a_1 (June temperature) and ending with a_6 (August precipitation), x_1 - x_3 are the temperatures for the respective months, and x_4 - x_6 are the precipitation for the respective months. All calculations were performed using Microsoft Excel with a significance level of $p \leqslant 0.05$. The study followed the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

In the years of the study during the summer growing season, differences between the average monthly temperature and the long-range temperature were found. A significant increase in the average monthly temperature was found compared to long-term observations: in June 2019, 2020, 2021 by +7.9°C, +8.9°C, and +8.3°C, respectively; in July 2020 and 2021 – by +7.4°C, and +10.5°C; in August 2020, 2021, and 2023 – by +8.7°C, +7.5°C, and +6.2°C. (Fig. 1).

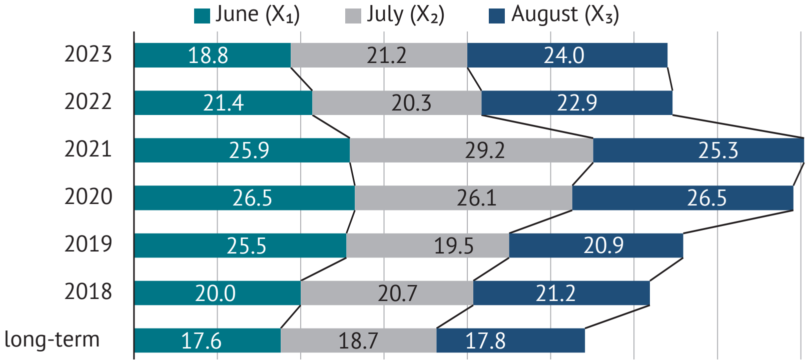

Figure 1. *Average monthly air temperature for 2018-2023 and long-term*
Source: *compiled by the authors of this study*

In contrast to the temperature regime, the monthly amount of precipitation during the study period was much lower than over the long-term observation period. In June 2019, 2022, and 2023, there was a significant deviation from the long-term average (28.3 mm), namely by -13.6 mm, -9.3 mm, and -11.1 mm, respectively. Only in June 2020 there was an excess of +9.4 mm. Indicators of precipitation deviations for July in all years of the study were characterised by negative values, from a maximum of -23 mm in 2020 to a minimum of -0.2 mm in 2018. Notably, August in most years of the study was characterised by dry conditions; the negative value of precipitation fluctuations ranged from no precipitation during the month in 2020 to 17.7 mm in 2022. Only in 2021 there was a positive increase in the monthly amount of precipitation to the long-term level, namely, +12.7 mm (Fig. 2).

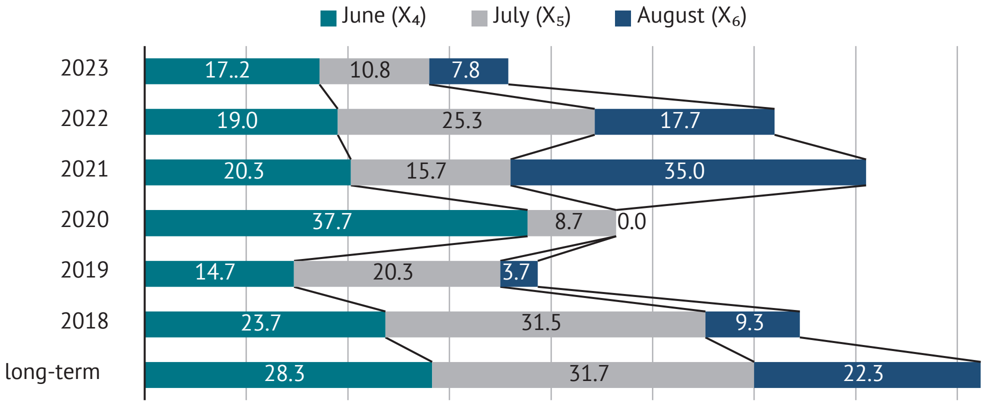

Figure 2. Average monthly precipitation for 2018-2023 and long-term
Source: *compiled by the authors of this study*

Thus, monthly precipitation amounts were largely insufficient to provide moisture in the soil, which negatively affected the formation of full-quality characteristics in potato cultivars. According to the results of the regression analysis, the interconnection between average temperature, monthly precipitation, and starch content in potato cultivars divided into different maturity groups was established. The analysis shows that for all maturity groups, the percentage of starch in tubers depends on the average monthly temperature in July and August. For early-ripening and middle-late cultivars, this trait was influenced by the monthly amount of precipitation in June and July; for middle early and mid-ripening cultivars, the starch content was determined by the amount of precipitation in July and August (Table 1).

Table 1. *Multiple regression equation of the connection between average temperature, precipitation, and starch content in tubers of potato cultivars of different ripeness groups, 2018-2023*

Maturity group	Multiple regression equations	Coefficient of determination (R^2)
Early	$y_1 = -9.36 - 0.41{*}X_2 + 1.46{*}X_3 - 0.11{*}X_4 + 0.07{*}X_5$	0.999
Middle early	$y_1 = 14.09 - 0.42{*}X_2 + 0.51{*}X_3 - 0.17{*}X_5 + 0.10{*}X_6$	0.998
Mid-ripening	$y_1 = 18.22 - 0.25{*}X_2 + 0.12{*}X_3 - 0.13{*}X_5 + 0.11{*}X_6$	0.979
Middle late	$y_1 = 8.47 - 0.20{*}X_2 + 0.68{*}X_3 - 0.06{*}X_4 - 0.06{*}X_5$	0.810

Source: *compiled by the authors of this study*

The correlation coefficient between the average monthly temperature and starch content in July for potato cultivars of all maturity groups was moderately positive (from +0.244 to +0.484). For middle early and mid-ripening cultivars in August, the correlation coefficient was high and positive (+0.682 to +0.738). According to the results of the correlation analysis between precipitation and starch content, an average negative correlation was found in June and July (-0.299 and -0.538) and a high positive correlation in August (+0.641) for mid-ripening cultivars, a high negative correlation in July for early, middle early and middle-late cultivars (-0.626…-0.827) (Table 2).

Table 2. *Correlation between temperature, precipitation, and starch content in potato cultivars of different maturity groups, 2018-2023*

Maturity group	X_1	X_2	X_3	X_4	X_5	X_6	$\bar{Y}_1$
$\bar{Y}_1$ early	-0.142	0.244	0.682	0.175	-0.626	0.101	1.000
$\bar{Y}_1$ middle early	0.127	0.458	0.738	0.024	-0.827	0.251	1.000
$\bar{Y}_1$ mid-ripening	0.162	0.484	0.524	-0.299	-0.538	0.641	1.000
$\bar{Y}_1$ middle-late	0.382	0.336	0.686	0.182	-0.824	-0.025	1.000

Note: *$\bar{Y}_1$ – average starch content in the maturity group*
Source: *compiled by the authors of this study*

J.S. Busse *et al.* (2019) and L. Prysiazhniuk *et al.* (2023) note that the starch content depends the most on the growing conditions in specific years. According to V.V. Hordienko (2021) and P. Zaviryukha *et al.* (2023), the starch content is determined by both varietal characteristics and the conditions of the years of research. There is a significant connection between these factors. As a result of the regression analysis, the interconnection between monthly precipitation, temperature, and starch content in tubers for each potato cultivar during the seasons of 2018-2023 was established. For cultivars of the early maturity group Vzirets, Radomysl, Svitlana, the middle early group Avanhard, Vyhoda, Opillia, Fanatka, and the mid-ripening cultivar Rostavitsia, the regression equation includes the average monthly temperature in July and August, as well as the amount of precipitation in June and July (Table 3). The starch content of tubers of the early cultivar Tyras, the middle early cultivar Partner, the mid-ripening cultivars Bazaliia, Alians, Charunka, and the middle-late cultivars Lietana and Oleksandryt was relatively dependent on the monthly temperatures in July and August and the amount of precipitation in July and August.

Table 3. *Multiple regression equation of the connection between average temperature, monthly precipitation, and starch content of potato cultivars, 2018-2023*

Cultivar	Multiple regression equations	Coefficient of determination (R^2)
	Early	
Vzirets	$y_1 = 3.47 - 0.13*X_2 + 0.65*X_3 - 0.02*X_4 + 0.06*X_5$	0.994
Tyras	$y_1 = 10 - 0.38*X_2 + 0.60*X_3 - 0.06*X_5 + 0.07*X_6$	0.875
Radomysl	$y_1 = -13.87 - 0.53*X_2 + 1.82*X_3 - 0.19*X_4 + 0.09*X_5$	0.999
Svitlana	$y_1 = -25.25 - 0.71*X_2 + 2.35*X_3 - 0.12*X_4 + 0.10*X_5$	0.976
	Middle early	
Partner	$y_1 = -1.49 - 0.80*X_2 + 1.43*X_3 - 0.07*X_5 + 0.16*X_6$	0.998
Mezhyrichka11	$y_1 = 9.1 - 0.14*X_2 + 0.45*X_3 - 0.11*X_5$	0.701
Avanhard	$y_1 = -2.95 - 0.32*X_2 + 1.21*X_3 - 0.17*X_4 - 0.01*X_5$	0.915
Vyhoda	$y_1 = 18.14 + 0.13*X_2 - 0.02*X_3 - 0.18*X_4 - 0.17*X_5$	0.999
Opillia	$y_1 = 16.88 + 0.12*X_2 + 0.04*X_3 - 0.04*X_4 - 0.12*X_5$	0.948
Fanatka	$y_1 = -15.92 - 0.50*X_2 + 1.82*X_3 - 0.10*X_4 + 0.02*X_5$	0.992
	Mid-ripening	
Bazaliia	$y_1 = 5.32 - 0.50*X_2 + 0.84*X_3 - 0.09*X_5 + 0.17*X_6$	0.987
Alians	$y_1 = -1.85 - 0.56*X_2 + 1.16*X_3 - 0.04*X_5 + 0.14*X_6$	0.827
Sontsedar	$y_1 = 25.88 - 0.25*X_3 - 0.14*X_4 - 0.15*X_5 + 0.05*X_6$	0.998
Charunka	$y_1 = 9.88 - 0.32*X_2 + 0.51*X_3 - 0.04*X_{5V} + 0.08*X_6$	0.992
Ivankivska rannia	$y_1 = 18.02 - 0.06*X_2 - 0.06*X_4 - 0.08*X_5 + 0.06*X_6$	0.968
Dzhavelina	$y_1 = 8.77 + 0.13*X_1 + 0.29*X_2 - 0.14*X_4 - 0.06*X_6$	0.999
	Middle late	
Lietana	$y_1 = 29.39 - 0.32*X_2 - 0.09*X_3 - 0.26*X_5 + 0.14*X_6$	0.913
Oleksandryt	$y_1 = -17.09 + 1.71*X_3 - 0.22*X_4 + 0.16*X_5 - 0.16*X_6$	0.598
Rostavytsia	$y_1 = 9.87 - 0.22*X_2 + 0.50*X_3 + 0.0002*X_4 - 0.06*X_5$	0.995

Source: *compiled by the authors of this study*

The dependence of starch content was determined by individual parameters of the meteorological regime for the cultivars Mezhyrichka 11 (temperature sums in July and August and precipitation in July), Sontsedar (temperature sums in August and precipitation sums in July and August), Ivankivska rannia (temperature sums in July and precipitation sums in July and August) and Dzhavelina (temperature sums in June and July and precipitation in June and August). T. Sonets and M. Furdyha (2022) confirm that potato cultivars of different maturity groups show different responses to weather conditions during specific growing seasons in the regions of cultivation.

According to the findings of M.M. Furdyga (2022), H. Górska-Warsewicz *et al.* (2021), and J. Hu *et al.* (2023), early-ripening potato cultivars are characterised by lower dry matter and starch content compared to late-ripening cultivars. A direct correlation between high starch content and late maturity of the cultivar was determined. S. Sood *et al.* (2024) argue that tuber starch content and maturity of potato plants are controlled by independent genetic loci. This highlights the prospect of developing early-ripening potato cultivars with high starch content. According to the findings of S. Siddiqui *et al.* (2022), the starch content is mainly determined by the characteristics of a particular cultivar.

The cluster analysis was performed based on the similarity of starch content during the growing seasons of 2018-2023. Using the cluster method, two groups of genotype distribution were identified at a distance of 20, which united cultivars with analogous indicators. The largest cluster includes 15 cultivars of different maturity groups, which is divided into two subclusters. The first subcluster includes mid-ripening cultivars such as Alians and Bazaliia, middle early cultivars such as Avanhard, Mezhyrichka 11, Partner, Vyhoda, Fanatka, and early-ripening cultivars such as Radomysl and Svitlana. These cultivars are characterised by a low starch content of 12.8-14.4%. The second subcluster consists of genotypes with an average starch content ranging from 14.5% to 15.4%. The subcluster includes mid-ripening cultivars – Ivankivska rannia, Charunka, Dzhavelina, middle-late Rostavytsia, middle early Sontsedar and early Tyras (Fig. 3). The second, more distant cluster includes the middle-late potato cultivars Lietana and Oleksandryt, the middle early Opillia, and the early-ripening Vzirets, which showed a high starch content of 16.6-19.2% during the study period. According to I. Samaniego *et al.* (2020) and R. Ilahy *et al.* (2023) varietal characteristics and weather conditions of cultivation in a particular year have a significant impact on the biochemical parameters of potato tubers, which affects the taste of tubers when boiled.

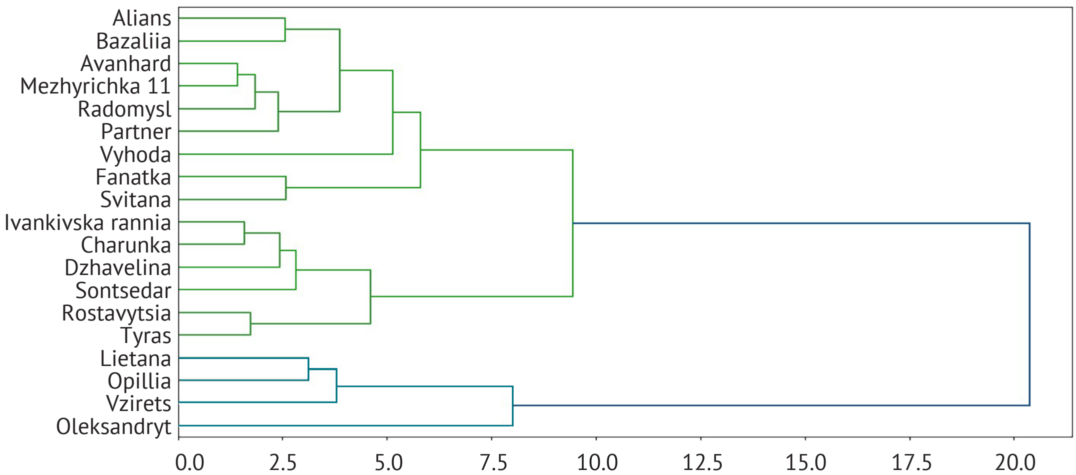

Figure 3. *Cluster analysis of potato cultivars by starch content indicators, 2018-2023*
Source: *compiled by the authors of this study*

During 2018-2023, a mathematical model that describes the combined effect of various climatic factors of the season on the taste characteristics of potato cultivars of different maturity groups was developed. The main meteorological factors that affect the taste of early potato cultivars are the average monthly temperature in July and August and the amount of precipitation in June and July (Table 4).

Table 4. *Multiple regression equation of the connection between average temperature, monthly precipitation, and taste of potato cultivars of different maturity groups, 2018-2023*

Maturity group	Multiple regression equations	Coefficient of determination (R^2)
Early	$y_2 = 7.02 - 0.10{*}X_2 + 0.19{*}X_3 - 0.04{*}X_4 - 0.02{*}X_5$	0.890

Table 4. Continued

Maturity group	Multiple regression equations	Coefficient of determination (R^2)
Middle early	$y_2 = 3.19 + 0.08*X_1 - 0.12*X_2 + 0.29*X_3 - 0.03*X_4$	0.998
Mid-ripening	$y_2 = 1.93 + 0.05*X_1 - 0.13*X_2 + 0.36*X_3 - 0.04*X_4$	0.926
Middle-late	$y_2 = 3.12 + 0.10*X_1 - 0.24*X_2 + 0.35*X_3 + 0.03*X_6$	0.989

Source: *compiled by the authors of this study*

However, the taste of middle early, mid-ripening, and middle-late genotypes was influenced by temperatures in June, July, and August, and monthly precipitation in June. For the middle-late cultivars, precipitation in August was a key factor that influenced the taste characteristics. Based on the correlation analysis, which accommodated the influence of weather conditions on taste characteristics, it was found that between the taste qualities of early-ripening cultivars, there is a negative, but insignificant and medium correlation with the temperature in July (-0.239) and the amount of precipitation in June and July (-0.457; -0.482) (Table 5).

Table 5. *Correlation between temperature, precipitation, and taste of potato cultivars of different maturity groups, 2018-2023*

Maturity group	X_1	X_2	X_3	X_4	X_5	X_6	$\bar{Y}_2$
$\bar{Y}_2$ early	-0.053	-0.239	0.088	-0.457	-0.482	-0.079	1.000
$\bar{Y}_2$ middle early	0.443	0.220	0.522	0.034	-0.751	-0.055	1.000
$\bar{Y}_2$ mid-ripening	0.187	0.248	0.628	0.085	-0.680	0.091	1.000
$\bar{Y}_2$ middle-late	0.280	0.142	0.534	0.234	-0.509	-0.052	1.000

Note: *$\bar{Y}_2$ – average score for taste in the maturity group*
Source: *compiled by the authors of this study*

The cultivars of the middle early group showed a weak positive and medium correlation between taste and temperature conditions in June-August (+0.443...+0.522), mid-ripening (+0.187...+0.628), and middle late (+0.280...+0.534). In terms of the connection between taste and precipitation, these maturity groups were characterised by a weak correlation in June and August and a negatively high (-0.680; -0.751) and medium (-0.509) correlation in July.

According to the results of the regression analysis, the interconnection between the independent variables – monthly precipitation and average monthly temperatures and the dependent variable – the taste of potato tubers of the corresponding cultivar during the growing season of 2018-2023 was determined. It was found that the taste of different potato cultivars, early – Vzirets, Tyras, and Radomysl, middle early – Mezhyrichka 11, Opillia, mid-ripening – Sontsedar and Ivankivska rannia, is significantly influenced by the temperature in July and August and the amount of precipitation in June–July (Table 6). For the formation of the taste characteristics of the early-ripening Svitlana cultivar, the middle early Fanatka, and the mid-ripening Dzhavelina, temperatures in June and July and precipitation in June-July (Svitlana), July-August (Fanatka), and June and August (Dzhavelina) are important.

Table 6. *Multiple regression equation of the connection between average temperature, monthly precipitation and taste in potato cultivars, 2018-2023*

Cultivar	Multiple regression equation	Coefficient of determination (R^2)
	Early	
Vzirets	$y_2 = 8.67 - 0.09*X_2 + 0.15*X_3 - 0.04*X_4 - 0.05*X_5$	0.712
Tyras	$y_2 = 5.78 - 0.06*X_2 + 0.18*X_3 - 0.03*X_4 - 0.02*X_5$	0.968
Radomysl	$y_2 = 7.15 - 0.16*X_2 + 0.24*X_3 - 0.03*X_4 - 0.02*X_5$	0.802
Svitlana	$y_2 = 11.15 - 0.05*X_1 - 0.02*X_2 - 0.05*X_4 - 0.04*X_5$	0.963
	Middle early	
Partner	$y_2 = 3.96 + 0.07*X_1 - 0.14*X_2 + 0.28*X_3 - 0.04*X_4$	0.985
Mezhyrichka11	$y_2 = 3.66 - 0.10*X_2 + 0.32*X_3 - 0.04*X_4 + 0.003*X_5$	0.804
Avanhard	$y_2 = 7.97 + 0.03*X_1 + 0.02*X_3 - 0.02*X_4 - 0.01*X_5$	0.622
Vyhoda	$y_2 = 7.25 + 0.08*X_1 + 0.001*X_3 - 0.03*X_4 - 0.03*X_5$	0.695
Opillia	$y_2 = 7.15 - 0.05*X_2 + 0.12*X_3 + 0.01*X_4 - 0.05*X_5$	0.964
Fanatka	$y_2 = 8.32 + 0.07*X_1 - 0.07*X_2 - 0.02*X_5 + 0.004*X_6$	0.975

Table 6. Continued

Cultivar	Multiple regression equation	Coefficient of determination (R^2)
	Mid-ripening	
Bazaliia	$y_2 = 5.32 - 0.50*X_2 + 0.84*X_3 - 0.09*X_5 + 0.17*X_6$	0.909
Alians	$y_2 = 1.74 - 0.17*X_2 + 0.41*X_3 + 0.01*X_5 + 0.02*X_6$	0.767
Sontsedar	$y_2 = 2.39 - 0.17*X_2 + 0.42*X_3 - 0.03*X_4 + 0.01*X_5$	0.912
Charunka	$y_2 = 2.74 - 0.14*X_2 + 0.33*X_3 - 0.01*X_5 + 0.03*X_6$	0.952
Ivankivska rannia	$y_2 = 8.62V - 0.05*X_2 + 0.04*X_3 + 0.01*X_4 - 0.03*X_5$	0.777
Dzhavelina	$y_2 = 9.01 - 0.11*X_1 + 0.10*X_2 - 0.05*X_4 + 0.01*X_6$	0.877
	Middle-late	
Lietana	$y_2 = 7.63 - 0.11*X_2 + 0.14*X_3 - 0.03*X_5 + 0.03*X_6$	0.989
Oleksandryt	$y_2 = 5.37 + 0.12*X_1 - 0.21*X_2 + 0.21*X_3 + 0.01*X_6$	0.980

Source: *compiled by the authors of this study*

Notably, in the early-ripening cultivar Partner and the middle-late cultivars Oleksandryt and Rostavytsia, a correlation between taste and average monthly temperature was observed throughout the summer period, considering differences in moisture supply. For the Partner cultivar, moisture is important in June, while for the middle-late genotypes it is important in August. According to the results of regression analysis, the manifestation of taste characteristics in the mid-ripening cultivars Bazaliia, Alians, Charunka, and the mid-late cultivar Lietana is determined by the temperature in July and August and the average monthly precipitation in July and August. Consumption of potatoes in food is increasingly recognised, but to be commercially successful, a cultivar must have improved flavour and meet high standards of consumer quality.

To determine the similarity of the indicators of taste characteristics in the studied potato cultivars during 2018-2023, the cluster analysis method was used. According to its results, the cultivars were divided into two clusters. The first cluster included cultivars that had good taste qualities in the range of 7.5-7.9 points during all seasons of research: Sontsedar, Radomysl, Svitlana, Dzhavelina, Ivankivska rannia, Tyras, Vyhoda, Charunka, Bazaliia and Alians. It is important to note that in this cluster, the cultivars Dzhavelina and Ivankivska early, Sontsedar and Radomysl were the most similar cultivars with the lowest genetic distance (Fig. 4).

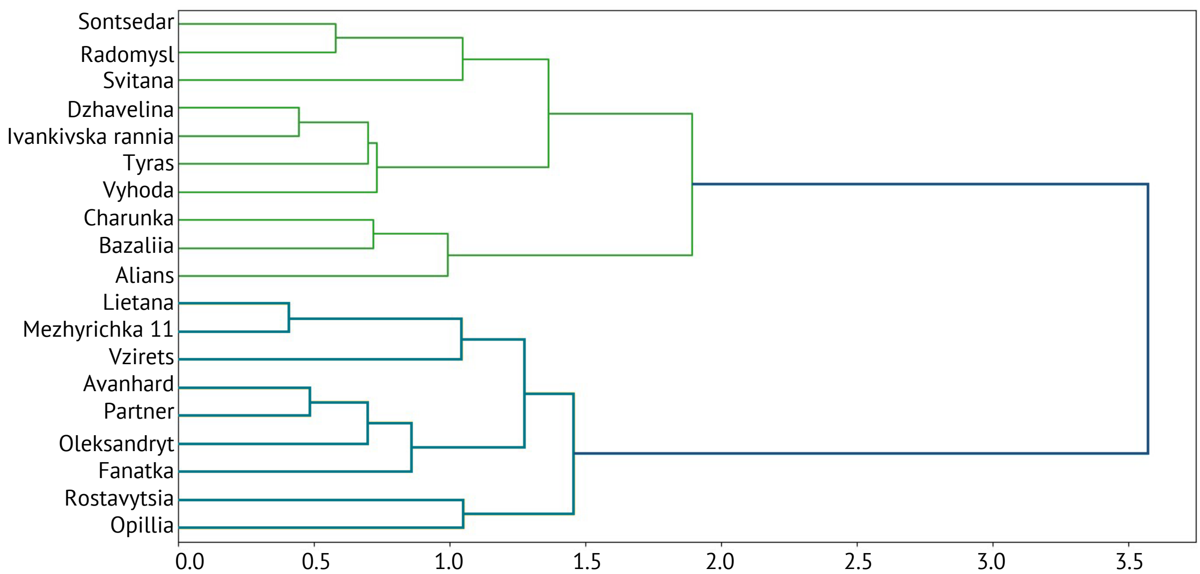

Figure 4. *Cluster analysis of potato cultivars by taste, 2018-2023*
Source: *compiled by the authors of this study*

The second cluster includes potato cultivars that have a higher taste rating by 0.2-0.5 points (within 8.1-8.4 points) compared to the average score of the first cluster, namely: Lietana, Mezhyrichka 11, Vzirets, Avanhard, Partner, Oleksandryt, Fanatka, Rostavytsia and Opillia. In terms of taste, the cultivars Lietana, Mezhyrichka 11, Avanhard and Partner are characterised by the smallest distance within this cluster. W.L. Morris and M.A. Taylor (2019), R.A. Bough *et al.* (2020), and N.N. Mudege *et al.* (2021) emphasise that sensory characteristics should become an integral part of the definition of traits in selection programs. Considering the growing impact of global climate change on Ukraine's agricultural sector, the study findings provide valuable information for breeders and scientists. These data will allow prompt measures to be taken to maintain key quality indicators in potato cultivars and to respond effectively to adverse weather conditions. In addition, they will help to optimise agronomic practices in potato growing and develop new methods of adaptation to climate change.

CONCLUSIONS

A mathematical model was developed and used to determine the complex influence of various climatic factors of the season on the taste characteristics and starch content, depending on the maturity group and varietal characteristics of potatoes. The results of the correlation analysis indicated a close positive connection between the average monthly temperature and starch content in August for middle early and mid-ripening cultivars. Between the amount of precipitation and starch content, a high positive correlation was noted in August for mid-ripening cultivars and a high negative correlation in July for early, middle early, and middle-late cultivars. The correlation between the independent variable (average monthly air temperature) and the dependent variable (taste) in different maturity groups is mostly weak negative or positive. The exception is August, when a moderate positive correlation was observed, except early-ripening cultivars. An important independent variable is precipitation, while the correlation analysis shows a medium to high degree of negative correlation in July. When determining the influence of weather conditions on the expression of taste characteristics of a particular potato cultivar, the interconnection between the taste of tubers and meteorological factors was established.

Increasing temperatures in August had a positive effect on the taste of Vzirets, Radomysl, and Tyras, while for Partner, Avanhard, and Vyhoda, temperatures in June and August were a key factor in increasing the taste index. Apart from these temperatures, the cultivars Oleksandryt and Rostavytsia responded to precipitation in August. Increased temperatures in August contributed to an increase in the evaluation of the taste of Opillia, Ivankivska rannia, Mezhyrichka 11, Sontsedar, Alians, Bazaliia, Charunka, and Lietana. It is worth noting the difference in the influence of monthly precipitation on the tasting assessment: for the first two genotypes, June rains were significant, for the next two – July rains, and for the Alians cultivar – precipitation in July and August, while the last three were influenced only by August precipitation. The Fanatka and Dzhavelina cultivars showed a high score for taste with precipitation in August but differed in temperature conditions: for the first cultivar, an increase in temperature in June was important, for the second – in July. The hierarchical cluster analysis allowed identifying a group of genotypes with consistently high starch content.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Вплив погодних умов Центрального Полісся України на прояв якісних показників сортів картоплі різних груп стиглості

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Анотація. Для українців картопля є ключовим продуктом харчування та найважливішою стратегічною культурою в овочевому сегменті, тому актуальним є дослідження якісних характеристик бульб картоплі. Метою роботи було вивчення впливу різних метеорологічних факторів на смакові показників та вміст крохмалю у бульбах різних сортів картоплі. Методи досліджень – лабораторні, аналітичні і математично-статистичні. У сортів різних груп стиглості виявлено, як позитивну так і негативну кореляцію між вмістом крохмалю в бульбах, смаковими якостями, середньомісячною температурою і опадами. Для одних сортів картоплі позитивний вплив на вміст крохмалю в бульбах був обумовлений синергетичною взаємодією температур у серпні та опадів у липні, для інших сортів цей вплив визначався температурою та опадами у серпні. Встановлено, що підвищення температури у серпні сприяло покращенню смакових характеристик ранньостиглих сортів, тоді як для середньоранніх і середньостиглих генотипів важливими факторами були підвищені температури у червні та серпні, а середньопізні сорти реагували на збільшення опадів у серпні. Для кожного, з 19 досліджуваних сортів виділено періоди з позитивним впливом середньомісячної температури та опадів на поліпшення смакових якостей. Кластерний аналіз дозволив ідентифікувати сорти картоплі з підвищеним вмістом крохмалю – Лєтана, Опілля, Взірець і Олександрит, з високими смаковими якостями – Лєтана, Межирічка 11, Взірець, Авангард, Партнер, Олександрит, Фанатка, Роставиця і Опілля. Результати досліджень можуть слугувати науковою базою для розробки політики, спрямованої на пом'якшення наслідків кліматичних змін, адаптацію існуючих сортів картоплі та підтримку стійкого виробництва картоплі в конкретному регіоні та створення нових пластичних генотипів картоплі зі стійкими якісними характеристиками

Ключові слова: S*olanum tuberosum* L.; стиглість, температура; опади; крохмаль; смак; диференціація сортів

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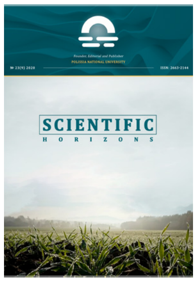

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Effects of different types of local potential manure on the availability and uptake of P and K of rice in Inceptisols

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Abstract. The availability of Inceptisols nutrients is not sufficient for organic farming activities in rice cultivation, therefore it can be optimized by adding organic fertilizers, one of which is manure. The study aims to determine the effect of various manure types on the availability and uptake of P and K nutrients of rice in Inceptisols. The study used a single-factor Randomized Complete Group Design with 10 treatments: T1 = control; T2 = NPK 200 kg/ha; T3 = cow manure 10 tons/ha; T4 = chicken manure 10 tons/ha; T5 = goat manure 10 tons/ha; T6 = quail manure 10 tons/ha; T7 = NPK 100 kg/ha + cow manure 5 tons/ha; T8 = NPK 100 kg/ha + chicken manure 5 tons/ha; T9 = NPK 100 kg/ha + goat manure 5 tons/ha; T10 = NPK 100 kg/ha + quail manure 5 tons/ha

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repeated 3 times with experimental plots measuring 2.5 m×4 m. The results showed that quail manure applied singly or in combination with NPK fertilizer had a substantial effect on available P, exchangeable K, and plant P and K uptake. This is determined by high P and K nutrient contents in manure and has a lower C/N ratio than other manures. The results showed that quail manure was able to increase the availability and uptake of P and K nutrients of rice plants in Inceptisols. Thus, quail manure can be a recommended organic fertilizer for rice cultivation

Keywords: organic fertilizer; macro-nutrients; organic matter; soil fertility; rice field

INTRODUCTION

Rice is a crop and a source of staple food for most of Indonesia's population. The increasing population is always followed by the demand for rice. The demand for rice that must be met causes rice fields to be continuously planted. Moreover, inorganic fertilizers, that are not balanced with organic fertilizers, are used. This decreases land productivity. The decline in land/soil productivity is related to soil properties, namely soil physical, chemical and biological properties. One of the chemical properties that has a direct influence on crop production is nutrients.

The availability of nutrients in the soil is important for plant growth and development. This is because plants cannot survive if nutrients are not available in the soil. Following A. Adekiya *et al.* (2020), plants that do not get enough nutrients will have poor performance that affects growth and reduces crop yields. According to Sh. Jiban *et al.* (2020), rice plants need P nutrients in root development, ripening, and early flowering, while potassium elements optimize root development, increase plant vigour, stimulate cell division, help neutralize organic acids, and maintain plant metabolism. However, the presence of these nutrients cannot meet the needs of plants due to several factors, such as leaching or the formation of complex compounds with other elements. Low nutrient availability also occurs in Inceptisol soil.

Based on the results of research by I. Septyani and F. Harahap (2022), Inceptisol soils have low organic C content and nutrients N, P, K. Thus, Inceptisols have low nutrient availability. Thus, Inceptisols have low fertility. According to H. Husein *et al.* (2021), the presence of soil organic matter content and the availability of macronutrients in the soil are indicators of soil fertility. The low phosphorus and potassium nutrients in Inceptisol soils are determined by a lengthy process of the mineral rocks weathering and the process of releasing nutrients into plant-available forms. In addition, J. Sardans and J. Peñuelas (2021) stated that the element potassium has high mobility so it is easily leached from the soil profile. Therefore, efforts are needed to increase the content of nutrients as well as soil organic matter, namely with manure.

Manure improves the physical, chemical, and biological properties of soil. Manure can increase soil fertility, and water retention and control soil temperature to improve plant growth and productivity. According to S. Suntoro *et al.* (2023), long-term application of manure can provide a residual effect on the availability of nutrients and a looser soil structure. Compared to inorganic fertilizers, organic fertilizers can provide complete nutrients, although in small amounts. Therefore, it is needed in large quantities to meet the nutrient needs of plants. According to M. Islam *et al.* (2021), the mineralization process of manure requires microbes to release nutrients into the soil. N. Rayne and L. Aula (2020) state that manure applied alone or in combination with chemical fertilizers can increase the accumulation of macronutrients and micronutrients in the soil. Based on research by P. Gao *et al.* (2023), the combination of manure with NPK fertilizer can have a significant effect on available P and total soil P levels than inorganic fertilizer (NPK) alone. S. Dhaliwal *et al.* (2022) reported that the use of organic fertilizers and inorganic fertilizers can significantly increase the uptake of macronutrients and micronutrients and increase the yield of basmati grain and straw. Therefore, a study was conducted to analyse the effect of various types of manure on the availability and uptake of P and K nutrients of rice plants in Inceptisols.

MATERIALS AND METHODS

Study area. This research was conducted in Gempol Village, Karanganom District, Klaten Regency, Central Java. Soil and plant analysis were analysed at the Soil Chemistry and Fertility Laboratory, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta. The research was conducted from May 2023 to March 2024.

Procedures. *Study Methods.* This research uses an experimental method with a Randomized Completely Group Design (RCBD). The study used 10 treatments with 3 replications, resulting in 30 experimental plots. Plot sizes were 2.5 m × 4 m. Rice plants were planted at 25 × 25 cm spacing. The rice variety used was Rojolele. The treatments used are presented in Table 1.

***Table 1**. Treatment in the research*

Code	Treatment	Dose			
		Manure		NPK	
		(kg/ha)	(kg/plot)	(kg/ha)	(kg/plot)
T1	Control	0	0	0	0
T2	NPK	0	0	200	0,2

Table 1. Continued

Code	Treatment	Dose			
		Manure		NPK	
		(kg/ha)	(kg/plot)	(kg/ha)	(kg/plot)
T3	Cow manure	10.000	10	0	0
T4	Chicken manure	10.000	10	0	0
T5	Goat manure	10.000	10	0	0
T6	Quail manure	10.000	10	0	0
T7	NPK + cow manure	5.000	5	100	0,1
T8	NPK + chicken manure	5.000	5	100	0,1
T9	NPK + goat manure	5.000	5	100	0,1
T10	NPK + quail manure	5.000	5	100	0,1

Source: *compiled by the authors*

Implementation of research. Tillage was done by ploughing the soil until muddy and levelling it. The experimental plots used were 2.5 m × 4 m in size. Manure application was done after tillage, i.e. 6 days before planting. NPK fertilization was done twice, 7 and 21 days after planting (DAP). Maintenance included irrigation, weeding, and pest and disease control. Soil and plant sampling were conducted at the maximum vegetative phase (60 days). Soil samples were taken in each plot with a total of 30 samples and plant tissue samples were taken 3 samples per plot with a total of 90 samples.

Soil and plant analysis. Soil analysis included pH (electrometric method); organic C (Walkley and Black method); available P (Olsen method); exchangeable K, Cation Exchange Capacity (CEC), and Base Saturation (BS) (1 N ammonium acetate extraction method pH 7). Plant analysis included: plant tissue P and K (extraction with HNO_3 and $HClO_4$). The nutrient uptake of the upper crop (shoot) is obtained from the multiplication of the crop dry weight with the crop nutrient content. Manure analysis includes: pH (electrometric method), total N (Kjeldahl method), total P, and total K (HNO_3 and $HClO_4$ extraction) (Balai Pengujian Standar Instrumen Tanah dan Pupuk, 2023)

Data analysis. The results were analysed using ANOVA at the 95% and 99% confidence levels, followed by Duncan Multiple Range Test (DMRT) at the 95% confidence level to see whether there were differences between treatments, Pearson correlation test to determine the strength of the relationship between the observed variables, and regression test to see how much influence the independent variable has on the dependent variable.

RESULTS AND DISCUSSION

Soil characteristics. The soil at the study site belongs to the Inceptisols order. Inceptisol soils have an issue of low organic matter and nutrients N, P, K. (Yuniarti *et al.*, 2021). This soil has a pH of 6.71 (neutral), Organic C 1.36% (low), CEC 17.64 me/100g soil (moderate), Available P 9.93% (low), Exchangeable K 0.21 me/100 g (low), Base Saturation 32.26% (low) which are presented in Table 2.

Table 2*. Soil characteristics at the study site*

Analysis	Value	Unit	Classification
pH	6.71	-	Neutral
Organic C	1.39	%	Low
Total N	0.12	%	Low
Available P	9.92	ppm	Low
Exchangeable K	0.20	meq/100 g of soil	Low
Cation Exchange Capacity	17.81	meq/100 g of soil	Medium
Base Saturation	32.26	%	Low

Source: *classification based on Balai Pengujian Standar Instrumen Tanah dan Pupuk (Balai Pengujian Standar Instrumen Tanah dan Pupuk, 2023*

Based on these soil characteristics, the Inceptisol soil in Gempol Village has low soil fertility. The low soil fertility is determined by low available nutrients and soil organic matter content. According to H. Husein *et al.* (2021), soil fertility can increase along with the increase in soil organic matter content, and natural soil fertility can be maximized if the soil pH ranges from 5.5 to 7.0, good drainage, and the presence of various microorganisms that support plant growth.

Characteristics of manure. The manure, employed in this study, is sourced from animal manure in the local area. Potential local manures include cow, chicken, goat, and quail manure. The four manures have a C/N ratio of <20, so the mineralization process will occur faster. This is because the C/N ratio can be used to measure the quality of organic matter, which shows the decomposition process of organic matter (Istikorini *et al.,* 2022). The four manures also have Organic C content and nutrients N, P, and K that can potentially input organic matter into the soil (Table 3).

***Table 3**. Characteristics of manure*

Treatment	Analysis					
	pH	Total N (%)	Total P (%)	Total K (%)	Organic C (%)	C/N
Cow manure	9.06	2.03	0.62	15.57	30.09	14.8
Chicken manure	7.68	2.44	0.26	8.88	31.56	13.0
Goat manure	8.85	2.29	0.16	7.91	27.25	11.9
Quail manure	9.64	3.32	1.67	12.75	32.14	9.7

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

Effect of treatment on soil chemical properties. Variance analysis showed that applying different types of manure had a highly significant effect on soil pH, organic C, and CEC (sig.<0.01). Table 4 shows that treatment A (control) is not significantly different from other types of manure treatments (treatments T4, T5, T6, T7, T8, T9, T10). This treatment shows that the pH has decreased slightly but is still in a neutral condition. This can occur due to a buffer solution that can maintain soil pH. According to C. Yuan *et al.* (2021), the application of soil organic matter increases the soil ph buffering capacity. Treatment T2 (NPK 200 kg/ha) experienced the greatest decrease in soil pH of 6.36 (slightly acidic). This is because inorganic fertilizers such as NPK fertilizer can produce H^+ ions which can lower soil pH. The T3 treatment (10 tons/ha cow manure) also decreased the soil pH to 6.51 (slightly acidic). This decrease can occur since cow manure has the highest C/N ratio compared to other treatments, so the decomposition process is slow. This slow decomposition causes the manure to release still organic acids that can reduce soil pH.

***Table 4**. Effect of treatment on soil chemical properties*

Code	Treatment	pH	Organic C (%)	CEC (meq/100g soil)
T1	Control	6.85 c	1.30 a	20.00 a
T2	NPK	6.36 a	1.43 a	23.78 bc
T3	Cow manure	6.51 ab	2.38 bcd	22.11 ab
T4	Chicken manure	6.68 bc	2.17 bc	22.72 bc
T5	Goat manure	6.70 c	1.85 ab	24.68 cd
T6	Quail manure	6.80 c	2.69 cd	22.21 abc
T7	NPK + cow manure	6.78 c	2.43 bcd	20.03 a
T8	NPK + chicken manure	6.79 c	2.35 bcd	22.26 abc
T9	NPK + goat manure	6.67 bc	2.54 bcd	23.39 bc
T10	NPK + quail manure	6.83 c	2.97 d	26.90 d

***Note:** the numbers followed by different letters in a column show significant results in the DMRT test with a level of 5%*
***Source:** compiled by the authors*

Organic C which showed the highest result, was found in treatment T10 (NPK 100 kg/ha + quail manure 5 tons/ha) at 2.97% (moderate). This can occur as quail manure has greater organic C than other manures. Apart from that, adding NPK fertilizer can also increase the decomposition of organic matter. The T10 treatment (NPK 100 kg/ha + quail manure 5 tons/ha) also had the highest CEC compared to other treatments at 26.90 me/100 g soil (high). According to I. Purnamasari *et al.* (2021), soil CEC depends on pH, soil texture, clay type, and organic matter content.

Effect of Treatment on Soil Available P and Phosphorus Uptake. P nutrient is an essential element that is vital in the growth and development of rice plants, which spurs root growth and accelerates flowering and fruit ripening. The analysis of variance showed that the application of manure had a very significant effect on the availability and uptake of phosphorus (Sig.<0.01). Table 5 shows the results of Duncan's multiple range test at the 5% significance level on soil P-availability and P uptake of rice.

The treatment that gave the highest soil available P and was significantly to other treatments was T10 (NPK 100 kg/ha + quail manure 5 tons/ha) at 20.70 ppm (moderate). Quail manure is an easily weathered manure that mineralizes nutrients faster. In addition, quail manure has a higher P nutrient than other manures. According to A. Antonov *et al.* (2021), quail manure is a high-quality fertilizer as it contains nutrients needed by plants and has a more saturated composition. According to S. Suntoro *et al.* (2023), applying organic fertilizers together with inorganic fertilizers compared to organic fertilizers alone can positively affect microbial biomass and improve soil health. Based on Figure 1, if quail manure is not combined with NPK (treatment P6), it also has the highest yield among manure types, at 16.70 ppm, but is still in the low category.

***Table 5**. Effect of treatment on soil available p and phosphorus uptake*

Code	Perlakuan	Available P (ppm)	Shoot Dry Weight (g/plant)	P Plant Tissue (%)	P Uptake (g/plant)
T1	Control	10.43 a	8.33 a	0.098 a	0.82 a
T2	NPK	12.70 b	33.67 bc	0.133 b	4.46 bc
T3	Cow manure	13.40 bc	33.00 bc	0.144 bc	4.76 bc
T4	Chicken manure	15.44 cde	29.33 bc	0.162 cde	4.74 bc
T5	Goat manure	13.94 bcd	36.00 cd	0.151 bcd	5.45 bc
T6	Quail manure	16.70 e	36.33 cd	0.167 de	6.05 c
T7	NPK + cow manure	15.06 cde	34.33 bc	0.162 cde	5.56 bc
T8	NPK + chicken manure	14.98 cde	25.33 b	0.161 cde	4.08 b
T9	NPK + goat manure	16.18 cd	34.33 bc	0.163 cde	5.59 bc

***Note:** the numbers followed by different letters in a column show significant results in the DMRT test at a 95% confidence level. T1: control, T2: 200 kg/ha NPK fertilizer, T3: 10 tons/ha cow manure, T4: 10 tons/ha chicken manure, T5: 10 tons/ha goat manure, T6: 10 tons/ha quail manure, T7: 5 tons/ha cow manure + 100 kg/ha NPK, T8: 5 tons/ha chicken manure + 100 kg/ha NPK, T9: 5 tons/ha goat manure + 100 kg/ha NPK, T10: 5 tons/ha quail manure + 100 kg/ha NPK*
***Source:** compiled by the authors*

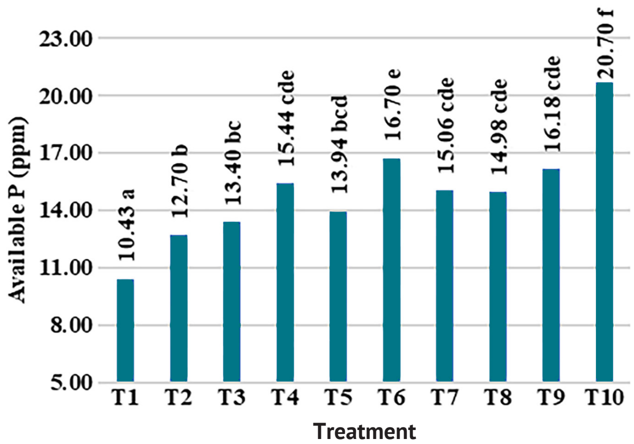

***Figure 1**. Effect of treatment on available P soil*

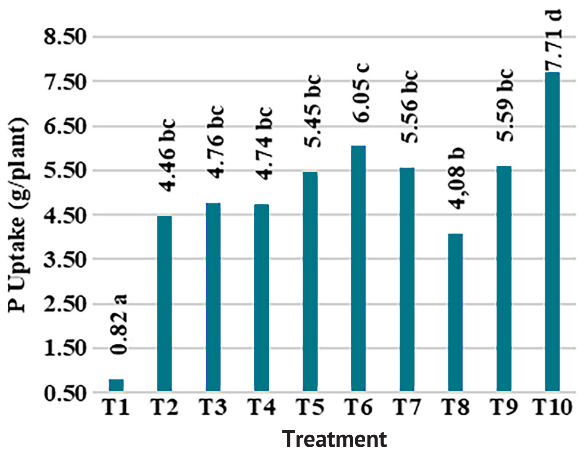

***Figure 2**. Effect of treatment on plant P uptake*

***Note:** T1: control, T2: 200 kg/ha NPK fertilizer, T3: 10 tons/ha cow manure, T4: 10 tons/ha chicken manure, T5: 10 tons/ha goat manure, T6: 10 tons/ha quail manure, T7: 5 tons/ha cow manure + 100 kg/ha NPK, T8: 5 tons/ha chicken manure + 100 kg/ha NPK, T9: 5 tons/ha goat manure + 100 kg/ha NPK, T10: 5 tons/ha quail manure + 100 kg/ha NPK*
***Source:** compiled by the authors*

Based on Figure 2, the treatment that showed the highest P uptake and was significant to other treatments was T2 (NPK 100 kg/ha + quail manure 5 tons/ha) at 7.71 g/plant. This is determined by the high availability of P nutrients in the soil, hence, rice plants can absorb P nutrients more. The research results by Z. Zaki *et al.* (2021) showed that quail manure increased wheat P uptake compared to peanut residue and animal manure. Based on the DMRT test, the application of NPK fertilizer was not significantly different from the application of 10 tons/ha manure (T3, T4, T5, T6) or the combination of 5 tons/ha manure with 200 kg/ha NPK fertilizer (T7, T8, T9). This can occur as the average availability of P in the NPK and manure treatments is moderate (Fig. 1).

Effect of Treatment on Soil Exchangeable K and Potassium Uptake. Potassium has a vital role in stem enlargement of rice plants, regulating enzyme activities, protein synthesis, and increasing the rate of photosynthesis. Analysis of variance showed that the application of manure had a significant effect on exchangeable K (Sig.<0.05) and had a very significant effect on K uptake in rice plants (Sig.<0.01). The results of Duncan's multiple range test at the 5% significance level on exchangeable K and K uptake of rice plants are presented in Table 6.

***Table 6**. Effect of treatment on soil exchangeable K and potassium uptake*

Code	Treatment	Exchangeable K (me/ 100 g of soil)	Shoot Dry Weight (g/plant)	K Plant Tissue (%)	K Uptake (g/plant)
T1	Control	0.17 a	8.33 a	1.93 a	16.06 a
T2	NPK	0.35 b	33.67 bc	3.90 bc	131.41 bc
T3	Cow manure	0.42 b	33.00 bc	3.71 bc	122.54 bc
T4	Chicken manure	0.30 ab	29.33 bc	3.89 bc	114.11 b
T5	Goat manure	0.44 b	36.00 cd	3.78 bc	136.20 bc
T6	Quail manure	0.44 b	36.33 cd	4.74 c	172.34 c
T7	NPK + cow manure	0.30 ab	34.33 bc	3.51 bc	120.62 bc
T8	NPK + chicken manure	0.36 b	25.33 b	4.10 bc	103.78 b
T9	NPK + goat manure	0.33 b	34.33 bc		106.78 b
T10	NPK + quail manure	0.46 b	44.33 d	3.35 b	148.52 bc

***Note:** the numbers followed by different letters in a column show significant results in the DMRT test at a 95% confidence level. T1: control, T2: 200 kg/ha NPK fertilizer, T3: 10 tons/ha cow manure, T4: 10 tons/ha chicken manure, T5: 10 tons/ha goat manure, T6: 10 tons/ha quail manure, T7: 5 tons/ha cow manure + 100 kg/ha NPK, T8: 5 tons/ha chicken manure + 100 kg/ha NPK, T9: 5 tons/ha goat manure + 100 kg/ha NPK, T10: 5 tons/ha quail manure + 100 kg/ha NPK*
***Source:** compiled by the authors*

Figure 3 shows that treatment T10 (NPK 100 kg/ha + quail manure 5 tons/ha) has the highest exchangeable K compared to other treatments at 0.46 meq/100 g soil in the moderate category. The exchangeable K results in the T4 (10 tons/ha chicken manure) and T7 (100 kg/ha NPK + 5 tons/ha cow manure) treatments were not significantly different from the control treatment. Based on the C/N ratio of manure in Table 3, both cow and chicken manure have a higher C/N ratio than other manures, so the decomposition process is slower. H. Shaji *et al.* (2021) state that cow manure is a mineral-rich fertilizer, but mineralization is slow. In addition, the K nutrient itself is mobile, so it is easily leached and lost from the soil solution. The T7 treatment has a low CEC of 20.03 meq/100 g soil (Table 4). Low CEC causes low soil exchangeable K because K is easily leached away. In this case, the high CEC can influence the soil solution to release K slowly and reduce the rate of K leaching in the soil (Wijaya & Budianta, 2023).

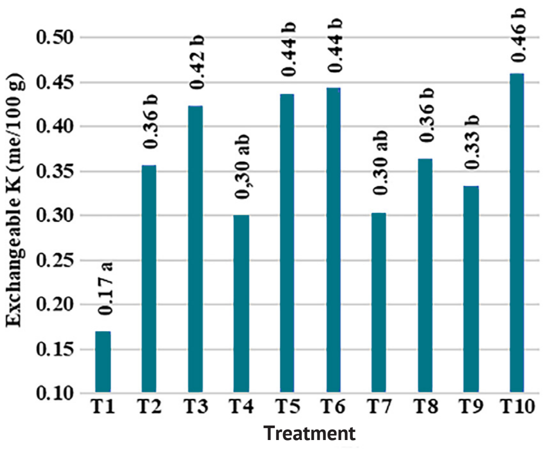

***Figure 3**. Effect of treatment on soil exchangeable K*

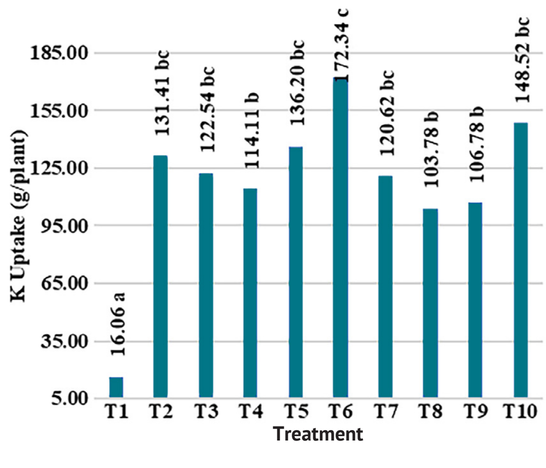

***Figure 4**. Effect of treatment on plant K uptake*

***Note:** T1: control, T2: 200 kg/ha NPK fertilizer, T3: 10 tons/ha cow manure, T4: 10 tons/ha chicken manure, T5: 10 tons/ha goat manure, T6: 10 tons/ha quail manure, T7: 5 tons/ha cow manure + 100 kg/ha NPK, T8: 5 tons/ha chicken manure + 100 kg/ha NPK, T9: 5 tons/ha goat manure + 100 kg/ha NPK, T10: 5 tons/ha quail manure + 100 kg/ha NPK*
***Source:** compiled by the authors*

Variance analysis showed that manure application had a substantial effect on the K uptake of rice plants. Figure 4 shows that the treatment that gives the highest K uptake of rice plants is P6 (10 tons/ha quail manure). The amount of K element absorbed by rice plants is determined by the concentration of K in the soil solution, if the concentration of K in the soil is high, then the uptake of K by plants is also high (Yuniarti *et al.,* 2023). Based on the DMRT test, treatment P6 was significantly different from treatment T1 (control), T4 (chicken manure 10 tons/ha), T8 (chicken manure 5 tons/ha + NPK 100 kg/ha), and P9 (goat manure 5 tons/ha + NPK 100 kg/ha). This is because there was no addition of nutrients in the control treatment, so K nutrients in the soil were not fulfilled. Meanwhile, chicken and goat manure have lower K nutrient levels than cow and quail manure (Table 3.), thus affecting the availability of K nutrients in the soil and impacting the K uptake of rice plants.

Correlation between Soil Variables and Plant Variables. Based on the correlation test results in Table 7, soil available P has a highly significant correlation with a very strong and positive to plant tissue P (r=0.736**) and plant P uptake (r=0.755**). This means that the higher the availability of P in the soil, the more P nutrients are absorbed by plants and enter the plant tissue. Figure 5 shows that the coefficient of determination (R^2) is 0.7503, meaning that plant tissue P levels are influenced by soil-available P levels of 75.03%. Figure 6 shows that the coefficient of determination (R^2) is 0.7745, meaning that plant P uptake levels are influenced by soil-available P levels of 77.45%.

***Table 7**. Correlation between soil variables and plant variables*

Variable	Correlation Coefficient (r)				
	P Plant Tissue	K Plant Tissue	P Uptake	K Uptake	Shoot Dry Weight
Available P	**0.736****	0.163	**0.755****	0.448*	**0.636****
Exchangeable K	0.458*	**0.468****	**0.559****	**0.596****	**0.567****
Organic C	**0.571****	0.276	**0.616****	**0.465****	**0.564****
CEC	0.428*	0.191	**0.549****	0.409*	**0.519****

***Note:** * = signifcance at P < 0.05 (significant correlation); ** = signifcance at P < 0.01(highly significant correlation*
***Source:** compiled by the authors*

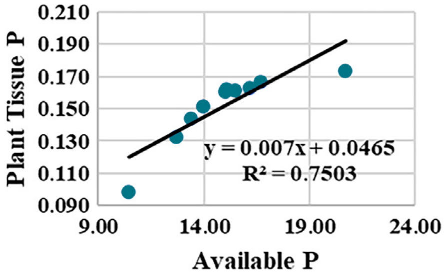

***Figure 5**. Relationship of soil available P to plant tissue P*
***Source:** compiled by the authors*

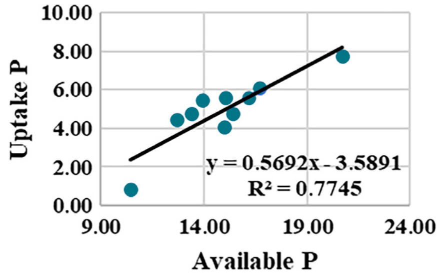

***Figure 6**. Relationship of soil available P to plant P uptake*
***Source:** compiled by the authors*

Exchangeable K had a substantial correlation with a moderate and positive relationship to tissue K (r = 0.468**) and plant K uptake (r = 0.596**). The relationship shows that the increasing concentration of soil exchangeable K will be followed by increased tissue K and K uptake of rice plants. Figure 7 shows that the coefficient of determination (R^2) value of 0.4898 means that plant tissue K content is influenced by soil exchangeable K concentration by 48.98%. Figure 8 shows that the coefficient of determination (R^2) of 0.7831 denotes that plant K uptake is influenced by soil exchangeable K concentration by 78.31%.

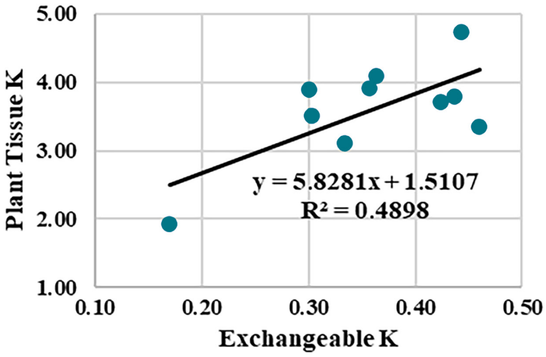

***Figure 7**. Relationship of soil exchangeable K to plant tissue K*
***Source:** compiled by the authors*

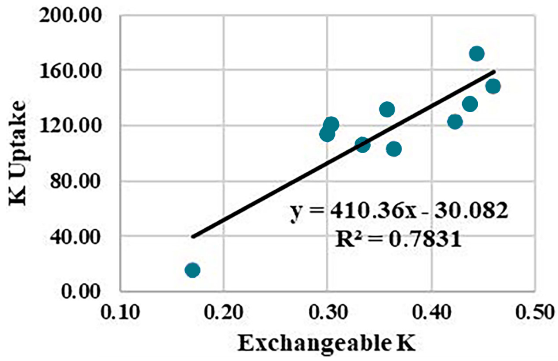

***Figure 8**. Relationship of soil exchangeable K to plant K uptake*
***Source:** compiled by the authors*

Organic C showed a substantial correlation with tissue P, plant P uptake, and plant K uptake. Based on the correlation coefficient value, organic C is moderately related to tissue P (r = 0.571**) and plant tissue K uptake (r = 0.465**). Meanwhile, organic C has a strong relationship with plant P uptake (r = 0.616**). The positive correlation results indicate that any increase in organic C value will be followed by an increase in tissue P content, P uptake, and plant K uptake. According to Soong *et al.* (2020), soil microorganisms need carbon to meet energy needs. In this case, organic C can spur soil microorganisms' activities to increase the soil's decomposition process. Figure 9 shows that the coefficient of determination (R^2) value of 0.7636 means that plant tissue P is influenced by soil organic C concentration of 76.36%. Figure 10 shows that the coefficient of determination (R^2) value of 0.635 means that plant P uptake is influenced by soil organic C concentration of 63.5%. Figure 11 shows that the coefficient of determination (R^2) value of 0.3726 denotes that plant K uptake is influenced by soil organic C concentration of 37.26%.

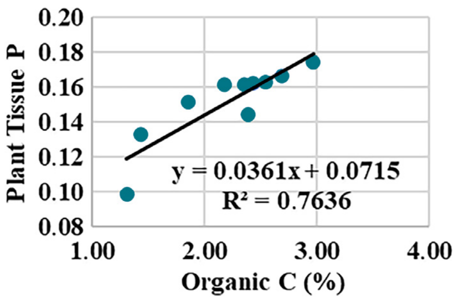

***Figure 9**. Relationship of organic C to plant tissue P*
***Source:** compiled by the authors*

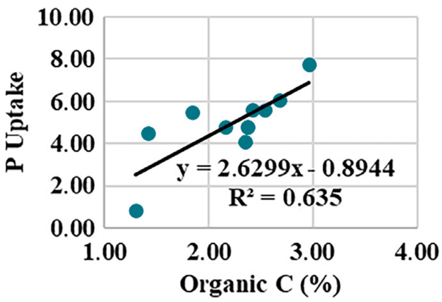

***Figure 10**. Relationship of organic C to plant P uptake*
***Source:** compiled by the authors*

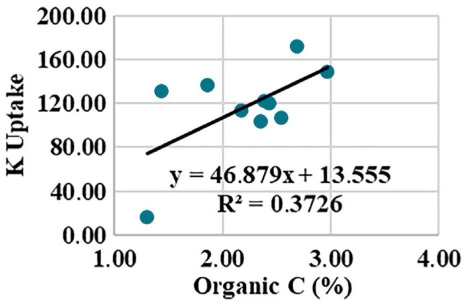

***Figure 11**. Relationship of organic C to plant K uptake*
***Source:** compiled by the authors*

The correlation analysis results show that CEC has a highly significant correlation with a moderate and positive relationship to plant P uptake (r = 0.549**). The decomposition process of organic matter can affect CEC as it can produce humic compounds that donate soil colloids so that soil CEC will increase. The increase in CEC is also determined by the increase in the negative charge of soil colloids derived from the dissociation of carboxyl or hydroxyl functional groups from organic compounds (Xu *et al.,* 2021). Organic matter as manure through its mineralization process can provide available phosphorus to the soil. In addition, organic matter also activates the decomposition process of the original soil organic matter to release phosphorus. The added organic matter can also form phospho-humate and phospho-vulvate complexes that plant more easily take up. In this case, applying soil organic matter can increase soil CEC, followed by an increase in P in the soil.

CONCLUSIONS

The application of manure had a significant effect on available P, exchangeable K, P uptake, and K uptake of rice. Application of quail manure 5 ton/ha and NPK fertilizer 100 kg/ha obtained the highest value on soil available P of 20.70 ppm (high) and soil exchangeable K of 0.46 me/100 g of soil (moderate). This is because quail manure contains the highest P and K nutrients and has the lowest C/N ratio than other types of manure so that it is more quickly mineralized. In addition, the application of NPK fertilizer to the soil can also increase P and K nutrients in the soil. The application of 5 ton/ha quail manure and 100 kg/ha NPK fertilizer also produced the highest plant P uptake of 5.59 g/plant because the presence of available P in the soil was high. P uptake was highly correlated with soil available P (r = 0.755**) and was influenced by available P by 77.45%. Meanwhile, K uptake of rice plants obtained the highest value at

10 ton/ha quail manure at 172.34 g/plant, but the fertilizer application was not significantly different from 5 ton/ha quail manure and 100 kg/ha NPK fertilizer. K uptake was highly correlated with exchangeable K (r = 0.596**) and influenced by exchangeable K 78.31%. Thus, 5 ton/ha quail manure and 100 kg/ha NPK fertilizer can be a dose recommendation and consideration in choosing the type of manure that can support the growth of rice in Inceptisols. Further research in this area needs to be conducted to determine the effect of quail manure and NPK fertilizer on different soil types and varieties of rice.

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CONFLICT OF INTEREST

None.

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Вплив різних типів місцевого потенційного гною на доступність та поглинання P і K рисом в Inceptisols

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Анотація. Забезпеченість поживними речовинами Inceptisols є недостатньою для ведення органічного землеробства при вирощуванні рису, тому її можна оптимізувати шляхом внесення органічних добрив, одним з яких є гній. Метою дослідження було визначити вплив видів гною на доступність та засвоєння поживних речовин P і K рисом, що міститься в Inceptisols. У дослідженні використовувався однофакторний рандомізований дизайн повної групи з 10 варіантами обробки: T1 = контроль; T2 = NPK 200 кг/га; T3 = коров'ячий гній 10 т/га; T4 = курячий гній 10 т/га; T5 = козячий гній 10 т/га; T6 = перепелиний гній 10 т/га; T7 = коров'ячий гній 5 т/га + NPK 100 кг/га; T8 = курячий гній 5 т/га + NPK 100 кг/га; T9 = козячий гній 5 т/га + NPK 100 кг/га; T10 = перепелиний гній 5 т/га + NPK 100 кг/га повторили 3 рази з розміром дослідних ділянок 2.5 м × 4 м. Результати показали, що перепелиний послід, внесений окремо або в поєднанні з NPK добривом, мав дуже значний вплив на доступність P, обмінний K, а також поглинання P і K рослинами. Це пояснюється тим, що перепелиний послід містить високий вміст поживних речовин P і K і має низьке співвідношення C/N порівняно з іншими видами посліду. Результати показали, що перепелиний послід здатен підвищити доступність та поглинання поживних речовин P і K рослинами рису в Inceptisols. Таким чином, перепелиний послід може бути рекомендованим органічним добривом для вирощування рису

Ключові слова: органічне добриво; макроелементи; органічна речовина; родючість ґрунту; рисове поле

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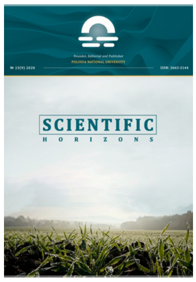

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An overview on persistent organic pollutants levels in the White Drin River, Kosovo

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Abstract. The purpose of this study was to assess the concentrations of persistent organic pollutants in the White Drin River, Kosovo region. The study focused on organochlorine pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and benzene, toluene, ethylbenzene, and xylenes. The White Drin River originates from Peja, Kosovo, and extends to the Albanian border near Kukesi, making it a significant water body. It is potentially affected by anthropogenic pollution due to its passage through Kosovo's urban areas, villages, farms, and industries. Sampling was conducted at 15 stations along the river, from the river waterfall to the Albanian border, during two distinct periods in 2023 (January – February and August – September). Organochlorine pollutants were concurrently extracted using liquid-liquid extraction followed by analysis using capillary gas chromatography equipped with an electron capture detector. Polycyclic aromatic hydrocarbons were isolated through a two-step liquid-liquid extraction, with

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dichloromethane and hexane. Benzene, toluene, ethylbenzene, and xylenes were isolated using headspace solid – phase microextraction assisted by polydimethylsiloxane fibre. Qualitative and quantitative analyses of polycyclic aromatic hydrocarbons, and benzene, toluene, ethylbenzene, and xylenes, were conducted via gas chromatography with a flame ionization detector. The analyses showed the presence of persistent organic pollutants in the river water samples during both sampling periods. Elevated concentrations of volatile polychlorinated biphenyls, benzene, toluene, ethylbenzene, and xylenes, and polycyclic aromatic hydrocarbons, were observed in the water samples during both periods. This study underscores the significance of investigating organic pollutants in Kosovo's water systems, considering both local geographic concerns and the broader global issue of environmental pollution

Keywords: organochlorine pesticides; polychlorinated biphenyls; polycyclic aromatic hydrocarbons; benzene, toluene, ethylbenzene, xylenes, water analyses; gas chromatography; electron capture detector; flame ionization detector

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INTRODUCTION

In recent decades, environmental pollution has emerged as a global concern. A variety of contaminants, including pesticides, pharmaceuticals, and industrial residues, are infiltrating water bodies through sewage systems, agricultural runoff, and atmospheric deposition. Persistent organic pollutants (POPs) have been detected in water bodies, highlighting their persistence and bioaccumulation tendencies. The easy accumulation of persistent organic compounds in the food chain can be mainly because of their hydrophobic properties and bio-magnification process (Nuro *et al.,* 2018). The presence of polycyclic aromatic hydrocarbons (PAHs) and BTEX compounds in surface water bodies can be mainly because of industrial and automobile transport, as well as mechanical activity, mechanical businesses, fuel stations, forest burning, etc.

The purpose of this study was to determine POP concentrations in water samples from the White Drin River in Kosovo. It is a vital resource for local communities and a valuable ecosystem of Kosovo. As the river flows towards the Albanian border, it merges with the Black Drin River to form the Drin River before flowing into the Adriatic Sea. It is crucial to evaluate pollution levels in its water, especially regarding POPs because it passes near urban, industrial, and agricultural areas. This transboundary river system, significant for its ecological importance and potential environmental impact, has not been investigated before for the presence of these organic pollutants. The river is under threat from unchecked urbanisation, agricultural practices, and industrial outputs leading to untreated waste discharge due to rapid population growth and socio-economic development, thereby jeopardising water quality and environmental sustainability, as concluded recently by S. Laha *et al.* (2022). Organochlorine pesticides have been extensively used in Kosovo for over half a century. Polychlorinated biphenyls (PCBs), although not used in Kosovo until the 1990s, were found in some electrical transformers from that period and were subsequently detected in various water ecosystems due to atmospheric deposition. PAHs and BTEX, primarily generated through vehicular transportation, coal mining, and other industries, are also influenced by forest fires and natural background. These pollutants exhibit high stability, significant bioaccumulation potential, and the ability to spread over long distances from their sources, persisting in the environment for many years (Nuro *et al.,* 2019).

Previous studies by E. Ferreira da Silva *et al.* (2024) have underscored the impact of land-use/land-cover dynamics and climate change on river water quality, reinforcing the significance of our research on the White Drin River. Pollutants like PAHs and BTEX compounds have been linked to adverse effects on water quality and human health according to a review by T. Olasehinde and A. Olaniran (2022). The increasing prevalence of Persistent Organic Pollutants (POPs) in various environmental compartments has been a subject of global concern due to their notorious effects on both human health and the environment (Adeniji *et al.,* 2022). In recent years, A. Mandal *et al.* (2024) have proven that the list of POPs keeps increasing, and their concentrations levels are widely varied region-wise. Y. Bununu *et al.* (2023) discussed the intricate relationships between land cover and land use change and climate change. They highlighted how these dynamics can affect food security, which could be linked to the health of river ecosystems. H. Zhang *et al.* (2023) further underscored the importance of understanding the unhindered connections and overlaps in aquatic ecosystems. They pointed out that microplastics, one of the most representative emerging contaminants, are carriers of other pollutants due to their strong adsorption capacity. This is particularly relevant to the present study as it highlights the potential for pollutants to be transmitted to aquatic organisms and humans through the extended food chain, thereby increasing the concentration of pollutants. W. Zhou *et al.* (2022) assessed the impact of urbanisation on river water quality. They found that the contents of pollutants such as nitrogen, trace metals, and organic pollutants were significantly accumulated in the lower reaches of cities, suggesting life-type pollution characteristics in urban rivers. This aligns with our observations of the unchecked discharge of untreated waste into the White Drin River due to urbanisation.

The present study underscores the urgent need to examine the water quality dynamics of the White Drin River and uncover the prevalence of persistent organic pollutants within its aquatic environment. By elucidating the origins and magnitudes of POP contamination, this study aims to provide valuable insights into the river ecosystem's ecological health and offer a roadmap for evidence-based conservation efforts.

MATERIALS AND METHODS

Water sampling in The White Drin River. The sampling was performed at 15 different stations along the White Drin River in February and September 2023. Sampling sites are presented in Figure 1. These time periods were chosen because February corresponds to the peak flow of the river, and the impact of nearby agricultural activities is at its minimum during this period while September corresponds to the minimum flow and agricultural and transportation activity is higher compared to other periods. For each station, a volume of 2.5 litres of water was collected in amber glass bottles with Teflon screw caps. The sampling procedure followed the guidelines specified in ISO 5667-3:2024 (2024). After collection, the water samples were preserved and transported at +4°C before undergoing analysis.

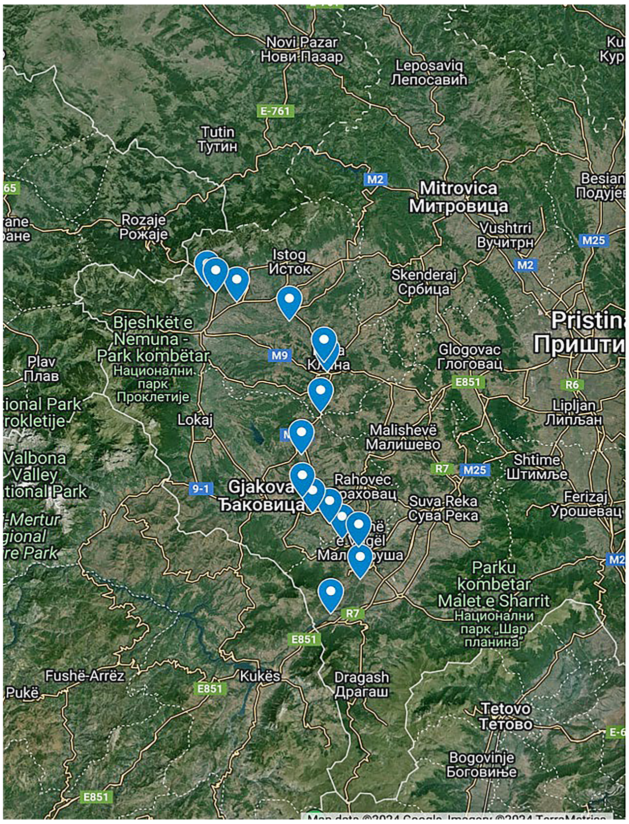

***Figure 1**. Sampling stations on the White Drin River, February and September 2023*
***Source:** Google Maps*

Treatment of water samples for pesticide and PCB analyses. Liquid-liquid extraction was used for extraction of organochlorine pesticide and polychlorinated biphenyls from water samples. One litre of water and 2×40 ml n-hexane were added in a separatory funnel as extracting solvent. After extraction, the organic phase was dried with 5 g of anhydrous Na_2SO_4 for water removal. A florisil column was used for the sample clean-up. 20 ml n-hexane/dichloromethane (4/1) was used for elution. After concentration to 1 ml hexane, the samples were injected in GC/ECD (Nuro *et al.*, 2018).

Gas chromatography analysis of pesticides and PCBs. Gas chromatography technique was used to determine the concentrations of various organochlorine pesticides and polychlorinated biphenyls from liquid matrices, using fused silica capillary column with electron capture detector (diphenyl dimethyl polysiloxane Rtx-5, 30 m×0.25 mm i.d.×0.25 μm). Prior to analysis, liquid-liquid extraction was used to extract chlorinated organic pollutants. n-Hexane was used as organic solvent for extractions. After the extraction, the organic layer passed through Na_2SO_4 anhydrous to remove the remaining water. The sample clean-up was performed in florisil column, n-Hexane/Dichloromethane (4/1) was used for elution. After clean-up and concentration procedures for all samples, organochlorine pesticides and polychlorinated biphenyls were analysed on a gas chromatograph Varian 450 GC analytical system completed with split/splitless injector with electron capture detector. Helium was used as a carrier gas with flow rate at 1 ml/min, while nitrogen was used as makeup gas (24 ml/min). Quantification of organochlorine pesticides and polychlorinated biphenyls was based on external standard method for lindane and its isomers, heptachlors, aldrins, chlordanes, DDTs, endosulfanes, and 7 PCB markers (Method 505…, n.d.).

Treatment of water samples for PAH and n-alkanes analyses. Two steps liquid-liquid extraction (LLE) was used for extracting PAHs from river water samples. One litre of water with firstly 40 ml dichloromethane (first step of LLE) and next 40 ml hexane (second step of LLE) as extracting solvent were added in a separator funnel. After extraction, the organic phase was dried with 5 g of anhydrous Na_2SO_4 for water removal. Extracts were concentrated to 1 ml hexane using Kuderna-Danish concentrator and then injected in GC/FID for qualification/quantification of PAHs (Nuro *et al.,* 2019).

GC/FID determination of PAH in water samples. Two-step LLE was used for extracting Polycyclic aromatic hydrocarbons from water samples. The sample was first extracted with dichloromethane (first step of LLE) and after that with n-hexane (second step of LLE) as extracting solvent in a separating funnel. After extraction, the organic layer passed through 5 g of Na_2SO_4 anhydrous to remove the remaining water. Extracts were concentrated using Kuderna-Danish concentrator to 2 ml final volume. Polycyclic aromatic hydrocarbons in water samples were quantified with a Varian 450 GC instrument equipped with a flame ionisation detector and programmable temperature vaporiser injector. 100% dimethylpolysiloxane phase column VF-1 ms capillary column (30 m×0.33 mm×0.25 μm). Helium was used as carrier gas at 1 ml/min. Detector temperature was 280°C. Nitrogen was used as the makeup gas. Hydrogen and synthetic air were used as flame detector gases at 30 ml/min and 300 ml/min, respectively. Environmental Protection Agency EPA 525 Standard Mixture was used for qualitative and quantitative analyse of polycyclic aromatic hydrocarbons. Quantification of polycyclic aromatic hydrocarbons was based on external standard method (EPA Method 610-Polynuclear Aromatic Hydrocarbons).

HS-SPME technique for determination of BTEX in water samples. BTEX was determined in water samples using solid phase micro-extraction in static head space mode (HS/SPME) followed by GC/FID technique. 5 ml of water sample was put in a 10 ml head space vial. 100 um PDMS fibre was used to extract BTEX from water samples. Adsorption process was conducted at 50 °C (using a water bath) for 45 minutes. The sample injection was performed manually at 280°C in a programmable temperature vaporiser injector (headspace mode was selected) of a Varian 450 Gas Chromatography instrument. Fused silica capillary column with dimensions of 30 m×0.33 mm×0.25 μm RTx, was used as a stationary phase. Helium was used as carrier gas at 1 ml/min, and nitrogen as a makeup gas. Detector temperature was maintained at 280°C. A mixture of known concentrations of benzene, toluene, ethylbenzene, and xylenes was used for qualitative and quantitative analyses based on external standard method according to (Method 8015d..., n.d.).

RESULTS AND DISCUSSION

This preliminary study showed the first data on organochlorinated pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbon and volatile organic hydrocarbons benzene, toluene, ethylbenzene, and xylenes in water samples of the White Drin River, Kosovo. Table 1 presents statistical data about analysed organochlorine pesticides (as individuals, their total and grouped in their classes) for both periods.

***Table 1**. OCP data in water samples of the White Drin River (February and September 2023)*

OCPs	Drin Bardhe River, February 2023					Drin Bardhe River, September 2023				
	Mean	Min	Max	Median	STDEV	Mean	Min	Max	Median	STDEV
a-HCH	0.216	0.000	1.269	0.092	0.345	0.721	0.000	7.676	0.104	1.951
b-HCH	0.133	0.015	0.381	0.050	0.137	0.188	0.007	1.251	0.031	0.342
Lindane	0.383	0.000	3.087	0.039	0.817	0.032	0.000	0.318	0.000	0.086
d-HCH	0.564	0.000	5.209	0.101	1.325	0.464	0.004	4.619	0.084	1.173
Heptachlor	0.322	0.000	1.534	0.062	0.474	0.064	0.000	0.598	0.000	0.159
Aldrine	0.138	0.000	1.010	0.041	0.266	0.099	0.000	0.570	0.023	0.154
Heptachlor epoxide	0.107	0.000	0.511	0.040	0.150	0.051	0.000	0.325	0.000	0.106
g-Chlordane	0.268	0.000	1.135	0.101	0.329	0.466	0.000	5.155	0.000	1.338
Endosulfan I	0.103	0.000	0.701	0.041	0.186	0.038	0.000	0.274	0.000	0.086
a-Chlordane	0.287	0.000	2.053	0.061	0.532	0.023	0.000	0.145	0.000	0.044
44-DDE	0.058	0.000	0.321	0.015	0.094	0.054	0.000	0.294	0.008	0.092
Dieldrin	2.087	0.000	9.350	0.245	3.039	0.304	0.000	0.924	0.218	0.342
Endrin	0.176	0.000	1.373	0.000	0.357	0.672	0.000	7.676	0.076	1.960
Endosulfan II	0.089	0.000	0.876	0.021	0.225	0.182	0.000	1.251	0.031	0.345
44-DDD	0.294	0.000	2.053	0.016	0.633	0.022	0.000	0.318	0.000	0.082
Endrin aldehyde	0.172	0.000	1.912	0.024	0.486	0.191	0.000	1.252	0.024	0.344
44-DDT	0.111	0.000	1.071	0.017	0.271	0.041	0.000	0.598	0.000	0.154
Endosulfan sulphate	1.883	0.000	6.890	0.196	2.540	0.074	0.000	0.570	0.013	0.151
Methoxychlor	0.118	0.000	1.104	0.028	0.278	0.104	0.000	0.606	0.009	0.168
Endrin ketone	0.974	0.000	2.480	0.082	1.184	0.105	0.000	1.227	0.000	0.315
Mirex	0.022	0.000	0.159	0.000	0.044	0.000	0.000	0.000	0.000	0.000
∑ OCPs	8.504	1.679	18.306	6.734	5.742	3.895	0.261	20.585	1.456	5.997
∑ HCHs	1.296	0.090	5.654	0.699	1.507	1.405	0.018	13.546	0.219	3.418
∑ Heptachlors	0.429	0.000	1.719	0.204	0.531	0.115	0.000	0.877	0.017	0.231
∑ Chlordanes	0.554	0.000	2.324	0.327	0.655	0.489	0.000	5.155	0.021	1.333
∑ Aldrins	3.547	0.082	9.478	2.826	3.212	1.371	0.030	9.052	0.676	2.280
∑ Aldrins	0.581	0.000	3.708	0.198	1.018	0.221	0.000	1.816	0.058	0.455
∑ Endosulfanes	1.883	0.000	6.890	0.196	2.540	0.294	0.000	1.623	0.092	0.435

***Source:** developed by the authors of this study*

The presence of Organochlorine Pesticides was observed in all analysed water samples collected from the White Drin River for both periods. Their presence in the White Drin River can be attributed to their prior use in nearby agricultural areas, recent arrivals due to soil runoff, water currents, and punctual sources within its watershed. The highest level of pollution was found on February with 8.51 ng/l while in September the average concentration was two times lower (3.90 ng/l). This difference should be mainly explained by the larger amounts of rainfall which affect the washing of agricultural lands, directly affecting their water levels. The levels of organochlorine pesticides in the White Drin River water samples were within the permissible limits set by European Union regulations (Directive 2013/39/EU, n.d.), where the total concentration of organochlorine pesticides should not exceed 50 ng/l for surface waters. Notably, the most polluted stations for both periods were found near Peja city, indicative of local agricultural activity (Fig. 2). This difference should be mainly explained by the larger amounts of rainfall that affect the washing of agricultural lands, directly affecting their water levels. Notably, the most polluted stations for both periods were found near Peja (WDB7 and WDB8 stations), indicative of local agricultural activity (Fig. 2).

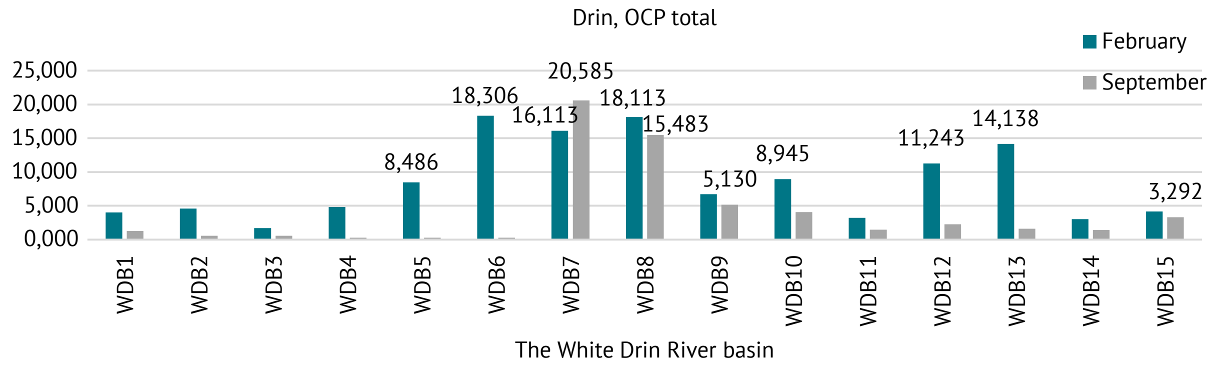

***Figure 2**. Total of OCPs in water samples of the White Drin River (February and September 2023)*
***Source:** developed by the authors of this study*

Some other stations (WDB6, WDB13, and WDB12) were found to have higher level in February. The maximum level of pollution for February was 18.31 ng/l at WDB6 station and the maximum level for September was 20.59 ng/l at WDB7 station. Stations with lesser pollution for both periods were form WDB1 to WDB4 stations located in the first part of the river. These stations have no agricultural activity developed on a high scale due to the characteristics of the mountainous terrain. In addition, this topography affects the higher velocity of water flow in the first segment of the river. The greater amount of water in February and the greater slope are factors that affect the reduction of pollution for these stations. Figure 3 shows the profile of the classes of pesticides included in the analysis. Their profile in February was: aldrins > endosulfanes > HCHs > chlordanes > DDTs > heptachlors. Their profile in September was: HCHs > aldrins > chlordanes > endosulfanes > DDTs > heptachlors.

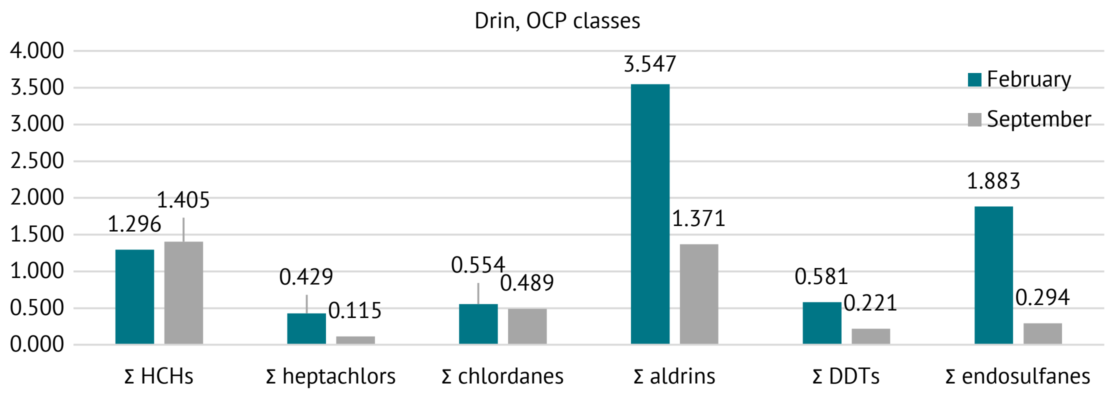

***Figure 3**. Organochlorine pesticides classes in water samples of The White Drin River*
***Source:** developed by the authors of this study*

The total of pesticide classes in no case exceeds the allowed rate for surface waters according to Directive 2013/39/EU (n.d.). A different profile of pesticide classes is observed for both periods. This should be related to dissimilar sources of pollution for different periods, e.g., in one period the biggest factor is the washing of the lands, while in another period the use of pesticides or their point sources near the White Drin River has a greater impact. Profile of individual pesticides in water samples of the White Drin River for both periods is presented in Figure 4.

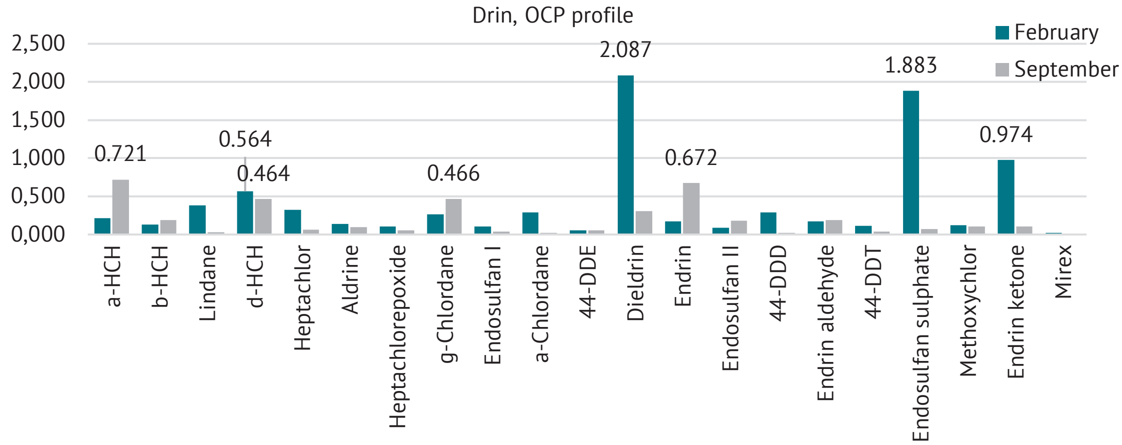

***Figure 4**. Profile of OCPs in water samples of The White Drin River, February and September 2023*
***Source:** developed by the authors of this study*

Some of the most frequently detected pesticides were, respectively, as follows: dieldrin > endosulfan sulphate > endrin ketone > d-HCH > g-chlordane (in February) and a-HCH > endrin > d-HCH > g-chlordane (in September). The active substances used as pesticides have not been identified in any case, but mostly their degradation products have been detected. This is related to the fact that these pesticides have not been used recently in the areas near the Drin River but are new arrivals from specific sources or from areas where these pesticides were used earlier. Some of these pesticides or their degradation products have been found as impurities in pesticides that are allowed to be used in agricultural areas near the river. Table 2 shows statistical data for PCB markers for both periods of sampling, February and September 2023. In addition, these chlorinated pollutants were identified in all analysed water samples.

***Table 2**. PCB data in water samples of the White Drin River (February and September 2023)*

PCBs	Drin Bardhe River, February 2023					Drin Bardhe River, September 2023				
	Mean	Min	Max	Median	STDEV	Mean	Min	Max	Median	STDEV
PCB 28	2.239	0.005	8.290	0.954	2.763	0.307	0.002	0.924	0.218	0.339
PCB 52	3.765	0.022	25.360	0.876	6.788	0.279	0.007	1.252	0.208	0.356
PCB 101	0.164	0.000	1.533	0.062	0.382	0.067	0.000	0.606	0.007	0.155
PCB 118	1.317	0.000	13.591	0.113	3.516	0.385	0.000	4.619	0.022	1.181
PCB 153	0.285	0.000	2.580	0.017	0.692	0.216	0.000	1.913	0.010	0.513
PCB 138	0.212	0.000	1.591	0.027	0.423	0.241	0.000	2.010	0.000	0.589
PCB 180	0.086	0.000	1.104	0.000	0.283	0.000	0.000	0.000	0.000	0.000
Total	8.067	0.243	38.890	3.423	10.491	1.495	0.066	5.719	0.943	1.704

***Source:** developed by the authors of this study*

Their presence could be mainly explained by the atmospheric deposition and industrial activity. The maximum level for PCB markers was found in February with 38.89 ng/l. The average level of PCB markers was 8.07 ng/l in February and 1.50 ng/l in September, respectively. This difference is also related to the amount of precipitation and the amount of water in the river; in February, this indicator is much higher than in September. The total PCB marker for each station in each period is presented in Figure 5. For February, the highest levels were found at stations WBD7 (38.09 ng/l), WDB11 (11.45 ng/l), WDB6 (17.34 ng/l), WDB5 (9.97 ng/l), WDB13 (9.46 ng/l), WDB8 (9.12 ng/l), and WDB10 (8.32 ng/l); for September, the highest levels were at stations WDB8 (5.72 ng/l), WDB10 (4.28 ng/l), and WDB9 (3.72 ng/l). The most polluted stations are near the areas where the industrial activity is higher. In addition, the amount of their deposits increases due to the discharge of some of its important effluents in this part of the river. Urban spills and industrial waste also affect the increase of their level in these stations.

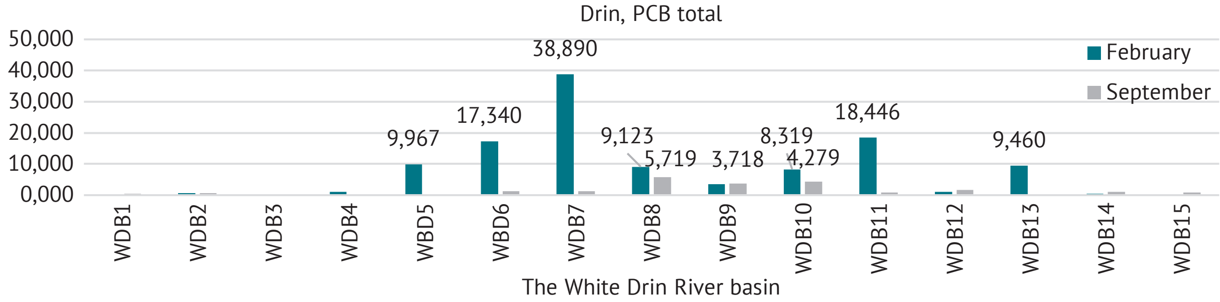

***Figure 5**. PCB markers in water samples of the White Drin River (February and September 2023)*
***Source:** developed by the authors of this study*

The profile of the marking PCBs is presented in Figure 6. Their profile for February was: PCB 52 > PCB 28 > PCB 118 > PCB 153 > PCB 138 while their profile for September was: PCB 118 > PCB 28 > PCB 52 > PCB 138 > PCB 153. In both periods, their profile is built according to the high presence of volatile PCBs because their main origin must be atmospheric deposits. The presence of heavier PCBs should be linked to their point sources. The PCB levels in the water samples from the White Drin River were comparable with those reported in earlier studies in Albanian water ecosystems (Nuro *et al.,* 2019).

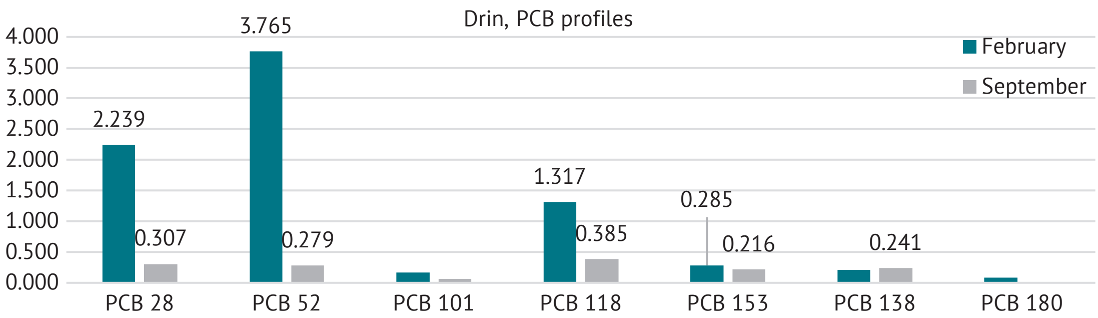

***Figure 6**. Profile of PCB s in water samples of The White Drin River*
***Source:** developed by the authors of this study*

Table 3 shows statistical data for polycyclic aromatic hydrocarbons in both periods of sampling, February and September 2023. PAHs were identified in about 75% of the samples in February and in about 30% of the samples in September. The presence of PAH in water samples must be a consequence of industrial activity, mining, road transport, urban spills, fires, etc. In February, the average level of PAH was 2.22 μg/l, and their maximum was 5.33 μg/l (WDB11) while in the month of September the average level was 3.43 μg/l, and the maximum was 46.44 μg/l (WDB15).

***Table 3**. PAH data in water samples of the White Drin River (February and September 2023)*

PAHs	White Drin River, February 2023					White Drin River, September 2023				
	Mean	Min	Max	Median	STDEV	Mean	Min	Max	Median	STDEV
Acenaftilene	0.231	0.000	2.040	0.000	0.561	0.033	0.000	0.263	0.000	0.077
Fluorene	0.185	0.000	0.970	0.000	0.337	2.575	0.000	38.621	0.000	9.972
Fenantrene	0.091	0.000	0.702	0.000	0.189	0.037	0.000	0.360	0.000	0.102
Antracene	0.146	0.000	0.718	0.000	0.233	0.009	0.000	0.130	0.000	0.034
Piren	0.379	0.000	1.645	0.224	0.480	0.368	0.000	5.291	0.000	1.363

Table 3. Continued

PAHs	White Drin River, February 2023					White Drin River, September 2023				
	Mean	Min	Max	Median	STDEV	Mean	Min	Max	Median	STDEV
Benzo[a]antracene	0.316	0.000	1.333	0.184	0.401	0.144	0.000	1.517	0.015	0.390
Krizene	0.212	0.000	1.125	0.000	0.377	0.037	0.000	0.276	0.000	0.091
Perilene	0.190	0.000	0.913	0.000	0.306	0.191	0.000	1.913	0.000	0.518
Benzo[b]fluorantrene	0.182	0.000	0.959	0.000	0.325	0.034	0.000	0.516	0.000	0.133
Benzo[k]fluorantrene	0.291	0.000	0.919	0.000	0.359	0.000	0.000	0.000	0.000	0.000
Indeo[123cd]Pirene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dibenzo[ab]Antracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[ghi]Perilene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	2.224	0.000	5.325	2.130	1.570	3.427	0.000	46.435	0.100	11.912

Source: *developed by the authors of this study*

Figure 7 shows the total PAH in the water samples of the White Drin River for the two periods. There is a different distribution of PAH for the two periods: in February, there were low levels of PAHs at many stations, while in September, PAH were identified in a large number in the station near the border with Albania. This may be related to the different origin of PAH for both periods and to the current values of these pollutants. During both periods, the starting stations were not contaminated with PAH.

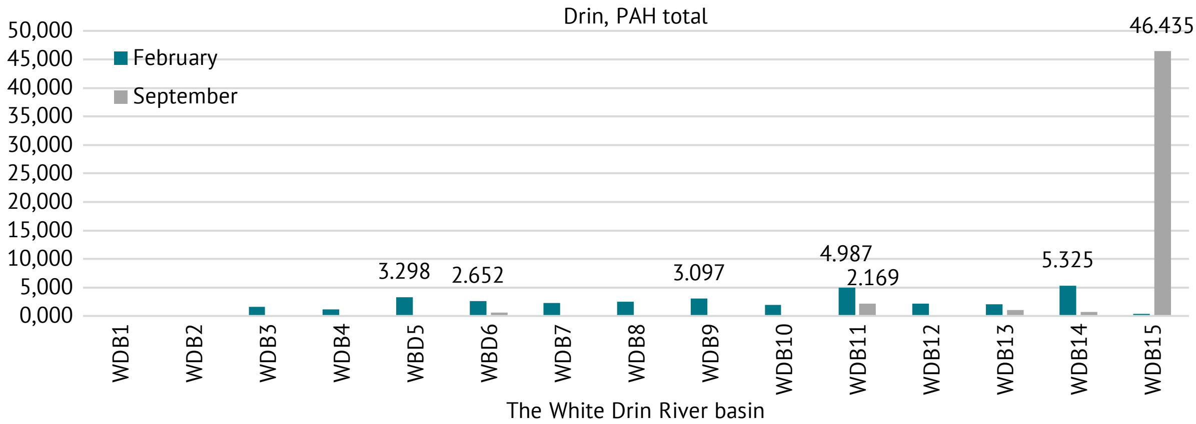

Figure 7*. PAHs in water samples of The White Drin River (February and September 2023)*
Source: *developed by the authors of this study*

Figure 8 shows PAH profiles in the water samples for the two periods. In February, the PAH profile was: pyrene > benzo[a]anthracene > benzo[k]fluoranthene > acenaphthylene > chrysene, while in September, the profile was: fluorene > pyrene > perylene. These PAHs indicate that their origin is mainly from urban or industrial discharges, mining, or other point sources. Only a small part of them come from thermal treatments such as industrial processes and transport emissions. The PAH levels in the water samples from the White Drin River were comparable or higher than the reported levels for Balkan area rivers. However, the concentration of PAH individuals, such as Fluorene, exceeded the permissible levels set by European Union regulations (Directive 2013/39/EU, n.d.).

Table 4 shows statistical data about BTEX in water samples of the White Drin River for both periods. Furthermore, benzene, toluene, ethylbenzene, and xylenes were detected almost for all water samples in February and 75% of samples in September. The origin of BTEX contamination could be similar, involving automobile transportation, industrial activity, and hydrocarbon spills, but temporal factors and momentum values may affect their levels. The average level of BTEX was 4.27 μg/l for February and 2.78 μg/l for September.

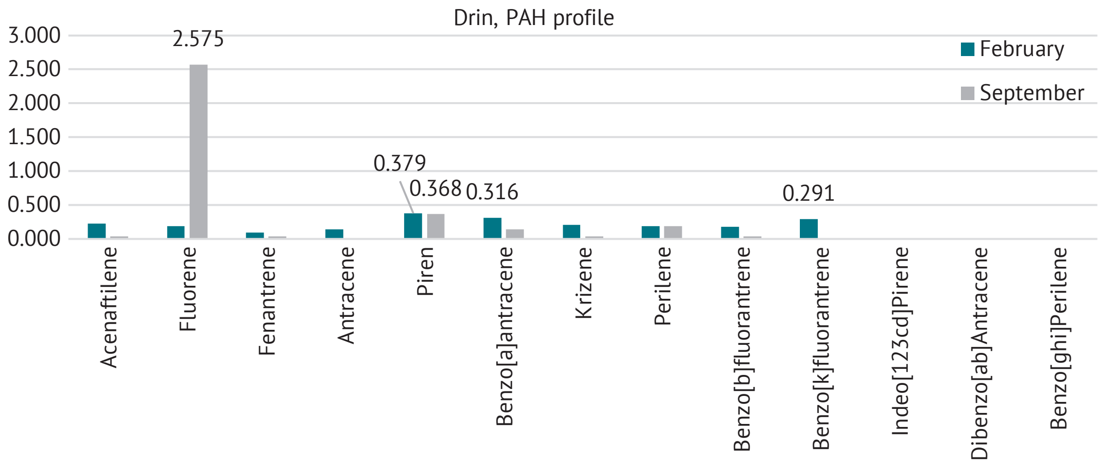

***Figure 8**. Profile of PAHs in water samples of The White Drin River*

***Source:** developed by the authors of this study*

***Table 4**. BTEX data in water samples of the White Drin River, February and September 2023*

BTEX	White Drin River, February 2023					White Drin River, September 2023				
	Mean	**Min**	**Max**	**Median**	**STDEV**	**Mean**	**Min**	**Max**	**Median**	**STDEV**
Benzene	2.074	0.026	11.250	0.782	3.062	0.295	0.000	2.450	0.046	0.669
Toluene	0.936	0.000	4.580	0.578	1.267	1.608	0.000	15.539	0.079	4.173
m-Xylene	0.489	0.022	1.277	0.514	0.345	0.057	0.000	0.640	0.000	0.166
p-Xylene	0.293	0.000	0.743	0.224	0.283	0.065	0.000	0.949	0.000	0.245
o-Xylene	0.332	0.000	1.910	0.053	0.548	0.698	0.000	6.457	0.000	1.801
Ethylbenzene	0.147	0.000	0.706	0.016	0.229	0.051	0.000	0.771	0.000	0.199
Total	4.271	0.738	12.707	2.868	3.585	2.774	0.000	17.989	0.175	5.278

***Source:** developed by the authors of this study*

Figure 9 shows the total BTEX for each station in both periods. Notably, BTEX has the same distribution as PAH for February. They are identified in all stations. The highest levels for February were the stations: WDB9 (12.71 μg/l), WDB6 (10.92 μg/l), WDB7 (7.88 μg/l) and WDB8 (4.13 μg/l). For September, there was a smaller number of stations where BTEX was detected, but in some of them the levels were significantly high, specifically, at stations WDB6 (17.99 μg/l), WDB15 (9.96 μg/l), and WDB14 (8.83 μg/l). This should be related to the origin of river water pollution with these pollutants.

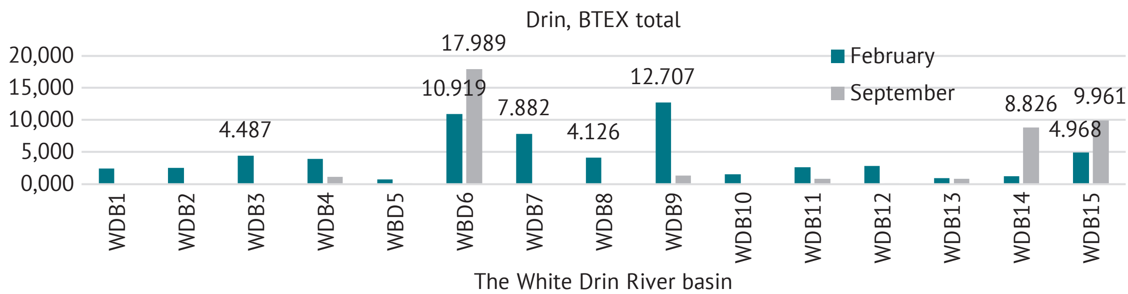

***Figure 9**. BTEX in water samples of The White Drin River, February and September 2023*

***Source:** developed by the authors of this study*

Figure 10 shows the profile of BTEX in water samples for both periods. BTEX profile in February was: benzene > toluene > m-xylenes > p-xylenes > o-xylenes > ethylbenzene while their profile in September was: toluene > o-xylene > benzene. In September, there appears to be a stronger influence of point sources or momentary values of water, while for February, it is a more constant source that may come from transport or industry emissions. Benzene and toluene were more abundant in the White Drin River. Notably, benzene concentrations exceeded the permissible levels according to European Union EU regulations (Directive

2013/39/EU, n.d.) at two stations (WDB6 and WDB9) in the White Drin River basin. BTEX levels in the water samples from the White Drin River were higher than the reported levels for Balkan area rivers.

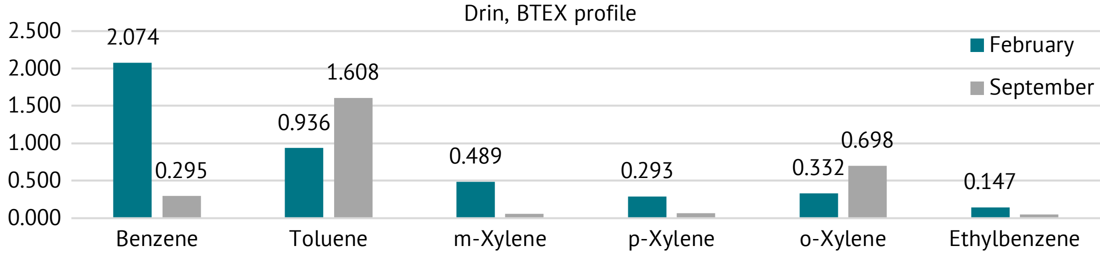

***Figure 10**. Profile of BTEX in water samples of The White Drin River for both periods*
***Source:** developed by the authors of this study*

According to the results presented above, a high-precision analysis of these parameters was conducted during two periods of the year. This led to the first-time discovery of different POPs in the White Drin River basin. Additionally, knowledge was gained about their mobility and persistence in this particulate river system. The concentrations of organochlorine pesticides in water samples collected from the White Drin River were evaluated according to the permissible limits established by European Union regulations, specifically Directive 2013/39/EU (n.d.), which mandates that the total concentration of OCPs in surface waters should not exceed 50 ng/L. Analysis revealed that the levels of both total OCPs and individual pesticides in the samples did not surpass the regulatory thresholds outlined in the Directive. However, isolated instances of excess were observed for specific compounds such as hexachlorocyclohexanes at station WDB7 (February 2023), endosulfan at station WDB10 (September 2023), and DDTs at station WDB5 (September 2023).

The heightened presence of these substances is attributed primarily to localised point sources proximal to the study areas. The concentrations of OCPs detected in the White Drin River water samples align with findings reported by various researchers across the Balkans regarding the levels of these contaminants in surface waters. Notably, recent studies conducted in Albania by A. Tafa (2022), C. Lancioni *et al.* (2022) indicated elevated levels of Polychlorinated Biphenyls (PCBs) in the Vjosa (Aoös) River, exceeding recommended standards, particularly following winter flood events, signifying substantial pollution within the river system. In a comprehensive review by C. Chiţescu *et al.* (2021), focusing on emerging and persistent pollutants in the aquatic ecosystems of the Lower Danube basin and northwest Black Sea region, the assessment encompassed seven studies pertaining to pesticides in surface water and sediment samples within the designated area. Selection of target compounds was based on literature documenting their occurrence as contaminants and their classification as priority substances under the Water Framework Directive.

Additionally, the review emphasised the significance of considering abiotic transformation products of these compounds, which may exhibit heightened toxicity, persistence, and bioaccumulation compared to their parent compounds. The prevalence of volatile PCBs in the study area is believed to stem predominantly from atmospheric deposition, while the presence of heavier PCBs is linked to identifiable point sources. Comparative analysis with previous studies conducted in Albanian water ecosystems, such as the study by A. Nuro *et al.* (2019), indicates that PCB levels in the White Drin River water samples, particularly during February, were comparable to or higher than those reported elsewhere. Moreover, investigations into organochlorine pesticides in Porto-Romano revealed elevated concentrations in both water and sediment samples, with mean concentrations of PCB markers exceeding levels observed in the White Drin River.

Similarly, the levels of polycyclic aromatic hydrocarbons (PAHs) detected in the White Drin River water samples were comparable to or exceeded reported levels in rivers across the Balkan region. Notably, concentrations of individual PAHs, such as Fluorene, surpassed the permissible limits stipulated by European Union regulations (Directive 2013/39/EU, n.d.). Investigations conducted by A. Nuro *et al.* (2019) in the Port of Durres and Porto-Romano identified volatile PAH compounds in water samples, attributing their presence to various anthropogenic activities including shipping, automotive emissions, and industrial operations. Moreover, C. Grigoriou *et al.* (2021) conducted a study on the monitoring of polycyclic aromatic hydrocarbon levels in mussels (Mytilus galloprovincialis) from aquaculture farms in the Central Macedonia region, Greece, using gas chromatography – tandem mass spectrometry. Their findings indicated moderate to low concentrations of PAHs at all sampling sites, with seasonal variations observed, particularly higher values during the winter period.

The use of diagnostic ratios suggested a mixture of petrogenic and pyrolytic sources for the PAHs detected. As for benzene, toluene, ethylbenzene, and xylenes (BTEX) levels in the White Drin River water samples, concentrations exceeded reported levels for rivers in the Balkan region. Notably, Benzene concentrations surpassed the permissible limits set by the European Union regulations (Directive 2013/39/EU, n.d.) at two stations (WDB6 and WDB15) along the White Drin River. This elevation in BTEX levels is likely attributable to local pollution sources affecting the river, particularly considering station WDB1 as a reference point. Comparative analysis with the study by A. Nuro *et al.* (2019) regarding BTEX levels in water samples from Porto-Romano indicates either comparable or lower concentrations, with Benzene concentrations remaining below the permitted level of 10 ng/L.

CONCLUSIONS

Organic pollutants, including pesticides, PCBs (polychlorinated biphenyls), PAHs (polycyclic aromatic hydrocarbons), and BTEX (benzene, toluene, ethylbenzene, and xylene) were detected in water samples collected from the White Drin River during the analysis conducted in February and September 2023. The concentration levels of organochlorine pollutants (OCPs and PCBs) were notably higher in samples near Klina (WDB 6 to WDB9) and near Prizreni and Albanian border (WDB14 and WDB15). It is worth noting that degradation products of pesticides were observed at higher levels than their active counterparts, which is indicative of the historical use of pesticides in Kosovo and the subsequent degradation processes. PCBs in their volatile form were found to be present at elevated concentrations in all water samples, potentially due to atmospheric deposition.

Some water samples also contained heavy PCBs, which could be linked to terrestrial sources. Momentum values might contribute to these findings. The presence of PAHs and BTEX in the water samples may be attributed to vehicle transportation and potential accidental spills of hydrocarbons from gas stations or mechanical businesses in the vicinity of both rivers. Certain individual pollutants, such as endrin ketone, endosulfan I, endosulfan sulphate, PCB52, PCB 118, acenaphthylene, and benzene were detected at relatively higher concentrations compared to other compounds. The presence of punctual sources and water currents could influence these variations. Overall, the concentrations of priority substances in the water of the White Drin River were generally below the permissible levels set for surface waters according to EU Directive 2013/39 EU. However, some individual pollutants, notably acenaphthylene and benzene, exceeded the permitted levels. It is crucial to emphasise the need for continuous monitoring of organic pollutants in Kosovo's rivers due to their persistent presence and potential environmental and health implications.

This study examined the presence of organic pollutants in water samples collected from the White Drin River in Kosovo, highlighting the significance of ongoing monitoring efforts in this critical water ecosystem. The findings of this study serve as a reference point for future analyses and studies not only in other water systems within Kosovo but also in the broader context of science and the food chain. By providing scientific information on pesticide application and management, this review underscores the importance of continued vigilance and proactive measures to safeguard water quality and environmental health.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Огляд рівнів стійких органічних забруднювачів у річці Біла Дріні, Косово

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Анотація. Метою цього дослідження було оцінити концентрації стійких органічних забруднювачів у річці Білий Дрин у Косовському регіоні. Дослідження було зосереджено на хлорорганічних пестицидах, поліхлорованих біфенілах, поліциклічних ароматичних вуглеводнях, а також бензолі, толуолі, етилбензолі та ксилолах. Річка Білий Дрин бере свій початок у Печі, Косово, і простягається до албанського кордону біля Кукесі, що робить її важливим водним об'єктом. Вона потенційно зазнає антропогенного забруднення через те, що протікає через міські райони, села, ферми та промислові підприємства Косова. Відбір проб проводився на 15 станціях вздовж річки, від водоспаду до албанського кордону, протягом двох різних періодів у 2023 році (січень-лютий та серпень-вересень). Хлорорганічні забруднювачі одночасно вилучали методом екстракції рідина-рідина з подальшим аналізом за допомогою капілярної газової хроматографії, оснащеної детектором електронного захоплення. Поліциклічні ароматичні вуглеводні були виділені за допомогою двоступеневої екстракції рідина-рідина з дихлорметаном і гексаном. Бензол, толуол, етилбензол і ксилоли виділяли за допомогою твердофазної мікроекстракції з насадкою з полідиметилсилоксанового волокна. Якісний та кількісний аналіз поліциклічних ароматичних вуглеводнів, а також бензолу, толуолу, етилбензолу та ксилолів проводили за допомогою газової хроматографії з полум'яно-іонізаційним детектором. Аналізи показали наявність стійких органічних забруднювачів у пробах річкової води протягом обох періодів відбору проб. Підвищені концентрації летких поліхлорованих біфенілів, бензолу, толуолу, етилбензолу та ксилолів, а також поліциклічних ароматичних вуглеводнів спостерігалися у пробах води протягом обох періодів. Це дослідження підкреслює важливість вивчення органічних забруднювачів у водних системах Косова, враховуючи як місцеві географічні проблеми, так і ширшу глобальну проблему забруднення навколишнього середовища

Ключові слова: хлорорганічні пестициди; поліхлоровані біфеніли; поліциклічні ароматичні вуглеводні; бензол, толуол, етилбензол і ксилоли; аналіз води; газова хроматографія; детектор захоплення електронів; полум'яний іонізаційний детектор

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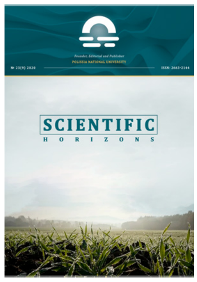

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Assessment of fat-and-oil products quality conformity (safflower oil)

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Abstract. The study aims to analyse the qualitative characteristics of safflower oil, including its fatty acid profile, and determine the acid and peroxide numbers. The study also investigated the levels of heavy metals in the oil and assessed its potential as an inhibitor of α-amylase and α-glucosidase enzymatic activity. In this study, standardised methods were used to analyse the fatty acid composition of safflower oil using a standard mixture of 37 fatty acid methyl esters (Supelco™ 37 Component FAME Mix), which ensured high accuracy in determining the fatty acid composition. The physical properties of safflower oil, such as density (0.94) and specific gravity (0.917), depend on the fatty acid composition and temperature. The refractive index, determined at 1.469, was used to estimate changes in the oil's unsaturation and viscosity (45.6 cP). Colour parameters (lightness 45.24, red-green scale -2.87, yellow-blue scale 21.04) confirm the authenticity of the oil. The results of gas chromatographic

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analysis confirmed that the composition of the samples did not meet the requirements of the standard. The study also included the evaluation of the inhibitory activity of safflower oil against the enzymes α-amylase and α-glucosidase, where one of the samples showed significant inhibition of α-amylase activity and the other α-glucosidase activity, indicating their potential use as natural inhibitors. The safety control of heavy metal content showed that the levels of lead, cadmium and other toxic elements in the oil are well below the permissible limits, confirming its safety for consumption. These data indicate that, although some safflower oil samples do not meet the standards for fatty acid composition, its potential as a natural enzyme inhibitor and safety in terms of heavy metal content opens up prospects for further research and possible optimisation of production processes

Keywords: acid number; fatty acids; heavy metal content; inhibition; state standard; heavy metal content

INTRODUCTION

In today's world, the issue of providing the population with safe and high-quality food enriched with vitamins, microelements and biologically active substances is of particular relevance. An unbalanced and irrational diet is one of the leading risk factors for the development of nutritionally dependent diseases, such as obesity, type 2 diabetes, cardiovascular diseases, certain types of cancer and others. In this regard, the search for new sources of biologically valuable substances and the development of functional foods that can compensate for nutritional deficiencies and improve public health is one of the most important tasks of modern nutrition science. In this context, safflower (*Carthamus tinctorius* L.), an oilseed crop with a unique complex of biologically active substances, is particularly promising. Following G.S. Aidarkhanova *et al.* (2021), safflower oil and extracted meal can be used as functional ingredients to enrich various foods, such as bakery products, dairy products, confectionery, meat and fish products. This, in turn, can significantly contribute to optimising food consumption patterns and improving public health.

Safflower, as a source of oil and fat products, has several outstanding advantages that determine its importance in human nutrition. Of particular note is the high content of linoleic acid in safflower oil, which reaches up to 80%. Linoleic acid is an essential fatty acid necessary for maintaining the health of the human body (Mukhametov *et al.*, 2023). This statement is supported by B.M. Iskakov *et al.* (2022) and M.T. Mursalykova *et al.* (2022), who also note the richness of safflower in B vitamins (B1, B2, B6), E, and K, as well as macro- and microelements such as potassium, magnesium, calcium, phosphorus, iron, copper and zinc. Moreover, safflower contains several biologically active substances, such as flavonoids, phytosterols and lignans, which have pronounced antioxidant, anti-inflammatory, antibacterial and other beneficial properties. Furthermore, safflower oil and safflower extract not only contribute to the improvement of internal health but also have a high value in the context of improving the appearance of the skin and hair. K.D. Rakhimov *et al.* (2020) identified the potential of safflower in nutraceuticals, where safflower oil and safflower extracts were used as the basis for the creation of biologically active food supplements (BAFS) aimed at preventing and correcting various diseases. Sh. Zhailaubayeva *et al.* (2023) showed that safflower has potential in the field of cosmetology. Given its rich composition, safflower oil can be successfully used as a component of cosmetic products for skin and hair care, making it a valuable ingredient not only for internal but also for external health and beauty improvement.

Many countries around the world have laws and standards governing the quality of fat and oil products. Quality conformity assessment is substantial for manufacturers to ensure that their products meet all the requirements and can be legally marketed (Musayeva *et al.*, 2024). S.T. Abildaev *et al.* (2023) employed statistical and heuristic (organoleptic) methods to assess the quality of fat and oil products. The authors addressed the analysis of the labelling of fat and oil products and concluded that it is necessary to strengthen control over the quality of labelling and packaging of products following the requirements, as well as the need for stricter control over the indication of trans fat content on the packaging of fat and oil products. These findings underline the importance of systematic monitoring and quality control of fat and oil products to ensure the safety and reliability of products on the market. One of the most important aspects of ensuring the quality of fat and oil products is to protect the health of consumers. Safflower oil, similar to other types of vegetable oils, can contain harmful impurities such as pesticides, heavy metals and carcinogens. Eating low-quality butter can lead to poisoning, allergic reactions and the development of various diseases (Bandura & Fialkovska, 2023). Quality conformity assessment was used to identify and withdraw substandard products from the market, thereby protecting the health and well-being of consumers. G. Dambaulova *et al.* (2023) note that butter adulteration by adding vegetable fats is a common type of fraud in the butter and fat industry.

Based on the above, there is an urgent need for a comprehensive analysis of the chemical composition, physicochemical properties and microbiological parameters of safflower oil to verify its compliance with established quality and safety standards. The study aims to identify the key factors affecting the quality of this product and to provide specific recommendations for improving production processes and ensuring a high level of consumer safety.

MATERIALS AND METHODS

In 2024, eleven different brands of safflower oil were purchased as part of a research project. The locations of purchase included pharmacies, markets, online retailers and cosmetic stores in Almaty, Kazakhstan. All samples were stored at a low temperature of about 4°C until they were used in the study. The samples were numbered with consecutive numbers for ease of organisation and analysis of the data. Each sample was assigned a unique number from 1 to 11, regardless of where it was purchased, which was used for record-keeping, storage, testing and references in the research report.

To accurately determine the composition of fatty acids in the samples, a standard mixture of 37 fatty acid methyl esters (Supelco™ 37 Component FAME (fatty methyl esters) Mix, FAME37, C4-24) was used in gas chromatographic analysis. This standard containing 100 mg of FAME37 was stored at -20°C to maintain its stability. In preparation for analysis, working solutions were prepared from this standard in an ice bath to prevent decomposition. To prepare a standard solution with a concentration of 400 mg/ml, 250 μl of dichloromethane was used, which was added to 100 mg of FAME37 standard. The resulting solution was mixed thoroughly with a shaking device. Then, for further dilution and preparation for injection into the gas chromatograph, 75 μl of this solution was mixed with 925 μl of CH_2Cl_2 and stirred on a vortexer.

For analysis by gas chromatography-mass spectrometer (GC-MS), 100 μl of FAME37 standard solution with a concentration of 30 mg/ml was placed in a special glass tube and hermetically sealed. Such precision in sample preparation ensured high accuracy and reproducibility of the analysis results. This method was used to study in detail the fatty acid profile of various samples, including food and biological materials. To study the effect of safflower oil on the activity of the α-amylase enzyme, the method described by H. Mechchate *et al*. (2021) was employed. The α-amylase enzyme was dissolved in water to obtain a final concentration of 4 U/ml. The substrate used was a 0.5% solution of potato starch in 20 mM phosphate buffer. The quality control of fatty acid composition, acid and peroxide numbers was determined according to GOST 5480-59 (Standard of the…, 2005).

Safflower oil was prepared in a solution of 100% MeOH at concentrations of 1 mg/ml, 0.5 mg/ml and 0.25 mg/ml. These samples were mixed with the α-amylase enzyme and incubated at 37°C. After the addition of the starch substrate, 50 ml of DNS (3,5-dinitrosalicylic acid) staining solution containing 96 mM 3,5-dinitrosalicylic acid, 5.31 M sodium potassium tartrate in 2 M NaOH was added to the mixture. The mixture was kept at 85°C for 15 minutes, after which it was diluted with water and left to cool to complete the reaction. The absorbance of the resulting solution was measured at 540 nm using an enzyme-linked immunosorbent assay (ELISA) plate reader. Acarbose was used for comparison.

To evaluate the inhibitory effect of safflower oil on the α-glucosidase enzyme, a method was also developed by H. Mechchate *et al*. (2021). The enzyme α-glucosidase type IV, isolated from *Bacillus stearothermophilus*, was dissolved in 0.5 M phosphate buffer with pH 6.5. The safflower oil was dissolved in 100% methanol to obtain concentrations of 1 mg/ml, 0.5 mg/ml and 0.25 mg/ml. These solutions were incubated with α-glucosidase in a 96-well microplate at 37°C. After the addition of the substrate consisting of 10 μl of 20 mM p-nitrophenyl-α-D-glucopyranoside, the reaction was left to proceed at the same temperature. The final assessment of the colour intensity was carried out using an ELISA plate reader at a wavelength of 405 nm. Control samples were used as a reference.

The concentrations of cadmium (Cd) and lead (Pb) in the products were determined by the atomic absorption method, which deals with the analysis of raw materials and food products for the content of toxic elements (Standard of the Republic…, 2005). The process involved the mineralisation of the sample by dry or wet ashing, after which the concentration of elements was measured in the mineralisation solution (in a 0.1 normal nitric acid solution) using flame atomic absorption spectrometry. The concentration of arsenic (As) was determined by atomic absorption at the resonant wavelength of 193.7 nm using the atomic absorption method, which provides an accurate assessment of the levels of these elements in products. These methods are key to ensuring food safety by identifying and quantifying potentially harmful toxic metals.

RESULTS

The physical properties of safflower oil, such as density and specific gravity, depend on its fatty acid composition and temperature. The density, defined as mass per unit volume, for safflower oil, was 0.940. Moreover, the specific gravity, which usually increases with the degree of unsaturation of the oil, was measured at 0.917. This value tends to decrease with increasing temperature, which reflects the temperature sensitivity of this parameter. The specific gravity and refractive index are crucial, but not conclusive, for the identification of pure substances. However, they are valuable for detecting any contamination or adulteration in oils. The refractive index of safflower oil was determined to be 1.469, which indicates a change in unsaturation due to processes such as hydrogenation and gives an indication of the viscosity of the oils, which was 45.6 cP. Colour parameters, including lightness, red-green scale and yellow-blue scale, are often associated with the quality of oils, especially those used in salads and shortening. For all samples of safflower oil, the lightness value was 45.24, the red-green scale was -2.87, and the yellow-blue scale was 21.04. These colour indicators are used to assess the quality of the oil and possible adulteration and show that the oil is genuine.

The results showed that out of 11 samples, only two, n1 and n5, met the standard for acid number, which indicates their good condition and proper storage (Table 1). The remaining 9 samples show acid values above 0.5, which may indicate oxidation due to improper storage or processing, which in turn reduces their shelf life and nutritional value. The acid number should not exceed 0.5, and the peroxide number should not exceed 10. As for the peroxide number, only samples n1 and n4 are within the normal range, which indicates a low level of oxidation of these oils and preservation of their taste. This makes them preferred for consumption, as the lower level of oxidised fatty acids provides better flavour and aroma. At the same time, the high peroxide number of the remaining samples can lead to rancidity, making the oil less suitable for use, especially in food products.

Table 1. *Indicators of acid and peroxide number of safflower oil samples of the Republic of Kazakhstan*

Sample	Acid number ± SD	Peroxide number ± SD
n1	0.2 ± 0.1	7.5 ± 1.6
n2	1.4 ± 0.1	28.6 ± 0.2
n3	1.3 ± 0.2	14.6 ± 0.3
n4	1.2 ± 0	8.2 ± 0.4
n5	0.4 ± 0	12.8 ± 2.1
n6	0.7 ± 0.1	14.8 ± 1.5
n7	0.8 ± 0.2	157.7 ± 6.1
n8	1.3 ± 0.1	25.4 ± 3.4
n9	1.9 ± 0.1	18.4 ± 1.9
n10	0.8 ± 0.1	87.8 ± 0
n11	1.1 ± 0.1	30.4 ± 1.5

Note: *SD – standard deviation*
Source: *compiled by the authors*

Firstly, there is a significant variation in the peroxide values among the samples, which may indicate differences in storage conditions or the age of the oils. The sample n7 stands out as having an extremely high peroxide number, which may indicate a critical deterioration in its quality. Such high values can be the result of prolonged exposure to light, temperature and oxygen, which leads to accelerated oxidative degradation. At the same time, the low acid number in samples n1 and n5 indicates that these oils were better protected from external factors or processed in a gentler way, which preserves their original qualities. This makes them potentially more valuable for use in food and other applications where oil quality is of paramount importance. The GOST 5480-59 standard distinguishes between two types of safflower oil, which are obtained from the seeds of the *Carthamus tinctorius* plant (Standard of the Republic of Kazakhstan No. 1428-2005, 2005). Type I oil is produced directly from the seeds of a given plant through expression or extraction processes. Type II oil, in turn, is made from the seeds of hybrid forms of the same plant. These two types of oil can differ in their chemical composition and properties. A problem arises when analysing purchased oil samples: the packaging usually does not indicate whether the oil is derived from hybrid or non-hybrid seeds. This makes it difficult to accurately assess their quality and compliance with standards. In this regard, to analyse the fatty acid composition of the samples under study, they were evaluated based on the criteria for type I oil, as indicated in Table 2.

Table 2. *Criteria for oil component content*

FAMEs components	Content range (%)
C16:0 (palmitic acid)	4-10
C18:0 (stearic acid)	1-5
Σ saturated FAMEs (C16:0 and C18:0)	5-15
C18:1 (oleic acid)	8-21
C18:2 (linoleic acid)	68-83
Σ unsaturated FAMEs (C18:1 and C18:2)	76-105

Source: *Standard of the Republic of Kazakhstan No. 1428-2005 "Edible Safflower Oil" (2005)*

From the table with the percentage of fatty methyl esters in safflower oil, several important conclusions can be drawn about the characteristics of this product. Particularly noteworthy are the high values of linoleic acid in each sample, which is typical for safflower oil and makes it a valuable source of omega-6 polyunsaturated fatty acids. This is of significant nutritional and dietary importance, as omega-6 acids are substantial in maintaining cardiovascular health and regulating metabolism. In addition, the presence of up to 21% oleic acid highlights the potential benefits of safflower oil for improving blood cholesterol levels, as oleic acid is a monounsaturated fatty acid that can help reduce LDL cholesterol (bad cholesterol) without reducing HDL cholesterol (good cholesterol). The presence of saturated fatty acids in smaller amounts, such as palmitic and stearic acids, which make up a smaller proportion of the total fatty acid composition, underlines the benefits of safflower oil as a source of unsaturated fat. This makes it the preferred choice for use in healthy foods compared to oils rich in saturated fat. The combination of fatty acids present in safflower oil reflects its potential utility in the food, pharmaceutical and cosmetic industries, where such characteristics can be particularly valuable in creating products that promote health and well-being. The quantitative analysis of fatty acid content in safflower oil samples was carried out using the chromatography method. To determine the concentrations, an approach based on measuring the peak areas on the chromatogram was used, followed by comparing the retention times with those of standard fatty acids.

The results presented in Table 3 show the fatty acid composition analysis of safflower oil, demonstrating its rich profile of mono- and polyunsaturated fatty acids, which range from 67.10% to 99.53% of the total fatty acid content. Among the fatty acids present in the oil, linoleic acid (C18:2) occupies a dominant position with a share ranging from 49.69% to 92.59%, which underlines the outstanding potential of safflower oil as a source of polyunsaturated fatty acids. Oleic acid (C18:1) is also present in significant amounts, ranging from 4.09% to 40.34%, while saturated fatty acids such as palmitic acid (C16:0) and stearic acid (C18:0) make up only a small proportion, ranging from 0.54% to 12.01% and from 0.05% to 1.35%, respectively. The saturated fat content of safflower oil ranges from 0.58% to 12.18%, making it an unsaturated fat source and a preferred choice for diets aimed at improving cardiovascular health. These data emphasise not only the quality of safflower oil as a food product but also its usefulness in dietary nutrition, helping to maintain optimal blood lipid levels and improve overall health. However, despite the positive characteristics of the fatty acid composition, the research results showed that none of the samples met all the requirements for safflower oil according to GOST 5480-59. This discovery highlights the need for further study and adjustment of the butter production and storage processes to ensure its compliance with GOST 5480-59 (Standard of the Republic of Kazakhstan No. 1428-2005, 2005).

Table 3. *Analysis of fatty acid composition of safflower oil samples from the Republic of Kazakhstan*

Fatty acids (FAMEs)	**n1**	**n2**	**n3**	**n4**	**n5**	**n6**	**n7**	**n8**	**n9**	**n10**	**n11**
Palmitic acid (C16:0)	3.8	4.49	10.81	4.52	3.04	6.77	0.59	1.9	1.88	2.1	2.47
Stearic acid (C18:0)	0.05	0.47	0.15	1.44	1.37	0.56	0.04	0.2	0.08	0.39	0.52
Σ saturated fatty acids (palmitic and stearic)	3.85	4.96	10.96	5.96	4.41	7.31	0.63	2.1	1.96	2.49	2.79
Oleic acid (C18:1)	4.09%	6.32%	37.34%	40.34%	24.51%	23.17%	9.37%	8.83%	6.25%	12.29%	9.75%
Linoleic acid (C18:2)	92.59%	87.73%	54.78%	49.69%	68.2%	69.52%	86.51%	82.61%	91.45%	84.81%	86.9%
Σ unsaturated LCs (Oleic and Linoleic)	96.68%	94.05%	92.12%	90.03%	92.71%	92.69%	95.89%	91.44%	97.70%	97.10%	96.65%

Source: *compiled by the authors*

The study evaluated the efficiency of inhibition of α-glucosidase enzyme activity using different concentrations of safflower oil samples. The α-glucosidase enzyme catalyses the final step in the hydrolysis of di- and oligosaccharides to monosaccharides, which is key to carbohydrate metabolism. The activity of this enzyme directly affects the level of glucose in the blood after a meal, thereby playing an important role in the pathogenesis of type 2 diabetes mellitus. The experimental study tested the inhibitory effect of various concentrations of vegetable oil on the activity of the α-glucosidase enzyme, which plays a critical role in carbohydrate metabolism by catalysing their breakdown into glucose. Three different concentrations were used for this purpose: 0.25 mg/ml, 0.5 mg/ml and 1 mg/ml. The results showed that most of the oil samples had no significant effect on the enzyme activity. However, an important observation was made for sample No. 11, which at a concentration of 0.25 mg/ml showed an inhibition of 7.41 ± 2.75%, which is statistically significant, although the clinical significance of this effect remains low.

When the sample concentration was increased to 1 mg/ml, the inhibitory effect decreased to 4.61 ± 1.04%. This decrease in efficiency can be explained by the phenomenon of saturation of the enzyme's reaction centres. When a certain concentration is reached, the enzyme's active centres become fully occupied, and further increases in oil concentration do not lead to an increase in the inhibitory effect. It is also possible that conformational changes in the enzyme structure occur, which may alter its ability to bind to the inhibitor, which also affects the activity of α-glucosidase. This highlights the potential of vegetable oils as sources of natural inhibitors for enzymes involved in carbohydrate metabolism. These results may indicate the presence of certain bioactive components in safflower oil that can modulate the activity of enzymes involved in carbohydrate metabolism. This indicates the potential of safflower oil as a source of natural α-glucosidase inhibitors, as well as the efficacy and safety of this inhibitor in the context of the treatment and prevention of type 2 diabetes.

For comparison, acarbose, a well-known α-glucosidase inhibitor, was used as a control standard. The results for acarbose were significantly higher, reaching 99.09 ± 0.49% at a concentration of 0.25 mg/ml, 99.74 ± 0.03% at 0.5 mg/ml and 99.78 ± 0.03% at 1 mg/ml. These data highlight the high efficiency of acarbose compared to safflower oil, confirming its use in medicine as a standard treatment for blood glucose control in diabetic patients. Thus, the study confirmed that safflower oil, except in one sample, has limited activity in terms of α-glucosidase inhibition, and its use as a potential inhibitor requires further research and modification. The study evaluated the ability of safflower oil samples to inhibit the activity of the α-amylase enzyme, which is responsible for the breakdown of complex carbohydrates in the body. The study determined that most of the oil samples did not have a pronounced inhibitory effect on this enzyme at different concentrations. The exception was sample No. 1, which showed moderate inhibitory activity. At a concentration of 1 mg/ml, this sample showed an inhibition of enzymatic activity at the level of 49.82 ± 3.07% (Table 4).

Table 4. *A-amylase activity inhibition values for each safflower oil sample and acarbose reference preparation*

Sample	Inhibition at 0.25 mg/ml	Inhibition at 0.5 mg/ml	Inhibition at 1 mg/ml
n1	-	5.14 ± 2.98	49.82 ± 3.07
n2	13.16 ± 3.69	-	7.93 ± 0.92
n3	-	14.71 ± 3.47	5.93 ± 2.01
n4	13.27 ± 3.74	3.22 ± 1.11	13.12 ± 1.13
n5	8.15 ± 3.74	4.64 ± 1.89	-
n6	-	10.93 ± 1.14	-
n7	7.70 ± 3.05	5.10 ± 1.26	20.08 ± 8.20
n8	15.28 ± 3.96	16.33 ± 1.12	23.27 ± 5.40
n9	26.99 ± 5.23	19.88 ± 2.56	23.42 ± 2.99
n10	38.36 ± 3.47	17.22 ±V4.42	16.11 ± 3.18
n11	-	7.15 ± 1.95	3.81 ± 5.88
Acarbohydrate	88.17 ± 6.19	93.58 ± 7.11	95 ± 0.04

Source: *compiled by the authors*

For comparison, acarbose, used as a reference in the experiment, showed 95% inhibition of α-amylase activity at the same concentration. This highlights the high efficiency of acarbose as a pharmaceutical α-amylase inhibitor, which is widely used to treat conditions associated with carbohydrate metabolism. Final testing of the quality of vegetable oils revealed various levels of heavy metal contamination, which, despite exceeding natural backgrounds, remain well below the established safe limits. These indicators can have a variety of health and environmental implications. For instance, sample No. 4 was found to contain the highest level of lead (Pb) at 0.065 mg/kg, which is 40% below the maximum permissible concentration. Despite compliance with the regulations, even low levels of lead can accumulate in the body over time, potentially leading to neurological and cognitive disorders, especially in children. The content of cadmium (Cd), which was found in the highest amount in sample No. 8 (0.009 mg/kg, 80% below the maximum permissible levels), is also a cause for concern. Cadmium is a carcinogen that can cause kidney failure and bone disease if exposed for a long time, even in low doses.

Arsenic (As), detected in samples No. 5 and No. 8 at 0.003 mg/kg (96% below the limit), is a toxic element that can cause skin, lung and other organ cancer with prolonged exposure. Nickel (Ni), present in sample No. 4 at 0.433 mg/kg, although within safe limits, can cause allergic reactions and aggravate respiratory diseases at high concentrations. However, when the information received was clarified, it was found that in Kazakhstan the average consumption of edible oil per person is about 36 grams per day, which exceeds the recommended norm of 29 grams by the World Health Organisation (WHO) (2024). This level of consumption of sunflower oil, which is one of the most popular in the region, amounts to approximately 1,116 grams per person per month. The predicted impact of this level of consumption on human health was estimated based on the average weight of an adult resident of Kazakhstan, which is 60 kg. The health risk assessment was based on specialised formulas proposed by the WHO, which consider both the quantitative and qualitative characteristics of the oil consumed.

Based on these analyses of the heavy metal content of vegetable oils in Kazakhstan, these products fully comply with the established safety standards. Studies have shown that the concentrations of metals such as lead, cadmium, arsenic and nickel in the human body during consumption are well below the permissible limits. This indicates that there is no direct risk to human health when eating these oils.

DISCUSSION

Despite the positive characteristics of the fatty acid composition of the safflower oil samples under study, none of them meet the requirements for this type of product following GOST 5480-59. This points to the need for further analysis and improvement of production and storage processes to ensure compliance with quality standards. However, to ensure a more objective and relevant interpretation of the data obtained, it is important to carry out a comparative analysis with the results of similar studies conducted by other authors.

The study of the importance of safflower oil quality is a significant topic in modern science. One of the key aspects in this area is to identify the positive characteristics of this product, such as the high level of polyunsaturated fatty acids, in particular linoleic acid. The study determined that quality problems with safflower oil samples may be related to improper storage or processing, which leads to a loss of nutritional value. M. Nazir *et al.* (2021), Z. Samai *et al.* (2022) and G. Lei *et al.* (2023), also addressed this aspect in their research, emphasising the need to improve the quality of safflower oil. This research has examined the effectiveness of filtration in improving oil quality, as well as the potential use of recycled products such as flax fibre in this process. The authors believe that filtration methods have a direct impact on the quality characteristics and shelf life of the oil and optimise subsequent refining processes. The introduction of efficient filtration methods can reduce production costs and improve the overall quality of the final product (Yaheliuk *et al.*, 2024). The use of recycled products as filter media is an innovative approach that could be promising in the context of improving safflower oil production processes. Thus, this study not only confirms the importance of safflower oil quality and the need to improve it but also opens new research methods based on innovative materials.

D. Alimi *et al.* (2022) and A. Khan *et al.* (2024), also highlight the positive characteristics of safflower oil, emphasising the importance of the fatty acid content of vegetable oils and their suitability for certain applications, whether food, industrial or medical. The authors note that the fatty acids present in vegetable oils (such as oleic, linoleic, lignoceric, elaidic, palmitic, palmitoyl and stearic) have significant pharmacological utility in both human and animal medicine, which is indicative of their high biological activity. Safflower oil has a fatty acid composition that is similar to olive oil, especially due to its high content of oleic and linoleic acids, as indicated by L. Ugolini *et al.* (2023) and Z. Najafi *et al.* (2022). This makes it an affordable alternative to olive oil, given its lower price for consumers. Safflower oil is also valued for its ability to reduce low-density lipoprotein (LDL), known as “bad cholesterol”, making it a popular choice in countries such as North America, Germany and Japan.

In addition, safflower oil causes minimal allergic reactions compared to other oils, making it suitable for use in cosmetic products. Studies by L. Xin *et al.* (2022) and L. Chehade *et al.* (2022) on ovariectomised rats showed that fat-free safflower seed powder can increase good cholesterol levels. At the same time, aqueous and ethanolic extracts of safflower seeds affect the level of triglycerides and total cholesterol in the blood plasma. The flavonoids, lignans and serotonin derivatives contained in safflower seeds play an important role in modulating and lowering cholesterol levels, improving the overall lipid profile of the body. This is especially important in conditions of estrogen deficiency. Such polyphenolic substances also help prevent LDL oxidation and the development of atherosclerosis, as shown *in in vitro* and *ex vivo* studies. This indicates the wide variety of uses and benefits of safflower oil, which can be exploited in Kazakhstan when purchased samples meet all the standards.

A comparative analysis of the effectiveness of safflower oil and the control standard, acarbose, in inhibiting α-glucosidase revealed a high activity of acarbose compared to safflower oil, which confirms the advantage of acarbose in this context. These results are in line with the findings of Ž. Tarasevičienė *et al.* (2023), who evaluated the effect of safflower oil on α-amylase and α-glucosidase in the context of weight control, noted the absence of an inhibitory effect in oil samples. The author also noted that the possible impact of low-quality oil samples on enzyme activity highlights the need for stricter quality control of safflower oil in further research and clinical practice.

A review of the studies by D. Deliorman Orhan *et al.* (2022), L. Song *et al.* (2023) and S. Liu *et al.* (2023) determined that these were the first to evaluate the quality of safflower oils on the Turkish market and their effectiveness in terms of two enzymes: α-amylase and α-glucosidase. As part of the work, 9 samples of safflower oil purchased on the local market were analysed and found not to meet the quality criteria set by the European Pharmacopoeia. The study found low oleic acid and high linoleic acid content, suggesting that oleic acid is oxidised to linoleic acid due to production and storage conditions. These results raise concerns about the methods of production and storage of butter, which may affect its quality. The analysis of the inhibitory effect of oils on the enzymes α-amylase and α-glucosidase showed that these oil samples do not have a significant effect on weight management by inhibiting the enzymes involved in carbohydrate digestion. This study highlights the need to improve the quality standards and storage conditions of safflower oil to meet pharmacopoeial requirements and achieve the desired health benefits. These results are directly confirmed by the study of safflower oil quality in the Republic of Kazakhstan, which makes these studies more objective and further points to the problems of state regulation of the standards of producers and the rules for preserving this product.

Before that, the American researcher M. Hugar *et al.* (2023) studied the effect of methanolic extracts of safflower seeds on the activity of the α-glucosidase enzyme and identified compounds such as N-p-coumaroylserotonin and N-feruloylserotonin, which showed a more pronounced inhibitory effect compared to acarbose. However, it is important to note that the chemical composition of secondary metabolites in seed oils may differ from that found in extracts. Another study by G. Sousa *et al.* (2022) showed that oleic and linoleic acids effectively inhibit glucosidase activity, which may be associated with the potential to combat diabetes. However, an important aspect is the degree of oxidation of oils and the compliance of their fatty acid content with the desired standards, which affects the assessment of their effectiveness and safety of use. It is this aspect, studied in the above research, that highlights the importance of these indicators. Having analysed the work of American scientists, it is possible to state that it was the discrepancy in acid content standards that in most samples did not give positive inhibition of amylase and glucosidase.

The study, which focused on the quality of edible oils, paid particular attention to the determination of acid and peroxide numbers, which are important for assessing the degree of freshness and oxidative stability of oils. S. Shinde *et al.* (2023) and P. Kadirvel *et al.* (2023) determined that the acid number measures the amount of free fatty acids and in this study, it did not exceed the maximum permissible level of 0.6 mg KOH per gram of oil, which is in line with WHO standards. This indicates good quality in terms of freshness. As for the peroxide number, which reflects the content of primary fat oxidation products, its values for the samples studied were also within the permissible limits and ranged from 1.09 to 2.43 mEq/kg. These indicators confirm that the oils have not undergone significant oxidation, which is an indicator of their quality and stability. The average peroxide values were compared with the WHO and Food and Agriculture Organisation international standards of 10 milli equivalents of active oxygen per kilogram of oil and found to be in line with these requirements. The lower peroxide values in some samples may be due to their high saturation with fatty acids, which contributes to oxidation resistance. In addition, the presence of antioxidants such as vitamin E in oils also contributes to improving their oxidative stability and extending their shelf life (Yaheliuk & Didukh, 2022). Thus, the data obtained indicate the high quality of the oils under study, confirming their safety and nutritional value for the consumer. This may explain the elevated acid value in the safflower oil samples from Kazakhstan, with normal peroxide values.

Following the analysis of the fatty acid composition of safflower oil by S. Pelaracci *et al.* (2022) and M. Tonguç *et al.* (2023), among saturated fatty acids, palmitic acid (C16:0) has the highest concentration of 6.02%, followed by stearic acid (C18:0) with 2.37%. Other saturated fatty acids, including lauric (C12:0), myristic (C14:0), heptadeconic (C17:0), arachidonic (C20:0), behenic (C22:0) and lignoceric (C24:0) are present in much smaller amounts, amounting to 0.07%, 0.11%, 0.04%, 0.37%, 0.23% and 0.12% respectively. In the total fatty acid balance of safflower oil, saturated fatty acids make up 9.61%, while unsaturated fatty acids make up 90.33%. Among the unsaturated fatty acids, monounsaturated fatty acids account for 14.07%, and polyunsaturated fatty acids (PUFAs) dominate 76.26%. This emphasises the high proportion of PUFAs in safflower oil, which makes it attractive for diets aimed at improving cardiovascular health and lowering cholesterol levels. In addition, the ratio of polyunsaturated to monounsaturated fatty acids in an oil expresses its nutritional value and stability. However, it is worth noting that an important aspect when choosing an oil is the ratio of omega-6 to omega-3 fatty acids, where in safflower oil omega-6 makes up a significant percentage (76.22%), which requires attention when included in the diet to prevent an imbalance of these acids (Kachanova *et al.*, 2023). These studies show both the indicators already tested in the above study and new ones. The ratio of omega-6 to omega-3 fatty acids has an important influence on the quality of safflower oil and should also be considered by producers.

Safflower oil has a variable composition and nutritional profile, which depends on the growing conditions, soil type and safflower varieties used. S. Adewinogo *et al.* (2021) and M. Ruyvaran *et al.* (2021) state that the future use of safflower oil in the food industry will depend on the successful selection of high-yielding plant varieties. Currently, safflower oil is actively used in the production of margarine and universal shortening for bakery products, as well as in emulsified shortening used for making cakes. Due to its high content of oleic and linoleic acids and antioxidants, safflower oil is an excellent choice for replacement in infant formula. Its natural flavour and mildness also make it a popular ingredient in seasonings, flavourings and dried fruits. These studies once again point to the great importance and breadth of application of safflower oil, if properly produced, which can significantly expand the production and export of this commodity in the Republic of Kazakhstan.

CONCLUSIONS

In this study, the quality of safflower oil was analysed using several indicators, including acid and peroxide numbers, as well as the ability of oils to inhibit the activity of α-glucosidase and α-amylase enzymes. Of the eleven samples, only two (n1 and n5) met the acid number standard, falling below the threshold of 0.5. This indicates that the samples are in good condition and have been stored correctly. The average acid number of the other nine samples is 0.75, which is higher than normal and indicates oxidation due to improper storage or processing. The study also determined that only samples n1 and n4 met the peroxide standard, which indicates a low level of oxidation and preservation of the oil's taste. This makes these samples preferable for consumption. However, despite the positive aspects in terms of acid and peroxide numbers, none of the samples meets all the requirements for fatty acid composition set out in GOST 5480-59 for safflower oil. This highlights the need for further study and adjustment of the oil production and storage processes.

The ability of the oil samples to inhibit the activity of the α-amylase enzyme was evaluated, and only sample No. 1 showed moderate inhibitory activity. This indicates the potential for safflower oil to be used as an inhibitor, but further research is needed to improve its effectiveness. Studies on the content of heavy metals in vegetable oils have shown that the products fully comply with established safety standards, which significantly reduces the health risks associated with the use of these oils. The study's shortcomings include the lack of long-term monitoring of oil quality changes over time, which could provide a more complete picture of its stability and resistance to oxidation. It is also worth noting that there is no comparison with other types of oils, which could help determine the unique properties of safflower oil. Lastly, although the effect of oil on enzyme activity has been investigated, the data was limited to only two types of enzymes, leaving questions about its potential impact on other key aspects of metabolism. Prospects for further research are based on the need to improve the production and storage processes of safflower oil to achieve compliance with pharmacopoeial standards, as well as to further study its potential use as an amylase inhibitor.

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CONFLICT OF INTEREST

None.

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Оцінка відповідності якості олійно-жирової продукції (олія сафлорова)

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Анотація. Метою даного дослідження був аналіз якісних характеристик сафлорової олії, включно з її жирнокислотним профілем, а також визначенням кислотного і перекисного чисел. Дослідження також було спрямоване на вивчення рівнів важких металів в олії та оцінку її потенціалу як інгібітора ферментативної активності α-амілази та α-глюкозидази. У цьому дослідженні застосовували стандартизовані методи для аналізу жирнокислотного складу сафлорової олії, використовуючи стандартну суміш метилових ефірів 37 жирних кислот (Supelco™ 37 Component FAME Mix), що дало змогу досягти високої точності у визначенні складу жирних кислот. Фізичні властивості сафлорової олії, як-от густина (0.94) і питома вага (0.917), залежать від жирнокислотного складу і температури. Коефіцієнт заломлення, визначений на рівні 1.469, допоміг оцінити зміни в ненасиченості та в'язкості олії (45.6 сП). Параметри кольору (світлота 45.24, червоно-зелена шкала -2.87, жовто-блакитна шкала 21.04) підтверджують справжність олії. Результати газохроматографічного аналізу підтвердили невідповідність складу зразків вимогам стандарту. Дослідження також включало оцінку інгібуючої активності сафлорової олії проти ферментів α-амілази та α-глюкозидази, де один зі зразків продемонстрував значне пригнічення активності α-амілази, а інший – α-глюкозидази, вказуючи на їхнє потенційне застосування як натуральних інгібіторів. Контроль безпеки за вмістом важких металів засвідчив, що рівні свинцю, кадмію та інших токсичних елементів в олії значно нижчі за допустимі межі, підтверджуючи її безпеку для вживання. Ці дані вказують на те, що, незважаючи на невідповідність деяких зразків сафлорової олії стандартам за жирнокислотним складом, її потенціал як натурального інгібітора ферментів і безпека за вмістом важких металів відкривають перспективи для її подальшого дослідження та можливої оптимізації виробничих процесів

Ключові слова: кислотне число; жирні кислоти; вміст важких металів; інгібування; державний стандарт; вміст важких металів

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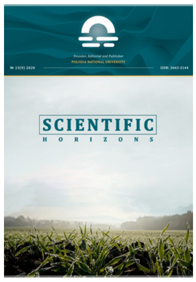

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Enhancing *Bifidobacterium* and lactic acid bacteria activity, and improving oxidative stability in functional algal concentrated yoghurt with *Spirulina platensis* powder

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Abstract. The purpose of this study was to examine the growing demand for healthy functional dairy products by investigating the incorporation of *Spirulina platensis* into concentrated yoghurt and evaluating its impact on starter cultures and product properties. A comprehensive analysis demonstrated the potential of spirulina to enhance bifidobacteria growth, acidity, PUFA content, and antioxidant activity in

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yoghurts, indicating its potential to improve the nutritional quality and oxidative stability of dairy products. The study investigated the impact of different *Spirulina* ratios on the activity of yoghurt starter cultures, including *Lb. casei*, *Lb. plantarum, Lb. acidophilus*, and *Bifidobacterium* mix. Three concentrated yoghurt samples were prepared, including a control, a probiotic sample, and a sample incorporating *Spirulina* powder. The findings suggest that while *Spirulina* did not significantly affect lactic acid bacteria, it noticeably stimulated the growth of *Bifidobacterium*. Treated samples showed increased acidity and TVFAs, with pH values displaying an inverse trend compared to the control. Clear differences in colour parameters and sensory evaluations distinguished control from treated samples. Additionally, *Spirulina* supplementation demonstrated a pronounced effect in enhancing antioxidant activity, as observed through DPPH radical scavenging activity, and influencing the peroxide value, reflecting improved oxidative stability in the yoghurt. This successful utilisation of *Spirulina* suggests its potential application in diverse edible algae in the food sector, especially in dairy products, enhancing both nutritional and sensory aspects, as well as contributing to improved oxidative stability

Keywords: Edible algae; functional foods; antioxidant activity; useful bacteria; dairy products

INTRODUCTION

The demand for functional foods that offer both nutritional benefits and enhanced health properties has surged in recent years, driven by an increasingly health-conscious consumer base. As the global population grows, so does the need for sustainable and innovative food solutions. In this context, the exploration of new ingredients with potential health-promoting properties becomes crucial. One such ingredient garnering attention is *Spirulina platensis*, a type of green algae known for its rich nutritional profile and potential health benefits. Incorporating *Spirulina* into dairy products such as yoghurt, presents an opportunity to create functional foods that not only provide essential nutrients but also contribute to improved gut health and oxidative stability.

Spirulina is great for children's development due to its high calcium and iron content (1,043.62 and 338.76 mg/100 g, respectively). It also includes selenium (0.0488 mg/100 g) and plant pigments (phycocyanin: 14.1% and chlorophyll: 1.4%) (Ali *et al.,* 2022). Strong antioxidants, physical chemistry, sensory qualities, fresh *spirulina*, and yoghurt are some of these ingredients. The components of the *spirulina* cell wall include lipids, carbs, and protein. As a result, *spirulina* arguably has a better nutritional bioavailability than other food sources, especially plant food sources (Hassan *et al.,* 2021). More protein (62%) may be found in *spirulina* than any other natural food. The whole flavonoid is present in *spirulina*. It has the highest natural concentration of carotene, phycocyanin, and vitamin E (Darwish *et al.,* 2020).

M. Golmakani *et al.* (2019) evaluated the effects of *Spirulina (Arthrospira platensis)* addition on the growth of probiotic *Lactobacillus casei* in bacteriologically acidified feta-type (BAF) cheese, along with assessing its chemical, textural, and sensorial characteristics. After 60 days of storage, significantly higher viable counts of *Lb. casei* (9.10-9.35 log CFU g^{-1}) were observed in *Spirulina* samples compared to the control (8.68 log CFU g^{-1}), indicating a more successful maintenance of *Lb. casei* counts in the probiotic BAF cheese containing *Spirulina*.

P. Thiviya *et al.* (2022) noted that macroalgae, or seaweeds, are becoming more popular as an alternative source of protein. They have an outstanding amino acid profile that is on par with other conventional protein sources and are rich in protein. Bioactive substances found in seaweed protein include lectins, free amino acids, peptides, and phycobiliproteins, which include, among others, phycocyanin, and phycoerythrin. The antihypertensive, antidiabetic, antioxidant, anti-inflammatory, antitumoral, antiviral, antibacterial, and several other advantageous functional qualities of seaweed proteins have been proved. As a result, proteins from seaweed may provide a healthy substitute for other sources for developing functional foods (Shazly *et al.,* 2022). Due to its distinct chemical composition, which includes vital amino acids, vitamins, natural colours, and fatty acids, spirulina has been used traditionally as a food supplement and provides a plethora of health benefits (Alshafei *et al.*, 2022).

H. Zahran *et al.* (2022) mentioned thar preserving yoghurt's oxidative stability is imperative for sustaining its quality and nutritional value over its shelf life. Oxidation processes can compromise yoghurt's flavour, texture, and overall quality, primarily due to the presence of unsaturated fatty acids and reactive compounds, influenced by storage conditions, ingredients, and microbial activity (Silva *et al.,* 2022). By assessing yoghurt's oxidative stability under varied conditions, insights into the potential role of *Spirulina platensis* in bolstering resistance to oxidative changes are elucidated, promising extended shelf life and enhanced product quality (da Silva *et al.,* 2019; Mesbah *et al.,* 2022).

Furthermore, there is curiosity in the as-yet-uncharted region of *Spirulina platensis's* impact on *Bifidobacterium* and lactic acid bacteria development in probiotic algal concentrated yoghurt. Thus, the purpose of this study was to investigate the effects of *Spirulina* supplementation on the activity of yoghurt starter cultures and the overall quality of concentrated yoghurt, thereby contributing to the development of healthier and more functional dairy products.

MATERIALS AND METHODS

At Cairo University in Egypt's Faculty of Agriculture, fresh raw cow milk was taken from the herd with a fat percentage of 3.5% and a Total Solids (TS) of 12%. One of the starting cultures utilised was a freeze-dried direct vat set kind of yoghurt starter culture that came from Chr. Hansen's Laboratories in Copenhagen, Denmark. It contained *Str. salivaricus subsp. thermophilus* and *Lb. delbrueckii ssp. bulgaricus*. Furthermore, strains of *Lactobacillus casei, Lactobacillus plantarum,* and *Lactobacillus acidophilus* were obtained from the National Research Centre (NRC) Dairy Microbiology Laboratory in Egypt. The probiotic culture was obtained from the identical facility as well. Through Walmart.com/Spring Valley USA, the powdered algal biomass was acquired from Wal-Mart Stores, Inc., Bentonville, AR 72716. Table 1 lists the nutrients included in *Spirulina platensis* powder.

***Table 1**. The composition per 100 g of Spirulina platensis powder*

Parameter	***Amount***
Energy	1.213 k j
Carbohydrates	23.9 g
Fat	7.72 g
Protein	57.47 g
Vitamins and minerals	***mg***
B_1	2.36
B_2	3.65
B_3	12.80
B_5	3.46
Iron	28.54
Manganese	1.89

***Note:** data mentioned on the label of the package*
***Source:** compiled by the authors of this study*

According to the methods described by D. Mohamed *et al.* (2017), MRS medium was used to count lactic acid bacteria in *Lactobacillus bulgaricus*, and M17 medium was utilised in *Streptococcus thermophilus* following the instructions provided by A. Hussein *et al.* (2017). Colony-forming units (CFU/g) were used to express the measurements of the findings. *Bifidobacterium* counts were determined by activating 1 ml of *Bifidobacterium* mix in a tube containing 10 ml MRS broth medium supplemented with 3% lithium chloride and 2% sodium propionate, in line with the protocols outlined by H. Abbas *et al.* (2017) and M. El-Shenawy *et al.* (2019). Colonies were counted to ascertain the growth kinetics after a 48-hour incubation period at 37 °C; the results were expressed as CFU/ml. *Staphylococcus* aureus was counted using Baird-Parker media (Oxoid) supplemented with egg yolk and potassium tellurite. The plates were incubated at 37°C for 48 hours. The tryptone-bile-glucuronic medium (TBX) (Oxoid) was used to count *E. coli*. The yeast and mould were counted using potato dextrose agar medium (pH 3.50), and they were subsequently cultured for 3-5 days at 25°C. The solid medium approach was used to identify the coliform group on the violet-red bile agar media plates after they were incubated for 24 hours at 30°C. Sterilised distilled water was used to prepare a suspension of *Spirulina platensis* at concentrations of 1, 3, and 5 mg/ml in media, which was then introduced to MRS broth medium tubes holding various bacterial cultures. Next, the tubes were incubated for 24 and 48 hours, respectively, at 37°C, according to D. Bhowmik *et al.* (2009). Additionally, a control was made without *S. platensis*.

A commonly used technique in the Middle East was employed to make samples of concentrated yoghurt (Zaky *et al.,* 2013). The milk sample was heated to 85°C for 15 minutes and then cooled to 40°C. From the sample, three sections were removed. Three product groups were developed: T1, a plain yoghurt with only 2% yoghurt starter (*Str. thermophilus* + *Lb. bulgaricus*, 1:1); T2, probiotic yoghurt with 2% Bifidobacterium mix + yoghurt starter; and T3, the algal sample with 2% yoghurt culture plus 2% *Bifidobacterium* mix with 3% *S. platensis* powder. Each cultured milk was produced following the yoghurt manufacturer's directions and then poured into sterilised plastic containers. The samples were incubated at 40°C until total coagulation was achieved. To make concentrated yoghurt, all the yoghurt samples were then salted with 2% NaCl, hung, and allowed to drain the whey. Samples were refrigerated and kept for 21 days at 5°C. The gross chemical composition of fresh samples was examined, as presented in Table 2.

***Table 2**. Total chemical makeup of samples of fresh and concentrated yoghurt*

Gross composition	**T1**	**T2**	**T3**
Total solids (%)	24.37	25.04	27.12
Fat content (%)	8.03	8.19	9.04
Protein content (%)	11.70	11.67	12.89
Ash content (%)	1.44	1.48	1.51

***Notes:** T1 –control, 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample containing 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix*
***Source:** compiled by the authors of this study*

According to AOAC (2012) recommendations, the samples' gross chemical composition, peroxide value, and acidity % were evaluated. A digital laboratory pH-meter device with a glass electrode (HI 94 1400, Hanna Instruments) was used to test pH readings. The methodology described by F. Cabrera *et al.* (2019) was used to determine the total volatile fatty acids (TVFAs) in the samples, which were then expressed as millilitres of 0.1 N NaOH per 100 mg sample.

The measurement of DPPH radical scavenging activity (RSA%) and free radical scavenging activity in the samples followed a modified methodology based on W. Mettwally *et al.* (2022). Using this approach, 2.9 mL of 1,1-diphenyl-2-pycrylhydrazyl (DPPH) dissolved in methanol was combined with 100 μL of the sample solution. A UV-visible spectrophotometer was used to measure the mixture's absorbance at 517 nm after vigorously shaking it for 30 minutes. The following formula was used to obtain the RSA%:

$$\text{RSA\%} = \frac{Abs.B - Abs.S}{Abs.B} x100, \quad (1)$$

where *Abs. B* and *Abs. S* are the absorbance values of the blank and sample, respectively. All measurements were conducted in threefold replication for accuracy and consistency.

The colour of the samples was assessed using a Hunter colourimeter Model D2s A-2 (Hunter Assoc. Lab. Inc., VA, USA). Before any measurements were made, the instrument was calibrated using a black tile at the bottom and a white tile at the top of the scale. The tri-stimulus colour values (L*, a*, and b*) were then recorded when the sample's flat layer specimen was positioned at the specimen port. Here, colour is represented by a*, which goes from red (+) to green (-), yellow (+) to blue (-), and darkness, represented by L*, which goes from black (0) to white (100).

The present study involved the sensory evaluation of yoghurt samples that were refrigerated for 7, 14, and 21 days, as well as fresh samples. Twenty-five panellists, who were members of the Dairy Sciences Laboratory, National Research Centre, Egypt, evaluated the samples' flavour, colour and appearance, body and texture, and overall acceptability. The samples were measured in 100 ml cups at 10°C and each sample was evaluated by three different individuals. The parameters were ranked on a scale from 1 to 7.

Mean values and standard deviations for physical properties and chemical composition were computed, followed by an assessment of formulation differences using analysis of variance (ANOVA) with a significance level of $p < 0.05$. Statistical analyses were performed using the SPSS 20.0 software package (SPSS Inc., Chicago, USA). Post-hoc analysis using Duncan's multiple range tests at a significance level of 5% was then conducted to find specific differences between the formulations (Steel & Torrie, 1960).

RESULTS AND DISCUSSION

Table 3 illustrates the counts of lactic acid bacteria and *Bifidobacterium* mix (log CFU/mL), portraying the influence of different concentrations of *Spirulina platensis* powder in pure media prior to its incorporation into yoghurt samples. The findings suggest that varying levels of *S. platensis* did not distinctly enhance the tested lactic acid bacteria, hinting at the potential necessity for algae concentrations exceeding 5 mg/mL to yield a more pronounced effect. However, noticeable enhancement was observed in the growth of *Bifidobacterium* mix, particularly evident when *Spirulina platensis* was utilised at a concentration of 5%. Specifically, *Bifidobacterium* counts reached 8.86 (log CFU/mL) after 24 hours, rising to 9.40 after 48 hours of incubation, suggesting that this concentration is more conducive to preparing the aforementioned probiotic yoghurt.

***Table 3**. Growth kinetics of lactic acid bacteria (log CFU/mL) added with S. platensis*

Concentration of *S. platensis*	***Lb. casei***		***Lb. plantarum***		***Lb. acidophilus***		***Bifidobacterium* mix.**	
	Time (h)							
	24	48	24	48	24	48	24	48
0 (Control)	6.90	7.33	7.00	7.80	7.20	8.25	7.30	8.60
1 mg/ml	6.50	6.80	6.88	6.50	7.00	6.80	7.50	8.70
3 mg/ml	6.70	6.95	6.80	6.75	6.90	7.00	7.60	8.55
5 mg/ml	5.60	6.40	6.00	6.20	6.55	6.30	8.86	9.40

***Source:** compiled by the authors of this study*

Previous research has repeatedly documented *Spirulina's* enhancing effect on lactic acid bacteria. *Str. thermophilus* was found to be promoted by *S. platensis* powder in milk by G. de Caire *et al.* (2000), a finding that was confirmed by L. Varga *et al.* (2002) with ABT-fermented milk containing *S. platensis* powder. After a period of refrigerated storage, the viable counts of *Str. thermophilus* were significantly greater in the probiotic and plain yoghurt samples, with variations of up to 1.0 and 1.6 log CFU/g, respectively. A. Akalin *et al.* (2009) also reported comparable results.

The microbiological analysis of yoghurt samples encompassed assessments for *Lb. bulgaricus, St. thermophilus, Bifidobacterium* mix, Coliform bacterial group, mould and yeast, *E. coli*, and *Staphylococcus aureus* at the initial stage and storage for 7, 14, and 21 days (Table 4). The enumeration of *Str. thermophilus*, *Lb. bulgaricus*, and *Bifidobacterium* mix in fresh yoghurt samples varied between 24×10^7 to 89×10^7 CFU/g. Subsequently, these counts increased during storage. Notably, T2 and T3 exhibited higher counts, particularly at 7 days of storage, reaching 65×10^7 and 21×10^8 CFU/g, respectively. However, the control group experienced a slight decrease to 7×10^7 CFU/g at 21 days, and analogous decreasing trends were observed in all samples at 21 days, recording counts of 25×10^7, 41×10^7, and 54×10^7 for T1, T2, and T3, respectively. This decline may be associated with acidity development over time (Chen *et al.,* 2017).

Table 4. *The bacterial counts of concentrated-yoghurt samples during 21 days of storage*

Samples		*Str. thermophilus*	*Lb. bulgaricus*	*Bifidobacterium* mix.	Coliform bacterial group	M.Y	*E. coli*	*Staphylococcus aureus*
Fresh	T_1	24×10^7	36×10^7					
	T_2	51×10^7	59×10^7	60×10^7				
	T_3	37×10^7	47×10^7	89×10^7				
7 (d)	T_1	36×10^7	52×10^7			9		
	T_2	73×10^7	94×10^7	95×10^7		8		
	T_3	65×10^7	75×10^7	21×10^8				
14 (d)	T_1	20×10^7	38×10^7			16		
	T_2	47×10^7	76×10^7	80×10^7		10		
	T_3	36×10^7	58×10^7	9×10^8		4		
21 (d)	T_1	7×10^7	13×10^7			32		
	T_2	22×10^7	41×10^7	54×10^7		17		
	T_3	25×10^7	38×10^7	83×10^7		10		

Notes: *T1 –control, 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix;* ▒ *= Nil*

Source: *compiled by the authors of this study*

S. platensis did not significantly raise the viable counts of *Str. thermophilus* in yoghurts, with a maximum rise of 0.5 log CFU/g in plain yoghurt compared to the control, according to a study by N. Kearney *et al.* (2008). After storage, viable counts in plain and probiotic yoghurts were 6.5 and 7.7 log CFU/g following the inclusion of 1% *Spirulina* powder. While *Lb. bulgaricus* increased by 1 and 1.3 log CFU/g in plain yoghurt compared to the control, viable counts of *Str. thermophilus* were slightly lower than in earlier investigations, at about 8 log CFU/g in algal yoghurts (Varga & Szigeti, 1998). After seven days of storage, the counts of moulds and yeasts, which were not present in the fresh control yoghurt, increased to 9 CFU/g. In samples enhanced with 2% yoghurt culture + 2% *Bifidobacterium* mix + 3% *S. platensis* powder, these microorganisms stayed undetected until 7 days of storage. Small counts (16 CFU/g) were observed for T1 at 14 days, and in other samples at the same interval, counts were recorded as 10 and 4 CFU/g for T2 and T3, respectively. These microorganisms, undesirable in yoghurt, pose potential risks to public health (Gallegos-Acevedo *et al.,* 2018). Such systems can enhance the bioavailability of certain compounds, affecting the penetration of bioactive compounds into cells (Pérez-Soto *et al.,* 2021). Notably, all bacterial pathogens, including the coliform bacteria, *Escherichia coli* and *Staphylococcus aureus*, were not detected in any yoghurt samples. N. Kearney *et al.* (2008) suggested that yoghurt starter bacteria and probiotic bacteria require nutrients for growth and survival, and *Spirulina platensis* powder could serve as a unique nutrient source due to its significant concentrations of vitamins, minerals, amino acids, and nucleic acid precursors.

Additionally, M. Guldas and R. Irkin (2010) found that at the conclusion of the storage period, the viable counts of lactic acid bacteria in all samples containing *Spirulina* powder were greater than 6 CFU/g, while the samples of yoghurt with control had lower counts of lactic acid bacteria. This suggests that *S. platensis* powder helps lactic acid bacteria survive when yoghurt is being stored. In contrast to the findings of A. Akalin *et al.* (2009), the counts of *L. bulgaricus* did not surpass those of other bacteria. According to earlier research (Varga *et al.,* 2002; Donkor *et al.,* 2006), the higher survival rate of *L. bulgaricus* and *L. acidophilus* in probiotic yoghurt may be related to competitive interactions among bacteria. At the conclusion of the storage period, *L. acidophilus* counts increased by 2.4 and 3.1 log CFU/g in samples containing 0.5% and 1.0% *Spirulina* powder, respectively. Growth curves showed that *L. acidophilus* outlived *S. thermophilus* and *L. bulgaricus*.

The presented acidity results, expressed as a percentage, showed variations across different samples (T1, T2, and T3) and storage times (fresh, 7 days, 14 days, and 21 days) (Fig. 1). The acidity values are integral to the sensory profile and quality of yoghurt, reflecting the fermentation process and metabolic activities of the microbial cultures present. For control – plain yoghurt, the acidity levels in T1 showed a gradual increase over the storage period. From fresh to 21 days, acidity increased from 1.40 to 1.50%. This incremental pattern is expected as lactic acid-producing bacteria, particularly *Lb. bulgaricus* and *St. thermophilus*, continue their metabolic activities during storage, leading to the accumulation of acids. T2 showed slightly higher acidity compared to the control (T1) at each time point. This increase can be attributed to the metabolic activity of the additional probiotic strain *Bifidobacterium* mix, which produces lactic acid along with other beneficial compounds. The acidity progression from fresh to 21 days follows a trend comparable to T1, with values ranging within 1.80-2.26%. On the other hand, the T3 sample, enhanced with *Spirulina platensis* powder, showed the highest acidity levels among the samples. The incorporation of *S. platensis* may contribute to the acidity through its metabolic byproducts or by influencing the activity of lactic acid bacteria. The acidity increased from 1.40 (fresh) to 1.50% (21 days), reflecting a trend comparable with T1 and T2.

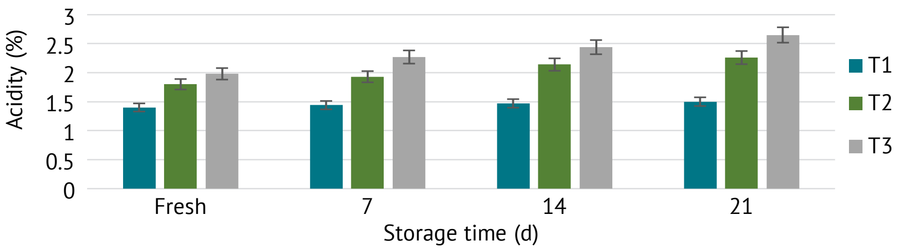

Figure 1*. Acidity (%) contents of yoghurt samples during the storage period*
Notes: *T1 – control, 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix*
Source: *compiled by the authors of this study.*

The acidity levels tended to increase progressively with the extension of storage time across all samples. This aligns with the natural fermentation process in yoghurt, where lactic acid bacteria consume lactose and produce lactic acid, contributing to the characteristic tangy taste. T3 consistently showed higher acidity compared to T1 and T2. The additional contribution from *Spirulina platensis* may enhance the fermentation process or influence the production of organic acids (Son *et al.*, 2023). T2, containing *Bifidobacterium* mix, showed slightly elevated acidity compared to T1. The presence of probiotic strains contributes to the overall acidification, supporting findings from microbiological analyses indicating increased counts of *Bifidobacterium* in T2. The acidity trend in T3 does not indicate a disproportionate surge despite the higher concentration of *Spirulina platensis*. This suggests that while *Spirulina* may influence acidity, its impact might be subtle and balanced within the microbial ecosystem.

The presented pH values represent the acidity levels in yoghurt samples for three different samples (T1, T2, and T3) at various storage times (fresh, 7 days, 14 days, and 21 days) (Fig. 2). The pH of yoghurt is a crucial parameter influencing its taste, texture, and overall quality. The pH values for T1 showed a gradual decrease from fresh (4.72) to 21 days (4.14). This decline was expected during yoghurt fermentation, reflecting the conversion of lactose to lactic acid by lactic acid bacteria. The pH values fall within the typical range for yoghurt. T2 followed a trend comparable to T1, with a decrease in pH from 4.76 (fresh) to 4.51 (21 days). The addition of Bifidobacterium mix may have contributed to the acidity, influencing the pH values during the storage period. Therewith, T3 showed a distinctive pattern, starting with a pH of 4.51 (fresh) and decreasing to 4.23 at 21 days. The incorporation of *Spirulina platensis* powder appears to have a more pronounced effect on pH reduction compared to T1 and T2.

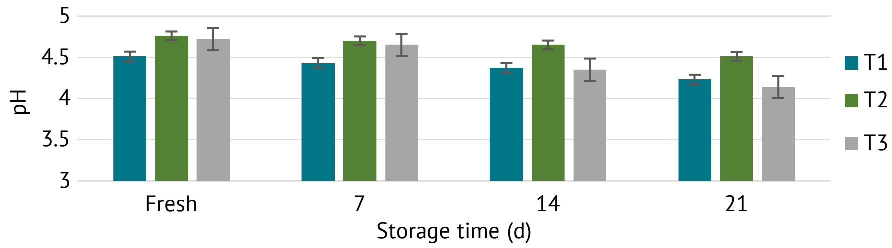

Figure 2*. pH values contents of yoghurt samples during the storage period*
Notes: *T1 – control, with 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix*
Source: *compiled by the authors of this study*

The observed decrease in pH values aligns with the findings of M. Guldas and R. Irkin (2010), who reported a slight decrease in pH with an increase in *Spirulina platensis* powder amount. The pH values reaching approximately 4.20 during the storage period are consistent with the current findings. L. Varga and J. Szigeti (1998) and L. Varga *et al.* (2002) also noted analogous trends in pH reduction caused by *Spirulina platensis* powder, supporting the idea that the addition of Spirulina promotes the growth of lactic acid bacteria, leading to increased acidity and a lower pH. The decrease in pH over the storage period is indicative of ongoing fermentation and acidification, essential for yoghurt development and preservation. T3 sample, containing *Spirulina platensis* powder, showed a more significant pH reduction, suggesting that *Spirulina* contributed to the overall acidity of the yoghurt. This could be attributed to the unique nutritional composition of *Spirulina*, which may enhance lactic acid bacteria activity.

The presented results show the Total Volatile Fatty Acids (TVFAs) content in millilitres of 1.0 N NaOH per 100 mg sample for three different samples (T1, T2, and T3) at various storage times (fresh, 7 days, 14 days, and 21 days) (Fig. 3). TVFAs are important indicators of the organic acid composition in yoghurt, providing insights into the metabolic activities of fermenting microorganisms. The TVFAs content in T1 showed a slight increase from fresh to 21 days, starting at 0.54 ml/100 mg and reaching 1.26 ml/100 mg. This rise is consistent with the progression of fermentation, where lactic acid bacteria convert lactose to lactic acid. The increase in TVFAs aligns with the expected organic acid production during the storage period. In addition, T2 showed a pattern comparable to T1, with a gradual increase in TVFAs over the storage period. The TVFAs content increased from 0.60 ml/100 mg (fresh) to 0.78 ml/100 mg (21 days). The addition of *Bifidobacterium* mix in T2 may contribute to the overall production of volatile fatty acids, enhancing the fermentation process. Therewith, T3 sample, enriched with *Spirulina platensis* powder, showed a more pronounced increase in TVFAs compared to T1 and T2. The TVFAs content started at 0.65 ml/100 mg (fresh) and reached 1.26 ml/100 mg at 21 days. The higher TVFAs levels in T3 may be attributed to the metabolic activities of both lactic acid bacteria and the unique characteristics of *Spirulina platensis*.

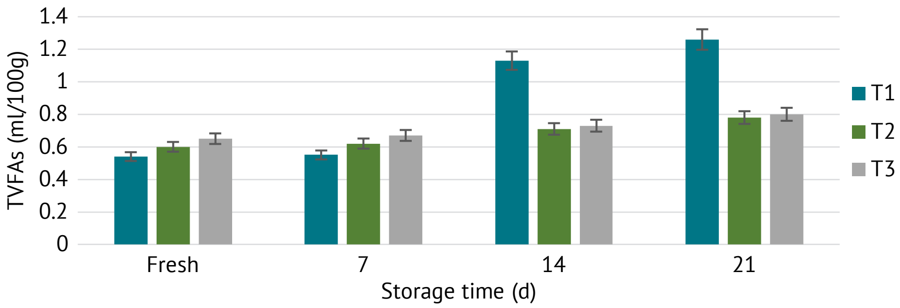

***Figure 3**. TVFAs contents of yoghurt samples during the storage period*

***Notes:** T1 – control, with 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix; TVFAs are measured as millilitres (ml) of 1.0 N NaOH per 100 milligrams of sample*

***Source:** compiled by the authors of this study*

The overall trend across all samples indicates a progressive increase in TVFAs during the storage period. This aligns with the continued metabolic activities of lactic acid bacteria and probiotic strains. T3 consistently showed higher TVFAs levels compared to T1 and T2. The incorporation of *Spirulina platensis* may contribute additional organic acids, influencing the TVFAs profile in the yoghurt. T2, containing *Bifidobacterium* mix, showed slightly higher TVFAs levels compared to T1. This supports the fact that probiotic strains contribute to the overall production of volatile fatty acids. T3's noticeable increase in TVFAs, especially at 21 days, suggests that *Spirulina platensis* may influence the organic acid composition. The unique nutritional profile of *Spirulina* may contribute to the production of specific volatile fatty acids. The antioxidant activity, expressed as inhibition percentage through DPPH radical scavenging activity, revealed distinctive patterns in the studied yoghurt samples over different storage periods (Fig. 4). In the fresh state, T3, the algal sample containing 2% yoghurt culture + 2% *Bifidobacterium* mix + 5% *S. platensis* powder, showed the highest antioxidant activity at 87.1%, followed by T2 (probiotic sample) at 58.2%, and T1 (plain sample) at 35.4%. As the storage period progressed, there was a general decline in antioxidant activity across all samples. However, T3 consistently maintained the highest inhibition percentage, even at 21 days, indicating its sustained antioxidant potential. T2 showed moderate antioxidant activity, while T1 showed the lowest values. These findings underscore the potential of *Spirulina platensis* in enhancing the antioxidant profile of yoghurt, with implications for product stability and health benefits.

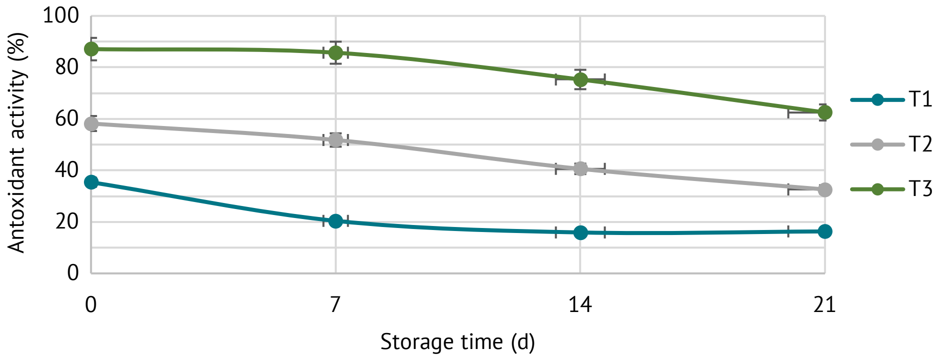

***Figure 4**. Changes in antioxidant activity of concentrated yoghurt samples during storage*
***Notes:** T1 – control, with 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix*
***Source:** compiled by the authors of this study*

S. da Silva *et al.* (2019) demonstrated the efficacy of spray-dried *Spirulina platensis* as a beneficial component for enhancing yoghurt formulations. The study emphasised that this ingredient not only preserved the nutritional composition of yoghurt but also exhibited a sustained improvement in antioxidant activity over the storage duration. The heightened antioxidant potential of *Spirulina platensis* can be attributed to the abundance of bioactive compounds, including α-tocopherol and phycocyanin. These compounds are known for their synergistic antioxidant properties, as highlighted by I. Santiago-Morales *et al.* (2018). While *Spirulina* contains various tocopherol forms, the predominant presence of α-tocopherol is primarily responsible for its antioxidant activity, with β- and δ-tocopherols contributing to anti-inflammatory effects, as outlined by A. Azzi (2018). This underscores the multifaceted antioxidant benefits associated with incorporating *Spirulina platensis* into yoghurt formulations, with implications for product quality and potential health advantages.

The peroxide values of the yoghurt samples, as presented in the provided data, reveal notable changes during the storage periods of fresh, 7 days, 14 days, and 21 days, across different samples (T1, T2, and T3). In the control sample (T1) with only 2% yoghurt starters, a gradual increase in peroxide values was observed (Fig. 5), suggesting a potential oxidation process occurring over time. In contrast, the probiotic sample (T2) containing 2% *Bifidobacterium* mix and yoghurt starter showed a more controlled increase in peroxide values, suggesting a moderated impact on oxidative changes. Interestingly, the algal sample (T3) containing 2% yoghurt culture, 2% *Bifidobacterium* mix, and 5% *S. platensis* powder showed the most effective mitigation of peroxide value elevation, showcasing the potential antioxidative properties of *Spirulina platensis*. This observation aligns with the known antioxidant capabilities of *Spirulina*, as discussed in previous studies by S. da Silva *et al.* (2019), I. Santiago-Morales *et al.* (2018). The progressive reduction in peroxide values with *Spirulina* incorporation suggests its role in enhancing the oxidative stability of yoghurt during storage, emphasising its potential as a functional ingredient for extending product shelf life.

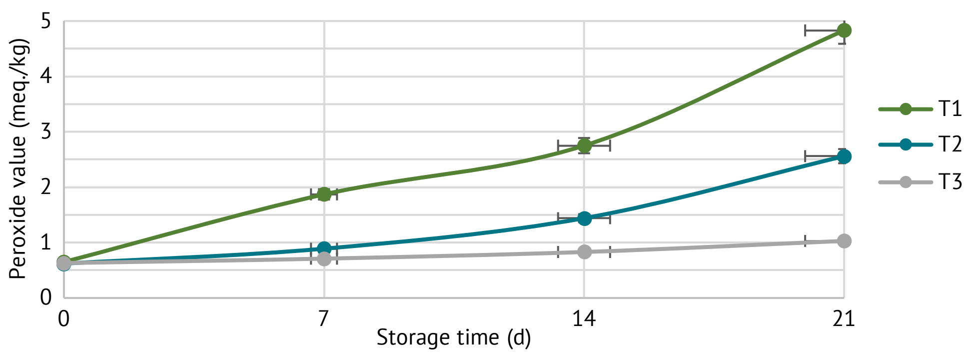

***Figure 5**. Changes in peroxide value of concentrated yoghurt samples during storage*
***Notes:** T1 – control, with 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix*
***Source:** compiled by the authors of this study*

The colour parameters (L*, a* and b*) of concentrated yoghurt samples (T1, T2 and T3) were evaluated over different storage periods (Table 5). These observations provide insights into the dynamic colour changes influenced by storage time and sample variations. T3 showed the highest L* value, indicating a lighter appearance compared to T2 and T1. This aligns with the addition of *S. platensis* powder, known for its green pigment. Over time, all samples show a decrease in L* values, suggesting a gradual darkening. The reduction in lightness may be attributed to a series of factors, including interactions between ingredients or storage-related processes. T3 The increase in b* values signifies a shift towards a slightly bluer colour during storage, highlighting the dynamic nature of colour changes in concentrated yoghurt (Flores-Mancha *et al.,* 2021).

The data presented in Table 6 shows a detailed sensory evaluation of concentrated yoghurt samples (T1, T2, and T3) over various storage periods (Fresh, 7 days, 14 days, and 21 days), using a ranking scale from 1 to 7 for attributes related to Body & Texture, Flavour, Appearance & Colour, and Overall Acceptability (Folkenberg & Martens, 2003). In the initial assessment (Fresh), all samples showed high rankings, reflecting favourable body and texture attributes. Over time, a consistent decline was observed in the rankings across all samples, suggesting a potential textural change during the storage period. This decline might be attributed to factors such as moisture loss or alterations in the structural integrity of the yoghurt. Initial Flavour rankings were relatively high across all samples, with T1 (plain sample) displaying a slight advantage. The 21-day evaluation showed a noticeable decrease in Flavour rankings for all samples. This decline could be associated with the development of acidity or changes in microbial activity during prolonged storage. T3 consistently secured higher rankings for Appearance & Colour across all storage periods, indicating that the inclusion of yoghurt culture, *Bifidobacterium* mix, and *Spirulina* powder contributes positively to visual appeal. The 21-day evaluation showed a slight decrease in rankings for all samples, which may be linked to colour changes or settling effects during storage. Initial Overall Acceptability rankings were relatively high for all samples, emphasising the overall positive reception of the concentrated yoghurt samples. While T3 maintained a favourable ranking throughout, other samples experience a decline in overall acceptability over the storage period, potentially due to cumulative changes in texture, flavour, or appearance.

***Table 6**. Sensory evaluation of samples during storage*

Parameters	Storage period (day)	T1	T2	T3
Body & Texture	Fresh	6.90	6.80	6.84
	7	6.82	6.78	6.82
	14	6.68	6.75	6.80
	21	6.65	6.70	6.73
Flavour	Fresh	6.65	6.75	6.68
	7	6.60	6.66	6.65
	14	6.33	6.50	6.64
	21	6.20	6.55	6.60
Appearance & Colour	Fresh	6.82	6.80	6.50
	7	6.71	6.68	6.48
	14	6.35	6.39	6.44
	21	6.15	6.25	6.40
Overall Acceptability	Fresh	6.90	6.90	6.82
	7	6.65	6.75	6.70
	14	6.41	6.55	6.50
	21	6.00	6.30	6.20

***Notei:** T1 – control, with 2% of yoghurt starters in the basic sample; T2 – probiotic sample with 2% Bifidobacterium mix + yoghurt starter; T3 – the algal sample with 5% S. platensis powder, 2% yoghurt culture, and 2% Bifidobacterium mix*
***Source:** compiled by the authors of this study*

The observed decline in sensory attributes, particularly in Body & Texture and Flavour during the storage period was consistent with the natural evolution of yoghurt products. Factors such as fermentation by-products, microbial activity, and physicochemical changes contributed to these alterations. T3 consistently outperformed other samples in terms of Appearance & Colour and Overall Acceptability, suggesting that the combination of yoghurt culture, *Bifidobacterium* mix, and Spirulina powder contributes positively to the visual appeal and overall consumer preference. The 21-day evaluation indicated the need for careful consideration of storage conditions and formulation adjustments to maintain optimised sensory attributes over an extended period. M. Barkallah *et al.* (2017) emphasised the useful application of *Spirulina* powder as a novel and enticing yoghurt-processing addition. *Spirulina* has other nutritional benefits in addition to being a natural colouring and flavouring ingredient. Its high content of dietary fibres and proteins also serves as a physical stabiliser, boosting mouthfeel, syneresis, and perceived viscosity, all of which help to maintain textural features. Interestingly, it was discovered that adding merely 0.25% of *Spirulina* was a substantial way to accelerate these positive benefits.

CONCLUSIONS

In this comprehensive study investigating the incorporation of *Spirulina platensis* powder into concentrated yoghurt, noticeable effects were observed across microbial, chemical, and sensory parameters during various storage periods. While the addition of *Spirulina* showed a more pronounced impact on *Bifidobacterium* growth, its enhancing effect on lactic acid bacteria was less clear, suggesting a potential need for higher concentrations. Microbial counts, particularly for *Str. thermophilus, Lb. bulgaricus*, and *Bifidobacterium* mix, showed dynamic changes during storage, with higher counts in *Spirulina*-containing samples. *Spirulina*-enriched samples demonstrated effectiveness in controlling moulds and yeasts, highlighting potential preservative qualities. Chemical parameters, including acidity and pH values, showed slight increases in treated samples, while the pronounced effect was noted in *Bifidobacterium*-supplemented samples. Colour properties showed noticeable changes, emphasising the need for careful consideration of *Spirulina* concentrations for colour stability. Sensory evaluation indicated that samples with a combination of *Bifidobacterium* and *Spirulina* achieved the highest acceptability scores.

Overall, the presented findings offer insight into the intricate interplay of *Spirulina platensis* in concentrated yoghurt, providing opportunities for both microbial enhancement and improved product quality. Future studies should focus on optimised *Spirulina* concentrations and delve into the mechanisms underlying its influence on microbial communities in yoghurt production. Furthermore, additional investigations could explore the specific compounds contributing to this antioxidant activity and optimise formulations for prolonged efficacy during storage. These avenues of research will contribute to the ongoing development of functional dairy products with enhanced nutritional and sensory properties, meeting the demands of health-conscious consumers in the modern food industry. Further research endeavours could explore innovative processing techniques to maximise the bioavailability of *Spirulina*'s bioactive compounds in concentrated yoghurt, paving the way for the development of novel functional dairy products with enhanced health benefits.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Підвищення активності біфідобактерій та молочнокислих бактерій, а також покращення окислювальної стабільності у функціональному водоростевому концентрованому йогурті з порошком *Spirulina platensis*

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Анотація. Це дослідження спрямоване на задоволення зростаючого попиту на здорові функціональні молочні продукти шляхом вивчення включення Spirulina platensis до складу концентрованого йогурту та оцінки її впливу на закваски та властивості продукту. Комплексний аналіз продемонстрував здатність спіруліни посилювати ріст біфідобактерій, кислотність, вміст ПНЖК та антиоксидантну активність у йогуртах, що вказує на її потенціал для покращення поживної якості та окислювальної стабільності молочних продуктів. У дослідженні вивчався вплив різних співвідношень спіруліни на активність йогуртових заквасок, включаючи Lb. casei, Lb. plantarum, Lb. acidophilus та суміш біфідобактерій. Було приготовано три концентровані йогурти, включаючи контроль, зразок пробіотика та зразок з додаванням порошку спіруліни. Результати показали, що хоча спіруліна не мала значного впливу на молочнокислі бактерії, вона помітно стимулювала ріст біфідобактерій. Оброблені зразки демонстрували підвищену кислотність і вміст TVFAs, причому значення pH мали зворотну тенденцію порівняно з контролем. Чіткі відмінності в параметрах кольору та сенсорних оцінках відрізняли контрольні зразки від оброблених. Крім того, добавка спіруліни продемонструвала помітний ефект у підвищенні антиоксидантної активності, що спостерігається через активність поглинання радикалів DPPH, і вплинула на значення пероксиду, що відображає покращену окислювальну стабільність йогурту. Таке успішне використання спіруліни свідчить про її потенційне застосування в різноманітних їстівних водоростях у харчовому секторі, особливо в молочних продуктах, покращуючи як поживні, так і сенсорні аспекти, а також сприяючи покращенню окислювальної стабільності

Ключові слова: їстівні водорості; функціональні продукти харчування; антиоксидантна активність; корисні бактерії; молочні продукти

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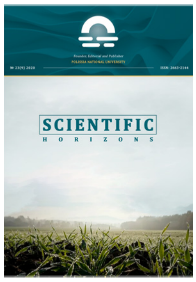

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Vegetable production under the influence of food insecurity, environmental factors, and international integration processes

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Abstract. The significance of vegetable production is driven by the need of the population for vitamin products, processing enterprises for raw materials, especially in wartime, in the face of food and environmental hazards, and the need to increase export opportunities, considering international integration processes. The purpose of this study was to investigate the impact of war on the economic availability and environmental safety of food, to identify and assess the components and vectors of

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food and environmental safety management, and to evaluate and promote exports in the context of international economic integration. The study employed the methods of analysis and synthesis, generalisation and specification, mathematical and graphical methods. Sources of information: data from the Food and Agriculture Organization of the United Nations (FAO), the International Trade Centre (ITC), and the State Statistics Service of Ukraine. The study analysed the current state of vegetable production, identified the key problems under the influence of food hazards, environmental factors, and integration processes. The study examined the impact of the war on the economic availability and environmental safety of food, estimated the volume of deficit in vegetable production, identified the principal economic and environmental problems and areas for improving the efficiency of the industry in the future. The volume of the deficit in vegetable production was found and the size of the lost sowing areas was determined; the reasons for the unsatisfactory state of vegetable production were identified. It was established that in recent years the country has experienced a temporary famine, which is unacceptable in the European space. It was found that, to minimise the agri-food crisis and environmental threats, it is necessary to focus on the implementation of the proposed measures to support production efficiency, the implementation of which will allow solving the issues of independence and food security of territorial communities, especially in times of war, and improve the functionality of governing bodies, economic entities, investors, scientists, and producers based on sustainable development. The practicality of the study findings is confirmed by the effectiveness of the developed proposals that can be used in the implementation of measures to increase vegetable production and exports

Keywords: food; ecology; vegetable growing; production; consumption; innovative development; export; international economic integration

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INTRODUCTION

Ukraine is among the leaders in global food security matters. Considering that the world's population is constantly growing, with projections suggesting that it will increase to 10 billion people in 2050, the number of hungry people could increase noticeably. According to N. Palapa *et al*. (2022), Ukraine can provide food for about ½ billion people. According to FAO (2023), the number of hungry people in the world has reached 811 million. The war in Ukraine is exacerbating food issues not only within the country, but also on foreign markets, the African continent and the Middle East. It was found that, despite their relatively low energy value, vegetables have valuable phytonutrients that serve as an essential source of antioxidants that neutralise the effects of reactive oxygen species and products of their interaction with organic molecules and nitrogen oxides (Recommendations for a healthy diet for adults, 2017). However, to this day, Ukraine still has an extremely insufficient range and variety of high-vitamin products. Furthermore, as a result of the hostilities, there is a shortage of vegetable and melon products, which affects the country's food and environmental security, and the food problem needs to be addressed with due regard to the possibilities of domestic production.

The participation of countries in integration processes plays a special role in the economic development of countries, their trade, production, and food security. Thus, the EU Treaty of Rome states that the objectives of the Common Agricultural Policy are to increase the productivity of the agricultural sector; stabilise markets; ensure the availability of supplies; guarantee that supplies reach consumers at reasonable prices, etc.

O. Mogylna *et al*. (2018), N. Kalyuzhna and L. Kudyrko (2023) note that trade integration stays a relevant form of cooperation between countries and a driver of their innovative and technological development, despite the intensifying trend of neo-protectionism and the aggravation of imbalances in national economies. Notably, the food security strategy should consider the forecast of supply and demand for food and agricultural raw materials, while their forecasting is based on the annual formation of the supply and demand balance, including changes in stocks, domestic production, internal consumption, exports, and imports. Therefore, international economic integration plays a special role in the development of trade and food security, especially in the current environment.

Many researchers are interested in food supply issues. However, modern reality and new environmental threats require systematisation and further research to reduce food threats, especially in the context of military, anthropogenic, and climate challenges. Moreover, during the occupation of the south of Ukraine, a considerable territory suitable for intensive vegetable production has been lost, equipment, logistics facilities, warehouses were looted, entire workshops of vegetable processing plants (PJSC Chumak) were taken out, crops were flooded, and unique environmental sites were destroyed (Mudrak, 2022; Blahopoluchna, 2022). As a result, the enterprises for shock freezing of berries, vegetables, and fruits located in the adjacent Ukrainian territories lack raw materials to fully utilise them (Sobkevich *et al*., 2023).

The problem of food security, according to V. Boyko and L. Boyko (2021), lies in the plane of almost all institutional aspects of the state: political, economic, and social, and requires the acquisition of skills in dealing with emergencies, rapid response to environmental hazards, considering the prospects for the long-term development and functioning of communities where over 8 million people living in their territories are currently internally displaced.

The established market institutions already need to be adjusted in the current environment. Thus, 13 concepts of regional and national state targeted programmes for the development of the vegetable industry created in 2010-2022 were not funded. However, at the same time, as a result of the performance of the main forecast indicators of these programmes, the normative consumption would be ensured not only within the internal agricultural market, but also the country's export level would be reached (Khareba & Rybak, 2018). Considering this, N. Markovych (2019) notes that vegetables and their processed products represent a considerable foreign economic reserve for increasing revenues and diversifying Ukraine's agricultural exports. As the global demand for vegetables is quite high and the culture of healthy eating encourages the population of many countries to increase their consumption of fresh or processed vegetables, Ukrainian agribusiness has a considerable potential to increase its exports. Therewith, it is worth considering the removal of trade barriers in trade with countries with which regional trade agreements (RTAs) have been concluded, which should help to increase exports and, accordingly, vegetable production.

The development of foreign trade is of particular significance for increasing production volumes, which is facilitated by the development of integration processes. B. Matkovski *et al.* (2022) emphasise the need to revise trade agreements with the EU and the Free Trade Agreement. Trade intensification and a partial change in the regional and commodity structure of trade occurred in all Western Balkan countries. It is proposed as a prerequisite that all countries try to secure the best possible position for agri-food products during pre-accession negotiations with the EU. However, according to the study, most Western Balkan countries have comparative advantages in exporting agri-food products. This is also worth considering for Ukraine, which also has regional trade agreements with the EU, as well as Canada, Turkey, the UK, and other countries.

Considering the above, the purpose of this study was to assess internal production and foreign trade in vegetables in Ukraine and the world, identify the principal economic and environmental problems and areas for improving the efficiency of the industry in the future in the context of the impact of environmental factors and integration processes.

MATERIALS AND METHODS

The study was conducted using methodological approaches that reveal the theoretical and practical content of the research object. To accomplish this task, conventional methods of economic analysis (methods of scientific intuition, abstract logical, and graphical methods), analysis (comparison, grouping), and generally accepted methods (mathematical and statistical, calculation and design, balance sheet, etc.) were used.

The methods of analysis and synthesis were employed to investigate foreign trade in vegetables; economic and statistical – to analyse the world vegetable market; abstract and logical – to form conclusions; graphical – to display trends in foreign trade; and the method of generalisation – to formulate proposals. The study investigated the change in the geographical structure of Ukraine's vegetable exports over 20 years (from 2004 to 2023), considering the development of international economic integration, identified the largest trading partners in the world market, considering their share in world exports and imports and the level of economic development. To expand the analysis, the period from 2004 to 2023 was used, considering changes at the global level and those specific to Ukraine.

The application of the methods of comparison, grouping, and index method helped to assess the normative and factual consumption indicators and analyse the degree of coverage of annual consumption norms for various food products in Ukraine in different periods. This made it possible to analyse pre-war and current levels of production of major crops, compare indicators, determine the degree of change, discuss the main reasons for these deviations, analyse possible consequences for the industries, identify reserves for increasing the competitiveness of enterprises in the vegetable market, and propose possible scenarios for replacing regional production of certain types of vegetable crops in Ukraine by 2025. The method of classification and grouping of the collected data helped to systematise the structure of vegetable seed producers in Ukraine, to determine the share of Ukrainian varieties and hybrids of vegetable and melon plants in the State Register as of 1 January 2024 (State register of plant varieties suitable for distribution in Ukraine, 2024).

The statistical methods allowed for the systematisation, processing, and further monitoring of numerical data to analyse the price situation in the agricultural market, to establish the regional variation in prices of agricultural enterprises in Ukraine and the relationship between them using coefficients of variation and correlation coefficients of prices in 2000 with prices in 2024. The method helped to structure the price situation in the agricultural market by product type and substantiate the need for government intervention in the vegetable sector to create equally competitive conditions for the distribution of income among all participants in the producer-processor-consumer and distribution infrastructure.

Using the questionnaire survey method, the study managed to collect data on 51 district markets in Ukraine, determine the structure of retail average prices for vegetable products in 2024, and calculate the cost of a "borshch set". Subsequently, by establishing a correlation based on the price comparison method and the normative cost limits "price formed based on supply and demand" and "minimum price", the study substantiated the amount of lost income that would allow the producer to secure the economic interest necessary for expanded reproduction.

The sources of information included statistical data of the Food and Agriculture Organisation of the United Nations (FAO, 2023) and the International Trade Centre (ITC, 2023), regulatory and legislative acts of Ukraine related to the agro-industrial complex (Law of Ukraine No. 2145-IX, 2022; Law of Ukraine No. 3116-XII, 1993); data of the State Statistics Service of Ukraine (n.d.), Ministry of Agrarian Policy and Food of Ukraine (n.d.).

RESULTS

The vegetable industry is a complex system of institutions, methods, and resources, including commodity production, seed production, processing, logistics, trade, and other essential components, which plays a significant role at the global and national level and has been developing dynamically, especially in the last 30 years. In the early 1990s, the world produced 88 kg per capita, while in 2022 – 235 kg. China produced the most vegetables per capita (over 400 kg), followed by Greece (296 kg) and Spain (273 kg).

Today, global production is 903.4 mn t. Leaders: China (451.6 mn t), India (77.2 mn t), the United States (38.9 mn t), Italy (13.6 mn t), Spain (12.7 mn t), Ukraine (9.4 mn t), and France (5.7 mn t) (FAO, 2023). According to the ITC (2023), Ukraine exported vegetables to almost 90 countries in 2023, while in 2004 it exported to less than 50 countries, which suggests a geographical diversification of exports. In 2023, Ukraine exported 72.1% of its top 10 importers, while in 2004 it exported 86.2% (Table 1). Notably, during the period under study, exports increased by 3.4 times, which means that geographical diversification of exports contributes to its growth.

***Table 1**. Share of Ukraine's vegetable exports to its largest importers in 2004-2023, %*

No. seq.	2004		No. seq.	2023	
	Importer	Share, %		Importer	Share, %
1	Hungary	26.0	1	Turkey	18.2
2	India	15.1	2	Poland	10.6
3	Spain	14.3	3	Italy	9.9
4	Italy	7.2	4	Moldova	7.9
5	Belarus	5.5	5	Malaysia	7.4
6	Pakistan	5.4	6	Bangladesh	6.4
7	Poland	3.8	7	Germany	4.4
8	Russia	3.2	8	Pakistan	2.6
9	Lithuania	3.1	9	United Kingdom	2.5
10	Germany	2.6	10	Sri Lanka	2.3

***Source:** calculated based on ITC data (2023)*

Another noteworthy fact is that in 2023, exports to Asian markets grew: while in 2003, only India, Pakistan, and Russia were among the largest importers, in 2023, Turkey, Malaysia, Bangladesh, Pakistan, and Sri Lanka were among the largest importers, and the share of exports to the latter countries was 36.8%. In 2004, the situation was analogous among the country's largest importers, except for India and Pakistan, with which regional trade agreements were concluded before and afterwards, and in 2022, except for Malaysia, Bangladesh, Pakistan, and Sri Lanka, as presented in Table 1 (ITC, 2023).

This suggests that the development of foreign trade contributes to integration, and the latter contributes to the former, specifically through the removal of trade barriers. Therewith, one should consider the harmonisation of product quality standards, improvement of product quality, country demand, and a series of other factors. As for the world's largest exporters and importers of vegetables, they are mainly developed countries (Table 2), and often they are included in both groups. These are, for instance, the USA, Canada, Italy, and France. China, Japan, and the US are not among Ukraine's largest importers, which is worth paying attention to, considering the feasibility of increasing vegetable exports, the size, and solvency of the population of these countries. Furthermore, Ukraine has regional trade agreements with Canada and the EU, which are the world's largest importers of vegetables, and Canada is a member of one of the most developed integration groups, the North American Free Trade Agreement, which may help to increase exports of Ukrainian products to this continent.

***Table 2**. The share of major exporters, importers, and Ukraine in the global vegetable market in 2022, %*

No. seq.	Largest exporters	Share in global exports, %	No. seq.	Largest importers	Share in global imports, %
1	China	12.2	1	USA	17.0
2	Mexico	10.9	2	Germany	8.8
3	Netherlands	9.9	3	United Kingdom	5.0

Table 2. Continued

No. seq.	Largest exporters	Share in global exports, %	No. seq.	Largest importers	Share in global imports, %
4	Spain	9.8	4	France	4.6
5	Canada	7.4	5	China	4.5
6	USA	6.1	6	Canada	4.3
7	France	3.4	7	Netherlands	3.5
8	Belgium	3.1	8	Japan	3.0
9	Turkey	2.5	9	Italy	2.8
10	Italy	2.4	10	Belgium	2.8
11	Ukraine	0.1	11	Ukraine	0.4

Source: *calculated based on ITC data (2023)*

According to FAO (2023), the largest vegetable producers are China, India, and the United States, accounting for 52.5%, 12.4%, and 2.3% of global production, respectively. Ukraine's share was only 0.9%, ranking 20th among producers and behind such countries as Nigeria, Uzbekistan, and Japan. Considering the natural and climatic conditions and resource endowment, it is advisable to promote the production and export of vegetables in Ukraine. Notably, Ukraine's trade balance in vegetables has been active and passive, but in recent years the periods of negative balance have become longer, and the value of the indicator has increased (Fig. 1).

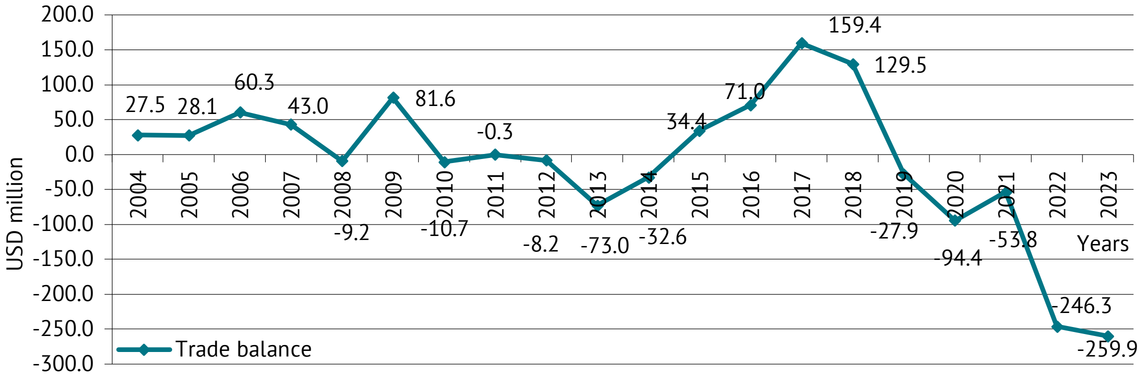

Figure 1. Ukraine's trade balance in vegetables for 2004-2023
Source: *calculated based on ITC data (2023)*

As for the countries of Ukraine's largest importers with which regional trade agreements have been concluded, according to ITC (2023), since 2004, the trade balance with Turkey was positive only in 2005 and 2017, with Poland – in 2004, 2006, 2016-2018, and with Italy – constantly, except for 2013, 2015-2016, 2018, 2022, and 2023. Generally, the values of the indicator in trade with major importers were both positive and negative, but the trade balance has been consistently positive since 2004 in trade with Pakistan, the United Kingdom, and since 2015 – Malaysia, Bangladesh, Sri Lanka, the United Arab Emirates, and Hungary. This suggests the presence and prospects of Ukraine's exports to the EU and Asian markets, the need to increase vegetable production, and the need to effectively use the free trade agreements concluded.

In terms of the commodity structure of Ukraine's vegetable exports, the largest exports were in 2023 (ITC, 2023). Dried leguminous vegetables, shelled, whether or not skinned or split (0713); Vegetables, uncooked or cooked by steaming or boiling in water, frozen (0710); Potatoes, fresh or chilled (0701); Other vegetables, fresh or chilled (excl. potatoes, tomatoes, alliaceous vegetables, edible brassicas [...], and leguminous vegetables) (0709). The largest imports are Tomatoes, fresh or chilled (0702); Onions, shallots, garlic, leeks and other bulbous vegetables, fresh or chilled (0703); Other vegetables, fresh or chilled (excl. potatoes, tomatoes, alliaceous vegetables, edible brassicas [...], and leguminous vegetables) (0709); Cucumbers and gherkins, fresh or chilled (0707), etc. In other words, Ukraine largely imports vegetables that it may well grow itself, although in this case, the seasonality of production must be considered, and therefore the focus should be on increasing internal production rather than reducing imports. It is worth considering which types of vegetables are most traded in Ukraine (Table 3).

***Table 3**. Share of certain types of vegetables exported and imported by Ukraine, 2023*

Vegetables with the largest share in Ukraine's exports, %			Vegetables with the largest share in Ukraine's imports, %		
Code	**name**	**%**	**Code**	**name**	**%**
0713	Dried leguminous vegetables, shelled, whether or not skinned or split	75.8	0702	Tomatoes, fresh or chilled	31.3
0710	Vegetables, uncooked or cooked by steaming or boiling in water, frozen	8.6	0703	Onions, shallots, garlic, leeks and other alliaceous vegetables, fresh or chilled	16.9
0701	Potatoes, fresh or chilled	5.1	0709	Other vegetables, fresh or chilled (excl. potatoes, tomatoes, alliaceous vegetables, edible brassicas, lettuce "Lactuca sativa" and chicory "Cichorium spp.", carrots, turnips, salad beetroot, salsify, celeriac, radishes and similar edible roots, cucumbers and gherkins, and leguminous vegetables)	15.2
0709	Other vegetables, fresh or chilled (excl. potatoes, tomatoes, alliaceous vegetables, edible brassicas, lettuce "Lactuca sativa" and chicory "Cichorium spp.", carrots, turnips, salad beetroot, salsify, celeriac, radishes and similar edible roots, cucumbers and gherkins, and leguminous vegetables)	4.4	0707	Cucumbers and gherkins, fresh or chilled	9.1
0707	Cucumbers and gherkins, fresh or chilled	2.2	0704	Cabbages, cauliflowers, kohlrabi, kale and similar edible brassicas, fresh or chilled	7.9
	Other	3.9		Other	19.6

***Source:** calculated based on ITC data (2023)*

Since vegetables are imported, which have all the conditions for growing in Ukraine, it is advisable to increase their production independently. We believe that the development of exports should help increase vegetable production in Ukraine. To increase exports, it is necessary to focus on the country's natural and climatic conditions, land availability, population, export prospects, considering the presence of importers of products where products are already exported, and regional trade agreements. It is worth considering that not only tariff, but also non-tariff barriers block trade, and therefore it is advisable to promote product quality and harmonise Ukrainian quality standards with European ones, which will allow Ukraine to expand its position not only in the EU market but also in other developed countries.

Considering the development of integration processes, it is worth emphasising that the EU-Ukraine Association Agreement addresses the issue of geographical indications, including recognised ones, supplementing them with new ones, the scope of their protection, the right to use, etc. It is also worth mentioning the regional trade agreements concluded by Ukraine and their impact on the development of foreign trade and, accordingly, production of products, including vegetables. Therewith, one of the key tasks is to meet internal demand with high-quality products. The analysis of the consumption balances of basic foodstuffs helped to identify three groups of products by the degree of availability: sufficient, low, and critical. The first group with sufficient consumption, provided that the consumption index is greater than 1, includes potatoes, vegetables, and bread (Table 4).

***Table 4**. Coverage of annual consumption norms for various food products in Ukraine, 2022, kg/person*

Indicators	**Group I (sufficient)**			**Group II (low)**						**Group III (critical)**
	Potatoes	**Vegetables**	**Bread and bread products**	**Oil**	**Eggs, pcs.**	**Sugar**	**Meat and meat products**	**Milk and dairy products**	**Fruits and berries**	**Fish and fish products**
Standard, kg/person										
Minimum	96	105	94	8	231	32	52	341	68	12
Rational	124	161	101	13	290	38	80	380	90	20
Consumed, kg/person										
Factually, kg/person	144	163	101	12.4	265	33	51	211	48	9.7
Ratio index: consumed/norm										
to the minimum standard	1.50	1.55	1.07	1.55	1.15	1.03	0.98	0.62	0.71	0.81
to the rational standard	1.16	1.01	1.00	0.95	0.91	0.87	0.64	0.55	0.53	0.49

***Source:** calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2023)*

If one analyses the state of the crop production sector during the military operations, according to 2022, almost 26% of the sunflower market was lost, 28.3% of the grain and legume market, and about 6% of the fruit and berry market. In 2022, 7.5 million tonnes of vegetables were produced. The deficit was 24.4%, or 2.4 mn t (Table 5). However, overall, if one analyses the pre-war period, i.e., compares 2021 with 2000, the vegetable market developed quite dynamically. Thus, even though the area under crops decreased by 16% during this period, due to a 1.9-fold increase in yields from 11.2 t/ha in 2000 to 21.4 t/ha in 2021, i.e., by 10.2 t/ha, gross vegetable harvest increased by 1.7 times and amounted to 9.7 mn t. In 2022, compared to 2021, production decreased by 2.4 mn t, and 85.9 thsd ha, or 18.6%, were lost. In 2023, it became possible to stabilise the situation and even increase gross vegetable production by 785.1 thsd t, or 10.5%. The sown area in 2023 increased by 21.8 thsd ha, or 5.8%. Private households played a key, stabilising role in these processes.

The retail sector is the main supplier of vegetables to Ukrainian markets and will continue to supply local markets. However, the negative aspects of their activities include a low level of mechanisation of production processes, high labour costs, low marketability, and the inability to form the required volumes of batches of products for wholesale. During the war period, in 2022, the share of households increased to 94.1%, while the share of melons increased to 97.6%. In 2023, the share of large-scale agricultural enterprises increased to 11.5%. Thus, private households will continue to supply local markets and play a leading role in providing the population with vegetables.

***Table 5**. Gross harvest, sown areas, and yields of major crops, 2000-2023*

Crops	Years				2021/2000		2022/2021		2023/2022	
	2000	2021	2022	2023	(+, -)	%	(+, -)	%	(+, -)	%
Gross harvest, thsd t										
Outdoor vegetables in the open field	5,821	9,935	7,512	8,297.1	4,114	170.7	-2,423	75.6	785.1	110.5
Sunflower	3,457	15,254	11,329	12,759	11,797	441.2	-3,925	74.3	1,430	112.6
Cereal and leguminous crops	24,459	75,143	53,864	59,772	50,684	307.2	-21,279	71.7	5,908	111.0
Fruits and berries	1,453	2,119	1,995	1,996	666	145.8	-124	94.1	1	100.1
Factory sugar beet	13,199	10,205	9,942	13,129	-2,994	77.3	-263	97.4	3,187	132.1
Potatoes	19,838	20,269	20,899	21,359	431	102.2	630	103.1	460	102.2
Sown area, thsd ha										
Outdoor vegetables in the open field	541	460.8	374.9	396.7	-80.2	85.2	-85.9	81.4	21.8	105.8
Sunflower	2,943	5,928	5,238	5,202	2,985	201.4	-690	88.4	-36	99.3
Cereal and leguminous crops	13,646	15,318	11,773	10,836	1,672	112.3	-3,545	76.9	-937	92.0
Fruits and berries	425	225	171	167	-200	52.9	-54	76.0	-4	97.7
Factory sugar beet	856	222	184	250	-634	25.9	-38	82.9	66	135.9
Potatoes	1,629	1,309	1,204	1,210	-320	80.4	-105	92.0	6	100.5
Yield, t/ha										
Outdoor vegetables in the open field	11.2	20	21.5	20.9	8.8	178.6	1.5	107.5	-0.6	97.2
Sunflower	1.22	2.56	2.16	2.45	1.34	209.8	-0.4	84.4	0.29	113.4
Cereal and leguminous crops	1.94	4.91	4.58	5.5	2.97	253.1	-0.33	93.3	0.92	120.1
Fruits and berries	3.84	10.8	11.6	11.9	6.96	281.3	0.8	107.4	0.3	102.6
Factory sugar beet	17.7	46.1	54.1	52.5	28.4	260.5	8	117.4	-1.6	97.0
Potatoes	12.2	15.5	17.4	17.7	3.3	127.0	1.9	112.3	0.3	101.7

***Source:** calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2024)*

The significance of full-scale agricultural production is growing, especially in the context of military operations, anthropogenic disasters, and the climate crisis. The situation is acutely complicated by the explosion of the Kakhovka HPP, which has adverse consequences primarily for internal and external consumers. In 2022, the company produced 272.3 thsd t of melons, which is 230.8 thsd t less than in the previous year (in 2021 – 503.1 thsd t). Analysing the pre-war production of melons in Ukraine, the southern region of the country was the leader, with a share of over 50% in total production. Kherson Oblast was the largest producer with 168 thousand tonnes, accounting for almost 70% of production in the south and 33% of the total. Next were Poltava and Zaporizhzhia Oblasts with 48.1 thsd t and 27.5 thsd t, respectively. Next, Dnipro Oblast produced

37 thsd t, followed by Mykolaiv and Odesa Oblasts with 31.4 thsd t and 26 thsd t, respectively. In 2022, the leaders were Poltava (46.4 thsd t), Dnipro (35.1 thsd t), Vinnytsia (29.5 thsd t), Odesa (22.6 thsd t), and Kirovohrad (20.7 thsd t) Oblasts.

In 2023, a more significant decline in vegetable production was explained by the regional affiliation with the oblasts where hostilities are ongoing. However, the overall decline in production was partially mitigated by the reorientation of farmers who switched to vegetable production in the face of a shortage in the internal market. As for the possibilities of regional substitution of the deficit supply of 2 mn t, Table 6 shows the forecasted production of vegetables by type.

Table 6. Forecast of regional substitution of vegetable production in Ukraine for 2025

Consumer oblast	Supply deficit, thsd t	Factually sown, thsd ha		Factual yield, t/ha		Forecast for 2025			
		2022	2023	2022	2023	Additional sowing required, thsd ha 2022	Supplier oblast 2023	Probable supply volumes, thsd t	Economic effect of the event, UAH mn,
				Cabbage					
Kherson, Kharkiv, Donetsk, Zaporizhzhia, Luhansk	-1,698.5	60.1	61.8	22.0	26.2	8.3-9.0	Vinnytsia, Khmelnytskyi, Ternopil, Volyn Rivne, Zakarpattia, Chernihiv, Odesa, Poltava, etc.	1,904.4	294.9
				Carrot					
Kherson, Kharkiv, Donetsk, Zaporizhzhia, Luhansk	-1,149.2	38.2	39.6	18.0	18.4	5.2-5.5	Volyn, Poltava, Khmelnytskyi, Rivne, Odesa, Chernihiv, etc.	1,154.9	203.9
				Beetroot					
Kherson, Kharkiv, Donetsk, Zaporizhzhia, Luhansk	-864.9	34.8	35.6	19.0	20.3	4.8-5.5	Zakarpattia, Chernihiv, Lviv, Sumy, Poltava, Khmelnytskyi, Cherkasy, Volyn, Ternopil, etc.	1,074.7	187.3
				Onions					
Kherson, Kharkiv, Donetsk, Zaporizhzhia, Luhansk	-2,145.9	44.2	45.3	15.0	23.6	11.4-12.5	Kirovohrad, Cherkasy, Sumy, Poltava, Odesa, Dnipro, etc.	2,149.9	388.6
				Tomato, pepper, aubergine					
Kherson, Kharkiv, Donetsk, Zaporizhzhia, Luhansk,	-12,906.0	51.5	52.4	35.0	45.4	25.8-26.5	Dnipro, Odesa, Mykolaiv, Kirovohrad, Cherkasy	12,587.0	947.1
				Gourds and melons					
Kherson, Kharkiv, Donetsk, Zaporizhzhia, Luhansk,	-2,308.2	33.9	34.6	8.1	10.1	25.0-30.0	Dnipro, Mykolaiv, Vinnytsia, Odesa, Kirovohrad, Poltava	2,340.5	256.5
Total	-21,072.7	262.7	269.3	–	–	80.5-89.0	–	21,211.4	2,278.3

Source: *calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2024)*

Thus, by 2025, it is planned to increase the area under cultivation:

- vegetables (borshch set), less common and green vegetables in Vinnytsia, Khmelnytskyi, Ternopil, Volyn, Rivne, Zakarpattia, Chernihiv, Odesa, Poltava, and other oblasts to 37-40 thsd ha (including cabbage – 8.28-9.0 thsd ha, carrots – 5.2-9.5 thsd ha, red beetroot – 4.8-5.5 thsd ha, onions – 11.4-12.5 thsd ha);
- warm-weather crops (peppers, aubergines, tomatoes, watermelons, melons) in Dnipro, Odesa, Mykolaiv, Kirovohrad, Cherkasy oblasts to 25.0-26.5 thsd ha.

Under severe stressful conditions, it is important to provide the country's population with the necessary amount of products with a high content of biologically active substances, vitamins, and microelements with a minimum level of contamination. This task can be most effectively achieved through the introduction of organic and energy-saving technologies for growing vegetable and melon crops, which are aimed at preserving the environment. The introduction of adaptive technologies for growing vegetable plants with biological crop rotations provides considerable resource savings, increased profitability of vegetable production (by 24%), and organic quality products (Table 7).

Table 7*. Comparison of costs of cultivation under intensive (standard) and adaptive systems in terms of UAH thsd per crop rotation*

Expenditure item	Crop rotation		Biologised to intensive, (+/–), %
	Intensive	Biologised	
Salary with accruals	46,720	51,870	+ 10
Fuels and lubricants	9,220	8,610	-7
Mineral and organic fertilisers	19,370	8,580	-126
Agrochemicals (plant protection products)	5,120	960	-433
Depreciation and amortisation expenses	13,580	10,810	-26
Repairs of fixed assets	9,050	7,210	-26
Expenses, total	162,050	136,990	-18
Profit	196,400	219,050	+10
Profitability level, %	115	151	+24

Source: *calculated by the authors of this study based on data from O. Vitanov et al. (2022)*

The key aspect of such technologies is the introduction of varieties and hybrids with high adaptive potential for cultivation in various agroclimatic zones; adapted to the requirements of alternative and organic cultivation technologies; with high compliance with technological regulations for processing and long-term storage; with a high content of biologically valuable components and high therapeutic and prophylactic properties; immune to major pathogens; genetically aligned, with a friendly yield, high marketable quality of vegetable products.

The existing network of research stations at the Institute of Vegetable and Melon fully covers the full range of soil and climatic conditions, which allows not only to create competitive varieties and hybrids for a particular zone, but also to establish highly efficient seed production. Breeding, production, and marketing need to be integrated into a single complex, with the mandatory introduction of a system of certification, licensing of seed production and sales, which will ensure quality assurance at all stages of its passage.

The internal market of vegetable seeds is represented by virtually all well-known international companies, as well as a series of Ukrainian producers; according to the conclusions of the Agricultural Marketing Project experts, approximately 60% of the vegetable seed market is controlled by the top 20 foreign companies, the remaining 40% of the seed market is represented by Ukrainian agricultural enterprises that have a passport for growing and selling seeds (22%) and illegal producers of vegetable seeds (18%).

According to analytical studies, the capacity of the imported seed market in Ukraine today is about EUR 16 mn, while the total vegetable seed market in Ukraine today reaches EUR 25 mn (Rud *et al.*, 2023). In recent years, Ukraine's seed industry has been in near decline. The propagation of seeds of low reproductions continues with insufficient varietal control and violations of agricultural practices, processing, cleaning, and storage of vegetable seeds. An entire series of seed farms do not have permission to grow and sell seeds. Often, seed production is carried out by farms that have not been certified and have no idea about the specifics of this industry. As a result, the Ukrainian market receives seeds with low sowing qualities and low reproductions.

Despite the general trend of decline in Ukrainian seed production, the achievements of scientists at the Institute of Vegetable and Melon of the National Academy of Agrarian Sciences of Ukraine have created a sufficient number of cultivars of vegetable and melon crops that can meet the most demanding consumer needs, but the demand for selection achievements is determined not only by the recommendation of new cultivars and heterotic F_1 hybrids, but also by the availability of sufficient high-quality seeds. Therefore, the creation of new varieties and hybrids should be accompanied by their rapid reproduction and active introduction into production.

In Ukraine, selection work is carried out with 59 vegetable, melon, and 43 rare plants. Every year, the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine, its network, and coordinated institutions submit an average of 23-25 cultivars and hybrids to the State Service for Plant Variety Rights Protection (Protection documents for plant varieties, n.d.) (Table 8).

Table 8. The number of cultivars and hybrids of vegetable and melon plants transferred to the State Service for Plant Variety Rights Protection in 2000-2023

Originating institution	2000	2020	2021	2022	2023	Total
Institute of Vegetable and Melon of NAAS	6	14	6	10	8	44
Dnipro RS	0	2	0	2	6	10
Donetsk RS	0	7	0	0	2	9
Kyiv RS	4	6	3	3	4	20
RS Maiak	6	2	4	0	2	14
Coordinated agencies	7	9	3	7	10	36
Total	23	40	16	22	32	133

Source: *calculated based on data from the State register of plant varieties suitable for distribution in Ukraine (2024)*

As of 1 January 2024, 321 cultivars and hybrids developed by the Institute, research stations, and coordinated institutions are in the State Register suitable for distribution in Ukraine (Table 9).

Table 9. The number of cultivars and hybrids of vegetable and melon plants in the State Register suitable for distribution in Ukraine as of 1 January 2024

Originating institution	Variety	Hybrid	Total
Institute of Vegetable and Melon of the NAAS of Ukraine	104	14	118
Dnipro RS	43	3	46
RS Maiak	63	2	65
Institute of Horticulture of the NAAS	19	7	26
Institute of Climate-Smart Agriculture of the NAAS	49	2	51
Zakarpattia State Agricultural Research Station of NAAS	12	–	12
Cherkasy State Agricultural Research Station of the National Research Centre Institute of Agriculture of NAAS	3	–	–
Total	293	28	321

Source: *calculated based on data from the State register of plant varieties suitable for distribution in Ukraine (2024)*

In recent years, a decline in vegetable seed production has been observed in Ukraine. This decline was primarily conditioned by the collapse of the seed production system, fierce competition from foreign firms, high material costs of seed production, the difficult political situation related to the military operations, and other factors. In total, the Register contains 1,581 cultivars and hybrids of vegetable, melon, and rare plants, of which 1,261 are vegetable cultivars. Out of the total number of varieties and hybrids, only 53% are Ukrainian (Fig. 2).

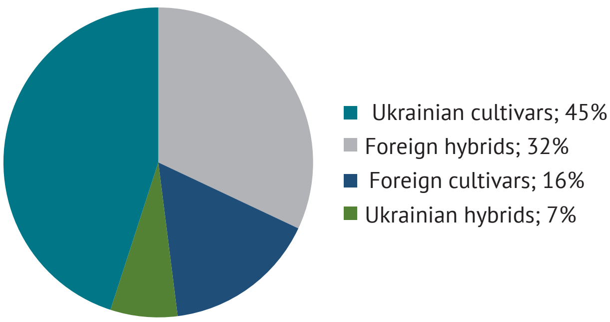

Figure 2*. Share of Ukrainian and foreign cultivars/hybrids in the Register of Plant Varieties of Ukraine (2023), %*
Source: *calculated based on data from the State register of plant varieties suitable for distribution in Ukraine (2024)*

The wide range of the 7 plant species (68% of the total) is conditioned by both their wide consumption and rich genetic diversity, which provides a diverse range of cultivars and hybrids with a series of economically valuable and morphological and biological traits. Thus, a tomato has over 20 shades of fruit colour alone, each of which deserves attention. According to statistics, today the varieties and hybrids of Ukrainian breeding occupy only about 45% of the sown area. In the species composition, the largest percentage is occupied by cultivars and hybrids – tomato (22%), cucumber (12%), white cabbage (10%), and onion (7%) (Fig. 3).

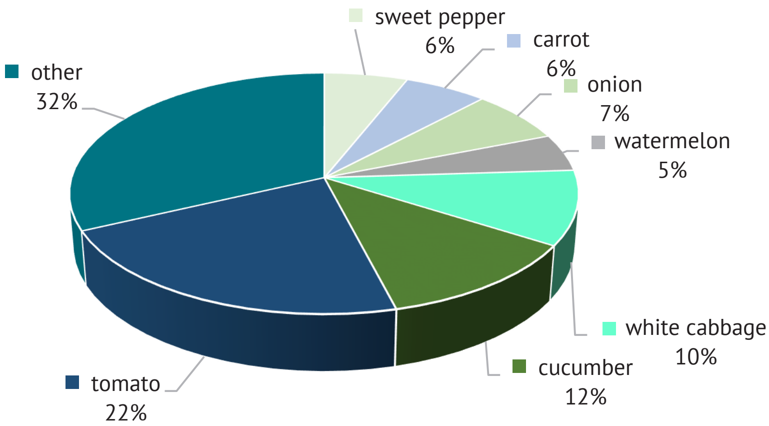

***Figure 3**. The structure of the most common plant species in the Register of Plant Varieties of Ukraine (2023), %*
***Source:** calculated based on data from the State register of plant varieties suitable for distribution in Ukraine (2024)*

The Institute of Vegetable and Melon of the NAAS and its network are engaged in the cultivation of seeds of higher reproductions and can provide the full volume of seeds needed for Ukraine (Table 10).

***Table 10**. The need for original, elite, and reproductive seeds of main vegetable plants for all categories of farms in Ukraine*

Crop	Commercial crop area, thsd ha	Seeding rate, kg/ha	Need for seeds		
			Certified, t	Baseline, t	Prebaseline, kg
White cabbage	29	1/0.3*	29.0/9.6	0.25/0.08	3/1
Tomato	38	1/0.3*	38.0/11.4	0.6/0.2	10/3
Cucumber	21	4	84	1.6	140
Carrot	15	3	45	1.1	15
Red beetroot	14	10	14	1.0	20
Onion	20	7	140	1.3	50
Radish	7	20	140	5.5	250
Sweet pepper	2.4	1	2.4	0.02	2
Aubergine	2.4	1	2.4	0.02	2
Zucchini	10	4	40	0.7	20
Watermelon	22	3	66	0.8	60
Melon	5.4	4	21.6	1.2	80
TOTAL	186.2	–	622.4	14.1	672

***Note:** * in the numerator – seed consumption for direct sowing method; in the denominator – seedling method*
***Source:** calculated based on data from the State register of plant varieties suitable for distribution in Ukraine (2024)*

However, to meet the need for such a large quantity of original and elite seeds, it is necessary to have a clear order from certified seed producers (Table 11).

***Table 11**. Production of baseline and certified seeds at the Institute of Vegetable and Melon of NAAS of Ukraine and at research stations in 2023*

Crops	Production volumes, kg	
	Baseline	Certified
White cabbage	23.9	141
Onion	40	278
Carrot	17	227
Red beetroot	112	468
Tomato	7.6	91.5
Other nightshade crops	2.5	18.9

Table 11. Continued

Crops	Production volumes, kg	
	Baseline	Certified
Cucumber	18.1	966
Watermelon	100	224
Other melons and gourds	10	1375
Other types of vegetable plants	360.4	46
	691.5	3835.4

Source: *calculated according to data from the State Statistics Service of Ukraine (2024)*

Only certified seeds were produced to cover an area of 5.7-7.6 thsd ha. The Institute's scientists are actively transitioning to heterotic breeding, specifically, the percentage of hybrids created, and hybrid seeds of pumpkin crops (cucumber, watermelon, melon) grown has increased significantly. Currently, the State Register of Plant Varieties contains 18 hybrids of internally sourced selection (24 together with research stations) (State register of plant varieties suitable for distribution in Ukraine, 2024). The production of hybrid seeds was substantially increased. In 2023, over 600 kg of hybrid cucumber seeds were produced, which will allow sowing over 1,500 ha of land and producing about 70,000 t of marketable products to ensure food security. A selection base was also developed for creating hybrids of nightshade crops (tomato, sweet pepper, aubergine), carrots, red beetroot, late-ripening cabbage, onions, and other crops. Despite the high labour intensity of hybrid seed production, the volume of hybrid seeds produced annually is growing. It is also necessary to consider the volume of seeds grown by commercial entities under licence agreements (Table 12). Considering the two-year cycle for some vegetable plants, in 2023, vegetable seeds were grown to cover the area of 55,313 ha, which is 13% of the total area under vegetable and melon plants in Ukraine (426.5 thsd ha) (Table 13).

Table 12*. Production of seeds of biennial vegetable plants in 2023 under licence agreements*

Crops	Sales volume of baseline seeds, kg (autumn 2021 – spring 2022)	Area under mother plantations, ha	Area under seed breeding plots, ha	Seed yield, kg/ha	Gross harvest of SS-1 seeds, t	Area sown with grown seeds, ha
Onions	91	16	160	400	64.0	8,000
Red beetroot	408	51	153	1,300	206.7	20,670
Carrot	27	7	42	400	12.6	2,100
Radish	30	2.5	20	600	10.0	1,250
Other root vegetables	92	19	76	500	38.0	9,500
Total					331.3	40,520

Source: *calculated according to data from the State Statistics Service of Ukraine (2024)*

Table 13*. Production of seeds of annual vegetable plants in 2023 under licence agreements*

Crops	Sales volume of baseline seeds, kg (2022)	Area sown with baseline seeds, ha	Seed yield, kg/ha	Gross harvest of SS-1 seeds, t	Area sown with grown seeds, ha
Tomato	5.9	11.8	100	1.18	2,360
Sweet pepper	2.7	2.7	100	0.27	270
Cucumber	2	0.4	200	0.08	13
Other melons and gourds	67	33.5	200	6.7	3,350
Dill	7.1	3	500	1.5	500
Salad	8	8	350	2.8	700
Total				12.53	7,193

Source: *calculated according to data from the State Statistics Service of Ukraine (2024)*

According to theoretical provisions, the completion of the process of forming a single market environment should be associated with minimal price fluctuations. In fact, the situation is quite different, indicating that the formation of a single market space is incomplete, and that supply and demand are spontaneous and sporadic. The reason for this situation is the general economic instability and high fuel prices and transport costs, which have had a negative impact on the collective farm vegetable market in general. The data in Table 14 suggest that the formation of a single market competitive environment is incomplete, as the coefficient of variation of regional prices (the range of variation) for vegetables is increasing.

***Table 14**. Regional variation of farm prices in Ukraine and the relationship between them*

Product name	Price variation coefficients, %		Correlation coefficient between 2000 prices and 2023 prices
	2000	2023	
Fruits and berries	32.6	45.3	0.49
Outdoor vegetables in the open field	11.5	43.6	0.17
Potatoes	22.8	18.8	0.29
Cattle meat	9.2	12.8	0.14
Sunflower	30.4	12.8	-0.29
Eggs	12.7	9.2	0.18
Cereals	7.9	8.8	-0.26
Whole milk	8.5	6.8	0.03
Sugar beet (factory)	10.5	6.2	-0.08
Pig meat	8.4	5.9	0.45

***Source:** calculated according to data from the State Statistics Service of Ukraine (2024)*

The range of variation was calculated as the ratio of the average monthly market price for 2023 to 2000. It was found that in 2000, this deviation was 11.5%, and in 2023 it reached 43.6% and was the highest among the main agricultural products, second only to fruits and berries. One can assume that the situation on the fruit and vegetable market will stay challenging in the near future. While a high territorial variation in prices for a particular product indicates localised exchange processes, the presence of moderate (up to 0.5) and significant (over 0.5) price correlation demonstrates stable differentiation of regional prices. In other words, Ukraine has a low level of formation of a single trading space in the fruit and vegetable market.

It is known that there is a monopolistic practice whereby large agricultural producers, including fruit and vegetable producers, determine the pricing policy and specialisation of production, which allows them to ensure the level of profit that will ensure survival in a hyper-competitive environment. However, today, considering that the lion's share of the vegetable market is held by small private households (about 90%), large-scale enterprises do not have a substantial impact on pricing policy. In other words, pricing policy is currently "dictated" by the private sector, which is also a feature of the vegetable market. All this led to a distortion (deformation) of the cost structure. Thus, in 1990, the share of material costs was 42%, labour costs – 30%, and net income – 28%. The profitability level of agricultural enterprises is slightly higher than that of private ones, at 11.1%.

In the context of commodity relations, the price ensures a balance between supply and demand. In 2022, grain and vegetable producers faced the phenomenon of price and cost incompatibility. Thus, in 2022, the price of onions, late cabbage, carrots, and beetroot was marginal, while the price of onions was even lower than the cost of production.

It was found that in 2015-2023, the cost of growing vegetables increased 3.1 times from UAH 56.3 thsd in 2015 to UAH 184.6 thsd in 2023 (State Statistics Service of Ukraine, 2024). Profitability decreased from 45% in 2015 to 8% this year. Vegetable production is carried out based on simple reproduction, which does not allow enterprises to recover costs in the required amounts. Therewith, the producer, regardless of the invested assets, cannot sell the products at its own price, and therefore in this case, state intervention is needed to promote the formation of equally competitive conditions for the distribution of income from sales in the market among all participants in the infrastructure link "producer-processor-consumer and marketing infrastructure" (Bryukhovetska *et al.*, 2019). However, in the Ukrainian reality, this aspect of market regulation is practically not implemented, which is one of the reasons for the considerable loss of income by agricultural producers (Table 15).

***Table 15**. Structure of retail average prices for vegetable products in the Ukrainian consumer market in 2023*

Indicator	Late cabbage		Onion		Carrot	
	UAH	%	UAH	%	UAH	%
Retail price in the retail network	20.0	100	33.0	100	29.8	100
Including the share of the price that remains:						
with the manufacturer	9.0	45.0	14.0	42.4	12.8	42.9
in the retail network	11.0	55.0	19.0	57.6	17.0	57.1

***Source:** calculated according to data from the State Statistics Service of Ukraine (2024)*

The table shows that over 55% of the retail price stays in the infrastructure part of the market, which is not directly involved in the production of this product, which is a negative phenomenon that creates demotivation for the producer. Thus, the state should help producers to receive adequate income by regulating market pricing processes through active actions on the borderline of "minimum price" and "price formed based on supply and demand". It means that the state should, by compensating for the lost profits (price difference), provide the producer with a minimum price to ensure expanded reproduction and, therefore, economic interest. Therefore, determining the minimum producer price is a necessary condition at the current stage of functioning of the agricultural economy. The state should determine how to compensate for the difference, otherwise producers will lose motivation to their businesses. The minimum price is determined at a given rate of technological inputs and asset ratios according to a given yield.According to the State Statistics Service of Ukraine (2024), despite the increase in market prices in the current year compared to 2022, the costs incurred for the production in the 2023 season do not cover the costs of their production (Tables 16, 17).

***Table 16**. Average consumer prices for borshch vegetables in Ukraine in 2023, UAH/kg*

Product name	December	January	February	March	April	May	June	July	August	September	October	November	December	Average annual price
White cabbage	13.0	12.8	13.9	22.2	23.8	37.6	45.6	23.3	11.0	9.1	8.5	8.8	11.2	19.0
Onion	30.6	32.1	42.3	52.1	52.7	56.2	55.0	36.1	18.1	12.9	13.1	13.4	15.1	33.3
Beetroot	12.3	12.2	11.4	10.9	9.8	9.7	10.4	32.4	14.6	10.3	9.2	9.4	11.5	12.7
Carrot	22.4	24.5	28.8	39.6	44.0	54.7	59.6	47.5	17.6	11.0	9.5	9.5	11.4	29.8
Potatoes	9.2	9.4	9.6	9.6	9.5	9.9	12.0	20.3	12.9	11.0	10.2	11.9	15.1	11.8

***Source:** calculated according to data from the State Statistics Service of Ukraine (2024)*

According to the Ukrainian Research Institute of Agricultural Productivity, as of 6 February 2024, there is an increase in the cost of a borshch set, as evidenced by the data of 51 regional and district markets of Ukraine for borshch vegetables (The cost of the "borscht set" ..., 2024). The price of sunflower oil fell. The prices of the above products were compared to the prices as of 23 January 2024. Thus, the minimum cost of borshch set products as of 6 February 2024 was UAH 29.76, while two weeks earlier the average cost was UAH 29.71, which indicates a price increase of UAH 0.05. According to the data, the largest price increases (+) were for potatoes, beetroot, cabbage, carrots, onions, and tomatoes (Table 17).

***Table 17**. The cost of a "borshch set": trends in April 2024 Price – standard cost ratio*

Product name	Quantity, g	Price as of 6 February 2024, UAH	Price as of 23 January 2024, UAH	Trend, %	Standardised production costs			Price to standard ratio, UAH/kg, +, -
					per 1 ha, UAH thsd	per 1 kg, UAH	pre product weight, UAH	
Potatoes	150	2.84	3.04	+6.9	255.4	7.3	20.27	+12.97
Cabbage	100	1.68	1.68	+0.24	135.9	2.5	11.20	+8.70
Carrot	50	0.96	0.98	+2.5	146.5	4.2	6.53	+2.33
Beetroot	50	0.97	0.97	+0.2	126.3	2.8	6.47	+3.67
Onion	50	0.98	1.01	+2.4	188.3	4.2	6.73	+2.53
Tomatoes	50	4.70	4.75	+1.1	213.5	3.6	31.67	+28.07

***Source:** calculated according to the State Statistics Service of Ukraine (2024); The cost of the "borscht set" ..., 2024*

Setting the minimum price level for the vegetable industry is significant for establishing scientifically sound cost standards while achieving a balance of material, labour, and cash resources, which regulate standard costs, raw materials, fuel, and other resources. The implementation of these technical and technological solutions in vegetable growing will reduce the cost per unit of production and ensure the development of vegetable growing in terms of expanded reproduction with a production profitability of at least 35%. Practical implementation of the proposed technical and technological solutions will allow solving the issues of economic independence of the regions, food, and national security, to reduce its import dependence, in the vector of institutional development of the economy and development of Ukraine's European integration policy.

DISCUSSION

Ukraine has every opportunity to ensure food security in the internal market and can substantially influence its strengthening at the global level. According to K. Mazur and Ya. Gontaruk (2023) and T. Oliynyk *et al.* (2019), vegetable production should be export-oriented, and in this case it can become efficient. Therewith, it is imperative to ensure measures to regulate the internal vegetable market to overcome its deficit through the possibility of substitution of production, which will allow national producers to overcome difficulties and strengthen their positions in the internal market. Furthermore, according to N. Palapa *et al.* (2022), L. Galat (2019), Ukraine's position in food security can be strengthened by other factors: rising incomes; achieving political stability; physical and economic availability of the required quantity and range of food, effective government policy, etc. At the same time, it is necessary to use the benefits of international economic integration, specifically, in terms of removing trade barriers, foreign direct investment, new technologies, etc. Considering this, Ukraine has already concluded regional trade agreements with such integration groups as the EU, the European Free Trade Association (EFTA), as well as dozens of countries, including Canada, the UK, and Turkey, which are significant trading partners in the world market, including in agri-food trade (Ministry of Agrarian Policy and Food of Ukraine, n.d.).

Thus, according to the researchers, to achieve this, Ukraine needs to solve a series of important sectoral tasks, including those related to food security under martial law, prevention of hunger, malnutrition of Ukrainians, etc. Thus, in the context of the shortage of vegetable production, it is necessary to identify new opportunities for regional production, ensure the possibility of substituting the production of certain vegetable crops by their types, and solve the problems of developing Ukrainian seed production and pricing.

The analysis shows a rather negative trend of decreasing vegetable production in Ukraine, especially in the context of military operations and environmental hazards, in contrast to the global dynamics, and confirms the relevance of recommendations on the feasibility of increasing it. Therewith, we fully share the opinion of R. Lohosha *et al.* (2018) on the need to orientate production towards the organic vector. Therewith, the EU-Ukraine Association Agreement (Association Agreement No. 984_011, 2023) states that the parties shall strengthen cooperation on environmental issues and intensify the development of green economies (Article 360), cooperate to promote the development of agriculture and rural areas (Article 403), etc.

To improve the efficiency of the formation and functioning of the vegetable market in Ukraine, especially in the context of its convergence with the EU markets, K. Mazur and Ya. Gontaruk (2023) suggest considering the practices of other countries. However, in our opinion, direct borrowing of the classical European model of the economic mechanism for regulating the vegetable market without accommodating sectoral characteristics and local organisational and economic conditions of the market environment is impossible, which is conditioned by the need to introduce an original and more efficient way of development. Furthermore, we believe that at the current stage of development, state support is needed, especially in the implementation of sectoral and regional programmes for the development of vegetable production in the future. At the same time, the amount of state support for the vegetable market depends on the real capabilities of the budget; tax, credit, price, investment, export-import, customs, and monetary policies. A. Gumenyuk and O. Harmatyuk (2021) note that in the future, it is necessary to increase Ukraine's competitiveness by introducing state levers for the formation of new integrated associations in vegetable production. The authors of the present study came to the same conclusion and believe that expanding integration ties will enable more efficient implementation of innovations at enterprises, reduce production costs, and increase the competitiveness of enterprises. This applies primarily to cooperation with developed countries and integration groups with which regional trade agreements have been concluded, including the EU, EFTA, Canada, the UK, etc.

As noted above and considering the findings of this study on the state, trends, features, and reasons for the decline in vegetable production, the issues of product competitiveness, increased profitability, consumer preferences, identification of regional reserves for production development, and improvement of product quality are still open. The study proved that the problem of food shortages should be solved with due regard to the possibilities of domestic production and maximum security guarantees. L. Teryokhina *et al.* (2020) share the same opinion, emphasising that today vegetable growing is the basis for sustainable development of crop production and requires the introduction of innovative technologies, considering regional characteristics. The introduction of zonal innovative technical and technological solutions, according to O. Mogylna *et al.* (2020), will help to solve the issue of economic independence of individual regions in the post-war economy. Therefore, considering the above, in the future, when developing the principal aspects of the strategy for the sustainable formation and functioning of the vegetable growing industry, priority should be given to the implementation of the innovation and investment model of development.

It was found that the dysfunctions of the vegetable market are caused by insufficient scientific understanding of the role of the factor of legal support for the regulation of the agro-industrial complex and the formation of sectoral markets. In this regard, we fully share the opinion of R. Lohosha *et al.* (2020) on the need to regulate the price mechanism and the complexity of institutional support as a necessary element of market reforms, especially in the context of food shortages. Other researchers, such as I. Gruzinska (2022), emphasise that the increase in the efficiency and competitiveness of the vegetable growing industry at both the national and regional levels is considerably influenced by factors such as technical and technological, biological, financial and economic, legal, social, etc. The present study proved that to improve the efficiency of the vegetable growing industry, it is necessary to improve the existing approaches by combining the institutional-legal, institutional-organisational, and institutional-informational components.

CONCLUSIONS

To overcome the production deficit, it is necessary to introduce an innovation and investment model for the development of the industry. Furthermore, efforts should be made to stimulate vegetable exports, diversify its geographical and product structure, and promote the export of processed products. Ukraine's vegetable exports have increased considerably since 2003 but are generally fluctuating. The trade balance was active and passive. Ukraine's largest exporters are mainly countries with which regional trade agreements have been concluded, while in 2003 these were countries with which RTAs were already in force or were about to be concluded. This suggests that integration promotes trade and vice versa. It is worth noting a positive trend, specifically the geographical diversification of vegetable exports, but some of the world's largest importers, such as China, the US, and Japan, are not among Ukraine's key importers. An analysis of the commodity structure of exports shows the need to diversify it and increase production of products that are largely imported, such as tomatoes, onions, and cucumbers. However, it is not a question of restricting imports, as the needs of consumers and the seasonality of vegetable growing must be considered. Exports should be increased through the use of RTAs, improved product quality, and harmonisation of quality standards with European ones, which should also help to provide the population with quality products and increase vegetable production. This is one of the main prerequisites for entering and increasing exports to developed markets, which will help to boost vegetable production.

One of the key factors of efficiency is sales, and a valuable tool for the comprehensive improvement of the vegetable growing economy is the improvement of pricing. Thus, with rising energy costs and higher wages for vegetable growers, the focus of the pricing policy is to partially increase prices while increasing labour productivity and reducing production costs. Labour productivity can be increased by mechanising labour-intensive processes, while costs can be reduced by introducing intensive vegetable growing technologies and standardised costs. Thus, the promotion and intensive implementation of modern scientific developments will considerably increase the profitability of the industry, ensure the sustainable development of vegetable agrocenoses, reduce the adverse impact of technology on the environment, improve product quality, and solve a series of socio-economic issues.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Овочівництво під впливом продовольчих небезпек, екологічних чинників та міжнародних інтеграційних процесів

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Анотація. Важливість виробництва овочів зумовлена потребою населення у вітамінній продукції, переробних підприємств у сировині, особливо у воєнний час, в умовах продовольчої та екологічної небезпеки та доцільністю нарощування експортних можливостей з врахуванням міжнародних інтеграційних процесів. Метою статті є дослідження впливів війни на економічну доступність та екологічну безпечність продовольства, визначення та оцінка складових та напрямків управління продовольчою та екологічною безпекою, оцінка та сприяння експорту продукції в контексті міжнародної економічної інтеграції. При дослідженні використовувались методи аналізу та синтезу, узагальнення та конкретизації, математичні та графічний метод. Джерела інформації – дані Продовольчої та сільськогосподарської організації ООН (ФАО), агентства Всесвітньої торгової організації (ITC), Державної служби статистики України. В результаті дослідження здійснено аналіз сучасного стану виробництва овочів, визначено основні проблеми під впливом продовольчих небезпек, екологічних чинників та інтеграційних процесів. Досліджено вплив війни на економічну доступність та екологічну безпечність продовольства, здійснено оцінку обсягів дефіциту виробництва овочевої продукції, визначено основні економічні та екологічні проблеми та напрями підвищення ефективності галузі на перспективу. Встановлено обсяги дефіциту виробництва овочів та визначено розміри втрачених площ посіву; причини незадовільного стану овочівництва. Визначено, що останніми роками в країні спостерігається досвід тимчасового голоду, що є неприпустимим у європейському просторі. Встановлено, що для мінімізації агропродовольчої кризи, екологічних загроз, необхідно спрямувати роботу щодо втілення запропонованих заходів для підтримки ефективності виробництва, впровадження яких дозволить вирішити питання самостійності та продовольчої безпеки територіальних громад, особливо в умовах війни, удосконалити функціонал органів управління, господарюючих суб'єктів, інвесторів, науковців, виробників на засадах сталого розвитку. Практичність результатів дослідження підтверджується ефективністю розроблених пропозицій, що можуть бути використані при впровадженні заходів щодо нарощування обсягів виробництва овочів та підвищення експорту

Ключові слова: екологія; овочівництво; виробництво; споживання; інноваційний розвиток; експорт; міжнародна економічна інтеграція

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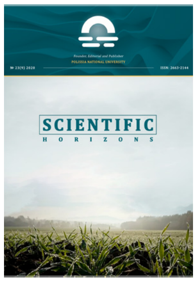

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Restoration of war-damaged soil fertility to ensure sustainable agricultural production, food security and global recognition of Ukraine

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Abstract. The introduces new agrotechnological crop rotations is relevant in the context of environmental protection. The study aims to investigate the effectiveness of introducing two crop rotations on degraded lands in the Mykolaiv region, where active military operations were conducted. The study determined that the introduction of new crop rotations led to a 1.3-fold increase in gross output compared to previous data. In a five-field crop rotation, growing perennial grasses for green fodder together with annual grasses for silage restored soil fertility and increased yields by 30 c/ha compared to existing economic indicators. Oat yields with perennial grasses increased by 18 c/ha. Growing corn for silage and green fodder provided an additional 100 cwt/ha. An increase in the yield of fodder roots and annual grasses for green fodder by 110 c/ha demonstrated the effectiveness of the new crop rotations. In a seven-season

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crop rotation, the introduction of perennial grasses increased soil fertility reduced soil erosion, and increased yields of winter wheat and sugar beet. Sugar beet yields increased by 25 c/ha, while potatoes and grain corn yields increased by 55 c/ha. The introduction of annual grasses, pulses and buckwheat helped to increase yields by 28 c/ha. The results of the study can be used by local communities to develop and implement environmental measures and programmes aimed at restoring the structure and fertility of damaged lands and preserving their quality

Keywords: crop rotation; plants; compaction; dunder molasses; organic fertilisers; phytoremediation

INTRODUCTION

The topic of the study needs to be explored, as one of the main environmental problems in Ukraine is the problem of soil degradation damaged by military operations. This problem exists because military operations are often accompanied by intense bombing, explosions and the use of chemicals that affect soil quality and fertility. Heavy metal contamination can harm agriculture through reduced yields, as well as loss of food quality and safety (Shaforost *et al.*, 2024).

One of the challenges of sustainable production of S. Shahini *et al.* (2023) notes a decrease in yields due to excessive application of inorganic fertilisers. According to the results of their study, the balanced application of organic nitrogen fertilisers not only contributed to an increase in yields but also supported the environmental sustainability of agricultural ecosystems. The impact of different types of organic fertilisers on the biodiversity of soil microorganisms and macroorganisms, such as biological nitrogen sources, composts, mulch, etc., should be further studied. The problem of low soil fertility and winter wheat yields is noted by A. Panfilova (2021). According to the findings, the use of the stubble biodestructor led to an increase in winter wheat yields, especially after spring barley and peas. The gap that needed to be addressed was to test the effect of stubble biodegradation on other soil and plant parameters, such as microelement balance, resistance to pathogens, or the impact on soil biodiversity.

The problem of the lack of optimal technologies for soil restoration is noted by O.O. Efremova and D.V. Repetskyi (2023). Based on the results of the study, it was recommended to introduce crop rotation, phytoremediation, chemical reclamation, reclamation and the application of organic fertilisers such as phosphate rock, phosphorus and potash fertiliser. A systematic assessment of the state of land resources aimed at monitoring soils and crops is needed. The problem of soil contamination with radionuclides, heavy metals, pesticides, oil and oil products is discussed by I. Boretska *et al.* (2021). According to the results of their research, energy crops such as miscanthus, willow, poplar, switchgrass, sorghum, sainfoin, red clover, and sweet clover are recommended for cultivation. The disadvantage of the study is that it did not consider the economic aspects of growing energy crops for phytoremediation.

The problem of soil contamination with cadmium was studied by H. Haller *et al.* (2023). The results of their work showed that *Amaranthus hypochondriacus* could be effectively used for the remediation of cadmium-contaminated sites due to its ability to hyperaccumulate this metal from the soil. To fully assess the potential of using *Amaranthus hypochondriacus* for remediation of cadmium-contaminated soils, additional research is needed, including on the impact of this process on the ecosystem. The problem of the heterogeneous distribution of elements titanium (Ti), iron (Fe) and copper (Cu), arsenic (As), strontium (Sr) and manganese (Mn) in plants and soil was investigated by V. Pidlisnyuk *et al.* (2020). Their study revealed that the high potential of miscanthus phytoremediation can be an effective tool for soil remediation. Further experiments and comparisons of laboratory and field conditions are needed to better understand the effectiveness of principal component analysis and general linear model approaches and their potential benefits for the ecological restoration of degraded ecosystems.

The need to study the problem of increasing nitrate concentration in soil contaminated with diesel fuel during the growing season was pointed out by V.O. Khomenchuk *et al.* (2023). As a result of the study, they determined that the application of biochar contributed to the enrichment of the soil with nitrates. The study can be supplemented by developing recommendations for the optimal use of biochar and other fertilisers for balanced nitrogen nutrition of plants. The problem of heavy metal contamination of soil, water and air because of military operations was noted by D. Papusha *et al.* (2023). As a result of their research, they recommended the introduction of optimal crop rotations with a variety of plant species, as well as the use of genetic engineering to create plants with an increased ability to cleanse the soil of contaminants. The paper does not fully cover all the possible consequences of heavy metal contamination of soil and water, such as the impact on human health and biodiversity.

The problem of reducing the sown areas of legumes and perennial grasses was noted by V. Gamajunova *et al.* (2021). Based on the results of their work, they recommended the use of farm manure and the incorporation of straw and stubble. The study's shortcoming was that it did not consider the possibility of secondary pollution of soil and water resources as a result of the use of commercial biodegraders. The need to create more productive and adapted varieties of giant miscanthus was noted by C. Wang *et al.* (2020). After conducting a scientific study, they found that the root system of miscanthus can effectively increase the distribution and transformation of various heavy metals such as lead, cadmium, and copper. The shortcomings of the scientific work include the limited number of studies on the impact of miscanthus on biodiversity and ecosystem processes.

The purpose of the study is to assess the effectiveness of introducing new crop rotations on the territory of the private rental company (PRC) "Victoria". Objectives: to develop a methodology for introducing new agricultural-technological crop rotations on degraded lands; to conduct an experimental study of the effectiveness of introducing two crop rotations: five- and seven-manure.

MATERIALS AND METHODS

In conducting the scientific work, research methods were used to analyse agrotechnical measures, and assess the yield and value of crop production, established by Law of Ukraine No. 962-IV (2003) and Resolution of the Cabinet of the Ministers of Ukraine No. 164-2010-p (2010). The study applied the method of crop rotation to increase soil fertility and preserve moisture. The method of characteristic (key) plots to determine the yield of the plant under study over large areas of germination of this plant. A method for determining field soil moisture is to measure soil weight before and after drying. The research was carried out during 2022-2023 on the arable land of PRC "Victoria", located in Mykolaiv region, Bashtanka district, Stantsiynske village. The soil cover is represented by the southern black soil of the Steppe zone of Ukraine.

The study of field moisture dynamics in sod-podzolic soils of the Mykolaiv region and the impact of molasses bards and mineral fertilisers on this process was conducted at the experimental field of the Educational and Research Centre of Mykolaiv National Agrarian University. The project envisages the introduction of two new crop rotations on the arable land of PRC "Victoria" with a total area of 759.0 ha. A fodder five-field crop rotation of 149.6 ha with an average field size of 29.9 ha and crop rotation was introduced near the main areas of existing fodder lands: 1 field – perennial grasses for green fodder and annual grasses for silage; 2 field – oats; 3 field – corn for silage and corn for green fodder; 4 field – fodder roots and annual grasses for green fodder; 5 field – oats with perennial grasses. On the remaining arable land, a seven-field crop rotation was designed for 609.4 hectares with an average field size of 87.1 hectares and the following crop rotation: 1 field – perennial grasses; 2 field – perennial grasses; 3 field – winter wheat; 4 field – sugar beet; 5 field – potatoes and corn for grain; 6 field – annual grasses, legumes and buckwheat; 7 field – spring barley with perennial grasses.

When designing the fields, one of the requirements was that the fields should be equal in size. Fields of the same size are more convenient for planning arable farming, controlling product accounting, etc. When designing fields, small paths to the fields should be avoided, while maintaining the integrity of existing arrays. In difficult conditions, deviations from the average field size of ± 10% or even more are allowed when placing fields. The characteristics of the designed fields by equilibrium are presented in Table 1.

Table 1. *Characteristics of fields by equilibrium*

Fields	Field area, ha	Average field size, ha	Deviation from the average field size (+/-)	
			ha	%
		Forage crop rotation		
I	25.1	29.9	-4.8	-3.2
II	29.9		-	-
III	29.9		-	-
IV	35		5.1	3.4
V	29.7		-0.2	-0.1
Total	149.6			
		Field crop rotation		
I	87.1	87.1	-	-
II	87.1		-	-
III	88.1		1.0	0.2
IV	87.1		-	-
V	87.1		-	-
VI	85.4		-1.7	-0.3
VII	87.5		0.4	0.1
Total	609.4			

Source: *compiled by the authors*

At PRC "Victoria", the crop rotation fields are designed to be equal in area, and rectangular in shape (length to width 3:1), with deviations from the average field size within the permissible range of ± 10%.

RESULTS

The hostilities caused both physical deterioration of the soil and chemical contamination. This was due to direct hits from shells, fires and the destruction of burnt military equipment that could contain oil products and other hazardous substances. The study by B. Biyashev *et al.* (2023) found that the content of various toxic substances in the combat zone exceeded the permissible limits several times, and the acidity of the soil was elevated. The consequence of this pollution was the spread of potentially toxic elements such as heavy metals and explosives. Crop rotation is a scientifically based alternation of crops in space and time, or only in time. Since crop rotation is the main element of agriculture, the crop rotation envisaged in it must be maintained all the time (in rotation). Crop rotation helps to reduce the number of weeds, pests and diseases. For some of the crop rotation fields, the design was based on a set of existing contours and therefore consisted of several small working plots (Table 2).

Table 2. *Explication of land by crop rotation fields*

Name of crop rotations	Average field size, ha	General area, ha	Including crop rotation fields						
			1 field	2 field	3 field	4 field	5 field	6 field	7 field
Forage crop rotation	29.2	149.6	25.1	29.9	29.9	35	29.7		
Field crop rotation	87.1	609.4	87.1	87.1	88.1	87.1	87.1	85.4	87.5

Source: *compiled by the authors*

In fodder rotation, the average field size is smaller (29.2 ha) compared to field rotation (87.1 ha). The increased average size of field crop rotation fields may indicate a larger scale of production and the possibility of more intensive use of land for field crops. The location of crops and their structure after the introduction of two crop rotations in the PRC "Victoria" are shown in Table 3. Perennial grasses for hay account for 23.1% of the total acreage, sugar beet – 11.5%, winter wheat and spring barley – 11.2%. The calculation of the value of gross crop production for the future compared to the actual situation is presented in Table 4.

Table 3. *Placement of crops in crop rotations*

Cultures	General area		Including crop rotations, ha		Total in crop rotation, ha	Deviation, ha
	ha	Option 1 Seven-season field crop rotation %	Option 2 Fodder five-field crop rotation			
Winter wheat	85	11.2	87		87	2
Spring barley	85	11.2	87		87	2
Oats	63.4	8.3		59.8	59.8	-3.6
Pulses	30.3	4	30.3		30.3	-
Buckwheat	30	4	25.7		25.7	-4.3
Sugar beets	87	11.5	87		87	-
Potatoes	60	7.9	60		60	-
Grain corn	17.9	2.4	27.1		27.1	+9.2
Silage corn	23	3		20	20	-3
Annual grasses for silage	39	5.1	31.1	7.9	39	-
Fodder root crops	10.4	1.4		10.4	10.4	-
Annual grasses for green fodder	20	2.6		19.5	19.5	-0.5
Perennial grasses for green fodder	22	2.9		22	22	-
Corn for green fodder	10.3	1.4		10	10	-0.3
Perennial grass hay	175.7	23.1	174.2		174.2	-1.5
Total crops	759	100	609.4	149.6	759	0

Source: *compiled by the authors*

Table 4. *Calculation of gross crop production under the project after the introduction of new crop rotations in the PRC "Victoria"*

Cultures	Area		Yields, hwt/ha	Gross yield	Conversion factor to conventional grain	Product yield in terms of conventional grain
	ha	%				
Winter wheat	87	11.2	37	3,219	1	3,219
Spring barley	87	11.2	38	3,306	0.8	2,644.8
Oats	59.8	2.4	38	2,272.4	0.7	1,590.7
Pulses	30.3	8.4	30	909	1.4	1,272.6
Buckwheat	25.7	4	19	488.3	1.4	683.6
Sugar beet	87	11.5	345	30,015	0.26	7,803.9
Potatoes	60	7.9	170	10,200	0.3	3,060
Grain corn	27.1	4	29	785.9	1.2	943.1
Silage corn	20.1	3	230	4,623	0.2	924.6
Annual grasses for silage	39	5.1	120	4,680	0.12	561.6
Fodder root crops	10.4	1.4	450	4,680	0.13	608.4
Annual grasses for green fodder	19.5	2.6	120	2,340	0.12	280.8
Perennial grasses for green fodder	22	2.9	150	3,300	0.15	495
Corn for green fodder	10	1.4	230	2,300	0.2	460
Perennial grass for hay	174.2	23.1	45	7,839	0.5	3,919.5
Total crops	759	100				28,467.6
Including per 1 ha of arable land						37.5

Note: *to calculate the output in terms of conditional grain per 1 ha of arable land, it is proposed to multiply 37.5 by 180 UAH (realised price of winter wheat) = 6,750 UAH*
Source: *compiled by the authors*

From the calculations, it can be concluded that the value of gross production in the PRC "Victoria" per 1 ha of arable land was 6,750 UAH, which indicated an increase in the value of gross production by 1.3 times compared to the existing state. For the soils damaged by the hostilities, the introduction of a five-field fodder crop rotation and a seven-field field crop rotation helped restore their fertility and increase crop yields.

In a five-field crop rotation, the cultivation of perennial grasses for green fodder and annual grasses for silage (total yields of 150 cwt/ha + 120 cwt/ha = 270 cwt/ha) generally led to a 30 cwt/ha increase in yield compared to the existing economic indicators (130 cwt/ha + 110 cwt/ha = 240 cwt/ha). Comparison of oat yields showed an increase of 18 centners per hectare. The cultivation of corn for silage and corn for green fodder resulted in a total yield of 460 cwt/ha (230 cwt/ha + 230 cwt/ha = 460 cwt/ha, respectively), which is 100 cwt/ha more than the previous crop rotation (170 cwt/ha + 190 cwt/ha = 360 cwt/ha). As a result, the yield of fodder roots and annual grasses for green fodder increased by 110 c/ha (450 c/ha + 120 c/ha = 570 c/ha) compared to the previous crop rotation (350 c/ha + 110 c/ha = 460 c/ha). Oats with perennial grasses increased soil fertility and restored soil structure.

In a seven-season crop rotation, the introduction of perennial grasses increased fertility and improved soil structure, reducing erosion. Winter wheat cultivation ensured efficient use of moisture and higher yields by 9 cwt/ha compared to the previous crop rotation, while sugar beet yields increased by 25 cwt/ha. Potato and grain corn yields increased by 55 c/ha (170 c/ha + 29 c/ha = 199 c/ha) compared to the previous year (120 c/ha + 24 c/ha = 144 c/ha). The introduction of annual grasses, legumes and buckwheat helped to provide the soil layer with organic residues, increase the biological nitrogen content and the development of soil microflora, and increase their yield by 28 c/ha (120 c/ha + 30 c/ha + 19 c/ha = 169 c/ha) compared to the previous figures (110 c/ha + 18 c/ha + 13 c/ha = 141 c/ha). A summary of the results of the design decisions is presented in Table 5.

Table 5. *Technical and economic indicators of the project*

	Indicators	Measurement unit	At the time of drafting	By the project
1	Total area of the village council	ha	1,063.3	1,063.3

Table 5. Continued

	Indicators	Measurement unit	At the time of drafting	By the project
2	PRC "Victoria Square"	ha	871	871
	including agricultural land	ha	858.8	858.8
	of them arable land	a	759	759
	pastures	ha	99.8	99.8
3	Number of crop rotations	pcs.	-	2
	including the aft five-point	ha	-	149.6
	field seven-point No. 1	ha	-	609.4
4	Crop production, per 1 ha of arable land	UAH	5,364	6,750

Source: *compiled by the authors*

Thus, the cost of crop production under the implemented project increased by 1,386 UAH compared to the economic indicators of the previous crop rotation, which indicated an increase in production costs and improved product quality. In addition to crop rotation planning, additional soil remediation methods such as phytoremediation to reduce heavy metals and organic fertilisation to combat soil compaction should be considered for the land in the Mykolaiv region that has been affected by the war. The hostilities in Mykolaiv region have contaminated almost 100,000 m^2 of soil (Tkach, 2023). Chemical contamination results from the leakage of fuel, combustion products that can settle on the ground from the air, and toxins from explosives in shells. However, ammunition explosions can cause not only chemical contamination but also mechanical contamination. The blast wave can lead to erosion and soil compaction in the area of agricultural land. Due to the effects of the blast wave, the fertile soil layer can be removed, its structure and composition can be altered, and vegetation and microorganisms that ensure its fertility can be destroyed. This can cause serious soil depreciation and make it difficult to restore the soil.

To reduce the concentration of mobile forms of heavy metals (cadmium, lead, copper, zinc, chromium, nickel), it is proposed to use a special fertilisation system by applying molasses dunder, which can detoxify heavy metals. Molasses dunder can be useful for combating soil over-compaction and heavy metal contamination of soils. It contains organic substances such as nitrogen, phosphorus and potassium, which nourish the soil, maintain its fertility, stimulate plant growth and can reduce heavy metal concentrations in the soil through phytoextraction or phytoremediation processes. The results of the study identified patterns and trends in the change of field moisture under the influence of various factors. Soil moisture plays a crucial role in the physiological processes and development of plants. Ensuring optimal moisture levels is critical for plant organogenesis and growth. The dynamics of field moisture in sod-podzolic soils of Mykolaiv region was studied and the effect of molasses bards and mineral fertilisers on this process was investigated.

In 2023, warm January and February were recorded, which facilitated fieldwork in April and May. July was the period with the highest air temperature (+20.7°C), but in general, the year was marked by predominantly dry weather with precipitation of 352 mm. Table 6 shows the results of the study of the effect of molasses dunder on changes in field moisture and density of soddy-loamy soil.

Table 6. *Influence of molasses dunder on the dynamics of changes in field moisture and density of soddy-loamy soil*

Variant	Soil layer, cm	May		June		July		August	
		P	W	P	W	P	W	P	W
Control (without fertilizer)	0-20	1.51	23.71	1.5	23.92	1.52	24.13	1.52	26.73
	21-40	1.56	23.5	1.6	23.92	1.63	24.02	1.55	25.75
Dunder – 10 t/ha	0-20	1.55	23.75	1.54	24.13	1.57	24.19	1.51	31.83
	21-40	1.53	23.52	1.71	24.76	1.71	24.78	1.83	27.71
Dunder – 20 t/ha	0-20	1.69	24.11	1.73	24.56	1.75	24.59	1.74	33.89
	21-40	1.7	24.03	1.84	24.34	1.85	24.35	1.75	21.9
Dunder – 30 t/ha	0-20	1.61	24.08	1.62	24.66	1.63	24.71	2.15	35.62
	21-40	1.64	24.32	1.69	23.98	1.71	24	1.49	31.29
$N_{90}P_{70}K_{170}$ – equivalent to 10 t/ha	0-20	1.63	24.06	1.58	24.32	1.59	24.29	1.93	26.18
	21-40	1.65	24.01	1.85	24.32	1.84	24.31	1.89	24.21

Note: *P – soil density, mg/cm^3; W – field humidity, %*
Source: *compiled by the authors*

The application of molasses dunder in different doses had a significant effect on the density of soil composition. In June, the variant with 10 t/ha of dunder was marked by an increase in field moisture by 0.04% compared to the control. In July and August, the application of dunder proved to be more effective, contributing to an increase in field moisture to 24.71%, providing additional soil moisture. In May, the application of 20 t/ha of dunder showed a decrease in the density of soddy-weak podzolic soil by 0.18 mg/cm^3 compared to the control. When applying 30 t/ha of dunder, the results showed a decrease in density by 0.08 mg/cm^3 compared to the control. A comparison with N90P70K170 mineral fertiliser in an equivalent dose showed the latter to be superior in terms of soil density. The study showed an important influence of molasses dunder on the dynamics of field moisture and soil density in sod-podzolic soils of southern Ukraine. The application of dunder has proven effective in increasing field moisture and reducing soil density, making it more suitable for crops. Measures to overcome the negative effects of chemical pollution should be aimed at restoring the fertility of damaged arable soils. The cultivation of giant miscanthus (*Miscanthus giganteus*) on reclaimed soils is recommended, which cleanses and improves soil structure and fertility, as well as reduces pollution or restores natural ecosystems after pollution. *Miscanthus giganteus* is used to remediate marginal and contaminated land.

Such a drought-resistant energy crop as miscanthus giganteus does not require annual ploughing for 25-28 years on the soils of the Ukrainian Forest-Steppe and grows without the use of plant protection products and fertilisers. The study noted that the plant can provide relatively cheap energy raw materials in the amount of 17-25 t/ha of dry weight already in the third year of cultivation (Damaged fields will..., 2022). A promising way to improve soil fertility is to apply organic fertiliser made from molasses dunder, a waste product of sugar production at sugar factories. Its composition is rich in organic substances that contribute to the accumulation of nitrogen, phosphorus, potassium, and important trace elements in the soil and restore soil fertility. Dunder molasses also has a positive effect on soil deoxidation. Thus, the choice of a strategy for remediation of contaminated soil using miscanthus giganteus culture and organic fertiliser in the context of chemical contamination is a promising solution for soil clean-up. Miscanthus giganteus is known for its ability to perform phytoremediation, meaning that it can absorb toxic substances from the soil through its roots and destroy them or accumulate them in its tissues. The use of organic fertilisers can promote plant growth and health by improving their phytoremediation ability and providing the necessary nutrients for their development.

DISCUSSION

Analysing the results of the study, it can be concluded that soil pollution as a result of hostilities has harmed natural ecosystems. The ecocide carried out by the aggressor state has destroyed the top fertile soil layer, which has been formed over centuries. Soils lose their fertility due to changes in physical, chemical and physicochemical properties.

This study determined that soil compaction caused by the movement of heavy machinery and vehicles had damaged its structure and degraded the soil environment. A similar issue was addressed by M.R. Shaheb *et al.* (2021). They obtained results that showed that soil compaction increased its bulk density and strength, decreased soil porosity and hydraulic properties, slowed the growth of crop roots, and reduced yields by up to 50% or more, depending on the amount and degree of soil compaction. The statement of the researchers is noteworthy, as delayed root growth reduces the efficiency of plant nutrients and water uptake, which in turn leads to lower crop yields.

The study determined that the introduction of annual grasses, legumes and buckwheat increased the content of nitrogen and organic matter in the soil. A similar problem was addressed by B.G. Jothilakshmi and J. Sivanantha (2024). Their study determined that the use of a legume crop rotation significantly improved soil conservation and increased nitrogen availability for other plants. This statement is noteworthy, as legumes are indeed able to enrich the soil with atmospheric nitrogen through symbiosis with nitrogen-fixing bacteria of the genus Rhizobium, thereby improving soil fertility for subsequent crops (Dymytrov *et al.*, 2023).

The study determined that the introduction of molasses dunder contributed to the increase of soil fertility, as molasses contained a significant amount of nutrients such as nitrogen, phosphorus, potassium, and trace elements. A similar issue was addressed by W. Hua *et al.* (2020). Their study found that the use of organic fertilisers increased the efficiency of nitrogen use, contributing to improved fertility and higher yields. This statement is noteworthy, as the use of organic fertilisers increases the number and diversity of microorganisms in the soil, which improves its structure and contributes to better moisture and nutrient retention (Yerzhanova *et al.*, 2021).

The study determined that the diversification of potato crop rotation with corn for grain had a positive impact on the restoration of soil damaged by the war. A similar issue was studied by M. Zong *et al.* (2024). Their study found that diversification of maize with winter rye halved nitrate leaching, increased soil carbon and nitrogen stocks, and improved the stability and productivity of maize yields compared to monoculture. Similar results were obtained in this study, which showed that potato and corn yields increased by 55 cwt/ha compared to the previous crop rotation.

As determined, corn for grain was an excellent precursor for the growth of legumes. A similar issue was raised by J. Hirzel *et al.* (2023). Their study shows that maize was the best previous crop to increase the yield of rapeseed and beans. In this study, similar conclusions were obtained, according to which a significant increase in the yield of legumes (beans) was found, which amounted to 30 c/ha under the condition of preliminary cultivation of corn. As noted, the use of crop rotation with legumes increased the content of biological nitrogen and improved soil fertility (Poliovyi *et al.*, 2023). A similar issue was studied by Á. Carrascosa-Robles *et al.* (2023). According to the results of their research, four legume cultivation systems with crop rotation and their combination with intercropping increased purslane production and soil enzymatic activity. The conclusions of the researchers are noteworthy, as this system contributes to improving soil structure, increasing the content of organic matter and microorganisms that restore soil fertility.

As demonstrated, potatoes and winter wheat used as previous crops were more productive than a legume crop such as peas (Vinyukov *et al.*, 2022). The study was conducted by P.A. Ooro *et al.* (2020). Their study results recommended the use of hyacinth beans *Dolichos lablab* (*L. purpureum*) and green peas as previous crops, as they proved to be more productive than potatoes or wheat. The results obtained in the present study contradict the findings of the researchers, which may be due to differences in agronomic practices such as sowing dates, crop density, pest and disease control methods, and the use of fertilisers and irrigation.

As recorded, when sugar beet and winter wheat are grown in a crop rotation, higher yields are obtained compared to grain corn. This issue was addressed by B. Boincean and D. Deny (2019). They determined that the yields of winter wheat and sugar beet in crop rotation were higher than those of corn and sunflower grown in continuous sowing. Similar conclusions were reached in this study, as it showed a high yield of sugar beet (345 c/ha), which is 316 c/ha more than corn.

The study determined that the introduction of winter wheat, spring barley and oats into the crop rotation had a positive effect on the yield of corn for silage. A similar issue was studied by E. Dube *et al.* (2023). The results of their work revealed that the inclusion of winter cover crops in maize production systems significantly improved soil organic matter content. The statements of the researchers are noteworthy, as winter crops have a strong root system that helps to store carbon and other organic matter in the soil, increasing its fertility.

The study determined that the use of phytoremediation technologies and the use of the giant miscanthus plant is important for improving the environment and human health. H. Haller *et al.* (2023). Their study revealed that the amaranth plant (*Amaranthus hypochondriacus*) can effectively extract cadmium (Cd) from the substrate even at low Cd concentrations (2 mg Cd kg per 1 kg dry weight), accumulating a significant amount of this metal in its aboveground biomass, in particular in stems and leaves. This statement is noteworthy since amaranth is indeed a well-known "hyperaccumulator" capable of actively absorbing heavy metals and partially accumulating them in its underground and aboveground parts.

To remediate the contaminated soil, it was decided to use the giant miscanthus culture and organic fertiliser (Donchak & Shkvaruk, 2024). A similar issue was studied by A. Tennakoon *et al.* (2024). Their study revealed the following reduced levels of heavy metal contamination in soil and water, which indicated the success of phytoremediation technologies. The results of the study by the researchers are noteworthy, as the use of green plants can help maintain soil cover, reducing the risk of erosion and loss of soil fertility. The study determined that the strategy of phytoremediation, and particularly the cultivation of giant miscanthus, was effective in reducing soil contamination with heavy metals. This problem was addressed by F.U. Rasool *et al.* (2023). Their research has shown that species of hyperaccumulator plants from the *Brassicaceae* family can actively accumulate heavy metals from the soil in their tissues. While agreeing with this statement, it should be noted that the opinion of the researchers is correct, as species of the *Brassicaceae* family, such as rutabagas and various types of mustard, can indeed demonstrate a high capacity for heavy metal accumulation.

As determined, the use of miscanthus in conditions of chemical contamination was an effective solution for soil purification. This issue was investigated by L. Wechtler *et al.* (2024). They present the results, according to which the joint cultivation of miscanthus and white clover increased the microbial biomass, and fungal density and stimulated the degradation of the bacterial population. The results of a study by the researchers are noteworthy, as an increase in microbial biomass and fungal density may indicate changes in the soil ecosystem that may be favourable for plant growth and soil nutrients.

As determined, the use of the giant miscanthus culture and the organic fertiliser under molasses contributed to the retention of soil moisture. This issue was studied by Z. Zgorelec *et al.* (2020). Their study determined that miscanthus is suitable for phytostabilisation and biomass production on soils contaminated with cadmium and mercury. This formulation of the researchers' conclusions is noteworthy, as the use of this plant can be useful for cleaning up contaminated soils, as well as for producing biomass that can be used as a source of energy or biofuel.

The study established that the use of miscanthus culture is effective for growing on damaged soils of the forest-steppe of Ukraine. This topic was studied by R.A. Newton *et al.* (2024). According to the results of the research, miscanthus biomass had high potential as an energy crop for reclaiming marginal lands and as an alternative energy source for climate change mitigation. The opinion of the researchers is noteworthy because miscanthus can be grown without the use of chemical fertilisers, and this plant can absorb carbon during its growth, helping to reduce greenhouse gas emissions.

As determined, phytoremediation technology contributed to the restoration of soil fertility. R. Thakur *et al.* (2022) addressed this issue. Their work demonstrated that the use of phytoremediation reduced the concentration of heavy metals in the soil by restoring their biologically active states. The conclusions of the researchers are noteworthy, as an important advantage of this remediation strategy is that this process is natural and contributes to the restoration of ecological stability and soil system functions without active interference with the natural landscape.

The study determined that the application of molasses dunder is effective in increasing field moisture and reducing soil density. This issue was addressed by S. Assefa and S. Tadesse (2019). Their research showed that organic fertilisers are superior to synthetic fertilisers, so they recommend the use of natural or combined fertilisers. The recommendations of the researchers are that the use of organic fertilisers helps to preserve soil properties and increase its fertility. As determined, the combination of giant miscanthus culture and organic fertiliser was an effective solution for cleaning the soil from heavy metal contamination. A similar topic was studied by E. D'Amours *et al.* (2021). The results of their research showed that the inclusion of a perennial cereal-legume forage mixture in a crop rotation with barley led to the accumulation of significantly higher nitrogen reserves in the soil in the 0-50 cm profile compared to a cereal monoculture. The results of my study did not coincide with the findings of the researchers, as they analysed the impact of molasses bards and mineral fertilisers on the process of changing field moisture in sod-podzolic soils.

The study found that the nitrogen, phosphorus and potassium contained in the molasses dunder are favourable substances for soil fertilisation. A similar topic was studied by M.J. Hawkesford and S. Griffiths (2019). Their study showed that genetic variation can improve the ability of plants to assimilate nitrogen from the environment, which leads to increased yields and reduced nitrogen losses. The conclusions of the researchers are noteworthy, as improving the ability of plants to assimilate nitrogen can indeed be achieved through the selection and development of plant varieties or hybrids with improved genetic properties. This section reviewed the literature and considered studies on soil compaction caused by heavy machinery and vehicles, and the impact of various agronomic practices, such as crop rotation, organic fertilisation, and phytoremediation technologies on soil fertility and crop yields.

CONCLUSIONS

The study found that in active military operations in the Mykolaiv region, the implementation of the project to introduce new crop rotations at PRC "Victoria" contributed to improving soil quality and increasing crop yields. The cost of crop production per 1 ha of arable land in the previous crop rotation was 5,364 UAH, while according to the new project, it was 6,750 UAH. Thus, the cost of crop production under the project increased by 1,386 UAH per hectare of arable land, which indicated positive changes in economic indicators and increased production efficiency.

As a result of analysing the impact of molasses dunder on the dynamics of field moisture and soil density in sod-podzolic soils of southern Ukraine, it was found that the application of molasses dunder is effective in increasing field moisture and reducing soil density. In particular, the application of molasses dunder in July and August contributed to an increase in field moisture by 24.71% compared to the control. The composition of the molasses dunder is rich in organic matter, which resulted in the accumulation of nitrogen, phosphorus, potassium, and important trace elements in the soil and the restoration of soil fertility. To improve soil fertility in the Mykolaiv region, it is recommended to grow giant miscanthus and apply organic fertiliser under molasses in conditions of chemical pollution. In the review of studies of chemical contamination with heavy metals in the Mykolaiv region, it should be noted that some data on crop yields are not available for analysis or that it is impossible to collect data due to hostilities.

Further research into the factors that affect soil quality and crop yields in the Mykolaiv region could include a detailed study of the impact of new crop rotations and organic fertilisers on the region's ecosystems, an analysis of the impact of different climatic conditions on the productivity of growing miscanthus giganteus and other crops, and the development of recommendations for optimal agronomic measures to maintain and restore soil fertility in the area of active hostilities and after their completion.

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CONFLICT OF INTEREST

None.

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Відновлення родючості ґрунтів, ушкоджених війною, для забезпечення сталого агровиробництва, продовольчої безпеки та світового визнання України

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Анотація. Дослідження необхідності впровадження нових агротехнологічних сівозмін являється актуальним в контексті охорони навколишнього середовища. Метою дослідження є вивчення ефективності введення двох рослинницьких сівозмін на деградованих землях в Миколаївській області, де проводились активні воєнні дії. По результатам дослідження виявлено, що впровадження нових сівозмін призвело до збільшення валової продукції в 1,3 рази порівняно з попередніми даними. У п'ятипільній сівозміні вирощування багаторічних трав на зелений корм разом з однорічними травами на силос відновило родючість ґрунту та збільшило врожайність на 30 ц/га порівняно з існуючими економічними показниками. Врожайність вівса з підсівом багаторічних трав зросла на 18 ц/га. Вирощування кукурудзи на силос та на зелений корм забезпечило додаткові 100 ц/га. Збільшення врожайності кормових коренеплодів та однорічних трав на зелений корм на 110 ц/га свідчило про ефективність нових сівозмін. У семипільній сівозміні введення багаторічних трав збільшило родючість та зменшило ерозію ґрунту, а також підвищило врожайність озимої пшениці та цукрового буряка. Врожайність цукрового буряка збільшилась на 25 ц/га, картоплі та кукурудзи на зерно зросла на 55 ц/га. Введення однорічних трав, зернобобових та гречки сприяло підвищенню врожайності на 28 ц/га. Результати дослідження можуть бути використані місцевими громадами з метою розробки та впровадження екологічних заходів та програм, спрямованих на відновлення структури та родючості пошкоджених земель та збереження їх якості

Ключові слова: сівозміна; рослини; ущільнення; барда мелясна; органічні добрива; фіторемедіація

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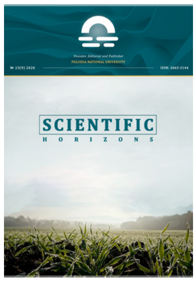

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Development of innovative processes in the field of agriculture of the Republic of Kazakhstan

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Abstract. Agriculture remains an important component of Kazakhstan's development, creating a significant part of the country's GDP. However, it still requires finding new opportunities to increase the efficiency of its functioning. Thus, the purpose of the work was to analyse the possibility of developing agriculture in the Republic of Kazakhstan, namely, with the help of innovations. The main method used in writing the article can be considered modelling, taking into account the number of models of functioning of

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state regulation in the country built in the work to improve innovation processes in the country. Other methods include analysis, induction, comparison, and others. This paper substantiates the need to improve state regulation in the field of innovation in agriculture of the Republic of Kazakhstan, and also describes the likely directions of development in this direction. In connection with the existing shortcomings in the management system, models of state support for enterprises in the agricultural sector were developed and proposed for the development of innovation in the industry. The presented models provide the possibility of using modern tools for regulating processes, taking into account a systematic approach, which ensures the coordination of actions of the relevant authorities to ensure both private and national interests. The main difference between the models proposed in the work and those existing in the Republic of Kazakhstan is the presence of a single centre that is fully responsible for the development of agriculture at the local and national levels, and ensures the achievement of an increase in innovation in it. Thus, the work allows re-evaluating the existing methods of agricultural development, and also brings new knowledge to the formation of the principles of public administration

Keywords: economy of Kazakhstan; state regulation; management; entrepreneurship; agricultural sector

INTRODUCTION

The development of innovative processes in the field of agriculture in the Republic of Kazakhstan is of paramount importance due to the country's vast arable lands and its significant potential for agricultural production. Innovations in agricultural practices, including the adoption of advanced technologies for crop cultivation, livestock breeding, and efficient water management, have the potential to substantially increase productivity, sustainability, and competitiveness in both domestic and international markets. Furthermore, given Kazakhstan's strategic position as a major player in the Eurasian food market, the advancement of agricultural innovation not only supports food security within the nation but also contributes to global food supply chains. This emphasis on innovation is crucial for addressing the challenges posed by climate change, resource scarcity, and the need for environmentally sustainable farming practices, ensuring that Kazakhstan can achieve long-term economic growth and maintain its natural resources for future generations.

The effective functioning of state institutions that carry out regulation is one of the components of sustainable economic and social development. In general, state regulation is the activity of the state in managing processes in any industry or component of the economy with the help of specialized executive authorities and local governments (Lowatcharin, 2021). The methods used by the authorities in this regard may be direct or indirect. In fact, this activity is the formation of influence on the part of the state through the organization of the implementation of laws for the implementation of a managerial function; it must ensure the comprehensive cultural and socio-economic development of the state. In turn, public administration in the field of innovation is the implementation of the management and control function for innovative activities in a country, industry, within a corporation, company, etc. (Rocha & Zavale, 2021).

State regulation of the agricultural sector in terms of innovation is an important component of the development of the industry, since without the introduction of the latest technologies it is impossible to achieve a sufficient level of competitiveness when selling the asset in foreign markets (Bjerke & Johansson, 2022). However, this component of the agricultural sector in many countries, including Kazakhstan, is in limbo, which is caused both by the instability of macroeconomic indicators, the general political and economic instability in the world, as well as the frequent change of priorities in public administration (Gallardo & Sauer, 2018). The modern complication of the agricultural sector in the Republic of Kazakhstan creates an urgent need for a comprehensive analysis of modern management and control in the sector by the state apparatus. Thus, in this paper, it was decided to consider what methods to improve the level of state regulation in the field of innovation in agriculture can be applied in Kazakhstan.

A significant number of scientists have been studying this and similar topics. G.U. Akimbekova and C.U. Akimbekova (2019) not only studied the prospects for the development of agriculture in Kazakhstan, particularly its condition in rural areas, but also highlighted the critical role of government support and policy in enhancing agricultural productivity and sustainability. G.K. Kurmanova *et al.* (2019) assessed and considered the current state of modernization of the agricultural sector in Kazakhstan, describing future promotion possibilities, and emphasized the importance of integrating digital technologies and smart farming techniques to boost efficiency and output. G. Lukhmanova *et al.* (2019), while advising on the introduction of innovative technologies in the agricultural sector, also pointed out the need for educational programs to equip farmers with the necessary skills and knowledge for adopting these technologies. R.N. Zhangirova (2020), in studying the existing problems in agriculture and focusing on micromanagement, underscored the significance of creating a more robust legal and economic framework to facilitate better cooperation between agricultural producers and technology developers.

Thus, the purpose of the work was to consider and evaluate the most relevant and effective methods for the development of state regulation in the field of innovation in the agricultural sector.

MATERIALS AND METHODS

Modelling can be considered the most important method when writing a paper, in view of a number of models built on the basis of advice and recommendations to describe some of the components of state regulation processes in the Republic of Kazakhstan. They offer methods for changing some of the processes that exist in the public sector of the country in the context of management in general, and in particular in agriculture. For the display of the models written in the work, a graphical method was used. Thus, the models in the work are depicted as blocks (which depict objects that function and act within the system) and direct links connecting them to each other. For building models, the forecasting method has also become important, to assess the impact of the described and proposed methods on the subsequent development of agriculture in Kazakhstan, as well as abstraction, to more clearly build models without taking into account insignificant factors. An important role was also played by abstract-logical methods of research; in particular, the formalization method made it possible to identify the complex structures responsible for state regulation in agriculture using separate blogs and relationships within the model (this was partially already mentioned above when describing the graphical method, but in a different context). For the same purposes, an analogy was used, which made it possible to level out some differences within the model objects, thereby simplifying it. In addition, an important method is analysis, given the significant amount of processed information from various sources. Also, the induction method was used in the work, with the help of which a general opinion was formed about the country's agriculture and its innovative sector based on certain available facts about it; deduction, in turn, was used to a much lesser extent.

Thus, the entire research process can be divided into several stages. First, the general state of the agricultural sector in Kazakhstan was assessed, and in particular, its innovative and investment components, as well as the methods of public administration operating in the country. Subsequently, a study was conducted on the effectiveness of the existing regulatory system. In addition, it was considered how the control and management of the processes existing in agriculture is carried out, what methods of supporting enterprises in the agricultural sector are used. It was also important to analyse the thoughts of other scientists about the possibilities of modernizing agriculture in general and Kazakhstan in particular, which is displayed towards the end of the article. Subsequently, on the basis of the analysed information, methods were developed to change the existing system of public administration; Note that this stage of the study can be considered the most important for the work. Also, based on theoretically substantiated hypotheses on how to increase the efficiency of the existing public administration system in agriculture, 5 different models were built that describe different components of this process. In addition, the reasons for their effectiveness in comparison with existing ones were described and proved. The paper was based on relevant government publications and reports, including the documents from the Ministry of Agriculture of the Republic of Kazakhstan (n.d.), Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (n.d.), Food and Agriculture Organization of the United Nations (FAO) (n.d.), The World Bank (n.d.).

RESULTS

In order to determine further directions for the development of innovations in agriculture, an institutional and organizational framework was formed. model of state regulation of innovation activity based on the studied experience (Xu *et al.,* 2020). It is shown in Figure 1.

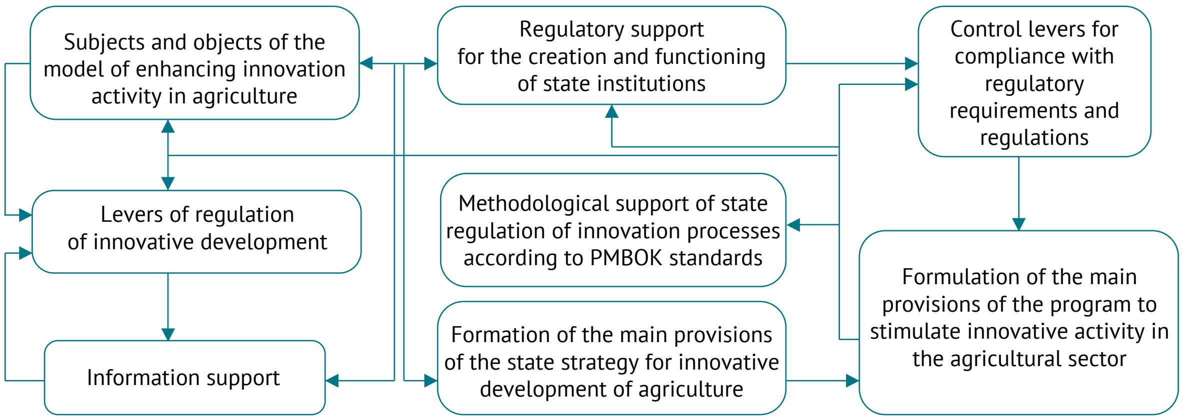

Figure 1. *Institutional and organizational model of state regulation of innovation activities in agriculture*
Source: *compiled by the authors*

Note that the model shown in Figure 1 is depicted taking into account the realities of the regulatory framework in Kazakhstan. In addition, it takes into account possible prospects for its development in the future. Although in the classical thought about the formation of mechanisms of state regulation, it is based only on the creation of a legal component that regulates the procedure and principles of functioning of subjects of state regulation and directly participants in the innovation and investment process, in the model above we take into account the peculiarities of the functioning of state bodies as separate important components of the innovation mechanism. politicians. Thus, the main components of the model are its subjects (bodies of state regulation and control over innovation processes in agriculture) and objects (processes of state influence on the part of authorities on innovation activity and the development of entrepreneurial initiatives in the agricultural sector of the country). The main links between the elements of this system are depicted by solid lines, depicting hierarchical links between them. In turn, the subjects of a single mechanism of public administration can only act in connection with the existing legal framework.

Justification of the state regulation process requires the development of standards and approaches to the introduction of investment incentives, since investments are the main driving force behind the development of innovations. Although this component is present in the existing model of state regulation, the standards themselves are at the stage of formation. In modern world practice, PMBOK (Project Management Body of Knowledge) project management standards developed by the international organization Project Management Institute (2022) have received recognition. It is worth noting that although this system is the most common, it has a significant number of disadvantages and shortcomings in its structure, which still need to be corrected (Elhameed, 2017). The qualitative functioning of the innovative component of the country and each of its sectors of the economy is impossible without the establishment of an investment system in the country. Its main components are shown below in Figure 2.

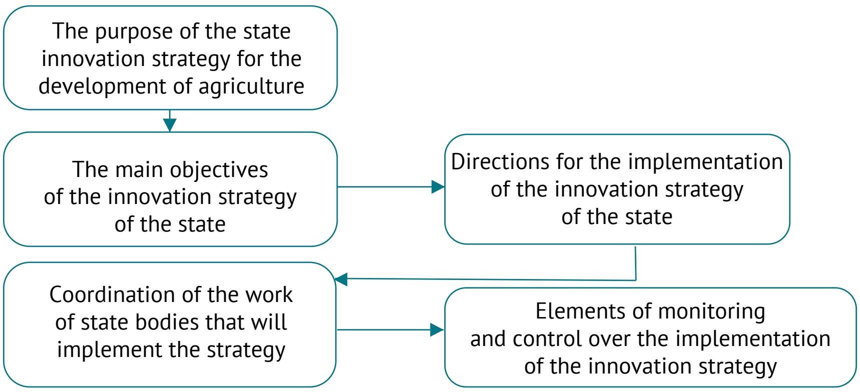

***Figure 2**. Components of the state investment strategy in agriculture and the interaction between them*
***Source:** compiled by the authors*

As can be seen from Figure 2, the main goal of the state investment strategy in the development of agriculture should be the formation of an effective policy for attracting financing to the sector by increasing its attractiveness. In turn, the overall created strategy for the development of the investment climate should be based on the above goal and its objectives. Among the main methods of increasing the attractiveness of the industry for investment, one can note the liberalization of the activities of enterprises, the reduction of regulatory influence, the maximum simplification of business processes (especially for small and medium-sized enterprises), the reduction of tax burdens both on companies and investors, etc. After determination of these methods (tasks), the determination and justification of the application of the most effective mechanisms for their implementation is carried out. It should be noted that this kind of body (responsible for investment development) existed until 2013, and its disbandment brought negative consequences for the subsequent development of agriculture and its competitiveness. Given this, it is worthwhile to provide the specifics of the functioning of the organizational and information mechanisms for the formation of state support based on the provision of consulting services. The algorithm for providing such services is provided below, in Figure 3.

An important role is played by the way in which the administrative mechanism of the system for regulating innovation activity in agriculture functions. In general, the situation that has developed in the Republic of Kazakhstan in terms of the organization of state activities is not sufficiently effective. The main reason for this is its fragmentation. Thus, the organization of state activity consists of state and regional government bodies, executive power and local self-government, having the authority to regulate innovation activities. Thus, their activities in the industry are not controlled in any way, which is why they cannot achieve their goals in terms of the development of innovation in agriculture. Moreover, due to their fragmented activities and inconsistency in achieving goals, they can harm the achievement of the final result through the use of diverse economic and regulatory methods. Thus, it would be useful to create one management centre that regulates the activities of all existing power lines in terms of achieving success in innovative development. This will simplify the process of negotiating many uncertain aspects of future agreements and reduce some administrative costs (Ravazzoli *et al.,* 2021).

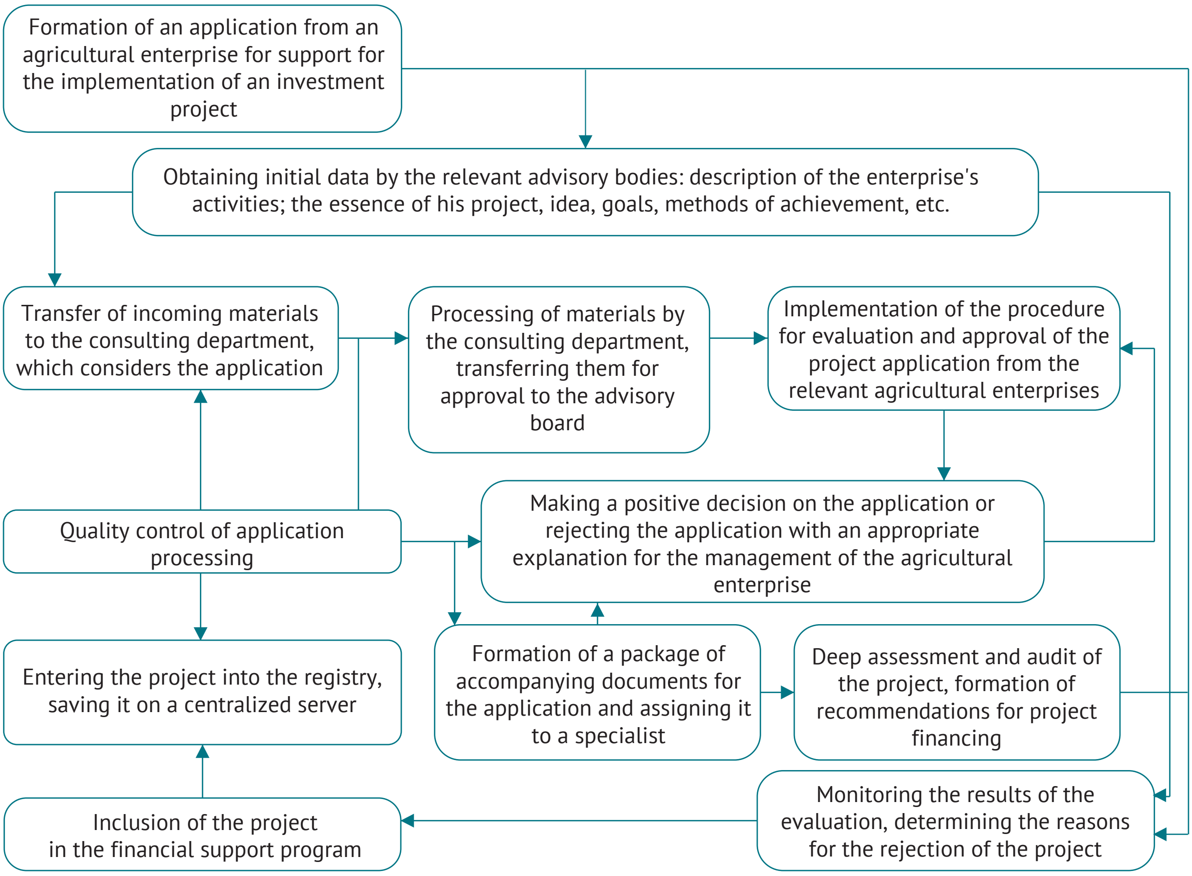

Figure 3*. Models of functioning of organizational and information support for enterprises of the agricultural sector based on the provision of consulting services*
Source: *compiled by the authors*

The algorithm presented in Figure 3 describes how the organizational and consulting support of agricultural projects should take place, following the example of the existing methodology of the Eurasian Bank for Reconstruction and Development (2022). It has modern methods and functionality for reviewing and implementing projects in 9 stages. In this case, the subject of the provision of services is the state body, and the object is the project itself. It should be noted that it is possible to entrust some consulting functions to credit institutions that carry out the project financing procedure (most often banks). Consulting services for the implementation of projects will be requested by the enterprises themselves or individual citizens. Proper handling of their requests is also important in order to increase the efficiency of the body. Thus, it is possible to provide some framework for conducting initial investment advice for clients, executed by the executive bodies. They are provided below in Table 1; authors note that these recommendations are the author's and can be changed in case of demand in this: nevertheless, they are quite basic and effective.

Table 1*. Proposed framework for the work of the state office for advising agricultural enterprises*

No.	Basic organizational foundations	Necessary steps for the implementation of institutional frameworks
1	Formed principles of the structure	Development of the structure of positions, instructions for their work, the formation of tasks for each of them, setting goals, the development of procedures for document turnover, reporting, performance evaluation and other components of the workflow

Table 1. Continued

No.	Basic organizational foundations	Necessary steps for the implementation of institutional frameworks
2	Subordination to the leadership of the state body for investment and development	Development of the work plan of the office and the resolution of the nature of its subordination to the state body for investment and development
3	Availability of information support for the possibility of high-quality and timely reporting	Development and implementation of information support for creating reports, conducting research, building analytical databases and connecting to state statistical databases to access even more information
4	Make it possible to create an electronic user account, as well as streamlining and creating an electronic document management system	Ensuring the systematization of the processes of functioning of the relevant body, developing a website and the possibility of creating electronic cabinets on it, connecting the created cabinet to the centralized database of the relevant leading state body
5	Free opportunity to use the created recommendations for the preparation of nationwide investment programs	Within the framework of the newly created regulations for the work of the relevant state body, provide for the possibility of making proposals for the subsequent state investment policy of the country
6	Establishing direct links and relationships with financial and credit institutions (primarily banks) to attract resources for investment projects	Establish links with financial institutions and create funds to finance selected projects of agricultural producers

Source: *compiled by the authors*

The organizational bases for the functioning of the state body for consulting agricultural enterprises given in Table 1 will make it possible to implement the above-described organizational and information model of state support for agricultural producers. The procedure for support and provision of consulting services should be formed on the basis of processing an application submitted by an enterprise or a citizen. One of the main components of its consideration should be an audit. Thus, after the applicant provides all the necessary data, the advisory board must select a specialist responsible for it, who will conduct an in-depth and high-quality analysis and provide recommendations regarding its financing. In this case, a certain level of riskiness may arise, since there is always a human factor that allows making mistakes when analysing the project, and hence providing low-quality recommendations. Thus, any data provided by the responsible person must be re-evaluated by other participants in the created state body. However, it is worth remembering when the ability of the state to influence the development of the project should be limited, in particular, to directly regulate the nature of their activities, the achievement of goals, etc. (Grovermann *et al.*, 2019).

The main methods of financing such projects can be: subsidies for financing agricultural enterprises, VAT refunds, purchases of products from the manufacturer, the formation of funds to ensure the development of agriculture; ensuring personnel development of agricultural workers. The subsequent development of the project may depend on which of the methods will be proposed by the appointed experts, since they can have a different impact on the project depending on the situation. The same applies to how competently these methods will be implemented. Note that the peculiarity of public management and management as a whole is not able to fully show the effectiveness of these methods and their potential; nevertheless, their rational use will still make it possible to have a positive impact on the country's agriculture as a whole.

Another effective tool for supporting agriculture and its innovation is the formation of special funds, the funds from which will be directed to the development of the industry. The system of functioning of such funds should provide for the main parameters of the system for stimulating investment activity, the main among which is simplified access to relatively inexpensive credit resources. This form of agricultural support is already functioning in Kazakhstan, but it has significant drawbacks and depends on the procedures for financing the state budget. In order to partially neutralize them, we can offer to combine private (bank) financing and state regulation. This system becomes more understandable after considering the proposed model for financing innovation, shown in Figure 4.

The model described in Figure 4 is a logical continuation of the model of support for agricultural enterprises described above. In it, a certain state body forms the preparation of an application submitted by an enterprise or a citizen of the project and, if it meets all the requirements, includes it in the state support program. Already from the beginning of the new budget year for the country, the company will be able to receive appropriate assistance from the state (in the form of tax incentives, loan financing, direct subsidies or other methods). In this case, there should be close ties between the relevant authority and banking institutions (a cooperation agreement has been signed and regulations have been approved within the framework of the state support program). It should be noted that the developed system of financing agriculture with the help of not only the state budget, but also private institutions, leads to budget savings. It can be seen if we consider the model in Figure 5 below.

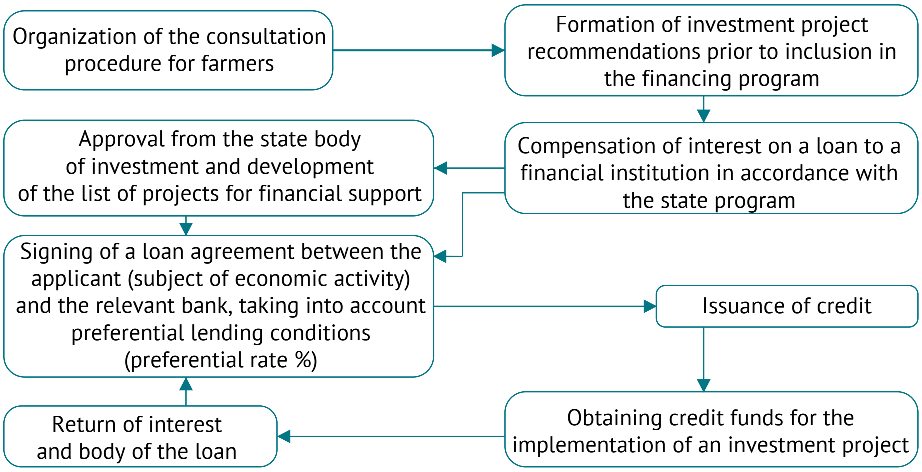

Figure 4. *Model of financing innovative activities based on attracting private (bank) capital*
Source: *compiled by the authors*

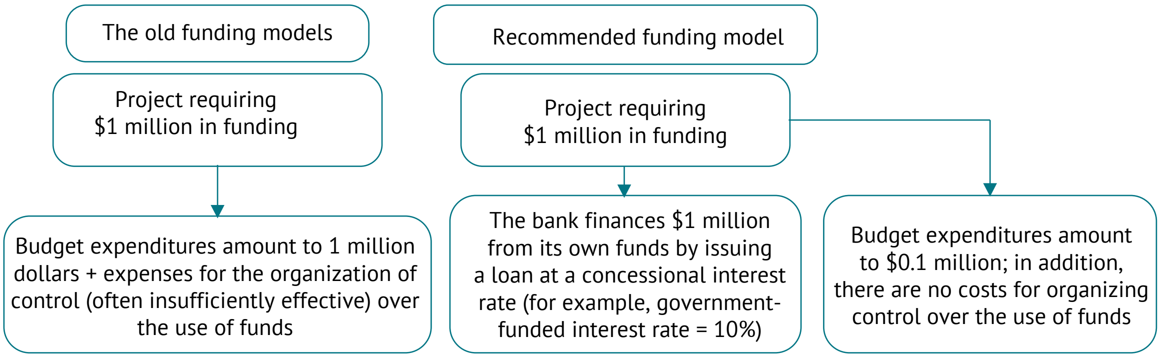

Figure 5. *Description of the benefits from the introduction of the recommended model of financial support for agricultural enterprises*
Source: *compiled by the authors*

Note that the model in Figure 5 of providing financial support is essentially Keynesian (Keynes, 2017), taking into account the newly formed principles of neo-Keynesianism and institutional theory. In particular, this concept is based on the principles of saving private capital in the economic system and an extensive system of state institutions and mechanisms for controlling public spending.

DISCUSSION

Agriculture in Kazakhstan plays an important role for the subsequent development of the country (Akimbekova & Akimbekova, 2019). Therefore, many scientists have considered methods for developing its innovativeness, including those that are different from those related to legal regulation and public administration. In particular, G.K. Kurmanova *et al.* (2019) studied the possibilities for modernizing the agrarian economy in the Republic of Kazakhstan and noted that, although the first steps to achieve certain success in innovation has already been achieved and modernization is the main priority of the state policy of the country, yet the optimization of agricultural production systems of the agrarian sector is at the formation stage. In other words, although the conditions for the development of innovation in agriculture exist, however, significant progress in this area has not been achieved. The authors also note that the development of innovation in agriculture will entail some positive effects in all sectors (for example, the level of development of logistics, transport, wholesale infrastructure will improve; some other industries will also experience a positive impact), as well as a decrease in the influence of negative externalities (reduction of negative externalities, the digital divide between urban and rural areas, improves the quality of life outside the city, ensuring a more rational use of natural resources, and others). Thus, the scientist comes to the conclusion that the subsequent increase in the innovativeness of the agricultural sector is the only possible option for the development of the sector.

Other scientists, in particular G. Lukhmanova *et al.* (2019) conclude that the modern process of modernization of the agricultural sector in Kazakhstan should be carried out taking into account the specific features of the industry. In particular, for the development of agriculture in Kazakhstan, the authors recommend using an integrated approach to innovative modernization. In addition, it is worth developing a clear plan for its implementation, consisting of a certain number of stages. In turn, R.N. Zhangirova (2020) considers the development of agriculture at a smaller level in her work. She notes that one of the main existing problems for the development of agriculture is the processes of interaction between institutions (individual entrepreneurs or scientists, laboratories, educational institutions, etc.) that produce innovative technologies and directly use them in production (directly agricultural companies). Indeed, the process of transferring the rights to use technology can be problematic, especially in the context of existing technologies in the legal framework of the country, its excessive volume and complexity.

Probably, another promising method for improving state regulation methods is the introduction of training programs for specialists in this field, who are sufficiently versed in both the creation of innovative projects and public management (Kryukova *et al.*, 2023). They would be able to provide high-quality qualified consulting support to agricultural companies wishing to increase the efficiency of using their own resources. It should be noted that a similar program was partially implemented in Kazakhstan (and many other developing countries) in 2019 together with the Eurasian Bank for Reconstruction and Development (2022): an outsourcing platform was created that can give advice and support to small and medium-sized businesses for their subsequent development. One of the options for improving this methodology is the creation of regional centres to support agricultural enterprises, in particular, in the application, creation and implementation of innovative projects (Taishykov *et al.*, 2023). In addition, together with the technologies of public administration in the field of innovation policy described in the paper, such training would help to achieve even better results. As noted by L. Biber-Freudenberger *et al.* (2018), due to the existing difficulties in implementing the optimization of investment policy in agriculture in Kazakhstan, there are the need to change the current direction of agricultural development to a larger and longer-term one. One of the main components of this direction should be the introduction of innovative technologies in the industry, the development of domestic and the purchase of foreign latest agricultural technologies (Amanova *et al.*, 2020).

Speaking about state regulation in principle, it is worth noting D. Gashu *et al.* (2019). They wrote that the principles of state regulation of the state are usually reflected in the current legal system in this or that legislation; certain acts. One of the important principles that should be followed when displaying the rules of functioning within the framework of innovation activity is the formation of the same conditions for the development of all property norms (Stepanenko *et al.*, 2023). As G. Gebremariam and V. Tesfaye (2018) write in their work, absolutely all agricultural producers should have the right to conduct activities related to profit and innovative development, while defining their rights in the conduct of this activity and be aware of their obligations. Without creating such basic conditions that guarantee equal conditions for doing business, investment and innovation processes, all attempts to revive agriculture, even with the help of direct state intervention through financing, will not have the desired effect (Luchechko & Gordiichuk, 2023). Note that probably the only exception to the rule regarding the provision of certain types of privileges are small and medium-sized enterprises. The reason for this is their importance for maintaining a high level of efficiency in the functioning of the national economy in any industry, including the innovation aspect, as N.A. Adam and G. Alarifi (2021) wrote about this in their work. Sometimes, as noted by E. Appolloni *et al.* (2020), and in the formation of the principles and laws of innovation activity, the peculiarities of territorial and sectoral development, their combinations can also play.

M. Carroll (2017) wrote about the components of the regulatory legal legislation of the Republic of Kazakhstan in his work. He noted that in the Republic of Kazakhstan it is necessary to improve the regulatory and legal conditions for regulating investment flows; in addition, an important goal is to ensure the balance of relations between the state and the private investor in the system of public-private partnership, to increase the attractiveness of the Republic of Kazakhstan for investments of national and foreign capital in the development of agriculture. The creation of stable legislation could provide state guarantees for the protection of investors over long periods of time, which would improve the investment climate in the country and attract new funds to it, including in the field of investment technologies (Taishykov *et al.*, 2024).

Thus, the main problems hindering the process of development of innovative activity, which were partially mentioned in the work of L.P. Steblyakova (2009), can be noted: the lack of a specific strategy for the development of agriculture, which would be combined with the general economic policy of the state, a low level legal support of innovation, poor coordination of the activities of state administration and local government in terms of supporting and ensuring the development of agriculture, the use of improper sources to raise funds to finance agricultural manufacturing companies and the lack of a system to stimulate entrepreneurial initiatives in agriculture . In turn, based on the recommendations described in the paper and the described models and methods, it is possible to describe the following likely benefits from their use: an increase in innovative activity in agriculture and an increase in financial and investment inflows (both external and internal) into the industry, the creation of a new motivation for agricultural producers, the formation of clear goals and objectives in achieving the modernization of the agricultural sector in the country, the simplification of procedures for obtaining state support for business and changing the methods of its financing, an increase in the number of small and medium-sized enterprises in the country, the establishment of tighter control over banking activities, in particular, in terms of the volume of loans issued and the levels of interest rates, an increase in long-term financing of the industry. And although the methods described in the work do satisfy many of the existing problems described, nevertheless, not all of them can be solved only by changing some of the components of the legislation.

CONCLUSIONS

The paper examined the general state of the agricultural sector in Kazakhstan as a whole, and in particular – in its innovative component. It was noted that although the industry has prospects for the introduction of the latest technologies, and the state is taking appropriate steps in this direction, however, so far one should not expect any quick success. In any case, the state authorities of Kazakhstan will have to carry out significant work in terms of state support, investment attractiveness, legal system and others in order to ensure the innovative development of the agricultural sector in the future.

Thus, in this paper, methods for improving the state of development of agriculture in the Republic of Kazakhstan, namely one of its components, namely innovation, were described and evaluated. It was proposed to create a separate centre for the development of agriculture and its innovative component, which would regulate the relevant processes in the industry at all levels, including local ones. In addition, an effective solution may be the creation of advisory groups that allow the implementation of projects proposed by agricultural companies or individuals, and, if proven to be effective, seek funding for them. In particular, it was proposed to change the main financing model in the Republic of Kazakhstan at the moment: in particular, it is more efficient to use private (primarily bank) capital to support projects of agricultural enterprises. It has been proven that this significantly reduces government costs, as well as increases the effectiveness of the support offered to enterprises, including by reducing the role of management and control by government bodies, which often turns out to be ineffective. It may be promising in further research to find new opportunities for the development of innovation in the agriculture of the Republic of Kazakhstan, as well as to improve or offer one's vision of the models shown in the work for increasing the efficiency of public administration in the country's agricultural sector.

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CONFLICT OF INTEREST

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Розвиток інноваційних процесів у сільському господарстві Республіки Казахстан

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Анотація. Сільське господарство залишається важливою складовою розвитку Казахстану, створюючи значну частину ВВП країни. Однак воно все ще потребує пошуку нових можливостей для підвищення ефективності свого функціонування. Таким чином, метою роботи було проаналізувати можливості розвитку сільського господарства в Республіці Казахстан, зокрема, за допомогою інновацій. Основним методом, використаним при написанні статті, можна вважати моделювання, враховуючи кількість побудованих в роботі моделей функціонування державного регулювання в країні для вдосконалення інноваційних процесів в країні. Серед інших методів - аналіз, індукція, порівняння та інші. У даній роботі обґрунтовано необхідність вдосконалення державного регулювання у сфері інноваційної діяльності в сільському господарстві Республіки Казахстан, а також описані ймовірні напрямки розвитку в даному напрямку. У зв'язку з існуючими недоліками в системі управління розроблено та запропоновано моделі державної підтримки підприємств аграрного сектору для розвитку інноваційної діяльності в галузі. Представлені моделі передбачають можливість використання сучасних інструментів регулювання процесів з урахуванням системного підходу, що забезпечує координацію дій відповідних органів влади для забезпечення як приватних, так і національних інтересів. Основною відмінністю запропонованих в роботі моделей від існуючих в Республіці Казахстан є наявність єдиного центру, який несе повну відповідальність за розвиток сільського господарства на місцевому та національному рівнях, а також забезпечує досягнення підвищення рівня інноваційності в ньому. Таким чином, робота дозволяє переоцінити існуючі методи розвитку сільського господарства, а також привносить нові знання у формування принципів державного управління

Ключові слова: економіка Казахстану; державне регулювання; управління; підприємництво; аграрний сектор

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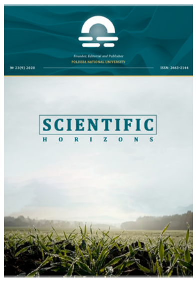

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The role of economics and management in the development of sustainable business models of agricultural enterprises

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Abstract. The relevance of this topic lies in the need to use economic and management strategies that can help agricultural enterprises adapt to a changing environment and ensure sustainable and resilient growth in the future. The purpose of the study was to examine the impact of economic and managerial factors on the development of agricultural enterprises, with a focus on creating sustainable business models.

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The methods used were analytical, statistical, and comparative. The paper examines the role of economics in the formation of sustainable business models of agricultural enterprises, focusing on optimizing the use of resources and adapting to market conditions. It is found that economic aspects include optimization of production processes, cost management and analysis of market trends. Efficient use of resources is a key aspect of sustainable business models of modern agricultural enterprises. The use of advanced technologies, such as precision farming and process mechanization, helps to increase productivity and reduce costs. Management of such market factors includes strategic planning, risk analysis and search for new development opportunities. An example of successful use of innovative technologies in agriculture is given on the sample of the American company John Deere. The article describes the strategy for developing sustainable business models for the Ukrainian company Myronivsky Hliboproduct, which includes the introduction of advanced agricultural technologies, diversification of production, optimization of resource use, development of local markets, improvement of risk management and promotion of social development of local communities. It is noted that the unfavourable conditions of war and economic instability pose serious challenges to the agricultural sector, but such conditions can also stimulate the search for new, more sustainable, and efficient business approaches. As a result, the development of sustainable business models for agricultural enterprises requires a comprehensive approach and systematic measures aimed at optimizing production, managing risks, and promoting the social development of local communities. The practical significance of the study lies in the possibility of increasing competitiveness, resource efficiency and sustainability in a changing market environment, which contributes to the sustainable development of the agricultural sector

Keywords: sustainable business models; management strategies; innovation; social responsibility; waste management

INTRODUCTION

The modern economy requires constant analysis and improvement of management strategies in all sectors of the economy, including the agricultural business. The development of agricultural enterprises in the context of sustainable business models is becoming an important task, given the current challenges and needs of society. The relevance of this area is determined not only by the fact that the agricultural sector is a key player in ensuring food security and economic development, but also by the fact that it faces numerous challenges that require new management approaches. Climate change, limited resources, increasing competition in the market and changes in consumer preferences are just some of the factors that affect the agricultural sector.

The issues that arise in connection with the development of sustainable business models in the agricultural sector are very broad and diverse. It covers economic, social, and environmental aspects, and also takes into account the impact of external factors such as market competition, regulatory policy and innovative technologies. The study of these aspects helps to identify the best strategies and approaches to building a sustainable business in the agricultural sector. One of the key components of the success of sustainable business models of agricultural enterprises is effective management. This includes not only optimizing production processes and resource potential, but also developing strategies for market adaptation, investment planning and risk management. This approach allows agricultural enterprises to adapt to changing market conditions and ensures sustainable growth in the long term.

In order to understand and analyse the role of economics and management in the development of sustainable business models of agricultural enterprises, it is worth considering the opinions of various researchers who have devoted their studies to aspects of agriculture, management and sustainable development. O. Shubalyi *et al.* (2020) focus in their study on the need for efficient use of resources and innovative approaches to ensure the sustainable development of the agricultural sector. They emphasize the key economic principles that contribute to sustainable production and increase the efficiency of agricultural enterprises I. Novak *et al.* (2023), in turn, explore a strategic approach to agribusiness management with a focus on achieving sustainable development. They analyse key aspects of management, such as planning, control, and analysis, which determine the competitiveness of enterprises. A.D. Nugroho and Z. Lakner (2022) pay attention in their study to the impact of economic factors on sustainable production in agribusiness. The authors explore the role of financial management and strategic planning in ensuring the sustainable development of agricultural enterprises. T. Mulyk and Y. Mulyk (2020) consider the importance of innovative technologies in improving the efficiency of agricultural enterprises in their work. They study different types of innovations and their impact on business activities. J.I. Uduji *et al.* (2019) study the impact of social responsibility on the sustainable development of agricultural enterprises in their publications. They analyse the interaction of enterprises with society and the impact of their actions on the social sphere. J. Jägermeyr *et al.* (2021) study the impact of the agricultural sector on the environment and develop strategies to reduce the environmental footprint of agricultural enterprises.

In general, researchers analyse key aspects such as efficient use of resources, strategic management, the impact of economic factors, innovation, social responsibility, and environmental sustainability. However, aspects such as the impact of market and political factors on the sustainability of business models of agricultural enterprises, as well as aspects of risk management and strategies for adapting to changes in the current global environment remain insufficiently studied. The purpose of the study is to conduct a comprehensive analysis of the role played by economic aspects and process management in the formation and further development of sustainable business models of agricultural enterprises.

MATERIALS AND METHODS

The methodology for the study of agricultural enterprises included several key steps aimed at collecting and analysing information to assess their financial sustainability and sustainable development. The initial step was a systematic analysis of specific data on the financial position of agricultural enterprises such as John Deere and MHP. The selected companies play a key role in agriculture and are considered world leaders in their respective industries. John Deere is known for its advanced technologies and innovations in agriculture, while MHP is one of the largest agricultural holdings in Ukraine and represents an important player in the global grain and poultry market. To obtain financial data on these companies, we analysed their financial statements for 2019-2023. To ensure the reliability of the data, we analysed their consolidated financial statements, which are public information and subject to certain reporting standards (2023 Annual Report, 2023; Investor relations & corporate governance, n.d.). This analysis included the study of key indicators such as revenues, expenses, net profit, shareholder value, investments in innovative technologies and social programmes.

To achieve the objectives of the study, various methods were used to assess the impact of factors on the sustainable development of agricultural enterprises in an objective and comprehensive manner. Comparative analysis was used to assess the effectiveness of various strategies and approaches used in the agricultural sector. This method made it possible to compare the performance of enterprises at the local and international levels, identify successful and ineffective practices, and identify key aspects that affect their sustainable development. In order to apply statistical analysis methods, in particular correlation analysis, the relevant financial and strategic indicators that have an impact on the financial performance of enterprises were first selected. After selecting the indicators, the relevant data from the financial statements reflecting the financial activities of the enterprises were collected. The data was then analysed using correlation analysis to establish statistically significant relationships between the selected indicators and the financial result. The analytical approach was used to formulate conclusions and recommendations based on the results obtained. The systematic analysis of the data was carried out considering the theoretical concepts of sustainable development and business models, which allowed understanding their role in the context of achieving successful development of agricultural enterprises. The recommendations were formulated based on the best practices and strategies aimed at improving the sustainability and efficiency of agricultural enterprises in the current environment.

A comprehensive approach was used to develop a strategy for the development of sustainable business models for the enterprise, which included several methods and tools. An analysis of the enterprise's internal factors assessed its current resources, ability to innovate, and level of organizational culture. This analysis allowed us to identify the strengths and weaknesses of the enterprise, as well as the resources that can be mobilized to achieve strategic goals. External factors were analysed, including market trends, the competitive environment, and the regulatory context. This analysis helped to understand the opportunities and threats affecting the company's operations and identify strategic directions for development. In addition, best practices and strategies that promote sustainable development in the agricultural sector were used to develop the strategy. This included studying successful enterprises, analysing their strategies and practical examples of implementing sustainable business models.

RESULTS

The role of economics in shaping sustainable business models for agricultural enterprises is crucial, as the efficient use of resources and the ability to adapt to market conditions determine their competitiveness and viability in the long term. Economic aspects include optimization of production processes, cost management, the ability to analyse market trends and ensure financial sustainability. In addition, sound financial planning and investment strategy allow agricultural enterprises to innovate and introduce new technologies, which helps to increase productivity and reduce negative environmental impacts (Schoneveld, 2020).

Efficient use of resources is an integral part of modern agricultural enterprises that strive for sustainable development. It is an important aspect of sustainable business models that ensures not only economic benefits but also environmental sustainability and social responsibility. Optimizing land use is a key element in ensuring high productivity and efficiency of production. The introduction of modern agricultural technologies, such as precision farming and the use of genetically modified plant varieties, allows for optimal conditions for crop growth and development, which in turn leads to higher yields and reduced losses (Rose *et al*., 2019). Water resource management requires improved irrigation systems, water conservation technologies, and rational use of water resources. Rational use of energy resources is an important component of sustainable development. The introduction of energy-efficient technologies and the use of renewable energy sources helps to reduce energy costs and reduce emissions of harmful substances into the environment. Overall, the efficient use of resources not only contributes to the profitability of agricultural enterprises, but also ensures their sustainability and resilience in the long term. This requires the introduction of advanced technologies, rational management, and a constant search for new approaches to optimizing production.

The financial aspect of the sustainable development of agricultural enterprises covers a wide range of activities that determine their sustainability and competitiveness in the long term. Sound financial planning plays a key role in ensuring efficient use of resources and maximizing profitability. This involves analysing financial flows, setting budgets, and developing strategies to reduce costs and optimize revenues (Fenyves *et al*., 2015). In addition, the use of investments to introduce innovative technologies is an important element of sustainable development. Investments in equipment modernization, introduction of environmentally friendly technologies and product quality improvement allow enterprises to remain competitive and meet modern market requirements. The impact of market forces on the sustainability of agricultural business models is an integral part of their success and sustainability. Changes in supply and demand, price competition, and regulatory restrictions can have a significant impact on the efficiency of enterprises. In this regard, successful agricultural enterprises must have a flexible and adaptive business strategy that allows them to respond quickly to changes in market conditions. This may include seeking new development opportunities, optimizing production processes, and developing competitive pricing strategies. Effective management of these market factors is critical to ensuring business success and sustainability in a constantly changing and unpredictable market environment.

The role of management in the development of sustainable business models of agricultural enterprises includes several key aspects that contribute to the success and sustainability of the enterprise in a changing market environment. Strategic management and planning play a crucial role in the formation and development of sustainable business models of agricultural enterprises. Effective strategic analysis allows enterprises to align their actions with long-term goals and choose optimal development directions, considering both internal and external factors affecting their operations (Donner *et al*., 2020). This allows businesses to adapt to changes in the market environment and respond in a timely manner to emerging challenges and opportunities. Careful planning allows for efficient resource allocation, avoidance of unnecessary costs, and balanced operation of all business units. In addition, it helps to increase labour productivity, reduce production cycle times, and improve product quality, which in turn has a positive impact on the company's competitiveness and profitability.

The use of innovative technologies in agriculture is a necessary step to ensure the sustainable development of agricultural enterprises. Advanced agricultural technologies such as precision farming, process mechanization and digital solutions play a key role in increasing productivity and reducing costs. Precision farming uses modern technologies such as global positioning systems (GPS) and sensors to maximize the use of land resources. This allows for precise dosing of fertilizers and crop protection measures, avoiding over- or under-fertilisation, and reduces costs of inputs such as fertilizers and pesticides (Michels *et al*., 2020). Mechanization of processes simplifies and speeds up production operations, ensuring efficient use of labour and reducing labour costs. The use of modern agricultural machinery, such as tractors, combines and seeders, can increase the speed and quality of agricultural work. The use of digital solutions, such as farm management systems and agricultural drones, helps businesses collect and analyse large amounts of data to make better management decisions. This helps to optimize production processes, increase resource efficiency, and reduce losses.

One example of a company that successfully uses innovative technologies in agriculture is the American company John Deere. This company is one of the leading manufacturers of agricultural machinery and equipment, and implements advanced agricultural technologies in its farm fields and production facilities. John Deere uses GPS systems and precision farming technologies to optimize the use of resources and increase yields. For example, their tractors are equipped with automatic steering systems that allow for precise steering and optimize the location and depth of tillage, minimizing overlap, and over-seeding. This helps to reduce the cost of fuel, fertilizers, and crop protection products, while ensuring optimum yields. In addition, John Deere actively uses digital technologies to monitor and manage production processes. They implement farm management systems that collect and analyse data on yields, soil moisture and other parameters to optimize production decisions. They also use agricultural drones to monitor plant growth and detect pests and diseases, which allows them to respond to problems quickly and efficiently. The company's revenues, net profit, and shareholder value increased significantly in 2019-2023 due to technology (Fig. 1).

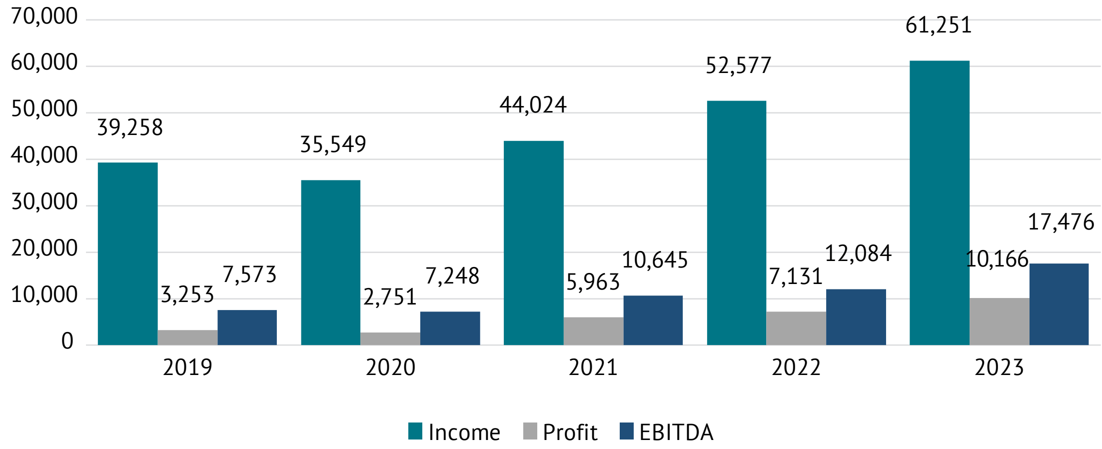

Figure 1. *Financial performance of John Deere from 2019 to 2023, USD million*
Source: *developed by the authors based on data from 2023 Annual Report (2023)*

The table shows that John Deere has shown a steady upward trend in revenue and profit over the past five years. From 2019 to 2023, the company's revenue increased by almost 56%, reaching $61.3 billion in 2023. This demonstrates the success of the company's development strategy and its ability to adapt to market changes. Corporate social responsibility is becoming an increasingly important component of sustainable business models. Active involvement in the development of local communities reflects a company's commitment to its social and environmental footprint. For example, businesses may engage in charitable giving, sponsoring local projects or initiatives aimed at improving the quality of life of residents. Supporting social programmes is also an important aspect of social responsibility. This may include providing social services for employees, such as health insurance, pension plans, and professional support (De Olde & Valentinov, 2019). Such programmes help to improve the quality of life of employees and increase their motivation and productivity. Compliance with labour and environmental standards is also an important aspect of corporate social responsibility. This means creating safe and healthy working conditions for their staff, as well as reducing negative environmental impacts (Zos-Kior *et al*., 2021). For example, businesses can implement energy-efficient technologies, reduce air emissions, and use renewable energy sources.

The state of development of sustainable business models of agricultural enterprises is dynamic and depends on many factors, such as economic conditions, political situation, technological progress, as well as regulatory policies and incentives from the state. The development of sustainable business models for agricultural enterprises in Ukraine, especially since the outbreak of war in 2022, has been subject to serious challenges. The war, accompanied by economic and political instability, has significantly complicated the operating environment of the agricultural sector and its ability to implement sustainable practices. One of the biggest challenges has been the threat to worker safety and reduced production capacity due to the hostilities and population displacement. This has resulted in reduced production, disrupted supplies and loss of access to markets, which has negatively impacted the financial position of many agricultural enterprises. On the other hand, the military events have also encouraged businesses to look for new, more sustainable, and efficient approaches to doing business. Reduced access to imported inputs and markets has forced companies to turn to domestic resources and develop local markets. This can stimulate innovation in the use of land, water, and energy to ensure sustainable production (Nehrey *et al*., 2022). Furthermore, war can also accelerate the process of reforming the agricultural sector, including liberalizing legislation, simplifying procedures and encouraging investment in sustainable business models. State support aimed at supporting agricultural enterprises in this difficult time can play a key role in facilitating their recovery and development.

The case study is a Ukrainian company in the field of food and agro-technologies – the private joint-stock company MHP. The company has significant resources in line with its status as a holding company. This includes large land areas for crops, modern equipment for tillage, cultivation and processing, and a wide network of employees. MHP's organizational culture can be described as high, as it is committed to achieving high standards of efficiency, innovation, and corporate responsibility. MHP demonstrates a high level of innovation capability (Investor relations & corporate governance (n.d.). This is evidenced by their investments in modern technologies to increase production efficiency, such as the introduction of precision farming, the use of high-yielding genetically modified seeds, and improved resource management. Figure 2 shows MHP's key financial indicators for 2019-2023.

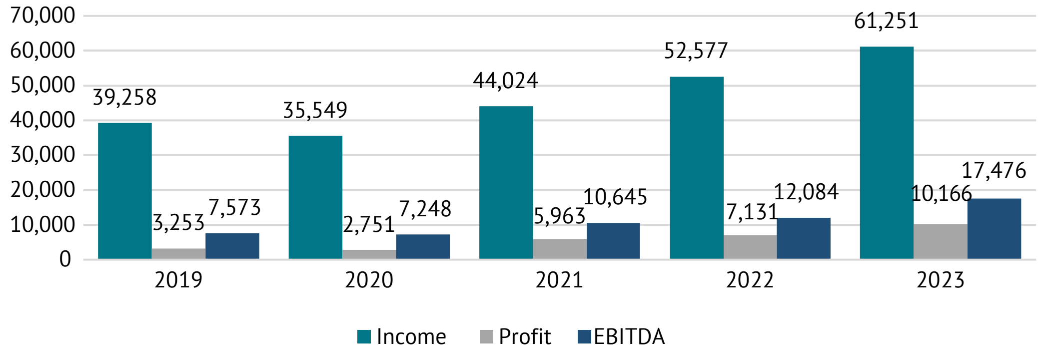

Figure 2. *MHP's financial performance from 2019 to 2023, USD million*
Source: *developed by the authors based on data from Investor relations & corporate governance (n.d.)*

Over the past 5 years, the company has shown significant revenue growth, which indicates its stability and potential for development. However, fluctuations in the level of profits indicate possible difficulties faced by the company in different economic conditions. The sustainability and effectiveness of management strategies that allow the company to adapt to changes in the market and achieve positive financial results in the medium term are important. A strategy for the development of sustainable business models for MHP has been proposed, which includes the following key areas: introduction of advanced agricultural technologies, diversification of production, optimization of resource use, development of local markets, improvement of risk management, and promotion of social development of local communities (Fig. 3).

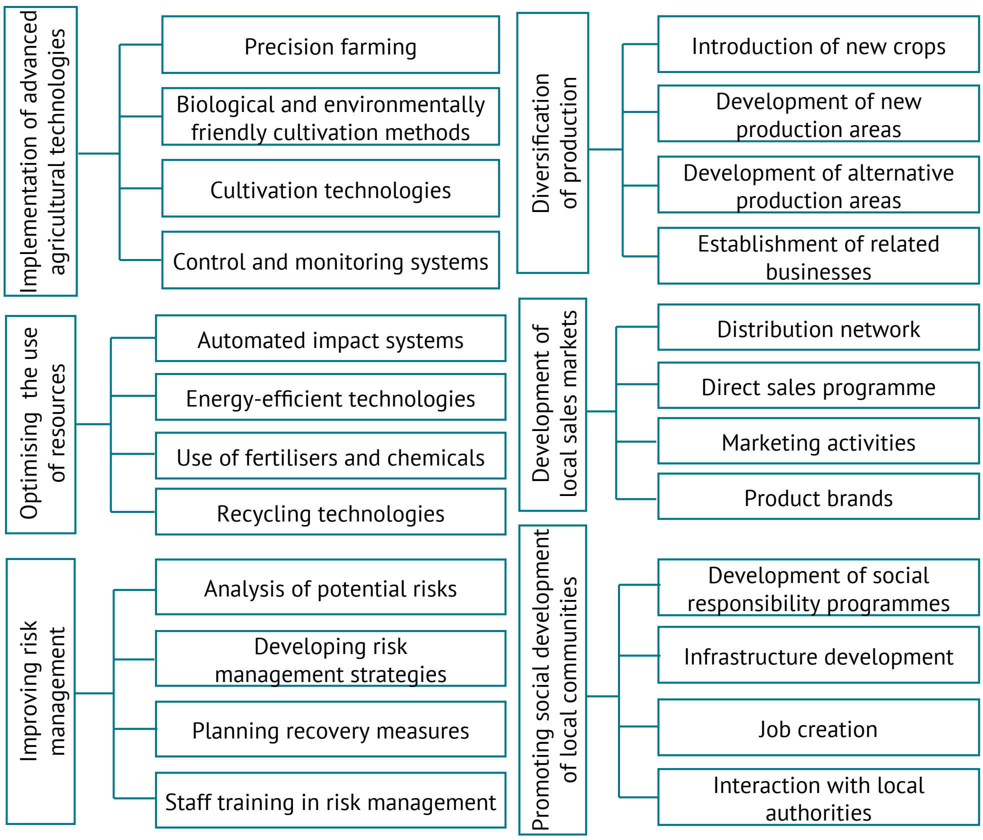

Figure 3. *Strategy for developing sustainable business models for MHP*
Source: *developed by the authors*

Several measures can be considered to introduce advanced agricultural technologies at MHP. Precision agriculture: the use of modern technologies such as geographic information systems (GIS), remote sensing and navigation systems to analyse and optimize the use of land resources. Investing in modern equipment such as seeders with automatic depth control, combines with crop monitoring systems and tillage equipment with automatic control. This allows increasing efficiency and reducing fuel and time consumption. Hydroponics, aeroponics and other advanced methods of growing plants can be used to ensure optimal growth conditions and yields. It is also worth considering the use of artificial intelligence and machine learning to predict plant development and respond to potential problems in a timely manner. Soil, climate, and plant monitoring systems, as well as automated irrigation, fertilizer, and crop protection management systems, should be implemented. This helps to optimize resources and ensures regular control over production. Use of biological plant protection methods and environmentally friendly fertilizers to reduce the environmental impact of agricultural activities.

To implement the strategy of diversifying production, MHP could expand its range of agricultural products by introducing new crops that can be grown at the enterprise. For example, additional types of cereals, vegetables, berries, or fruit trees can help expand markets and reduce production risk. Using land resources for the development of alternative production activities, such as forestry, beekeeping, or energy crops, can help to expand the enterprise's activities and reduce production risk. Considering the possibility of establishing complementary activities, such as agritourism, farmers' markets or the production of raw materials for local processing, can help to reduce risk and dependence on individual crops. To optimize the use of resources, MHP can install modern irrigation systems that automatically monitor soil moisture and meteorological conditions. Energy-efficient equipment and lighting systems can be used, as well as alternative energy sources such as solar panels or wind turbines. The introduction of agricultural waste recycling technologies and their use as sources of additional resources or energy will minimize losses and reduce the negative impact on the environment. The development of local markets includes expanding the sales network at the local level to reduce dependence on foreign markets and ensure stable demand for products. This means actively involving local consumers in the consumption of products, developing marketing strategies to increase brand awareness, and expanding the range of goods and services that meet the needs of local consumers.

Improving risk management involves considering potential challenges, such as natural disasters, economic fluctuations and political instability caused by war, and developing strategies to manage them. This means systematic risk analysis, development of emergency plans and monitoring of risk management measures to reduce the impact of risks on the business and ensure sustainability. Promoting the social development of local communities involves the development and implementation of social responsibility programmes and projects. This may include financial support for local initiatives, infrastructure development and provision of social services. These strategic measures are aimed at ensuring the sustainability and successful development of MHP in the face of war and economic instability. By implementing the above initiatives, the company can seek not only to overcome the dangers and difficulties associated with the unpredictable current geopolitical and economic climate, but also to ensure stability and successful development in the near future.

The results of the study show that the economic aspect plays an important role in the formation of sustainable business models of agricultural enterprises. Efficient use of resources and the ability to adapt to market conditions determine their competitiveness and viability in the long term. Optimization of production processes, cost management, analysis of market trends and financial stability are key aspects that affect the efficiency of agricultural enterprises. As an important component of sustainable development, the economic aspect requires attention to financial planning and investment strategies that allow businesses to innovate and implement new technologies.

DISCUSSION

Efficient use of resources is an integral part of modern agricultural enterprises striving for sustainable development. Optimizing land use, implementing modern agricultural technologies and managing water and energy efficiently helps to increase productivity and reduce negative environmental impact. The role of financial stability and efficient use of resources in ensuring the long-term viability of enterprises is also important. M.J. López-Serrano *et al.* (2021) also aim to analyse the economic aspects of sustainable agricultural development, in particular, cost optimization and financial planning. These authors explore how agricultural enterprises can use their resources and cash efficiently to achieve sustainable development. Cost optimization can include the rational use of raw materials, energy, and other resources, as well as cost management at different stages of production. Comparing with the current study, which also includes an analysis of the economic aspects of sustainable development, we can see some common points. Both studies focus on financial planning and cost management as key components of successful sustainable agricultural development. Both studies look at the efficient use of resources and cash to ensure sustainability and balance in agriculture.

The role of governance in the development of sustainable business models for agricultural enterprises includes several key aspects that contribute to the success and sustainability of the enterprise in a changing market environment. Strategic management and planning play a crucial role in the formation and development of sustainable business models of agricultural enterprises. Effective strategic analysis allows enterprises to align their actions with long-term goals and choose optimal development directions, taking into account both internal and external factors affecting their operations. N. Siebrecht (2020) also studied the impact of strategic planning on the success of implementing innovative solutions in agriculture. He analysed the effectiveness of different strategic approaches, such as horizontal and vertical integration, as well as adaptive management. In addition, he studied the impact of strategic partnerships with other industries, such as technology companies and research institutions, on the creation of innovative solutions in agriculture. The results of this study are similar to the current study in that they also analyse the strategic aspects and impact of innovation on agricultural development. However, the current study is more focused on describing specific strategies and innovations that are considered in the context of sustainable development. The author's study is more general in nature, describing various aspects of strategic planning and innovation in agriculture.

In modern agriculture, innovative technologies are becoming the basis for efficient farming (Hajiyeva *et al.*, 2024). One of the most important technologies that plays a key role in this process is precision farming. Mechanization of processes involves the use of modern agricultural machinery to perform various agricultural operations. For example, modern tractors, combines and other machines can increase the speed and quality of work, reduce labour costs, and improve the management of production processes (Musayeva *et al.*, 2024). The use of farm management software, sensors for data collection, analytical systems for information processing, and other information and communication technologies is also important. The study by K. Takahashi *et al.* (2020) aims to research the impact of innovative technologies on agriculture, their use to increase productivity, and reflects an important aspect of modern agricultural development. The authors examine specific technologies, such as artificial intelligence, blockchain, modern agricultural machinery, and others, and their impact on agricultural production efficiency. Compared to the current study, common aspects can be identified, but the authors' study is more specific and focuses on individual technologies and their impact on specific aspects of production. Whereas, the current study looks at the broader context of innovation in agriculture and its impact on sustainable development.

In their study, M. Tudi *et al.* (2021) analysed the environmental impact of agricultural activities and the supply of environmentally friendly technologies, emphasizing the importance of a balanced approach to agricultural development that takes into account its impact on the natural environment. This research includes analysis of greenhouse gas emissions, soil and water pollution, and the impact of agrochemicals and other chemicals on ecosystems. The current study also examined the effectiveness of technologies such as reducing the use of chemical fertilizers, using alternative energy sources and other initiatives aimed at reducing the negative environmental impact of agricultural activities. The authors focused more on specific aspects of the environmental impact of agriculture and proposed specific technological solutions, while the current study looked at general aspects of environmental responsibility.

Corporate social responsibility is becoming an increasingly important element in the development of sustainable business models (Yatsiv & Cherevko, 2022; Yatsiv *et al.*, 2022). Active involvement in the development of local communities reflects a company's commitment to social and environmental issues. Businesses can make charitable contributions, support local projects or initiatives aimed at improving the quality of life of residents (Polinkevych, 2023). Support for social programmes is an important aspect of corporate responsibility, including the provision of social services to employees, such as health insurance, pension plans and professional support. The study by J. Janker and S. Mann (2020) aims to explore the interaction between businesses and local communities to promote social and economic development. This study examines aspects such as the impact of enterprises on the local economy, job creation, support for social programmes and other initiatives aimed at improving the quality of life of the local population. Similar to the current study, the authors also note the importance of social aspects of sustainable development, such as support for local communities and social programmes. There is a commonality in the approach to studying the social aspects of sustainable development, in particular, the interaction between businesses and local communities, but the authors' study focuses more on specific interactions between businesses and communities.

The study by E. Loizou *et al.* (2019) analyses the impact of political factors on agricultural development and regulatory policy setting, which includes an analysis of legislative and regulatory initiatives established by the government that affect the activities of agricultural enterprises. This includes an assessment of subsidies, tariffs on imports and exports of agricultural products, and environmental and land regulations. The current study does not discuss political aspects directly, but points to the impact of economic and political instability on agriculture. This may mean considering the overall political situation and its impact on the business environment, including the effectiveness of government support programmes for agriculture, the level of investment in the sector, and the degree of stability of legislation and regulatory policies (Matviishyn & Harbarynina, 2023).

In general, the key aspects of sustainable agricultural development, such as economic, managerial, social, environmental, and political factors, were identified. The research results showed that effective cost management, strategic planning, innovation, and partnerships with local communities are key components of sustainable agricultural development. The importance of using environmentally friendly technologies and considering the political influence on the industry was also emphasized. Considering these aspects, it can be said that achieving sustainable agricultural development requires a comprehensive approach that considers various aspects.

CONCLUSIONS

This study analysed various aspects of sustainable agricultural development and their interrelationship with economic, environmental, social, and political factors. In particular, the importance of cost optimization and financial planning, the introduction of innovative technologies, resource, and risk management, as well as interaction with local communities and compliance with social responsibility standards were explored.

The paper highlights the importance of efficient use of resources and rational financial planning as key aspects of sustainable agricultural development. The introduction of innovative technologies has proved to be an effective means of increasing productivity and reducing the negative impact on the environment. It was found that social responsibility and interaction with local communities contribute to the formation of a positive image of the enterprise and ensure its sustainability in the long term. In addition, this study draws attention to the impact of market factors and governance on the success of agricultural business models. Modern agriculture is in a constant state of flux, as the market environment is subject to frequent changes, such as changes in supply and demand, competitive pressures, and changes in regulatory requirements.

Examples of successful companies such as John Deere confirm that the introduction of advanced technologies and social responsibility not only improves production efficiency, but also builds a stable reputation and market positioning. The company's net profit increased from $3,253 million in 2019 to $10,166 million in 2023. The study also led to the development of a strategy for sustainable business models for MHP, which has seen fluctuations in financial results depending on various external and internal factors. The development strategy included a wide range of initiatives, such as the introduction of advanced agricultural technologies, diversification of production, optimization of resource use, development of local markets, risk management and social responsibility.

Further research could focus on the impact of new technologies, such as artificial intelligence, on production efficiency and resource management in agriculture. In addition, an important area of research could be the analysis of the social impact of agricultural enterprises on local communities and rural development.

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CONFLICT OF INTEREST

None.

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Роль економіки та менеджменту у розвитку сталих бізнес-моделей аграрних підприємств

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Анотація. Актуальність даної теми полягає в необхідності використання економічних та управлінських стратегій, що може допомогти аграрним підприємствам адаптуватися до змінного середовища та забезпечити стале та стійке зростання у майбутньому. Мета дослідження полягала у вивченні впливу економічних та управлінських факторів на розвиток аграрних підприємств з орієнтацією на створення сталих бізнес-моделей. Серед використаних методів було застосовано аналітичний, статистичний та порівняльний. У роботі досліджено роль економіки в формуванні сталих бізнес-моделей аграрних підприємств, зосереджуючись на оптимізації використання ресурсів та адаптації до ринкових умов. Виявлено, що економічні аспекти включають оптимізацію виробничих процесів, управління витратами та аналіз ринкових тенденцій. Ефективне використання ресурсів є ключовим аспектом сталих бізнес-моделей сучасних аграрних підприємств. Застосування передових технологій, таких як точне землеробство та механізація процесів, сприяє збільшенню продуктивності та зменшенню витрат. Управління такими факторами ринку включає стратегічне планування, аналіз ризиків та пошук нових можливостей розвитку. Наведено приклад успішного використання інноваційних технологій у сільському господарстві на прикладі американської компанії John Deere. Описано стратегію розвитку сталих бізнес-моделей для української компанії Миронівський хлібопродукт, яка включає впровадження передових агротехнологій, диверсифікацію виробництва, оптимізацію використання ресурсів, розвиток місцевих ринків збуту, вдосконалення управління ризиками та сприяння соціальному розвитку місцевих громад. При цьому зазначено, що несприятливі умови війни та економічної нестабільності створюють серйозні виклики для аграрного сектору, проте такі умови можуть також стимулювати пошук нових, більш сталих та ефективних підходів до бізнесу. Як результат, розвиток сталих бізнес-моделей аграрних підприємств вимагає комплексного підходу та систематичних заходів, спрямованих на оптимізацію виробництва, управління ризиками та сприяння соціальному розвитку місцевих громад. Практичне значення дослідження полягає в можливості підвищення конкурентоспроможності, ефективності використання ресурсів та забезпеченні стійкості в умовах змінного ринкового середовища, що сприяє сталому розвитку аграрного сектору

Ключові слова: сталі бізнес-моделі; стратегії управління; інновації; соціальна відповідальність; управління відходами

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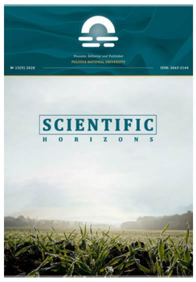

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Prospects for the introduction of a green economy in the agricultural sector of Ukraine for the next 10 years

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Abstract. The relevance of the study is due to the deterioration of the environment and the low level of application of green technologies in the agricultural sector of Ukraine. The aim was to outline the current problems for farmers in the use of green farming methods and to find solutions. The study assessed the level of use of certain green technologies in agricultural production in Ukraine. The main results obtained in this work are: determining Ukraine's place in the Green Future Index ranking in various areas during 2021-2023 and comparing it with Iceland, Finland, and Norway;

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identifying areas of green technologies that need to be developed in Ukraine during martial law and after the war (precision and organic farming, the introduction of biotechnology to create genetically modified organisms and the transition to alternative energy sources). The study of the dependence of farmers' propensity to use green technologies on the size of farming confirms its undeniable presence. The analysis of foreign experience in precision agriculture allowed formulating recommendations for foreign companies entering the Ukrainian market to promote the use of precision agriculture in Ukraine. The findings on the growing electricity shortage helped to justify the further use of alternative energy sources in the context of the conflict. A study of the negative impact of the hostilities on Ukrainian land allowed classifying such types of impact and developing measures to restore the soil. The assessment of the use of technologies in agriculture helped to identify areas for the introduction of a green economy in the agricultural sector in Ukraine, which will help to increase agricultural yields without harming the environment and increase its competitiveness. The results and conclusions have practical implications for the Government in developing agricultural policy and for farmers in managing their farms

Keywords: precision agriculture; agricultural products; innovative technologies; renewable energy; welfare; yield

INTRODUCTION

Over the past 20 years, climate change has been a fundamental global challenge for all of humanity. Every year, environmental damage and global warming become more and more threatening to human health. Climate change affects food security and the survival of humanity. The European course of economic development chosen by Ukraine envisages the approximation of economic development to the principles of a green economy, which means innovative and strategic ways of economic development that take into account the improvement of environmental and social effects that ensure sustainable economic growth. Ukraine's agricultural sector is already actively using green technologies. However, the wartime events, which have become particularly acute since the beginning of the full-scale invasion, have significantly complicated and impeded the improvement of all areas of the country's development. The agricultural sector is particularly affected by the hostilities in the eastern, southern and northern parts of Ukraine, and the agricultural sector as a whole is experiencing financial difficulties, a shortage of workers and other problems. In this regard, it is important to analyse the state of application of green technologies in agriculture and develop proposals for the introduction of a green economy in wartime, which would help to increase the efficiency of agriculture as a leading industry in Ukraine.

It is important to study theoretical and methodological approaches to defining the essence of the concept of green economy in order to substantiate the essence of certain categories and concepts used in the development of measures aimed at identifying the main factors that can bring agriculture closer to the use of green technologies. The study of the essence of the green economy was paid attention to by T. Zinchuk *et al.* (2022), who emphasized that the main idea of the transformation of the national economy after the war is to modernize the economy and implement the principles of its recovery. The study of the green economy in the context of globalization has been paid due attention to by L. Horbach *et al.* (2024) and O. Petrenko (2023), who argue that green technologies that reduce carbon emissions are important for income and employment growth, as well as for increasing public and private investment. In addition, O. Petrenko emphasizes that the government should make decisions that support the improvement of environmental friendliness in the agricultural sector, in particular: support the exchange of knowledge between representatives of different agricultural enterprises.

Due to military events and long-term physical and chemical impact on agricultural land, it is depleted and quite polluted, which necessitates a number of measures to improve soil quality. Research in this area was carried out by I. Smolii and N. Dikhtyarenko (2023), who highlighted that the implementation of the "greening" of the agricultural economy requires the elimination of environmental problems: degradation of agricultural land, pollution of species, and carbon emissions into the atmosphere. However, the studies of the above-mentioned scholars hardly highlight the principles that should be taken as a basis for the application of green technologies in Ukraine. Reducing carbon emissions is one of the ways to achieve a green economy in agriculture as part of the global community's efforts to mitigate climate change (Matyushenko *et al.*, 2022). However, the relationship between innovations in green technologies and carbon emissions' reduction has not been sufficiently studied. Research in this area was conducted by F. Dong *et al.* (2022), who identified the countries (Luxembourg, Norway, and Switzerland) with the lowest emissions and emphasized that innovations in green technologies directly affect carbon efficiency. Conducting research in this area, P.S. Michael (2022) examined available technologies to reduce carbon and pollution emissions and prevent biodiversity loss, and pointed to the specific role of technology in promoting sustainable agriculture to improve rural livelihoods.

The introduction of digital technologies in agriculture spurs increased production, yet it is crucial to consider the unique natural and other characteristics of each region in Ukraine. This perspective is supported by M. Hong *et al.* (2023), who examined the relationship between the digital economy and green agricultural development, analysing the temporal and spatial effects of the digital economy, along with heterogeneity across dimensions and regions. The development of various economic sectors should be grounded in the principle of social responsibility to society. The agricultural sector faces numerous challenges that threaten its long-term sustainability, such as environmental degradation, climate change, and social and economic inequality (Rumiantseva *et al.,* 2022). Addressing these challenges can be guided by a green economy and sustainable development perspective, which offers a framework for fostering agricultural development while preserving natural resources and enhancing social equity in the region. This highlights the significance of environmentally friendly and socially responsible agricultural practices, the necessity for sustainable resource management, and the advancement of renewable energy sources. Research by M. Gavrilović *et al.* (2023) demonstrated that adhering to the principles of a green economy and sustainable development can ensure agriculture remains a vital and sustainable source of economic growth and development for future generations. K. Mehta *et al.* (2022) also explored this issue, examining the economic, social, and environmental characteristics of the sector and identifying significant challenges and opportunities for the green economy in the country.

Despite significant scientific contributions to the implementation of a green economy in the agricultural sector, the methods that can be employed in Ukraine's agricultural sector to enhance the environmental friendliness of crops and digitalize production need further exploration. The study aimed to assess the current state of green technology implementation in Ukraine's agricultural sector and to propose suggestions for its expansion. The primary objectives were to identify the benefits of a green economy for the agricultural sector and determine which areas should be developed for implementation in agriculture.

MATERIALS AND METHODS

The research on this issue was carried out based on the data of the agricultural sector of Ukraine for the period 2021-2023. The prospects for the introduction of green technologies in agricultural production were assessed using the following methods:

- a comprehensive approach to studying the challenges faced by agricultural enterprises in growing crops and cultivating land in Ukraine during the war;
- the average percentage of precision farming technologies used by certain categories of farmers;
- a comparison of the indicators of the agricultural sector of Ukraine with similar data from other countries;
- a random method for determining the estimated timing of activities;
- a graphical method of displaying data.

The Green Future Index (2023) for Ukraine is ranked among 76 countries and compared to Iceland, Finland, and Norway based on data from the MIT Technology Review's Special Content Unit. This overall ranking assesses the performance of the economies under study in the following five pillars: carbon emissions, energy transition, green society, clean innovation, and climate policy. Information on the total area of land under organic farming was obtained from the web portal Our World in Data (Organic agricultural area…, n.d.), which contains an analysis of data on poverty, disease, climate change, war, and other indicators. Determining the average percentage of precision farming technologies for different categories of farmers (1 – cultivating up to 1,000 ha; 2 – from 1 to 3 thousand ha; 3 – from 3 thousand to 10 thousand ha; 4-10 thousand ha and more) allowed determining which category of farmers has a more positive attitude towards precision farming.

To analyse the legal framework regulating the cultivation of genetically modified organisms (GMOs), the Law of Ukraine No. 3339-IX "On State Regulation of Genetic Engineering Activities and State Control over Placing Genetically Modified Organisms and Products on the Market" (2023) is taken into account. Using a comprehensive approach, the article investigates and identifies problematic issues related to the application of organic and precision agriculture in the agricultural sector of Ukraine in the pre-war period and during the war.

The data on the structure of energy sources used in Ukraine was obtained from the German online platform Statista (n.d.), which specializes in collecting and visualizing data from around the world. Information on damage to agricultural land caused by physical and chemical damage to the soil as a result of hostilities was analysed on the basis of data from the official resource of the Ministry of Environmental Protection and Natural Resources of Ukraine (n.d.). The graphical method is used to depict the presentation of the principles of the green economy, demonstrate Ukraine's place in the Green Future Index (2023) ranking in various areas during 2021-2023, and the structure of electricity production in Ukraine in 2023. To determine the approximate timeframe for the implementation of certain areas of the green economy in agriculture for the next 10 years, the time periods up to 2034 were randomly selected.

RESULTS

The essence and role of the green economy. The term "green economy" was initially introduced by scientists specializing in economics and ecology (Anderson, 2024). It gained international prominence in 2008 during the global financial crisis when the United Nations Environment Programme (2021) highlighted the importance of incorporating environmental initiatives into economic recovery plans worldwide. The Global Green New Deal report (2009) outlined economic recovery policies that prioritize global sustainability (Anderson, 2024). Despite this, the global economy remains marked by humanity's excessive consumption, which harms nature and contributes to climate change. In 2015, UN member states adopted the Sustainable Development Goals for 2030, aiming to reduce environmental impacts globally and implement significant economic and institutional changes (Partners for Inclusive Green Economies, 2019).

The green economy concept emphasizes reducing carbon emissions, increasing energy and resource efficiency, and preventing biodiversity loss. The Partners for Inclusive Green Economies (2019) document, presented at the UN High-level Forum on Sustainable Development, outlines five fundamental principles of a green economy. These principles explain how economic growth can be aligned with environmental sustainability and social inclusion (Fig. 1).

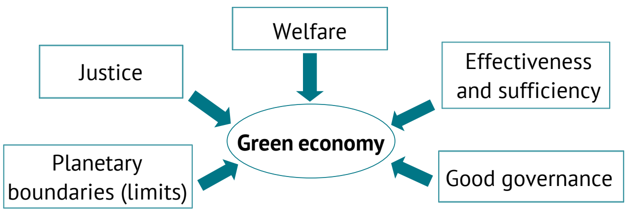

Figure 1. *Five principles of a green economy*
Source: *compiled by the authors*

Figure 1 illustrates that the fundamental principles of a green economy involve balancing the well-being of the population with the preservation of a clean environment. Specifically, the principle of well-being emphasizes the importance of providing open access to basic resources and education, fostering an environment where businesses can thrive. The principle of equity focuses on ensuring the fair distribution of resources and opportunities across all generations. The principle of planetary boundaries aims to limit the impact of human activities on the planet's nature, as exceeding these limits compromises the ability to regulate the environment. Advocating for sustainable production and consumption, the principle of efficiency and sufficiency emphasizes the development of low-carbon, resource-efficient, diverse, and circular economic models. This principle promotes responsible consumption and the fulfilment of basic needs. Additionally, the principle of good (effective and accountable) governance is crucial for the success of a green economy. It requires business entities to base decisions on a blend of scientific research, economic analysis, and practical knowledge, and to create a financial system that ensures economic growth does not compromise environmental health (Partners for Inclusive Green Economies, 2019).

The principles described above sufficiently reveal the essence of the green economy. Agriculture plays a key role in ensuring the well-being of humanity, as it is directly linked to food production and environmental impact. Most of the natural resources needed to produce products are extracted from the earth and often used only once and then discarded. This process is called "take – make – waste", which means the irrational use of natural resources that harms the environment. Since 1970, natural resource extraction has increased 3-fold, and according to scientists, it is expected to grow by 70% by 2050. Given the projected increase in global population to 9 billion people by 2050 (United Nations Environment Programme, 2021), the need to provide humanity with food, fuel and other resources that should be produced with minimal environmental impact will become more acute in the future. The most financially costly Sustainable Development Goals in 2022 were dominated by those related to the implementation of environmental projects, namely Goal 7 "Affordable and Clean Energy", Goal 11 "Sustainable Cities and Communities" and Goal 13 "Climate Change Mitigation", which accounted for 48% of the funding for all goals (Sustainable Bonds Insight, 2023).

A comparative ranking of 76 countries and territories in terms of their ability to develop a sustainable, low-carbon future is presented in The Green Future Index, 2023. The index measures the extent to which a country's economy is transitioning to a clean energy, industry, agriculture, and society through investments in renewable energy, innovation and the green economy. According to The Green Future Index (2023), the countries that are most prepared for a low-carbon future are Iceland (6.69), Finland (6.68) and Norway (6.37). Ukraine ranked 47th in this ranking in 2023 with a score of 4.38 (Fig. 2).

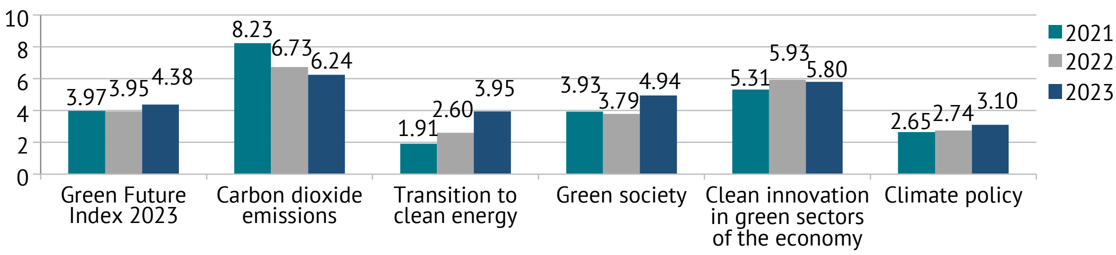

Figure 2. *Ukraine's ranking in the Green Future Index in different areas in 2021-2023*
Source: *compiled by the authors based on The Green Future Index (2023)*

The data in Fig. 2 shows that Ukraine has risen in the ranking among 76 countries in almost all indicators over the past three years. A particularly positive trend is observed in the Transition to clean energy and Green Society indicators. However, Ukraine needs to make significant efforts to reduce carbon dioxide emissions and reduce its environmental impact (The Green Future Index, 2023).

Overall, Ukraine is making some progress in implementing green technologies, but additional efforts are needed in all sectors of the economy. One of the sectors that provides food for the population and is a key player in Ukraine's trade and economic relations on the global market is agricultural production. Ukraine has an enormous potential for the development of agricultural production, given its high land fertility and favourable climate for growing many crops that are essential for the food supply of the world's population. At the same time, the slow development of agricultural technologies, inefficient use of agricultural land, increased use of pesticides, which affects the quality and environmental friendliness of products and land fertility, as well as military operations in Ukraine that lead to air and soil pollution, increase the relevance of new green technologies that will help the agricultural sector reach a new level of development.

Prospects for expanding the use of precision (accurate) farming. Global trends in the use of green technologies in the agricultural sector focus on the application of the latest technologies that can increase productivity and reduce the environmental impact of agriculture. Such technologies include:

- precision (accurate) agriculture, which is based on observations, measurements and timely response to changes in crop cultivation;
- the use of organic farming (compost for soil fertilization, green fertilizers, biological pest control, crop rotation technologies (alternating crop species or varieties on the same sown area over a certain period of time), which lead to increased soil fertility);
- introduction of biotechnology to create genetically modified organisms that do not require the use of large amounts of fertilizers and pesticides;
- switching to alternative energy sources (wind, solar, water, geothermal and other types of energy).

Precision farming means that plants receive exactly what they need for growth, development, and yield (Lopushnyak *et al.*, 2022). These needs are determined with high precision thanks to the latest technologies, including: electronic positioning and speed (GPS), sensor technology, computer information technology and robotics. Precision farming technologies have already penetrated agriculture in Ukraine to a large extent, but further implementation is needed to increase their technological efficiency. For example, the level of precision farming application varies depending on the category of agricultural producers: small farmers are the least common, while large agricultural holdings are quite developed, as some of them have their own structural units, such as innovation departments. The results reflect the current state of application of precision farming technologies by different categories of farmers: small farmers with less than 1,000 ha and 1,000-3,000 ha, medium farmers with 3-10,000 ha, and large farmers with more than 10,000 ha of land per region (Table 1).

Table 1. *Information on the use of precision farming technologies by different categories of farmers*

Categories of farmers	Use of electronic field maps, %	Land digitization, %	Autopilots, GPS trackers, %	Satellite imagery/NDVI	Own weather stations and soil moisture sensors, %	Access to finance
up to 1,000 ha	15	90	-	1/10	< 20	complicated
1-3 thousand ha	47	90	> 50	38	up to 50	complicated
3-10 thousand ha	67	91	8 out of 10	> 50	> 50	more affordable
10+ thousand ha	95	93	90	> 80	> 75	more affordable

Source: *compiled by the authors based on Netherlands Enterprise Agency (2021)*

Table 1 shows that farmers with up to 1,000 ha of land do not consider using integrated farm management systems, as the implementation of such a system requires both a financial component and a pre-formed information base for their own company. Owners of up to 1,000 ha and 1-3 thousand ha face problems with the integrated and consistent use of precision farming technologies. The category of farmers with 10,000 ha or more implement technologies centrally. The process of testing and scaling for all innovations takes up to 3 years, such as Kernel. This category of farmers uses satellite imagery, drones (both independently and with the help of relevant specialized companies), implementation of FieldView and Cropio management systems (Netherlands Enterprise Agency, 2021).

In conformity with the results of the farmers' survey, the average level of precision farming technologies use for all categories of surveyed agricultural enterprises is 51.2%. The most popular technologies are electronic field maps, which are used more by medium and large agricultural companies. It should be noted that among certain groups of farmers, the level of digitized field maps reaches 91-95%. Only 20-30% of surveyed farmers are engaged in soil compaction mapping

(Netherlands Enterprise Agency, 2021). Farmers should support moisture sensors in their fields more. According to statistics on foreign experience of precision farming, in 2006, more than 80% of farmers in the United States used such technologies, which helped to increase grain yields to 90 c/ha. It has been proven that the costs of precision farming technologies can be recouped within 2-4 years after their introduction (Tsilyuryk, 2023). In accordance with experts, the precision agriculture market is expected to reach USD 21.9 billion by 2031, an increase of 10.7% compared to 2023 (USD 9.7 billion) (Netherlands Enterprise Agency, 2021). In order to spread the use of precision farming, foreign companies entering the Ukrainian market need to:

- find a representative or dealer of services (equipment) who can maintain direct contact with farmers and provide technical support for the operation of this equipment;
- establish cooperation with existing educational projects, participate in exhibitions and events to present technologies for the development of precision agriculture;
- clearly define the pricing policy in Ukraine so that the price of the product/service is clear and affordable compared to the price of competitors;
- apply to local authorities for financial support to purchase the latest technologies;
- develop partnerships with local governments to obtain up-to-date data on harvesting progress, as well as land use violations, burning of crop residues;
- unite the efforts of groups of farming companies, which will provide additional benefits for getting closer to local governments and large agricultural holdings.

Consequently, the use of modern technologies such as satellite imaging, sensors, GPS, and information technology to precisely manage crop production and resource use can help reduce the use of fertilizers and pesticides.

The use of organic farming, GMOs and the transition to alternative energy sources in the agricultural sector. Ukraine's state planning documents in the field of biodiversity conservation, in particular, the extent to which they meet the priorities and objectives of the European Green Deal, namely the EU Biodiversity Strategy 2030 (2020), show that one of the goals for Ukraine is to achieve a high level of organic farming. As of 2023, this figure is 8% for EU countries and 1.1 for Ukraine. The Strategy states that the goal for the EU by 2030 is to increase organic farming to 25%, and for Ukraine – to 3%. Organic production is developing in Ukraine. The share of agricultural land is the part of the land area (including arable land, pastures or wild areas) that is cultivated according to specific organic standards. The share of such land varies from year to year, depending on various factors affecting agricultural development (Table 2).

Table 2. *Use of organic agriculture in Ukraine, 2009-2022*

Name of the indicator	2009	2010	2018	2020	2021	2022
Total agricultural area, ha	41,280,000	41,280,000	41,330,000	41,310,000	41,310,000	41,000,000
Organic agricultural area, ha	270,190	270,230	233,500	410,580	370,110	263,619
Share of organic agricultural area, %	0.7	0.7	0.6	1	0.9	0.6

Source: *compiled by the authors based on Organic agricultural area, Ukraine, 1992 to 2021 (n.d.), Area of organic land and the number of operators decreased in Ukraine – Results of 2022 (2023)*

Table 2 shows that in 2020, the area of certified agricultural land growing various organic products was the highest in the last decade (over 400 thousand ha), which placed the country in 20th place among the world leaders in organic farming. In 2022, the area under organic production decreased by almost 40% and accounted for about 0.6% of the total agricultural land. This is primarily due to the outbreak of hostilities in Ukraine, the occupation of a large territory and shelling, which made some land unusable. Comparing the area of agricultural land under organic farming in other countries, it is worth noting that, for example, in Poland, this figure is 3.79%, in Romania – 4.42%, in Hungary – 5.82%, in Slovakia – 13.45%, in the Czech Republic – 15.81%, i.e. significantly higher than in Ukraine. The use of biotechnology, in particular genetically modified organisms, plays an important role in the new green economy, as the cultivation of GMOs is a step in agriculture towards increasing yields, increasing plant resistance to pests or drought, reducing the need for pesticides and fertilizers, and gaining other economic and environmental benefits (Litvinova *et al.*, 2023).

The seminar "Biotechnology in the agricultural sector: international experience of state regulation and market development" noted that if used in the EU at the level of, for example, North America, total greenhouse gas emissions could be reduced by 7.5% of their total volume, which is 33 million tonnes of CO_2 annually. Studies have shown that the agriculture index for EU countries increased by 7% between 1995 and 2019, while the same indicator in the US increased by 38%. In the US, GMOs have been grown and consumed for the past 30 years (since 1994). GM crops are a key factor in mitigating climate change (Tsybulska, 2023). In recent years, no

GMO products have been registered in Ukraine, despite the fact that such products were available on the market. Thus, according to the United States Department of Agriculture (USDA) Biotechnology and Other New Production Technologies Annual report, unofficial GMO cultivation in Ukraine is about 50-65% GMO soy, 10-12% rapeseed, and less than 1% GMO corn (GMO policy in Ukraine, 2024). In the context of European integration and the approximation of Ukrainian legislation to EU requirements on GMOs, the Verkhovna Rada of Ukraine adopted the Law of Ukraine No. 3339-IX (2023) on 23 August 2023, which will come into force on 16.09.2026.

The implementation of the Law contributes to the achievement of systematic compliance of Ukrainian legislation with EU requirements in the field of GMO cultivation and handling, as the Law of Ukraine No. 3339-IX (2023) is based on 8 key EU regulations in the field of GMOs. The Law provides for European mechanisms for the state registration of GMOs, establishing requirements for the use of labelling "with GMOs", "without GMOs", "produced from GMO raw materials", according to the rules followed by agricultural producers in the EU. The implementation of the Law of Ukraine No. 3339-IX (2023) is expected to increase the efficiency and transparency of state regulation procedures in the field of GMOs. In the context of the green economy, it is important for the agricultural sector to use renewable energy sources, which are produced from sources that are renewable and do not pollute the environment as much as nuclear power plants. Consumers, including agricultural enterprises, are shifting from fossil fuels to green energy around the world to reduce their impact on climate change and air and soil pollution. In terms of renewable energy, the EU has set a target to increase its renewable energy share from 32% to 42.5% by 2030 (Table 3).

Table 3. *European countries that are leaders in the use of alternative energy sources*

Country	Utilization rate	Main sources
Norway	75.8	hydro, wind, solid and liquid biofuels, as well as heat pumps
Sweden	66	
Finland	47.9	water, wind, and solid biofuels
Latvia	43.3	hydropower
Denmark	41.6	wind and solid biofuels
Estonia	38.5	
Portugal	34.7	solid biofuels, wind, hydro, and heat pumps
Austria	33.8	hydro and solid biofuels

Source: *R.A. Hughes (2024)*

As can be seen from Table 3, wind, hydropower and solid fuels are the main renewable energy sources in Europe. The average rate of renewable energy use across European countries is 23%. By 2050, the EU aims to become the world's first climate-neutral continent under the European Green Deal. The use of renewable energy helps to diversify energy supplies, which is extremely important in times of increasing energy shortages, which is relevant for Ukraine. However, in Ukraine, the percentage of renewable energy use remains low (about 15%) (Fig. 3).

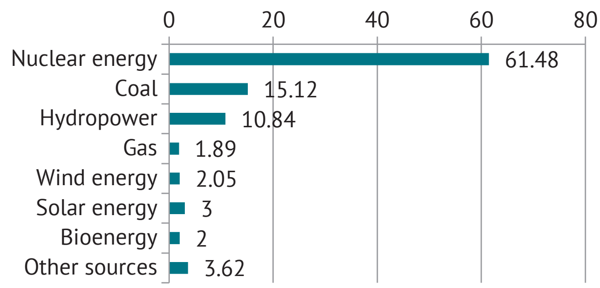

Figure 3. *Structure of electricity generation in Ukraine in 2023*

Source: *compiled by the authors based on Statista (n.d.)*

Fig. 3 shows that nuclear power remains the largest source of energy in Ukraine, while renewable energy sources still need to be further developed in their use.

Explosives contamination in the agricultural sector and identification of the main areas for improving the prospects for implementing a green economy in the agricultural sector in Ukraine. Explosives contamination of soil has a negative impact on the improvement of environmental sustainability in the agricultural sector. For example, military operations in Ukraine have contaminated more than 5 million ha of agricultural land. According to preliminary estimates by the Ministry of Environmental Protection and Natural Resources of Ukraine (n.d.), the full-scale military invasion caused damage to agricultural land in Ukraine in excess of UAH 19 million. Scientists say that even if a munition does not explode or explodes incorrectly, about 20-40% of hazardous substances enter the soil. The impact on Ukrainian soil from military operations can be distinguished by the following types:

- physical impact – creation of trenches and ditches, soil compaction from heavy machinery;
- fires – burning the top layer of soil fertility;
- chemical pollution – toxic elements, explosives.

Research on the impact of military equipment on soil was conducted in the United States, using a 57.2 tonne M1A1 tracked tank. The results confirmed the negative impact on medium and heavy loamy soils after just 1 pass of the vehicle. Soil compaction resulted in the formation of less biomass of vegetation cover (Ministry of Environmental..., n.d.). Heavy metal pollution is also significant: the bullets release lead, which is then absorbed by plants. In addition to lead, other metals enter the soil, such as chromium (Cr), mercury (Hg), nickel (Ni), arsenic (As), zinc (Zn), and others. Plants can accumulate heavy metals. Based on the analysed data on the implementation of the green economy in agriculture in Ukraine and the factors that can accelerate this process, it is advisable to draw up an action plan for the implementation of the green economy in the agricultural sector of Ukraine for the next 10 years (Table 4).

Table 4. *Action plan for the implementation of the green economy in agriculture until 2034*

Direction of the event	Characteristics of the event	Estimated completion date
Training and professional development	Training of agricultural workers and managers of agricultural companies on the essence and methods of applying green technologies	Constantly
Assessment and planning	Evaluation of methods and technologies for improving the environmental friendliness of agriculture and planning the introduction of new technologies	2024-2026
Transition to organic and precision farming	Use of organic fertilizers, crop rotation, digitization of land plots, use of satellite equipment, drones.	2024-2028
Changing approaches to cultivation and tillage	Introduction of drip irrigation to conserve water, cultivation methods that reduce soil erosion, GMO cultivation.	2024-2029
Use of renewable energy sources on farms	Installation and expansion of wind and solar power generation equipment	2024-2034
Restoration of soil from physical impact, fire, and chemical contamination	Mine clearance of the territory. Digitization of sites using satellite equipment. Analysis of the content of pollutants. Analysing the possibilities of farming in certain areas and their further intended use. Disposal of contaminants from the soil and restoration of damaged areas for further use	After the cessation of hostilities in a certain territory

Source: *compiled by the authors*

Table 4 presents a list of measures that need to be taken in Ukraine to continue the trend of greening the agricultural sector in the next 10 years. The ongoing military operations in Ukraine have a particularly negative impact, which is difficult to counteract even with the accelerated transition to organic farming, increased use of new technologies and other measures. Restoration of soil fertility after the war is expected to take decades, depending on the area that has been damaged, polluted and destroyed. This will require significant financial investments, for which the Government should be prepared, as it is difficult to imagine the recovery of the country as a whole without restoring agriculture. Thus, the assessment of the prospects for introducing a green economy in the agricultural sector has shown that Ukraine has already made many steps in this direction, but at the same time, it is necessary to increase the area cultivated organically, apply innovative technologies for precision farming, expand opportunities for the use of alternative energy sources and other measures. To this end, an action plan has been developed to guide the development of the agricultural sector in line with the requirements and trends of the green economy.

DISCUSSION

Improving agricultural production in Ukraine to align with the principles of the green economy is crucial, especially as the demand for increased agricultural output rises and the challenges of field cultivation and harvesting in conflict regions become more pronounced. The findings of this study suggest that the proposals are aimed at expanding the opportunities for implementing the green economy in agricultural production to meet sustainable development goals. The paper emphasizes that the green economy concept is a vital tool for achieving sustainable development goals globally, irrespective of a country's development level. N. Houssam *et al.* (2024) reached similar conclusions, noting a link between the green economy and three variables: gross domestic product (GDP) per capita, overall unemployment, and poverty. While supporting this view, it is important to note a statistically significant negative relationship between the green economy and poverty in developing countries. In formulating a green economy strategy for the agricultural sector, I. Smolii and N. Dikhtyarenko (2023) identified targets for the near future, including increased resource efficiency, reduced energy dependence, and enhanced export potential of the agricultural sector. However, the current level of financial support for green economy measures is insufficient.

The study highlights the benefits of the green economy for the environment, product environmental friendliness, and public health. Scholars' opinions on the green economy's impact on economic growth are divided: some believe green growth can be achieved without compromising economic growth, while others argue that sustainable development cannot occur if intensive consumption continues to drive economic growth. C.I. Fernandes *et al.* (2021) contend that technology transfer and sustainable innovation contribute to green growth, positively impacting economic growth – a perspective that merits agreement.

Humanity's environmental pressure on the planet has been increasing, elevating environmental threats. At this stage, green innovations are seen as the optimal solution for sustainable development, combining economic growth and environmental protection (Bochko *et al.,* 2024). A. Koseoglu *et al.* (2022) demonstrated that economic growth is the main cause of environmental degradation, while urbanization has no statistically significant impact, and renewable energy consumption mitigates the ecological footprint. M.J.G. Wani *et al.* (2024) also emphasized the role of foreign direct investment and globalization in the G7 economy, noting that green economic growth is essential for sustainable development and that green energy positively contributes to green economic growth in both the long and short term.

The study underscores the importance of precision agriculture, which can positively impact the adoption of a green economy in agriculture. The conclusions drawn are supported by other authors, as precision agriculture has the potential to meet the growing demand for food sustainably, using a more accurate and resource-efficient approach to agricultural management. Smart farming technologies optimize this process, as confirmed by A. Monteiro *et al.* (2021), who reviewed the latest scientific and technological trends in crop production and developed proposals for farmers on applying technology in agriculture.

The article highlights that precision farming technologies can significantly reduce pesticide use. However, E. Anastasiou *et al.* (2023) stress that the adoption of these technologies by the farming community is crucial and requires proper incentives to encourage wider acceptance of green technologies among farmers. The study underscores the importance of using drones in agriculture for monitoring plant conditions and processing levels, noting that farmers who cultivate larger areas tend to use drones more frequently. Supporting this, M. Michels *et al.* (2020) studied drone use among large German farmers, finding that factors such as the farmer's age, knowledge of precision farming technologies, and farm size influence the adoption process. Similarly, A. Bai *et al.* (2022) examined drone use in Hungary, confirming that farm size, age, main job, and education level affect drone usage frequency. Emphasizing the importance of transitioning to precision agriculture, certain factors can either facilitate or hinder this process. R.W. Verburg *et al.* (2022) point out that diversifying certified products and government support through subsidies are key to scaling up precision agriculture. M. Gemtou *et al.* (2024) highlight the need to encourage farmers to adopt sustainable practices, while T. Begho *et al.* (2022) identify financial, personal, and agronomic factors as potential barriers, noting that advice and training, soil quality, irrigation, income, and credit can facilitate the adoption of new practices.

To reduce agriculture's environmental impact, the article advocates for organic farming practices, such as fertilizing soil with compost, using green fertilizers, and implementing crop rotation technologies. Despite the benefits, not all farmers are transitioning to organic farming, influenced by various factors. R. Sapbamrer and A. Thammachai (2021) identify relevant factors including gender, income, education level, positive attitudes, normative and moral obligations, organic farming experience, production costs, and farm ownership, along with technology support and competition from organic farmers. M. Canavari *et al.* (2022) similarly emphasize the importance of personal characteristics such as age, education level, and perception of bureaucracy.

When considering factors that influence the adoption of cleaner production technologies, Z. Niu *et al.* (2022) emphasize the need to account for these elements. The study reveals that in foreign countries, including Ukraine's geographical neighbors, the area under organic cultivation is significantly larger than in Ukraine. However, these countries face similar challenges. For instance, G. Király *et al.* (2022) found that in Hungary, the transition to organic farming is not motivated by the perception of adverse weather events. Additionally, A. Mazurek-Kusiak *et al.* (2021) note low demand for products from certified organic farms in Poland and Hungary, leading to decreased motivation among farmers to adopt organic practices. They also highlight main barriers to establishing organic farms, such as the need to adapt to EU requirements and the use of only natural fertilizers.

A study on the prospects of transitioning agricultural production to a green economy has revealed that biotechnology and GMO cultivation can enhance crop yields, improve resistance to pests and diseases, and reduce the need for chemical treatments. W. Yali (2022) supports this position, noting that, if used properly, GMOs can boost the economy without causing significant harm. However, the full potential of GMOs requires thorough research. N.J.C. Pardo *et al.* (2023) emphasize that GMO introduction must consider environmental and social sustainability unique to each area. In Lebanon, R.J. Roberts and V. Naimy (2023) found that GMOs improve plant resistance to weather and pests, reduce pesticide use, eliminate the need for chemical fertilizers, increase yields, and enhance the nutritional value of products. However, as M. Liu and H. Liu (2024) note, farmers' acceptance of GMOs depends on perceived value, but financial support from state and local governments can facilitate adoption by mitigating perceived risks.

Therefore, encouraging the use of GMOs and other green technologies in agriculture should involve government or community support, adapting these technologies to local conditions, and improving the system of agricultural machinery maintenance, research, and development, as argued by P. He *et al.* (2021). The transition to alternative energy sources in agricultural enterprises is also crucial, especially given the electricity shortages in Ukraine due to infrastructure attacks. Achieving global goals, such as increasing renewable energy production and promoting sustainable development, relies on using natural gas as a transitional fuel to renewable energy (Kovalenko & Khandogina, 2022). R.R. Esily *et al.* (2023) concur, noting that carbon and natural gas emissions, ICT trade, and urbanization positively correlate with economic progress, although renewable energy has a negligible impact. Thus, intensifying efforts to use natural gas as a transitional fuel is recommended.

L. Chandra Voumik *et al.* (2022) also studied the environmental impact of increased energy consumption, emphasizing the need to reduce carbon emissions among various approaches to developing Bangladesh's economy and improving environmental quality. M. Mohsin *et al.* (2022) highlight that public spending on research and development of sustainable energy resources will result in low carbon emissions through improved production processes. In conclusion, the study indicates that to improve prospects for a green economy, measures such as expanding precision and organic farming, transitioning to alternative energy sources, and cultivating GMOs should be implemented. These steps will reduce environmental pollution, increase yields, and enhance the environmental friendliness of agricultural products. The study's results align with findings from other researchers, both Ukrainian and foreign, highlighting the importance of these conclusions for developing the agricultural sector during martial law and post-war recovery.

CONCLUSIONS

The study indicates that the development of green technologies in Ukraine's agricultural sector over the past decade has shown a trend of increasing and expanding various approaches to enhance the environmental friendliness of soil cultivation, crop fertilization, crop monitoring, and energy source selection. The goal and technology analysis set forth in this paper lead to several key conclusions. Understanding the fundamental principles of the green economy has allowed for the formulation of development directions for green technologies in agriculture and increased utilization of natural resources in soil cultivation and energy production.

An analysis of precision agriculture usage shows that farmers with larger agricultural land areas are more prepared to adopt these technologies, with their usage frequency being 2-3 times higher than that of smaller farmers. The average level of precision farming technology application in Ukraine across all categories of agricultural enterprises is approximately 51.2%, which is 30 percentage points lower than in the United States, where 80% of farmers utilize these technologies. The study found that the area of land under organic production in Ukraine is quite small (about 0.9%), and since the onset of the full-scale Russian invasion, this has decreased to 0.6%. This decrease reflects two main wartime obstacles: reduced safe cultivation areas and diminished farmer willingness and financial capacity. The article analyses the use of GMOs in Ukraine to increase yields, revealing that their adoption level is relatively low. However, it highlights the positive impact of the government's relevant legislation regulating the cultivation and sale of GMOs. It also establishes that alternative energy sources in agriculture help reduce financial costs and environmental emissions. Currently, nuclear energy comprises the largest share (61.5%) of Ukraine's energy structure, while alternative energy sources account for about 5%, which is low compared to other countries.

The study points out that the most negative impacts on the environment, soil quality, and green technology development in agriculture stem from pollution caused by explosives, fires that burn the top fertile soil layer, and field compaction from heavy machinery. To improve the prospects for implementing the green economy in agriculture, an action plan is proposed in the following areas: training and professional development; assessment and planning of methods and technologies to improve agricultural environmental friendliness; transition to organic and precision farming; use of renewable energy sources; and restoration of soil from physical impact, fire, and chemical pollution. These measures will accelerate the introduction of a green economy in the agricultural sector over the next 10 years and enhance the competitiveness of Ukraine's agricultural sector. However, the study on financing the adoption of green organic and precision farming by farmers remains promising and requires further exploration. To improve the accuracy of the study results, it is essential to investigate ways to encourage farmers to use green technologies. Future research should focus on a more detailed examination of the factors influencing farmers' choices regarding green technologies.

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CONFLICT OF INTEREST

None..

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Перспективи впровадження «зеленої» економіки в аграрний сектор України на найближчі 10 років

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Анотація. Актуальність дослідження зумовлена погіршенням екології та низьким рівнем застосування «зелених» технологій в аграрному секторі України. Метою було окреслити актуальні проблеми для фермерів при використанні «зелених» методів ведення агрогосподарства та знайти їх вирішення. У дослідженні оцінювався рівень використання окремих «зелених» технологій в процесі аграрного виробництва в Україні. Головними результатами, отриманими у цій праці, слід вважати: визначення місця України у рейтингу Індексу зеленого майбутнього за різними напрямами протягом 2021-2023 років та порівняння його з Ісландією, Фінляндією та Норвегією; виявлення напрямів «зелених» технологій, які необхідно розвивати в Україні в період воєнного стану та після війни (прецизійне та органічне землеробство, впровадження біотехнологій для створення генетично модифікованих організмів та перехід на альтернативні джерела енергії). Вивчення залежності схильності фермерів застосовувати «зелені» технології від величини фермерства підтверджує її безперечну наявність. Аналіз зарубіжного досвіду застосування точного землеробства дозволив сформулювати рекомендації щодо поширення використання точного землеробства в Україні для іноземних компаній, які виходять на український ринок. Висновки про зростання дефіциту електроенергії сприяли обґрунтуванню подальшого використання альтернативних джерел енергії в умовах. Дослідження негативного пливу бойових дій на українські землі дозволило класифікувати такі види впливу та розробити заходи щодо відновлення ґрунту. Оцінка застосування технологій у сільському господарстві спряла виокремленню напрямків для впровадження «зеленої» економіки в аграрному секторі в Україні, які сприятимуть підвищенню врожайності сільськогосподарської продукції без шкоди для екології та підвищенню її конкурентоспроможності. Результати та висновки мають практичну значимість для Уряду при розробці аграрної політики та працівників сільськогосподарських підприємств при веденні господарства

Ключові слова: прецизійне землеробство; сільськогосподарська продукція; інноваційні технології; відновлювальна енергія; добробут; врожайність

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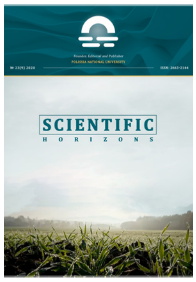

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Electronic tracking and identification of animals in agriculture for monitoring herd development and health

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Abstract. Agricultural business methods are no longer possible without computer technology, which helps to identify animals, record productivity and monitor their health. Therefore, the study aims to conduct a comparative analysis of the functionality of the main dairy farm management software for their objective assessment from the point of view of milk producers. For this purpose, information from the official websites of software products was analysed and scientific articles analysing this software were collected. As a result, all software products were divided into 3 categories: software for

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controlling dairy productivity and managing processes on a dairy farm from dairy equipment manufacturers; such software products include DairyPlan C21 (GEA), DATAFLOW II (Milkline), AfiFarm (Afimilk), DelPro (DeLaval) and FARMSOFT (Farmtec a. s.); dairy farm management software DairyComp 305 and UNIFORM-Agri, as well as farm software from post-Soviet developers – MilkCentre (CIAB Expert). Programmes from dairy equipment manufacturers were almost at the same level and had virtually all the necessary blocks for identifying, controlling and managing animals on a dairy farm. The software developed for dairy farm management is more effective in tandem with one of the milking parlour programmes. This class of software expands the possibilities for managing reproductive and veterinary work on the farm, as well as reduces the workload on staff by generating automatic reports for regulatory authorities and management. The third class of programs is the least developed compared to the above, but it compensates for this shortcoming by constant improvement due to the continuous contact of developers with the manufacturer. Thus, there is a significant number of software products on the software market that can provide dairy management for farms of various sizes

Keywords: software; peripherals; production management; reproduction; digitalisation of the industry

INTRODUCTION

Agricultural business practices are designed to reduce production costs and increase profitability. Such problems are most pressing in livestock farming, as this sector of agriculture employs a significant portion of human resources daily. Reducing labour and financial costs can be achieved by implementing advanced methods of monitoring the productivity and health of animals during their productive use. This will reduce the number of staff on the farm and, at the same time, increase the efficiency of herd management and control over the processes taking place on the farm. This can be achieved by using specific software products that can automatically collect the necessary information about animals and generate tasks and reports for specialists and managers aimed at improving the efficiency of animal use. The introduction of such automated information systems in Kyrgyzstan's livestock industry will not only increase the productive longevity of animals in the country but also improve their genetic potential, which is a promising area of Kyrgyz agricultural science.

According to the National Statistical Committee of the Kyrgyz Republic, as of the end of 2023, the number of animals was cattle – 1.8 million head, including 902,000 cows (Livestock and poultry…, 2024). About 50% of the cow population is kept in collective farms, and the rest in individual households. The number of small cattle was 6.2 million, of which 57% were in farm herds. Poultry had an even larger population – almost 7 million heads. The bulk of the livestock, just like other animals, was concentrated in collective and private farms – 61%. The number of pigs in the country was small and amounted to only 29.6 thousand. Information from the Statistical Committee indicates that in Kyrgyzstan, the bulk of cattle and small ruminants are in herds that can be used to apply information technology to increase their profitability.

The study of the prospects for the introduction of digitalisation in Kyrgyzstan is being carried out as part of the implementation of the United Nations Development Programme "Digital Kyrgyzstan" (Sanarip Kyrgyzstan), designed for 2019-2023 (Advancing Digital Transformation…, 2023). The report points out that digital technologies are a key factor not only in economic growth but also in achieving the Sustainable Development Goals, which are directly related to the well-being of people and society.

Following A. Karbekova and A. Abdykalykova (2023), the level of development of digital technologies in Kyrgyzstan is still at an early stage, although some livestock enterprises are already using some components of such a system – computerised ration balancing, herd management software, an electronic livestock identification and tracking system, and a breeding programme. These are mainly farms that specialise in milk production. Following A.O. Okenova (2019), Kyrgyzstan is ahead of such post-Soviet countries as Uzbekistan, Tajikistan and Turkmenistan in terms of the dynamics of digitalisation among neighbouring countries but lags far behind neighbouring Kazakhstan. Therefore, K.K. Toktorov *et al.* (2020) suggest that the introduction of automated information systems in dairy farming will improve breeding work with animals and thereby increase milk yields by 2-2.5 times and reach the level of Kazakhstan. This can be achieved by optimising and adjusting the ration and targeted breeding. C.A. Timashev (2020) points to the need to introduce digital technologies in Kyrgyzstan's agriculture. His main theses point to the focus on smart livestock technologies in the dairy cluster and sheep breeding.

However, according to T. Bekov (2022), the main constraint to the introduction of digital technologies in livestock production in the Kyrgyz Republic is the high price of such innovative products and the small size of farms that keep animals. According to his information, 95% of all farms are represented by small farms with small land plots. According to C. Timashev (2020), an information system for animal identification has already been developed in partnership with the French IT company SENOE, which consists of four modules: registration of the farmer and animal housing, identification of animals, herd management and distribution of tags, registration of animal movements.

Thus, given that the most promising livestock sector in Kyrgyzstan, where it is possible to introduce an automatic information system, is dairy farming, due to the high rate of payback and partial development of computer technologies in this sector of livestock, the purpose of this work was to conduct a comparative characterisation of existing software products for managing, monitoring the productivity and health of animals on a dairy farm. One of the tasks was to group software products according to various criteria and identify the advantages and disadvantages of such software.

Based on Internet search results on request: "Modern methods of control over the identification, productivity and health of farm animals", 8 software products for dairy farms from leading international and several European companies were selected for comparison, which can provide a full range of electronic animal identification works to control and manage all works in the maintenance of the dairy herd. The comparative analysis included integrated products DairyPlan C21 (from GEA), DATAFLOW (Milkline), DairyComp 305 (DigiFarm Software), AfiFarm (Afimilk), UNIFORM-Agri and DelPro (DeLaval), MilkCentre (Ciab Expret (Ukraine)), FARMSOFT (Farmtec a.s. (Czech Republic)).

To conduct an objective comparison, information from the official website of the software product on the main features and limitations of the program, and conducted a literature review of articles with a high impact factor for the last 3-5 years with information on the functioning of a particular system in an operating farm. When selecting scientific articles for the review, first, sources with a high citation level and published in Web of Science, Scopus, and Google Academy databases were selected. All the software was evaluated according to the same criteria – veterinary unit, reproductive technologies, feeding control, remote access and availability of a mobile version.

THE STATE OF DIGITALISATION IN DAIRY FARMING

Recently, digital information systems have been actively introduced into the livestock industry to manage the farm and conduct business more efficiently, which is made possible by combining a system of innovative technological solutions with mobile applications (Schulze Schwering & Lemken, 2020). This approach reduces decision-making time and cuts costs at the same time. This is made possible, according to T. Groher *et al.* (2020), through the introduction of electronic measuring instruments and specialised sensors, electronic controls and electronic databases that are integrated into one system. An analysis of the information available on the Internet shows that there are a huge number of software products to simplify the work of livestock farmers (Neethirajan & Kemp, 2021). Given that the term "smart agriculture" has emerged recently, it is worth noting at this stage that there are already a significant number of commercial solutions and platforms for different types of animals (Buka *et al.*, 2023), which indicates the urgency of the problem.

Most of these digitalisation approaches, according to J. Munz *et al.* (2020), relate to the dairy industry, and M. Goller *et al.* (2021) point out that the maximum number of software products has been developed for this sector of livestock production in the last decade alone. One of the reasons for this "digitalisation" of the industry is the significant involvement of people in the milk production process, and, accordingly, the significant dispersion of information required for herd management (Wrzecińska *et al.*, 2023). In addition, technological approaches to creating comfortable conditions for animals without restricting their freedom of movement, even within the premises for their keeping, according to H. Buller *et al.* (2020), increase their welfare in the production process. However, this approach depersonalises animals and reduces the control of staff over productivity, health, reproduction and other indicators. Therefore, many software vendors offer software solutions specific to a particular subject area. A. Kassahun *et al.* (2022) point out that many enterprises have previously used special software products for a specific type of work in dairy farming – calculation and control of rations, breeding programmes, individual control of cow milk production, etc. These were separate programmes designed for a specific employee – a manager, a zootechnician, a veterinarian. But recently, one vector of work has been identified – the integration of such software products into a single, unified system for monitoring and managing the herd (Deschenko & Lykhach, 2024). In addition, such programmes have undergone some improvements. A visual control of feed intake with its computerised analysis, and automatic measurement of animal weight by body measurements made with digital video cameras were added to feed programmes (Cominotte *et al.*, 2020). Breeding programmes now address and prevent the possibility of inbreeding for several breeds, and conduct breeding modelling based on optimal selection of parental pairs (Bezen *et al.*, 2020). Computer software for veterinary specialists on the farm, now, in addition to registering sick animals and registering medicines used, can conduct visual monitoring of the condition of animals in real time (Tassinari *et al.*, 2021; Issimov *et al.*, 2022), computer detection of lameness in cows and other metabolic diseases (Kang *et al.*, 2021).

This excludes the most intensively developing area of cow milk productivity control, where not only individual control of cow productivity and its milk quality parameters is carried out, but also productivity forecasting (da Rosa Righi *et al.*, 2020), the use of artificial intelligence for modelling milk and predicted productivity (Fuentes *et al.*, 2020; Pogranichniy *et al.*, 2023) and other innovative solutions. This area has been developing most actively since the introduction of milking robots

(Simões Filho *et al*., 2020; Chikurtev *et al*., 2024) and the implementation of a voluntary milking strategy (Wildridge *et al*., 2020) in industrial milk production technology. R. Matson *et al*. (2021) point out that the voluntary milking system was primarily aimed at reducing the need for labour on farms.

Thus, new peripheral equipment for collecting information and methods of processing has recently been introduced and integrated into livestock software. On the other hand, according to E. Maltz (2020), the development of dairy farming management technologies stimulates the search and development of new types of sensors and their integration into a single system or software product to obtain new information about animal productivity or health.

Agriculture is a complex structure, whose profitability depends on many different factors, and according to A. Lytos *et al*. (2020), can only be effectively supported by computerised systems. D. Piwczyński *et al*. (2020) point out that such digital technologies for dairy farming enterprises are based on the human-machine-animal system, and this interaction is based on the analysis of the large amount of data obtained, followed by the construction of an algorithm for organising and managing processes on the farm. At this stage, according to V. Cabrera *et al*. (2020), analysing the data is one of the biggest challenges facing the dairy industry today. This is due to the increased flow of various information from the same animal into a common database, and its integration and analysis is a rather difficult task. Moreover, F. Carillo and F. Abeni (2020) point out that it is necessary to address that dairy farms differ in terms of herd size (production scale), available technology and equipment. Therefore, for the effective management of all processes on a dairy farm, complex software products are preferable, capable not only of collecting information from animals but also of conducting its primary analysis, grouping the data obtained depending on the predictors and building a logical chain to improve milk production technology.

COMPREHENSIVE SOFTWARE PRODUCTS FOR DAIRY FARM MANAGEMENT

Addressing the significant challenges in creating a unified software product for the identification of animals in the herd, as well as monitoring their productivity, development and health, which are necessary for making operational decisions, this part of the review analysed the most well-known and used integrated software products on dairy farms in the post-Soviet countries.

Among these well-known and used products, the bulk is software developed by the manufacturers of dairy equipment installed on the dairy farm. This approach to creating a software product has significant advantages due to the full integration of peripheral devices (sensors, measuring instruments and other sources of information) to link dairy equipment with the database and software for analysing the information received. In addition, such companies have recently been allocating significant sums of money to develop new sensors and conduct research to improve and expand the functionality of their software to increase their competitive position. Among them are DairyPlan C21 by GEA, DATAFLOW II by Milkline, AfiFarm by Afimilk, DelPro by DeLaval and FARMSOFT by Czech manufacturer Farmtec a.s. Only a small part of the existing software products from dairy equipment manufacturers was included in the comparison sample.

The software products that were originally developed for dairy farm management and later on, at the software level, were connected to modules that could integrate various peripheral devices into these programmes – DairyComp 305, and UNIFORM-Agri. Separately, for the sake of completeness, MilkCentre software product from the Ukrainian company Cib Expert was analysed. This system is included in the review since most dairy farms in the post-Soviet space use low-cost milking parlours and animal and feeding control systems produced by local manufacturers that cannot provide the necessary integration to get a complete picture of the herd. According to the producers, MilkCentre will be able to solve such problems by actively cooperating with the customer directly on their farm. Thus, this analysis collected software products from different categories of vendors, but primarily those that are more common in post-Soviet countries. A comparative description of the different programmes based on the same criteria is provided in Tables 1-3.

Table 1. *Comparative characteristics of dairy farm management software*

Indicator	Software		
	DairyPlan C21	**DataFlow II**	**Dairy Comp 305**
Productivity	Individual and overall assessment of milk production, Mastitis control, animal sorting	Collecting information from the milking parlour about the milk yield per cow. Auto-detection of mastitis	Information on monitoring the milking parlour; lactation curves; analysis of control dairy cows (somatic cells, production analysis, fat/protein ratio)

Table 1. Continued

Indicator	Software		
	DairyPlan C21	DataFlow II	Dairy Comp 305
Veterinary module	Determining the need for treatment of sick animals. Prescribing, conducting and reviewing treatment	Rumination control, graphs and playback tables. Control of the rumination department.	Treatment regimens; a list for the veterinarian; control of treatment; forming vaccination lists; dynamics of morbidity; lists for hoof trimming
Reproduction	Determining hunting by motor activity	Hunting by motor activity + rumination + body temperature	Control of the ceiling check; insemination analysis; launch control; analysis of the litter; analysis of artificial insemination schemes.
Feeding	Concentrate control	Rumination-based feeding control	Module is missing
Analytics	Calf forecast, dry cows, list for the vet	Graphical and tabular information on productivity and reproduction	Graphical and tabular information on productivity and reproduction
Mobile application	DPMobil 2	DataFlow II Milking	-
Additional options	Determination of weight in motion. The quality of cleaning of dairy equipment. Monitoring the temperature of the milk in the tank. Control of calf feeding when using special feeders. Identification system with conveyors	Two types of sensors: tracker and rumination. Rumination control to determine the functional state of animals. Real-time updates, and email notifications of events. Heat stress control	Growth and weight of young animals, safety monitoring, and analytics of the reasons for culling. Analysing the timeliness of technological transfers from group to group. Remote access extends the application's functionality through the VAS Pulse Platform – mobility,

Source: *compiled by the authors.*

Table 2. *Comparative characteristics of dairy farm management software*

Indicator	Software		
	Milk Centre	FarmSoft	Uniform-Agri
Productivity	By importing information from milking parlour software or manually entering milk yield information	Automatic entry of milking data for animals using the identification system.	Work with all groups of cattle (main herd, bulls, young animals, work with history). Daily monitoring of milk production. A unique Dutch method for calculating peak performance – SPP Analysys
Veterinary module	Accounting for veterinary drugs	Accounting for medicines and procedures (diagnoses, treatment plans)	Monitoring of animal health (somatic cell count, use of medicines, registration of diseases and preventive measures)
Reproduction	Information is entered by the operator for further analysis and grouping	Motor activity – to determine rumination to monitor postpartum complications.	Keeping a stock of semen by bull. Monitor playback performance through reports and analyses.
Feeding	A mechanism for the production and distribution of feed according to recipes and rations has been implemented	Control of feed distribution (correct distribution and ration)	Connecting to the feed computer
Analytics	Moving animals in groups and between farms. Special reports compare the plan with the actual work performed or materials used.	Economic report on drug consumption suggested and custom report templates	Productivity. Reproduction. Health. Veterinarian's list. Economics.

Table 2. Continued

Indicator	Software		
	Milk Centre	FarmSoft	Uniform-Agri
Mobile application	-	FarmSoft	Uniform App
Additional options	Control of young stock rearing, automatic generation of documents for accounting and veterinary services, standard weight values, feed consumption rates, and animal treatment protocols. Possibility of remote connection.	Animal accounting (general information, individual animal card, registration of changes), animal weighing.	Comparison of farms. Cloud synchronisation. Communication with trackers. Work with several herds. Networking. Generate personalised reports on any required indicators. Diary – the programme reminds what actions to take and with which groups of animals
Peculiarities	Ability to work with conveyors at the development stage		

Source: *compiled by the authors.*

Table 3. *Comparative characteristics of software products for monitoring and analysing animal performance*

Indicator	Software	
	DelPro	AfiFarm
Productivity	Detailed information on animal, group and herd productivity. Real-time information on milk yields	Monitors the condition and performance of the herd and individual animals,
Veterinary module	Diagnosis of mastitis, ketosis. Vaccination. Automatic generation of a list for the vet	Early diagnosis and treatment of mastitis, ketosis and metabolic disorders, as well as cow nutrition and acidosis. Warning of prolonged calving.
Reproduction	Definition of hunting Ceiling control. Tracking of reproductive disorders	Monitoring of cows and heifers, accurate and timely detection of animals in heat, improvement of calving periods
Feeding	Quality control of the diet	Accurate data on rumination and feed intake
Analytics	Plan for the future	Graphical and tabular information on productivity and reproduction
Mobile application	DelPro Companion	Afi2Go Pro + option to work with a mobile gadget
Additional options	Microclimate control. Visual inspection	Quality of milk from each cow, AfiCollar monitors animal behaviour (rumination, feed intake and motor activity)

Source: *compiled by the authors.*

The analysis of the functionality of software products from dairy equipment manufacturers shows that most of these programs are at the same level. This is also confirmed by similar functionality in other programmes not included in this comparison, such as HerdMetrix от BouMatic, Lely Horizon от Lely, FULLEXPERT® from Lemmer Fullwood GmbH and other similar companies, but less well known in the post-Soviet countries.

Such software products contain significant functionality for managing a dairy farm. This is determined by the companies themselves being manufacturers of sensors for identifying animals and recording their activity, which allows them to constantly expand and improve animal control methods (Post *et al.*, 2020; Lee & Seo, 2021). The main function of such software is to control the milk production of cows, regardless of the type of dairy equipment used. The dairy productivity accounting unit is implemented at a high level in all programmes from manufacturers of equipment for dairy farms. All programmes in this category can record individual cow milk production, determining milk yield, milk conductivity and other indicators, thereby controlling animal performance at the programme level and signalling possible udder diseases, including mastitis. This is the functionality of most dairy farm management software, as pointed out by M. Bausewein *et al.* (2022). In their research, they showed high reliability ($p < 0.05$) of the results obtained during the diagnosis of milk in software products from DeLaval and GEA and the actual results on the number of somatic cells in raw milk. This can be extrapolated to software from other companies, even lesser-known ones, such as the Czech company Farmtec a.s. (FarmSoft software). Following R. Codl *et al.* (2021), using the Vitalimeter 5P sensor from this manufacturer, it was also possible to easily identify animals with early signs of disease. The biggest differences between the programmes presented were in the use of different approaches to obtaining additional information about the animal. In such programmes as DelPro and DairyPlan C21, the algorithm for collecting information is based on tracking the movement of animals. The number of steps made by the animal was used to determine the physiological state of the cow, the presence of sexual desire or other symptoms of diseases that have a high correlation with motor activity. Another way to collect information about the animal was to determine the number of chewing movements (rumination) – Afimilk or both methods were implemented in the software and are used, depending on the type of sensor used – DATAFLOW II and FARMSOFT (Leso *et al*., 2021). As a result of the information received from the sensors, the software sorts the animals into different lists, which are then passed on to the artificial insemination technician and veterinarian for work. Such information is displayed both directly on the main computer monitor screen and, on the employee's, mobile phone. It should be noted that almost all herd management software products for dairy farms have implemented the ability to connect to the program remotely and have mobile applications (Khmelovskyi *et al*., 2019). This approach can be used to obtain information about a problem animal, such as prolonged labour or other emergencies, more quickly. Thus, the software can automatically monitor the physiological state of animals and distribute animals based on software algorithms. Following A. Janocha *et al.* (2023), the DelPro software product can improve reproductive performance in a group of highly productive cows due to more efficient control of the animal population. Similar positive results from the use of software algorithms from other manufacturers were reported by X. Zhou *et al.* (2022) for the early detection of various diseases in the DATAFLOW II programme and N. Najm *et al.* (2020) for the early detection of ketosis symptoms with DairyPlan C21.

In addition, all software products have a veterinary unit that keeps records of used veterinary drugs and compiles lists of animals for vaccination or pregnancy checks. Some programmes, such as AfiFarm and FarmSoft, also provide treatment plans for several diseases and monitor their progress. The biggest difference in software products from dairy equipment manufacturers is the various additional options that are less implemented in competing products. For instance, according to the official websites of each of the products under comparison, GEO has included in its DairyPlan C21 programme the ability to determine the weight of an animal in motion, as well as a whole block of subroutines that control the washing of dairy equipment and the temperature of milk in the tank (control of its cooling). Other software products have the following unique features: DATAFLOW II – control of heat stress in animals; FarmSoft – integration of scales into the system to monitor the condition of cows and track postpartum complications; DelPro – monitoring the microclimate in animal premises, as well as integrated visual control; AfiFarm – determining the quality of milk individually from each cow, warning of prolonged lactation.

Thus, by and large, all software products sold with the manufacturer's dairy equipment have significant functionality that is sufficient to manage and monitor the condition of the dairy herd, and they do not require the purchase of additional software. Software products such as DairyComp 305 and UNIFORM-Agri have more advanced functionality than those from dairy equipment manufacturers. They are more focused on management and process control in the dairy herd. As a standalone software, they are rarely used on the farm, as they have limited functionality for working with trackers and other peripheral devices. Therefore, in most cases, these programmes function in tandem with one of the above milkshake programmes. However, their main difference from the programmes supplied with dairy equipment is that they expand the opportunities for specialists to monitor not only dairy cows but also to track the growth and development of young animals, the timely transfer of animals to groups, analysis of young animal deaths and other processes not related to dairy livestock. In addition, this software also provides an opportunity to compare the performance of a farm with others where this system is installed and operating. Following M. Capel (2020), more advanced functionality of such programmes became possible due to the implementation of the ability to manually enter additional information into the programme database about certain events, such as vaccination, testing of animals for latent forms of mastitis and other events. In contrast to the programmes presented in the first part of the review, these software products provide much more information for veterinarians and artificial insemination technicians and improve their work efficiency by monitoring planned activities daily. The software algorithms monitor the main reproductive parameters for cows, as indicated by V. Schweinzer *et al.* (2020) and thereby monitor the effectiveness of cow synchronisation programmes for heat and insemination efficiency. Given the features of these programmes, D. Gonzalez (2023) recommends using them to control animal reproduction on small farms where there is a lack of specialists.

An important component of these two programmes is their significant integration with other software products installed on farms. They can import a range of animal data into their database, and in turn, export information on farm performance for reporting, tracking breeding information, and linking to the feed programme. For instance, the UNIFORM-Agri software product guidelines indicate that it is possible to automatically pull information into the programme database from local producers' milking machines, generate and transfer the necessary information to the 1C program: Accounting, automatic generation and sending of reports to the Animal Identification Agency, which reduces the number of routine tasks for farm workers (Opportunities when using…, 2011). The wide network of offices and representative offices of these companies in post-Soviet countries should also be considered. Thus, of the countries closest to the Kyrgyz Republic, DairyComp 305 is in Russia and UNIFORM-Agri in Kazakhstan.

Milk Centre should be mentioned separately, not to compare it with the previous software, but to distinguish it as a whole class of programmes created in post-Soviet countries to improve the efficiency of dairy farms. Such programs include software products such as: "M-Complex, Coral Cattle Farm: Herd Management", "Dairy Farm" and other similar projects. The advantage of such developments is the continuous improvement of the software based on regular interaction between developers and farm staff and the customisation of the programme to the needs of each farm, which is paying off. In addition, it should be noted that the price of these products is much lower.

Thus, summing up the results of the review of the materials on the presented software products for controlling the quantitative and qualitative indicators of farm animals, using the example of dairy farming, it is possible to conclude that there are different classes of software in this industry for the effective management of all processes on a dairy farm – from animal identification to animal reproduction and health management.

CONCLUSIONS

The analysis of literature sources and the results of the analytical review of the software used in dairy farming to identify and control the productivity, reproductive capacity and health of productive animals allowed us to draw the following conclusions and suggestions for further work. The maximum number of software products developed to monitor the productivity of farm animals and manage their reproduction and productive health relates to the dairy farming industry. All software for managing processes on a dairy farm can be divided into: programmes created by dairy equipment manufacturers – DairyPlan C21, DATAFLOW II, AfiFarm, DelPro and FARMSOFT. These software products are characterised by a high integration of measuring and other peripheral devices for high-quality control of individual productivity and the physiological state of animals in the herd. These programmes are self-sufficient and can carry out all the processes of dairy farm management.

For more effective control of all processes on the farm, including the rearing of young animals, deeper monitoring of reproduction problems of high-yield cows and problems with their health, there are DairyComp 305 and UNIFORM-Agri programmes, which were originally developed for dairy farm management. These software products are tightly integrated with other software on the farm and allow for the automatic generation of the necessary information and reports for regulatory authorities. Particular attention should be devoted to livestock control programmes developed by companies in the post-Soviet space. Their distinguishing characteristic is a much smaller functional set of methods for monitoring and managing the productive health of cows. The missing functions are compensated for by constant contact between developers and producers to find the necessary solutions, which also makes these programmes a competitor in farm management.

Given the constant development of modern technologies in the Kyrgyz Republic, it is necessary to introduce the digitalisation of dairy cattle in the field of identification, breeding and monitoring of the physiological condition of animals as soon as possible, as well as the rapid introduction of modern scientific achievements in software for dairy farms, it is necessary to constantly monitor software products for the effective conduct of dairy business.

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CONFLICT OF INTEREST

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Електронні відстеження та ідентифікація тварин у сільському господарстві для контролю за розвитком і здоров'ям стада

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Анотація. Методи ведення сільськогосподарського бізнесу вже неможливі без комп'ютерних технологій, що допомагають в ідентифікації тварин, обліку продуктивності та контролі їхнього здоров'я. Тому метою роботи стало проведення порівняльного аналізу функціональності основних програм для управління молочною фермою для їхньої об'єктивної оцінки з точки зору виробників молока. Для цього було проаналізовано інформацію з офіційних сайтів програмних продуктів та зібрано наукові статті, в яких проводився аналіз цього забезпечення. У результаті всі програмні продукти було поділено на 3 категорії: програми для контролю молочної продуктивності та управління процесами на молочній фермі від виробників молочного обладнання; до таких програмних продуктів віднесено DairyPlan C21 (GEA), DATAFLOW II (Milkline), AfiFarm (Afimilk), DelPro (DeLaval) та FARMSOFT (Farmtec a. s.); програми для менеджменту молочною фермою DairyComp 305 і UNIFORM-Agri, а також забезпечення для ферм від розробників із пострадянського простору – MilkCentre (Ciab Expert). Програми від різних виробників молочного обладнання перебували практично на одному рівні та мали практично всі необхідні блоки для ідентифікації, контролю та менеджменту тваринами на молочній фермі. Програмне забезпечення, що розроблялося для менеджменту молочної ферми, є більш ефективним у тандемі з однією з програм для доїльного залу. Цей клас програм дає змогу розширити можливості з управління репродуктивними та ветеринарними роботами на фермі, а також знизити навантаження на обслуговуючий персонал завдяки формуванню автоматичних звітів для контролюючих органів і керівництва. Третій клас програм найменш розвинений порівняно з перерахованими вище, але компенсує цей недолік постійним удосконаленням, за рахунок постійного контакту розробників з виробником. Таким чином, на ринку програмного забезпечення існує значна кількість програмних продуктів, здатних забезпечити управління молочного виробництва для ферм різних розмірів

Ключові слова: програмне забезпечення; периферійні пристрої; менеджмент виробництва; репродукція; «цифровізація» галузі

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