НАУКОВІ ГОРИЗОНТИ

УДК 63

Співзасновники:
Поліський національний університет, ТОВ «УКР ЖИТ НГ»

Редакція, видавець:
Поліський національний університет
Рік заснування: 1998
Періодичність випуску: щомісячно

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Поліського національного університету
(протокол № 1 від 28 серпня 2024 року)

Рішення національної ради України
з питань телебачення і радіомовлення № 1533.
Ідентифікатор медіа – R30-01593

Науковий журнал включено до категорії А Переліку наукових фахових видань України, у яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора та кандидата ветеринарних, економічних, сільськогосподарських і технічних наук зі спеціальностей: 051 – Економіка; 071 – Облік і оподаткування; 072 – Фінанси, банківська справа та страхування; 073 – Менеджмент; 075 – Маркетинг; 076 – Підприємництво, торгівля та біржова діяльність; 101 – Екологія; 133 – Галузеве машинобудування; 201 – Агрономія; 202 – Захист і карантин рослин; 203 – Садівництво та виноградарство; 204 – Технологія виробництва і переробки продукції тваринництва; 205 – Лісове господарство; 206 – Садово-паркове господарство; 208 – Агроінженерія; 211 – Ветеринарна медицина (наказ МОН України № 1166 від 23 грудня 2022 р.)

Журнал представлено у міжнародних наукометричних базах даних, репозитаріях та пошукових системах: Інституційний репозитарій Поліського національного університету, AGRICOLA, CAB Abstracts and Global Health (CABI), Index Copernicus, Реєстр наукових видань України, Національна бібліотека України імені В. І. Вернадського, Crossref, Directory of Open Access Journals (DOAJ), ERIH PLUS, International System for Agricultural Science and Technology (AGRIS), Dimension, Polska Bibliografia Naukowa, Google Scholar, Ulrichsweb Global Serials Directory, UCSB Library, EBSCO, Scopus, University of Oslo Library, University of Hull Library, SOLO – Search Oxford Libraries Online, European University Institute, Leipzig University Library, Cambridge University Library, Zendy, OUCI (Open Ukrainian Citation Index), Worldcat, CORE

Адреса редакції:
Поліський національний університет
10008, б-р Старий, 7, м. Житомир, Україна
E-mail: info@sciencehorizon.com.ua
https://sciencehorizon.com.ua/uk

SCIENTIFIC HORIZONS

UDC 63

Founders:
Polissia National University, "UKR ZHYT NG" LLC

Editorial and Publisher:
Polissia National University

Year of foundation: 1998
Frequency of issue: monthly

Recommended for printing and distribution
via the Internet by the Academic Council
of Polissia National University
(Minutes No. 1 of August 28, 2024)

Decision of the National Council
of Television and Radio Broadcasting of Ukraine No. 1533.
Media identifier – R30-01593

The scientific journal is included in category A of the List of scientific professional publications of Ukraine, in which the results of dissertations for the degree of doctor and candidate of veterinary, economic, agricultural, and technical sciences can be published in the following specialties: 051 – Economy; 071 – Accounting and Taxation; 072 – Finance, Banking and Insurance; 073 – Management; 075 – Marketing; 076 – Entrepreneurship, Trade and Exchange Activities; 101 – Ecology; 133 – Sectoral Engineering; 201 – Agronomy; 202 – Plant Protection and Quarantine; 203 – Horticulture and Viticulture; 204 – Technology of Production and Processing of Livestock Products; 205 – Forestry; 206 – Park and Gardening Management; 208 – Agricultural Engineering; 211 – Veterinary Medicine
(Order of the Ministry of Education and Science of Ukraine No. 1166 of December 23, 2022)

The journal is presented international scientometric databases, repositories and scientific systems: Institutional Repository of Polissia National University, AGRICOLA, CAB Abstracts and Global Health (CABI), Index Copernicus, Register of Scientific Publications of Ukraine, Vernadsky National Library of Ukraine, Crossref, Directory of Open Access Journals (DOAJ), ERIH PLUS, International System for Agricultural Science and Technology (AGRIS), Dimension, Polska Bibliografia Naukowa, Google Scholar, Ulrichsweb Global Serials Directory, UCSB Library, EBSCO, Scopus, University of Oslo Library, University of Hull Library, SOLO - Search Oxford Libraries Online, European University Institute, Leipzig University Library, Cambridge University Library, Zendy, OUCI (Open Ukrainian Citation Index), Worldcat, CORE

Editors office address:
Polissia National University
10008, 7 Staryi Bvld., Zhytomyr, Ukraine
E-mail: info@sciencehorizon.com.ua
https://sciencehorizon.com.ua/en

НАУКОВІ ГОРИЗОНТИ

Том 27, № 9
2024

НАУКОВИЙ ЖУРНАЛ
Засновано 12 березня 1998 р.
Періодичність випуску: дванадцять разів на рік

SCIENTIFIC HORIZONS

Vol. 27, No. 9 2024

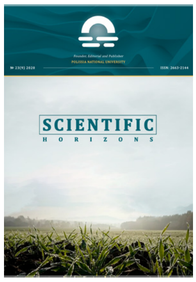
SCIENTIFIC JOURNAL
Year of establishment: Since March 1998.
Publication frequency: Twelve times a year

ЗМІСТ

CONTENTS

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 9-19



UDC 636.52/.58.09:616.36-084:615.244
Doi: 10.48077/scihor9.2024.09

Hepatosis in broiler chickens: The role and efficacy of therapeutic and prophylactic agents containing hepatoprotectors

Ruslan Dubin*
PhD in Veterinary Sciences, Associate Profesor
Odesa State Agrarian University
65012, 13 Panteleimonivska Str., Odesa, Ukraine
https://orcid.org/0000-0003-3540-0816
Kateryna Rodionova
PhD in Veterinary Sciences, Associate Profesor
Odesa State Agrarian University
65012, 13 Panteleimonivska Str., Odesa, Ukraine
https://orcid.org/0000-0002-7245-4525
Irina Popova
PhD in Veterinary Sciences, Associate Profesor
Odesa State Agrarian University
65012, 13 Panteleimonivska Str., Odesa, Ukraine
https://orcid.org/0000-0002-9942-0464
Zhanna Koreneva
PhD in Veterinary Sciences, Associate Profesor
Odesa State Agrarian University
65012, 13 Panteleimonivska Str., Odesa , Ukraine
https://orcid.org/0000-0003-2730-5990
Halyna Rebenko
PhD in Veterinary Sciences, Associate Professor
Sumy National Agrarian University
40021, 160 Herasyma Kondratieva Str., Sumy, Ukraine
https://orcid.org/0000-0002-1884-4901

Article's History:
Received: 29.03.2024
Revised: 01.08.2024
Accepted: 28.08.2024

Abstract. The preservation of poultry stock can be improved by incorporating therapeutic and preventive agents, including hepatoprotectors, into the diet. This study aimed to evaluate the effect of an experimental drug containing hepatoprotectors on the health of broiler chickens. The research sought to identify the potential of the preparation to enhance liver function and overall poultry stock survival. The study was conducted from 2023 to 2024 at Odesa State Agrarian University. Investigations were carried out

Suggested Citation:
Dubin, R., Rodionova, K., Popova, I., Koreneva, Zh., & Rebenko, H. (2024). Hepatosis in broiler chickens: The role and efficacy of therapeutic and prophylactic agents containing hepatoprotectors. *Scientific Horizons*, 27(9), 9-19. doi: 10.48077/scihor9.2024.09.

**Corresponding author*

to assess the effects of the experimental preparation in the following doses: 1.0 g/kg body weight (therapeutic dose), 2.0 g/kg body weight (double therapeutic dose), and 5.0 g/kg body weight (fivefold therapeutic dose) over 30 days. The experiment was conducted on 500 Cobb 500 broiler chickens aged 1 to 40 days. Additionally, biochemical blood parameters were measured and analysed using a Polish biochemical selective automatic analyser, the Hitachi 902. Studies have established that the optimal dose of the experimental drug for hepatosis in broiler chickens is 1.0 g/kg body weight. After administration of the drug, the serum bilirubin content decreased by 27.3%, lactate dehydrogenase activity decreased by 17.1%, aspartate aminotransferase activity decreased by 16.4%, alanine aminotransferase activity decreased by 19.3%, and vitamin A content increased by 25.6%, while the phagocytic activity of pseudoeosinophils increased by 23.1%. The results of the studies have proven that the experimental drug normalises liver function, positively affects the biochemical composition of blood, promotes growth, provides protection and natural resistance of the broiler organism, and even improves the quality of poultry products. Based on the above, it is necessary to improve methods for early diagnosis of liver function disorders in poultry and apply effective methods for correcting metabolic processes

Keywords: liver; hepatoprotectors; erythrocytes; haemoglobin; leukocytes

INTRODUCTION

Poultry farming is a sector of agriculture characterised by high liquidity within the market environment and rapid, dynamic development. The profitability of feed is significantly higher than in other branches of animal husbandry, therefore the cost of poultry meat is the lowest, which makes poultry production affordable for consumers (Bogach *et al.,* 2021). A decisive factor for the rearing of young stock is the onset of productivity – 130-150 days (depending on the cross of chickens). At this point, the metabolic load on the poultry reaches its maximum. Approximately 2-3 weeks before the start of egg production, significant changes occur in the structure and function of the oogenic organs and the metabolism of young hens (Paliy *et al.,* 2021; Dotsenko *et al.,* 2021). With the onset of sexual maturity, under the influence of the endocrine system, the intensity of metabolism changes, especially mineral metabolism, to form powerful reserves of calcium, which are actively used for the formation of egg cells. The liver plays a key role in this process, as it synthesises the active form of vitamin D (Ponomarenko *et al.,* 2021).

Recent studies have highlighted a high prevalence of liver diseases in both meat and egg-laying poultry. The liver is frequently involved in overall pathological processes associated with non-infectious, infectious, and parasitic diseases. According to A. Agbonon and M. Gbeassor (2019) and A. Baradaran *et al.* (2019), non-infectious diseases in poultry often include liver pathologies such as hepatitis or liver dystrophy, and these conditions have been diagnosed in 5.0-50.8% of cases. These pathological processes are often more pronounced in egg-laying poultry, which can be attributed to the specific metabolic characteristics of chickens and their housing conditions. Authors T. Bemela Mawulom *et al.* (2021), and X. Chen *et al.* (2023) noted that poultry diseases such as avian hepatitis and hepatic steatosis are prevalent on farms with mixed ownership. Clinically, this manifests as general weakness, reduced mobility, obesity, anaemia of the ears and comb, decreased egg production, increased levels of urea, creatinine, and bilirubin in the blood, and a decrease in the number of red blood cells. In addition to hepatocellular changes, kidney and heart dystrophy, individual haemorrhages in the liver are also observed in diseased birds.

Hepatitis or hepatic steatosis is caused by a disruption in the metabolism of substances, characterised by the degeneration and necrosis of liver cells and the impairment of all liver functions. As noted by P. D'Souza *et al.* (2019), this reflects on the overall condition of the bird and its productive characteristics, which can lead to mortality. A crucial prerequisite for effective prevention of liver diseases is a complete and balanced diet. When keeping poultry, feeding should correspond to the physiological state, be complete in terms of overall nutrition, protein composition, mineral content, and vitamins, and meet the specific needs of the species and age of the bird. Since contamination of feed with mycotoxins often causes liver dystrophy and hepatitis, feeding animals with high-quality feed is an important aspect of prevention. Therefore, it is necessary to eliminate adverse factors that can affect the quality of compound feed, such as energy imbalance in the feed, the presence of toxic metabolites, amino acids, vitamins, etc.

In foreign practice, complex preparations based on vitamins B4, B12, E, methionine, and selenium are often used. These substances complement each other and enhance the protective functions of the liver. The pathogenesis of liver diseases is primarily based on damage to cellular elements, especially hepatocytes, leading to dysfunction, dystrophic changes, inflammation, cell lysis, necrosis, and fibrosis (Feng *et al.,* 2019; Erukainure *et al.,* 2020). Therefore, hepatoprotectors are used to restore liver cell metabolism. The search for highly effective hepatoprotectors for liver protection in poultry is a pressing issue. According to C. Gregg *et al.* (2022), hepatoprotectors can be classified into the following groups: plant-based hepatoprotectors, phospholipid preparations, organ preparations, amino acid derivatives, selenium-containing preparations, ursodeoxycholic acid preparations, synthetic drugs, and preparations from other groups.

Therefore, addressing the problem of normalising metabolic processes in poultry and restoring the morpho-functional state of the liver through the use of hepatoprotectors is one way to increase the efficiency of poultry farming and the production of high-quality products. This objective has informed the aim of the current study.

MATERIALS AND METHODS

A study conducted between 2023 and 2024 at the Odesa State Agrarian University aimed to investigate the effects of the drug Hep-A-Stres on the performance of broiler chickens and meat quality. The hepatoprotector was used to normalise metabolism, enhance overall resistance and productivity, prevent and treat hepatic steatosis, during stressful periods, and accelerate growth during the finishing period. Hep-A-Stres is a clear, oily liquid ranging from colourless to yellowish, with the possibility of slight sediment. The composition of 1 ml of the drug contains: carnitine hydrochloride – 25 mg; D, L-methionine – 10 mg; sorbitol – 200 mg; choline chloride – 18.75 mg; magnesium sulphate heptahydrate – 10 mg; benzyl alcohol – 15 mg; distilled water – up to 1 ml.

- Carnitine hydrochloride increases muscle mass and improves heart function by stimulating metabolic processes and enhancing the body's endurance. It reduces the risk of hepatic steatosis and improves the uptake of vitamins and minerals into cells, exhibiting antioxidant properties.
- Methionine and choline chloride contribute to the synthesis of liver enzymes, which is crucial for detoxification, and help lower blood cholesterol levels due to their lipotropic effects.
- Sorbitol and magnesium sulphate regulate intestinal transit and enhance bile flow.

The study was conducted on 220 chicken embryos and 120 Cobb 500 broiler chicks. The experiment involved injecting 0.1 ml of the drug into the yolk sac of the embryo at dilutions of 1:10, 1:100, and 1:1000. Each dose was tested on 25 embryos. At the time of the experiment, the chicken embryos were divided into 3 groups of 30, while the control group contained 20 intact embryos that were injected with an isotonic sodium chloride solution. On the 19th day of incubation, embryonic development was assessed. This included measuring body weight, cranio-caudal length, and the development of the pectoral and pelvic limbs. To examine the effect of the preparation on the offspring after hatching, 30 eggs were retained in each group and incubated until the chicks hatched. The resulting 120 chicks were reared to 40 days of age. The technical parameters of rearing were following the recommended practices for this crossbreed. Weekly measurements of the live weight of the broiler chickens were taken. Live weight is an indicator of bird development and reflects the impact of feeding and rearing conditions.

The clinical and physiological condition of the broiler chickens was assessed daily through visual inspection of the flock and observation of behaviour, appetite, and overall health. Physiological status was evaluated at the beginning and end of the experiment using morphological and biochemical blood parameters. Blood samples were collected from the brachial wing vein or after decapitation of the bird for biochemical analysis. Haematological parameters were determined, including red blood cell count, white blood cell count, haemoglobin concentration, erythrocyte sedimentation rate (ESR), and the percentage of band neutrophils, eosinophils, and monocytes (Kanda *et al.,* 2020). Additionally, biochemical blood parameters were measured and analysed using a Polish Hitachi 902 biochemical selective automated analyser. Blood samples were prepared according to the manufacturer's instructions (2010/63/EU).

To investigate drug resistance in broiler chickens, 30 ten-day-old chicks were divided into four groups. The first group served as a control. The second, third, and fourth groups were experimental. Hep-A-Stres was added to the diet of chickens in the experimental groups at doses according to Table 1. This means that each group received a specific dose of the drug per kilogram of body weight for 30 days, corresponding to the indicated doses: 1.0, 2.0, and 5.0 g/kg body weight, respectively. The data from this study allowed for a comparison of the efficacy and safety of different doses of the drug on chickens compared to the control group.

Table 1*. Experimental design for broiler chickens*

Group	Drug	Dose, g/kg body weight
1 – control	-	-
2 – experimental	Hep-A-Stres	1.0
3 – experimental	Hep-A-Stres	2.0
4 – experimental	Hep-A-Stres	5.0

Source: *compiled by the authors*

Physicochemical methods for determining meat freshness were conducted by national standards DSTU 3136:2017 (2019), DSTU 3143-95 (2009), and DSTU 3143:2013 (2014). The amino acid composition of the meat was determined using an automated multi-functional infrared spectrometer manufactured by "Infrapid-61" (Hungary). Meat samples were prepared according to the manufacturer's instructions. Statistical analysis was performed using the Statistica 6.0 software package. The significance of mean differences was evaluated using Student's t-test. All experimental studies were conducted by modern methodological approaches and complied with the relevant requirements and standards, specifically meeting the requirements of DSTU ISO/IEC 17025:2005 (2006). Animal husbandry and all manipulations were carried out following the provisions of the Order on the Procedure for Carrying out Experiments and Experiments on Animals by Scientific Institutions (Law of Ukraine No. 249, 2012), and the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (1986).

RESULTS

Based on the external examination, no differences were observed between the foetuses of the control and experimental groups. The length of the forelimbs and hindlimbs, as well as the body weight, did not show any statistically significant differences compared to the control. Therefore, based on this study, it can be concluded that the experimental drug, at the indicated doses, does not exhibit embryotoxic or teratogenic effects on chicken embryos (Table 2).

***Table 2**. Dimensions and weight of chicken embryos, n = 20 (M ± m)*

Group	Pectoral length, mm	Pelvic length, mm	Body size, mm	Body weight, g
Control	31.9 ± 1.76	65.7 ± 2.58	77.1 ± 3.33	22.9 ± 3.24
After administration of isotonic solution	31.8 ± 1.79	65.1 ± 3.58	76.8 ± 3.22	22.8 ± 4.16
Experimental				
1:10	31.4 ± 1.25	65.7 ± 2.21	75.1 ± 3.44	23.8 ± 3.19
1:100	31.7 ± 1.63	66.6 ± 3.25	76.0 ± 3.28	23.3 ± 4.11
1:1000	31.4 ± 2.79	65.7 ± 3.26	75.8 ± 4.34	23.5 ± 3.14

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

During the examination of the larynx, nasal cavity, eyeballs, brain, internal organs, and skeletal system of embryos on a series of parallel cross-sections of the body, neck, and head, no anatomical deviations were found in the topography and morphology of the internal organs, in the rate of ossification of the skeletal bones, and their spatial orientation. The conducted studies showed that the highest percentage of chick hatching was observed in the second and third experimental groups. Thus, the drug under investigation not only lacks embryotoxic effects but also stimulates the sequential development of embryos. They do not have a teratogenic effect, and therefore, they can be included in the diets of breeding poultry. In the next stage of the study, the tolerability of the experimental drug in broiler chickens was determined. The results of the experiments showed that the use of the drug contributed to an improvement in the activity of the birds. The average daily weight gain of the birds was 5.5-7.9% higher than the control values for all applied doses of the experimental drug (Table 3). This indicates that the drug contributes to improving the health and development of broiler chickens, which may indicate its tolerability and effectiveness in poultry farming conditions.

***Table 3**. Results of the tolerability test of the experimental drug in broiler chickens*

Indicator	Groups			
	1 – control	2 – experimental	3 – experimental	4 – experimental
Number at the start of the study, heads	30	30	30	30
Mortality	1	-	-	-
Survival rate, %	96.6	100	100	100
Feed consumption per kg of weight gain, kg	1.81	1.76	1.77	1.78
Average daily gain, g	46.4	50.1	49.8	48.9

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

Regarding feed consumption per unit of production, the indicators were within the zootechnical standards for this cross of poultry. However, in the experimental groups, feed conversion was higher compared to the control after the application of all doses (by 1.6-2.8%) compared to the control group. The effect of the experimental drug on the morphological and biochemical blood parameters is presented in Tables 4 and 5.

Table 4. *Morphological parameters of the blood of broiler chickens, n = 10 (M ± m)*

Indicator	Groups			
	1 – control	2 – experimental	3 – experimental	4 – experimental
Baseline data				
Erythrocytes, million/μl	2.87 ± 0.20	2.81 ± 0.15	2.90 ± 0.17	2.85 ± 0.14
Leukocytes, thousand/μl	28.9 ± 1.39	28.3 ± 1.25	28.2 ± 1.21	28.4 ± 1.14
Haemoglobin, g/l	94.4 ± 4.12	94.1 ± 4.23	94.9 ± 4.26	94.6 ± 4.22
Leukogram, %				
Basophils	2.7 ± 0.32	2.5 ± 0.28	2.1 ± 0.39	2.4 ± 0.41
Eosinophils	6.3 ± 0.41	6.4 ± 0.57	6.2 ± 0.61	6.0 ± 0.59
Pseudoeosinophils	26.1 ± 1.85	26.5 ± 1.29	26.7 ± 1.33	25.4 ± 1.33
Lymphocytes	58.3 ± 0.92	58.4 ± 1.19	58.1 ± 1.15	60.1 ± 1.29
Monocytes	6.6 ± 0.69	6.2 ± 0.55	6.9 ± 0.53	6.1 ± 0.79
After administration of the drug				
Erythrocytes, million/μl	2.98 ± 0.20	3.05 ± 0.14	3.06 ± 0.21	3.05 ± 0.22
Leukocytes, thousand/μl	29.9 ± 1.52	29.7 ± 1.51	29.8 ± 1.52	30.2 ± 1.63
Haemoglobin, g/l	94.9 ± 4.31	95.0 ± 4.28	96.4 ± 4.47	96.3 ± 4.42
Leukogram, %				
Basophils	2.8 ± 0.45	2.1 ± 0.41	2.0 ± 0.41	2.1 ± 0.46
Eosinophils	6.1 ± 1.14	6.8 ± 1.11	6.3 ± 1.10	6.1 ± 1.11
Pseudoeosinophils	27.0 ± 1.5	28.1 ± 1.2	29.6 ± 1.1	29.8 ± 1.3
Lymphocytes	56.3 ± 1.2	56.5 ± 1.5	56.9 ± 1.2	57.1 ± 1.4
Monocytes	7.8 ± 0.7	6.5 ± 0.6	6.4 ± 0.5	6.2 ± 0.4

Source: *compiled by the authors*

Table 5. *Biochemical parameters of the blood of broiler chickens, n = 10 (M ± m)*

Indicator	Groups			
	1 – control	2 – experimental	3 – experimental	4 – experimental
Baseline data				
Total protein, g/L	2.32 ± 0.16	2.30 ± 0.11	2.29 ± 0.10	2.30 ± 0.12
Inorganic phosphorus, mmol/L	7.63 ± 0.22	7.61 ± 0.25	7.70 ± 0.20	7.60 ± 0.11
Total calcium, mmol/L	10.46 ± 0.24	10.44 ± 0.21	10.38 ± 0.20	10.28 ± 0.33
Vitamin A, μg/ml	0.32 ± 0.026	0.31 ± 0.021	0.33 ± 0.026	0.32 ± 0.024
Carotene, μg/g	308.2 ± 12.7	307.7 ± 12.9	306.4 ± 11.28	310.7 ± 11.9
AST, nmol/(h/L)	0.52 ± 0.054	0.51 ± 0.053	0.52 ± 0.059	0.51 ± 0.58
ALT, nmol/(h/L)	0.23 ± 0.020	0.24 ± 0.019	0.21 ± 0.017	0.23 ± 0.023
After administration of the drug				
Total protein, g/L	2.37 ± 0.18	2.39 ± 0.15	2.39 ± 0.17	2.38 ± 0.14
Inorganic phosphorus, mmol/L	8.01 ± 0.34	8.11 ± 0.39	8.09 ± 0.31	8.10 ± 0.33
Total calcium, mmol/L	12.23 ± 0.31	12.81 ± 0.30	12.91 ± 0.32	12.89 ± 0.31
Vitamin A, μg/ml	0.34 ± 0.030	0.33 ± 0.032	0.34 ± 0.038	0.34 ± 0.039
Carotene, μg/g	309.3 ± 6.74	340.2 ± 6.11*	347.9 ± 6.13*	350.3 ± 6.27*
AST, nmol/(h/L)	0.54 ± 0.061	0.53 ± 0.060	0.55 ± 0.059	0.52 ± 0.066
ALT, nmol/(h/L)	0.25 ± 0.019	0.24 ± 0.030	0.25 ± 0.022	0.24 ± 0.026

Note: * – $P < 0.05$
Source: *compiled by the authors*

Haematological analysis revealed a trend towards increased red blood cell count and haemoglobin levels in chickens from the 3rd and 4th experimental groups. However, no statistically significant changes in the morphological blood parameters of the experimental chickens were observed throughout the study period. Analysing the leukogram, it can be concluded that after drug administration, it did not change significantly, with only a trend towards an increase in pseudoeosinophils observed. The obtained results may indicate that the drug has a minimal impact on the haematological parameters of chickens, but this warrants further investigation to elucidate the exact mechanisms of its effect on the avian organism.

The data presented in Table 5 shows that the administration of the drug caused an increase in serum carotene levels in the 2nd, 3rd, and 4th experimental groups by 9.9%, 12.5%, and 13.1%, respectively, compared to the control values (in all cases $P < 0.05$). Regarding other biochemical blood parameters, they did not show significant changes and remained within the physiological norm. Thus, the conducted studies showed that Hep-A-Stres, at the tested doses, did not cause significant deviations in the bird's metabolic processes. During the macroscopic examination of the internal organs, no pathological changes were observed.

Based on the conducted research, it can be concluded that the drug, at the tested doses, was non-toxic to poultry. Its prolonged application (for 30 days) at doses of 1.0, 2.0, and 5.0 g/kg body weight (the therapeutic dose and two- and fivefold doses of the therapeutic dose) had no negative impact on the function of vital organs and systems in chickens, physiological and biochemical blood parameters, and did not cause changes in the structure of their organs. The next stage of the research will determine the effect of the drug on certain factors of the body's natural resistance (Table 6).

***Table 6**. Indicators of natural resistance in broiler chickens, n = 10 (M ± m)*

Indicator	Groups			
	1 – control	2 – experimental	3 – experimental	4 – experimental
		Hep-A-Stres		
		0.5 g/kg	1.0 g/kg	2.0 g/kg
Baseline data				
Bactericidal activity of blood serum, %.	35.33 ± 2.67	36.21 ± 2.43	34.88 ± 2.71	35.65 ± 3.22
Lysozyme activity of blood serum, %.	16.12 ± 1.22	15.94 ± 1.34	16.12 ± 1.43	16.77 ± 1.42
Phagocytic activity, %.	40.21 ± 1.76	40.23 ± 2.15	39.11 ± 2.43	40.23 ± 3.24
After administration of the drug				
Bactericidal activity of blood serum, %.	37.22 ± 2.35	38.75 ± 2.43	40.14 ± 2.53	40.43 ± 2.36
Lysozyme activity of blood serum, %.	17.12 ± 1.13	18.21 ± 1.43	19.12 ± 1.45	18.97 ± 2.15
Phagocytic activity, %.	40.23 ± 2.34	41.65 ± 3.12	49.51 ± 2.27*	49.19 ± 2.40*

***Note:** * – P < 0.05*
***Source:** compiled by the authors*

The table shows that the administration of the maximum dose of the drug to chickens in the 3rd and 4th experimental groups significantly increased the phagocytic activity of pseudoeosinophils compared to the control (23.1% and 22.3%, respectively). Although there was a trend towards increased bactericidal activity of serum in chickens of all experimental groups (from 4.1% to 8.6%), these changes were not statistically significant compared to the control. The increase in phagocytic activity of pseudoeosinophils can be explained by the high bioavailability and effectiveness of the drug's components and their synergistic action. Thus, the conducted studies showed that the drug, at the highest doses (1.0 and 2.0 g/kg body weight), increases the natural resistance of the organism and increases the average daily gain and survival rate of broiler chickens. However, the dose of 1.0 g/kg is considered optimal, as a higher dose (2.0 g/kg) does not cause a significant increase in weight or improvement in immune status in birds, and a lower dose (0.5 g/kg) is considered less effective. The next stage of the study was a physicochemical assessment of the broiler meat, as shown in Table 7.

***Table 7**. Physicochemical parameters of broiler chicken meat, n = 10 (M ± m)*

Indicator	Groups			
	1 – control	2 – experimental	3 – experimental	4 – experimental
Drugs		Hep-A-Stres		
		0.5 g/kg	1.0 g/kg	2.0 g/kg
pH	6.42 ± 0.07	6.04 ± 0.05	5.94 ± 0.06	6.2 ± 0.03
Reaction to peroxidase with benzidine	Doubtful	Positive	Positive	Positive
Acid number of fat, mg KOH	0.92 ± 0.08	0.94 ± 0.07	0.96 ± 0.07	0.92 ± 0.05
Determination of acidity-oxidation coefficient	0.36 ± 0.07	0.54 ± 0.08	0.54 ± 0.07	0.56 ± 0.09
Reaction with formalin	Doubtful	Negative	Negative	Negative

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

The table shows that the pH of the meat from the experimental broiler chickens indicates a mature and good quality state, while the pH values of the meat from the control group broiler chickens suggest a diseased state. The freshness and quality of the meat are also confirmed by indicators such as the acid-oxidation ratio and the acid number of the fat. When the drug was added, the acid-oxidation ratio of the meat from broiler chickens in all experimental groups was within the range of 0.54-0.56, while this value in the control group was 0.36. The benzidine reaction was positive in the meat of the experimental groups and negative in the formalin reaction, while in the meat of the control group broiler chickens, this indicator was doubtful.

Therefore, all the investigated parameters indicate that the meat of broiler chickens from the experimental groups, where the experimental drug was applied, corresponds to a mature and good quality state, while the meat of broiler chickens from the control group is classified as meat from diseased poultry according to all the investigated parameters. The determination of the content of essential amino acids, such as tryptophan and hydroxyproline, is an important method for assessing the nutritional value of meat (Table 8)

***Table 8**. Biological value of broiler chicken meat, n = 10 (M ± m)*

Indicator	Groups			
	1 – control	2 – experimental	3 – experimental	4 – experimental
		Hep-A-Stres		
		0.5 g/kg	1.0 g/kg	2.0 g/kg
Hydroxyproline, %	0.23 ± 0.03	0.22 ± 0.05	0.21 ± 0.04	0.21 ± 0.05
± compared to control, %	-	-4.3	-8.6	-8.6
Tryptophan, %	1.20 ± 0.05	1.24 ± 0.09	1.28 ± 0.04	1.29 ± 0.06
± compared to control, %	-	+3.3	+6.7	+7.5
PQI	5.2 ± 0.31	5.6 ± 0.28	6.1 ± 0.29	6.1 ± 0.32
± compared to control, %	-	+7.7	+17.3	+17.7

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

Tryptophan, which is found in large quantities in intracellular proteins, is a positive indicator of meat quality, whereas hydroxyproline, which is primarily found in connective tissue, is a negative indicator of quality. The ratio of these amino acids reflects the biological value of meat, known as the protein quality index (PQI). In the experimental groups of broiler chickens, the content of tryptophan in the breast muscles was 3.3-7.5% higher than in the control group, while the content of hydroxyproline was correspondingly lower by 4.3-8.6%. This resulted in a protein quality index of the meat in the experimental groups being 17.3-17.7% higher than in the control groups.

DISCUSSION

In industrial poultry farming, the high stress on the bird's organism leads to persistent disruptions in the functional activity of liver cells, even with minor deviations in metabolic processes. Symptoms of liver diseases often do not manifest immediately but only after a certain period, separated from the onset of the pathological process. According to scientists J. Heeren and L. Scheja (2021), antioxidants, such as flavonoids, play a key role in restoring liver function and increasing the overall resistance of the poultry's organism. Flavonoids, along with other antioxidants that enter the body through feed, are important components of the cell's antioxidant system. They can act as traps for free radicals and chelate metal ions involved in peroxidation. Polyphenolic compounds, to which flavonoids belong, can interact with various lipid radicals and stabilise them, forming phenol radicals that do not participate in oxidative processes.

In the studies conducted by O. Juanola *et al.* (2021) and S. Kismiati *et al.* (2023), it was found that alpha-tocopherol, which possesses a phenolic structure, interacts with lipid peroxide free radicals during lipid peroxidation reactions by donating a hydrogen atom. This process reduces the lipid peroxide to a hydroperoxide, thereby halting the progression of lipid peroxidation. The free radical generated from alpha-tocopherol as a result of this reaction stabilises and does not participate in further chain reactions. It can directly interact with lipid peroxide radicals, reducing them and converting them into a stable oxidised form known as tocopherol quinone. Such a reaction contributes to the cessation of lipid oxidation and helps maintain the stability of fats in products. According to S. Marimuthu *et al.* (2022), the role of antioxidants in regulating cellular immunity is an established fact. The intracellular redox balance acts as a regulatory factor in T-cell activation processes, macrophage secretion of lymphokines, and cellular apoptosis. Thus, the functional synergy of antioxidants indeed enables the achievement of maximum protective effects and high stability of the preparation at lower concentrations of antioxidants.

Research is being conducted into the interactions of various antioxidants within the body, allowing for the creation of optimal antioxidant compositions. A significant aspect of the experimental drug's application in these studies was the emphasis on a comprehensive assessment of the clinical and biochemical status of broiler chickens. This is a crucial step in ensuring their optimal health and productivity, justifying optimal doses of the experimental drug for broiler hepatosis to ensure effective treatment and prevention of diseases in poultry, as well as investigating the physicochemical composition and biological value of broiler chicken meat. Similar results were obtained by O. Oke *et al.* (2020), as they confirmed the effectiveness of using hepatoprotectors for broiler chickens in terms of reducing the feeding period. This is of great importance for industrial poultry farming, where growth rate and productivity are key factors helping to ensure the efficiency and cost-effectiveness of poultry meat production. The research results showed that the experimental drug does not cause local irritation, has no embryotoxic or teratogenic properties, and has a low allergic potential, making it safe and convenient to use for poultry throughout the entire growing period.

When selecting a hepatoprotector, preference was given to this experimental drug, which has been frequently used in Ukraine in recent years. Research by K-Y. Tian *et al.* (2020) confirm the positive impact of using Carnivet L and Introvit A on the general condition and productivity of broiler chickens. A significant increase in the content of total protein in blood serum by 16.9% indicates an improvement in protein metabolism and the overall physiological state of the bird. Of particular interest is the effect of these drugs on the meat quality of broilers. An increase in the acid-oxidation coefficient of meat to 0.54-0.56 indicates the maturity and good quality of the meat, which is an important quality indicator. For comparison, in the control group, this indicator was significantly lower (0.36), indicating less mature and possibly lower-quality meat. Another important aspect is the increased content of tryptophan and decreased content of hydroxyproline in the breast muscles of experimental groups of broiler chickens. Tryptophan, as an essential amino acid, plays an important role in protein synthesis and can positively affect the growth and development of poultry. A decrease in the level of hydroxyproline, which is a marker of collagen, may indicate an improvement in meat texture, as a decrease in the amount of collagen makes the meat softer and juicier. These results confirm the effectiveness of using Carnivet L and Introvit A in improving meat quality and the physiological state of broiler chickens, which can be beneficial for increasing the profitability of production and meeting consumer demands for the quality of food products.

The results of the current research align with the data presented by R. Trofimiak and L. Slivinska (2021). Administration of the drug Carcesel into the diet of broiler chickens significantly increased their performance indicators. In particular, the experimental group showed an increase in pre-slaughter live weight by 2.76-5.02% and carcass weight by 2.93-5.89% compared to the control group. This indicates the effectiveness of the drug in stimulating bird growth and increasing their final productivity. In addition, an increase in muscle tissue mass by 3.32-6.75%, breast muscle mass by 3.53-7.83%, and edible carcass parts by 3.33-6.47% was noted. These indicators demonstrate an improvement not only in overall weight but also in the quality characteristics of the meat, which is an important factor for commercial poultry farming.

According to the research of S. Wang *et al.* (2023), the increased productivity of the broilers in the experimental group can be attributed to the higher protein quality index (PQI), which was 3.92-7.84% greater compared to the control. Additionally, the meat preparation technique score was also 3.92-7.84% higher than the control's 1.81-3.61%. During the experiment, a positive impact on the nutritional value of meat was observed, with the protein content of muscle tissue increasing by 7.5%, fat content by 8.3%, and energy value by 4.8%. Overall, the authors' results emphasise the importance of optimising the feeding of broiler chickens to achieve better performance and meat quality, which can be beneficial both economically and from a nutritional standpoint.

The results of the current organoleptic study confirm the findings of V. Yaremchuk *et al.* (2020) and V. Yaremchuk and L. Slivinska (2020). According to their data, feeding broiler chickens various immunostimulants had a significant impact on the digestibility of key nutrients. Specifically, the digestibility of organic matter increased by 3.92%, protein by 7.80%, fat by 5.35%, fibre by 6.7%, and NFE (nitrogen-free extract) by 1.7%. This contributed to better nutrient absorption and, consequently, more efficient feed utilisation. Their data showed that feeding broiler chickens with various immunostimulants indeed significantly affected the digestibility of important nutrients. In particular, the digestibility of organic matter increased by 3.92%, protein by 7.80%, fat by 5.35%, fibre by 6.7%, and NFE (nitrogen-free extract) by 1.7%. This improved nutrient absorption and allowed for more efficient feed utilisation. The experimental broiler chickens showed higher average daily weight gains (3.11-10.79%) and live weight at slaughter (3.7-10.29%) compared to the control group. The improvement in feed conversion, i.e., the ability to more efficiently convert feed into weight gain, allowed for better utilisation of the biological potential of poultry meat productivity. This not only increased pre-slaughter weight and carcass weight but also increased the slaughter yield of dressed carcasses by 2.52-2.68%. The yield of edible carcass parts also reached 85.0-86.1%, which is an important indicator for assessing the productivity and quality of whole meat.

The results obtained show that the meat from broiler chickens after the administration of the drug "Hep-A-Stres" meets the highest quality standards and has a high biological value. This highlights the effectiveness of this drug not only in restoring liver function but also in increasing the overall productivity and natural resistance of poultry. Given the positive results obtained, it is recommended to include the drug "Hep-A-Stres" in the diet of broiler chickens to improve the health, productivity, and meat quality of chickens. This is important for producers who want to obtain high-quality products.

CONCLUSIONS

The results obtained from the study confirm the safety of the drug "Hep-A-Stres" when used at various stages of chicken development. The absence of a negative impact on the development of chicken embryos, including appearance, limb length, and body weight, indicates that the drug has no embryotoxic or teratogenic effects. The positive effect of the drug on tolerability, especially the activity and average daily weight gain of broiler chickens, also confirms its effectiveness. The increase in average daily weight gain in the experimental group compared to the control by 5.5-7.9% was significant, indicating that the drug contributed to improved growth and overall condition of the birds. The findings of this study allow for the conclusion regarding the safety and effectiveness of the "Hep-A-Stres" preparation for use in the feed of broiler chicks.

The results obtained demonstrated that this drug has a positive impact on the organisms of growing broiler chickens. The addition of the drug to feed during broiler chicken feeding is non-toxic. Long-term application in doses 3-5 times higher than the therapeutic dose does not have a negative impact on the physiological state, morphological and biochemical composition of the blood, and does not cause changes in the structure of hepatocytes. Veterinary and sanitary examination of the meat of broiler chickens showed that the quality of the meat in the control and experimental groups corresponded to the indicators of fresh healthy chicken meat. However, physical and chemical differences were noted. Based on the research results, it is recommended to include this drug in the feed of broiler chickens. This contributes to the restoration of liver function and increases the productivity and natural resistance of poultry. To achieve the best results, poultry producers should adhere to the established dosages of the drug and recommendations for use, which are based on further research and expert recommendations. The potential for further research lies in the thorough study of the drug's effects on field metabolic and organic systems of agricultural and exotic poultry.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Agbonon, A., & Gbeassor, M. (2019). Hepatoprotective effect of *Lonchocarpus sericeus* leaves in CCl4-induced liver damage. *Journal of Herbs Spices & Medicinal Plants*, 15(2), 216-226. doi: 10.1080/10496470903139512.

[2] Baradaran, A., Samadi, F., Ramezanpour, S.S., & Yousefdoust, S. (2019). Hepatoprotective effects of silymarin on CCl4-induced hepatic damage in broiler chickens model. *Toxicology Reports*, 6, 788-794. doi: 10.1016/j.toxrep.2019.07.011.

[3] Bemela Mawulom, T., Kokou, I., Oke, O.E., & Agbonon, A. (2021). Hepatoprotective effects of *Vernonia amygdalina* (Astereaceae) extract on CCl4-induced liver injury in broiler chickens. *Animals*, 11(12), article number 3371. doi: 10.3390/ani11123371.

[4] Bogach, M., Paliy, A., Liulin, P., Perots'ka, L., Bohach, O., Pyvovarova, I., & Palii, A. (2021). Parasites of domestic and wild pigeons in the south of Ukraine. *Biosystems Diversity*, 29(2), 135-139. doi: 10.15421/012118.

[5] Chen, X., Zhao, M., Zheng, A., Purba, A., Chen, Z., Qiu, K., Wang, Z., Chang, W., Cai, H., & Liu, G. (2023). Evaluation of the application value of cottonseed protein concentrate as a feed protein source in broiler chickens. *Animals*, 13(23), article number 3706. doi: 10.3390/ani13233706.

[6] D'Souza, P., Marimuthu, S., Kaninathan, A., & Selvam, R. (2019). Modulatory effect of Kolin PlusTM, a polyherbal formulation on muscle growth development in choline deficient diet model of broilers: A genomic analysis using microarray. *International Journal of Scientific Reports*, 5(12), 344-350. doi: 10.18203/issn.2454-2156.IntJSciRep20195298.

[7] Dotsenko, E., Paliy, A., Morozenko, D., Dotsenko, R., Zemlianskyi, A., & Pavlichenko, O. (2021). Dose-dependent effect of chronic exposure to lead acetate on the dynamics of the content of delta-aminolevulinic acid and essential trace elements in the serum of laying hens. *Regulatory Mechanisms in Biosystems*, 12(4), 689-695. doi: 10.15421/022195.

[8] DSTU 3136:2017. (2019). *Agricultural poultry for slaughter. Technical requirements*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=73413.

[9] DSTU 3143:2013. (2014). *Poultry meat. General technical conditions*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=81578.

[10] DSTU 3143-95. (2009). *Poultry meat (carcasses of chickens, ducks, geese, turkeys)*. Retrieved from https://lib.dsau.dp.ua/book/62222.

[11] Erukainure, O.L., Chukwuma, C.I., Sanni, O., Matsabisa, M.G., & Islam, M.S. (2020). Histochemistry, phenolic content, antioxidant, and anti-diabetic activities of *Vernonia amygdalina* leaf extract. *Journal of Food Biochemistry*, 43, article number e12737. doi: 10.1111/jfbc.12737.
[12] European convention for the protection of vertebrate animals used for experimental and other scientific purposes. (1986). Retrieved from https://rm.coe.int/168007a67b.
[13] Feng, D., Zou, J., Su, D., Mai, H., Zhang, S., Li, P., & Zheng, X. (2019). Curcumin prevents high-fat diet-induced hepatic steatosis in ApoE−/− mice by improving intestinal barrier function and reducing endotoxin and liver TLR4/NF-κB inflammation. *Nutrition & Metabolism*, 16, article number 79. doi: 10.1186/s12986-019-0410-3.
[14] Gregg, C.R., Tejeda, O.J., Spencer, L.F., Calderon, A.J., Bourassa, D.V., & Starkey, J.D. (2022). Impacts of increasing additions of choline chloride on growth performance and carcass characteristics of broiler chickens reared to 66 days of age. *Animals*, 12(14), article number 1808. doi: 10.3390/ani12141808.
[15] Heeren, J., & Scheja, L. (2021). Metabolic-associated fatty liver disease and lipoprotein metabolism. *Molecular Metabolism*, 50, article number 101238. doi: 10.1016/j.molmet.2021.101238.
[16] ISO/IEC 17025:2005. (2006). Retrieved from http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=50873.
[17] Juanola, O., Martínez-López, S., Francés, R., & Gómez-Hurtado, I. (2021). Non-alcoholic fatty liver disease: Metabolic, genetic, epigenetic and environmental risk factors. *International Journal of Environmental Research and Public Health*, 18(10), article number 5227. doi: 10.3390/ijerph18105227.
[18] Kanda, I., Robertson, J., Meinkoth, J., & Brandão, J. (2020). Complete blood cell count and white blood cell counting method comparison in 49-day-old bobwhite quail (*Colinus virginianus*). *Journal of Avian Medicine and Surgery*, 34(2), 132-141. doi: 10.1647/1082-6742-34.2.132.
[19] Kismiati, S., Sarjana, TA., Mahfudz, L.D., & Prayitno, D.S. (2023). African leaf (*Vernonia amygdalina*) extracts improve Japanese quail (*Coturnix coturnix japonica*) carcass traits. *Veterinary World*, 16(4), 773-778. doi: 10.14202/vetworld.2023.
[20] Law of Ukraine No. 249 "On the Procedure for Carrying out Experiments and Experiments on Animals by Scientific Institutions". (2012, March). Retrieved from https://zakon.rada.gov.ua/laws/show/z0416-12#Text.
[21] Marimuthu, S., Suresh, S., & D'Souza, P. (2022). Identification of lipid regulatory genes modulated by polyherbal formulation in chicken liver tissues using transcriptome analysis. *Journal of Advanced Veterinary and Animal Research*, 9(3), 432-439. doi: 10.5455/javar.2022.i611.
[22] Oke, O.E., Alo, E.T., Oke, F.O., Oyebamiji, Y.A., Ijaiya, M.A., Odefemi, M.A., Kazeem, R.Y., Soyode, A.A., Aruwajoye, O.M., & Ojo, R.T. (2020). Early age thermal manipulation on the performance and physiological response of broiler chickens under hot humid tropical climate. *Journal of Thermal Biology*, 88, article number 102517. doi: 10.1016/j.jtherbio.2020.102517.
[23] Paliy, A.P., Mashkey, A.N., Faly, L.I., Kysterna, O.S., Rebenko, H.I., & Palii, A.P. (2021). Ecology of zoophilic flies in livestock biocenoses of Ukraine. *Biosystems Diversity*, 29(3), 258-263. doi: 10.15421/012132.
[24] Ponomarenko, G.V., Kovalenko, V.L., Balatskiy, Y.O., Ponomarenko, O.V., Paliy, A.P., & Shulyak, S.V. (2021). Bactericidal efficiency of preparation based on essential oils used in aerosol disinfection in the presence of poultry. *Regulatory Mechanisms in Biosystems,* 12(4), 635-641. doi: 10.15421/022187.
[25] Tian, K.-Y., Guo, H.-F., Li, N., Zhang, Y.-H., Wang, Z., Wang, B., Yang, X., Li, Y.-T., & Zhao, J. (2020). Protection of chickens against hepatitis-hydropericardium syndrome and Newcastle disease with a recombinant Newcastle disease virus vaccine expressing the fowl adenovirus serotype 4 fiber-2 protein. *Vaccine*, 38(8), 1989-1997. doi: 10.1016/j.vaccine.2020.01.006.
[26] Trofimiak, R.M., & Slivinska, L.G. (2021). Diagnostic value of echocardiographic indices of left atrial and ventricular morphology in dogs with myxomatous mitral valve disease (MMVD). *Ukrainian Journal of Veterinary and Agricultural Sciences*, 4(1), 16-23. doi: 10.32718/ujvas4-1.04.
[27] Wang, S., Li, C., Zhang, C., Liu, G., Zheng, A., Qiu, K., Chang, W., & Chen, Z. (2023). Effects of Sihuang Zhili granules on the diarrhea symptoms, immunity, and antioxidant capacity of poultry challenged with lipopolysaccharide (LPS). *Antioxidants*, 12(7), article number 1372. doi: 10.3390/antiox12071372.
[28] Yaremchuk, V., Slivinska, L., & Stronskyi, Y. (2020). Morphological particulars of the liver of laying hens of breed "Lohmann Brown" under hepatosis. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Veterinary Sciences*, 22(97), 69-73. doi: 10.32718/nvlvet9712.
[29] Yaremchuk, V.Y., & Slivinska, L.G. (2020). Prevention of hepatosis in laying hens using hepatoprotectors Hep-A-Stress and Hepasan-VS. *Ukrainian Journal of Veterinary and Agricultural Sciences*, 3(3), 8-14. doi: 10.32718/ujvas3-3.02.

Гепатоз у курчат-бройлерів: роль та ефективність застосування лікувально-профілактичних засобів із гепатопротекторами

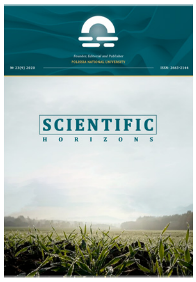
Руслан Дубін
Кандидат ветеринарних наук, доцент
Одеський державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0003-3540-0816
Катерина Родіонова
Кандидат ветеринарних наук, доцент
Одеський державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0002-7245-4525
Ірина Попова
Кандидат ветеринарних наук, доцент
Одеський державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0002-9942-0464
Жанна Коренєва
Кандидат ветеринарних наук, доцент
Одеський державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0003-2730-5990
Галина Ребенко
Кандидат ветеринарних наук, доцент
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160. м. Суми, Україна
https://orcid.org/0000-0002-1884-4901

Анотація. Збереженість поголів'я можна поліпшити, вводячи в раціон лікувально-профілактичні препарати, в тому числі гепатопротектори. Мета дослідження полягала в оцінці впливу дослідного препарату, що містить гепатопротектори, на здоров'я курчат-бройлерів. Дослідження спрямоване на виявлення потенціалу препарату для покращення функції печінки та загального збереження поголів'я сільськогосподарської птиці. Дослідження було проведено у період з 2023 р. по 2024 р. в Одеського державному аграрному університеті. Були проведені дослідження для вивчення ефектів експериментального препарату в таких дозах: 1,0 г/кг маси тіла (терапевтична доза), 2,0 г/кг маси тіла (подвійна терапевтична доза) і 5,0 г/кг маси тіла (5 терапевтичних дозах) протягом 30 днів. Дослід проводили на 500 курчатах-бройлерах кросу Кобб 500 віком від 1 до 40 днів. Крім того, вимірювали та досліджували біохімічні показники крові за допомогою польського біохімічного селекційного автоматичного аналізатора Hitachi 902. Дослідженнями встановлено, що оптимальною дозою дослідного препарату при гепатозах курчат-бройлерів є 1,0 г/кг маси тіла. Після прийому препарату вміст білірубіну в сироватці крові знизився на 27,3 %, активність лактатдегідрогенази знизилася на 17,1 %, активність аспартатамінотрансферази знизилася на 16,4 %, активність аланінамінотрансферази знизилася на 19,3 %, вміст збільшився. Вітамін А збільшився на 25,6 %, а фагоцитарна активність псевдоеозинофілів зросла на 23,1 %. В результаті досліджень доведено, що дослідний препарат нормалізує роботу печінки, позитивно впливає на біохімічний склад крові, сприяє росту, забезпечує захист і природну опірність організму бройлерів і навіть покращує якість продукції птахівництва покращувати. І з вище вказаного необхідно вдосконалювати методи ранньої діагностики порушень функцій печінки у птиці і застосовувати ефективні методи корекції метаболічних процесів

Ключові слова: печінка; гепатопротектори; еритроцити; гемоглобін; лейкоцити

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 20-31



UDC 619:615.31:564.72
Doi: 10.48077/scihor9.2024.20

Results of iodine-based treatment application in carp aquaculture within closed water systems

Tetiana Fotina*
Doctor of Veterinary Sciences, Professor
Sumy National Agrarian University
40021, 160 Herasim Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0001-5079-2390

Yuri Yarmoshenko
Postgraduate Student
Sumy National Agrarian University
40021, 160 Herasim Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0003-2108-2431

Yevheniia Dudnyk
PhD
Sumy National Agrarian University
40021, 160 Herasim Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0002-0735-3779

Lidia Kovalenko
PhD in Veterinary Sciences, Associate Professor
Sumy National Agrarian University
40021, 160 Herasim Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0002-4350-2284

Ylia Negreba
Senior Lecturer
Sumy National Agrarian University
40021, 160 Herasim Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0001-8437-9617

Article's History:
Received: 11.03.2024
Revised: 18.07.2024
Accepted: 28.08.2024

Abstract. The study aimed to monitor the prevalence of ectoparasites and bacterial infestations in carp and to determine effective dosages of a new iodine-based treatment for disease prevention. The research found that carp were affected by ectoparasites *G. kobayashii* at 43.32%, *L. cyprinacea* at 46.67%, and *P. lusiana* at 31.71% in fish farming facilities within the Sumy Region. Treatment with the iodine-based product resulted in a reduction of infestation levels to 0.2%, including a decrease in the incidence of

Suggested Citation:
Fotina, T., Yarmoshenko, Yu., Dudnyk, Ye., Kovalenko, L., & Negreba, Y. (2024). Results of iodine-based treatment application in carp aquaculture within closed water systems. *Scientific Horizons*, 27(9), 20-31. doi: 10.48077/scihor9.2024.20.

*Corresponding author

gyrodactylosis by 89.92-97.35%, lernaeosis by 79.13-95.91%, and philometroidosis by 81.30-91.16% compared to monitoring results. In investigations of bacterial infestations, it was found that the contamination of carp was higher for *E. coli* at the PC "Shmatukha" by 8.0%, *Aeromonas hydrophila* by 47.97%, and *Aeromonas salmonicida* by 31.39%. Additionally, *Pseudomonas anguilliseptica* was detected at 19.48%, *Streptococcus iniae* at 13.27%, and *Micrococcus spp.* at 38.14% at LLC "Ryasnyanske". The presence of *Staphylococcus aureus* was recorded at 21.37%, and *Listeria monocytogenes* at 11.43% at LLC "Bdzhola"; these figures were lower than those observed in other farms. Following treatment with the iodine-based agent, contamination of fish by *E. coli* decreased by 98.96% at the PC "Shmatukha", 99.2% at LLC "Bdzhola", and 84.32% at LLC "Ryasnyanske". Contamination of carp by *A. hydrophila* decreased by 94.51% at the PC "Shmatukha", 80.28% at LLC "Bdzhola", and 99.15% at LLC "Ryasnyanske". The presence of *A. salmonicida* was reduced by 97.23% at the PC "Shmatukha", 94.00% at LLC "Bdzhola", and 79.06% at LLC "Ryasnyanske". Contamination by *S. aureus* decreased by 92.15% at the PC "Shmatukha", 98.74% at LLC "Bdzhola", and 93.89% at LLC "Ryasnyanske". The levels of *S. iniae* decreased by 80.90% at the PC "Shmatukha", 99.63% at LLC "Bdzhola", and 83.30% at LLC "Ryasnyanske". Contamination by *L. monocytogenes* was reduced by 96.25% at the PC "Shmatukha", 96.08% at LLC "Bdzhola", and 98.13% at LLC "Ryasnyanske". Furthermore, *Micrococcus spp.* levels decreased by 93.74% at the PC "Shmatukha", 96.37% at LLC "Bdzhola", and 92.26% at LLC "Ryasnyanske", in comparison to the monitoring results. The practical value of this study lies in controlling the spread of ectoparasites and developing preventive measures to eliminate ectoparasites and bacterial infestations in carp prior to their release into water bodies

Keywords: fish ectoparasites; intensity of invasion; bacterial microflora; control; prevention

INTRODUCTION

The prevention of infectious diseases in commercial fish is of great importance to both producers and consumers. The development of effective and safe measures to prevent the spread of infectious agents in aquaculture is a pressing issue for scientists and farmers.

In the cultivation of commercial fish, systematic diagnostic monitoring and timely disease prevention are crucial (Kochmann *et al.,* 2023). Research by N. Peter *et al.* (2023) has shown that parasites can affect internal organs and systems, and alter fish behaviour. The prevalence of parasitic infestations in fish increases with chemical pollution of water bodies (Pravdová *et al.,* 2023). Studies by N. Umasuthan *et al.* (2020) have demonstrated that ectoparasite infestations reduce immunity and contribute to the development of bacterial and viral infestations in fish. Parasitic diseases in fish lead to significant economic losses in both wild and farmed environments. Research by G. Rigos *et al.* (2024) has shown that the lack of rotation of antiparasitic drugs in aquaculture has led to the emergence of parasite resistance. A review of antiparasitic treatments has highlighted the need for greater control and regulation of their usage.

Formalin is often used as an effective treatment for ectoparasites and fungi in fish (Othmen *et al.*, 2024). However, research by E.R. Fetherman *et al.* (2023) has shown that formalin can lead to the death of fish fry and eggs, depending on the concentration. Additionally, increasing the concentration of the disinfectant and its continuous use can lead to the development of resistance in microorganisms. Consequently, the formation of resistant bacterial strains reduces the effectiveness of the disinfectant, making its use impractical. Research by S.I. Islam *et al.* (2024) has shown that bacterial diseases are a significant problem, affecting both wild and farmed fish species. Common pathogens include streptococci, staphylococci, *E. coli*, *Listeria*, and *Pseudomonas aeruginosa*. A thorough investigation into fish bacterial pathogens, their prevalence, and the development of control and prevention methods is necessary. Therefore, controlling the spread of bacterial infestations among wild fish populations and in aquaculture is a priority. Studies by K. Buchmann (2022) have shown that parasites adapt well to changes in their environment and to antiparasitic agents. Scientists therefore propose combining various methods for parasite control, such as chemical, mechanical, and biological. However, specific agents and protocols for antiparasitic treatment of fish have not yet been proposed. Research by S. Zhou *et al.* (2021) has demonstrated the antiparasitic activity of dioscin, an active compound in *D. collettii var. Hypoglauca*, against *G. kobayashii*. However, studies have shown that 0.6 mg/L of dioscin does not completely eliminate the parasite but only temporarily removes it from the host. Therefore, the development and improvement of measures to control fish ectoparasites are still ongoing.

Due to the harmful effects of chemical disinfectants on the environment and fish, researchers B.Y. Harmansa *et al.* (2023) proposed investigating the antiparasitic effects of essential oils from *Mentha piperita, Citrus limon* and *Melaleuca alternifolia*. The results of their studies showed that *Melaleuca alternifolia* oil was the most effective, but all three plant essential oils had a weak antiparasitic effect. Researchers Q. Ma *et al.* (2024) note that chemical compounds such as formalin, hydrogen peroxide, and mebendazole are widely used to kill fish ectoparasites. However, the frequent use of these agents leads to increased parasite resistance and water pollution.

Fish are often contaminated with both ectoparasites and bacterial microorganisms simultaneously. Therefore, there is a need for an environmentally safe yet effective disinfectant capable of simultaneously eliminating parasites and microorganisms from the fish's surface. For treating parasitic keratitis in humans, researchers N. Szentmáry *et al.* (2020) suggested the use of povidone-iodine, which has been effective against this rare and hard-to-treat condition. A promising area of research is the exploration of a broader spectrum of antiparasitic activity of povidone-iodine. The compound has shown activity against adenoviruses, mumps, measles, and influenza, as well as enveloped and non-enveloped viruses. Studies by R. Barreto *et al.* (2020) demonstrated povidone-iodine's high antibacterial activity and its ability to disrupt bacterial biofilms when treating acute and chronic wounds in patients. There is a need to assess its effectiveness in eliminating opportunistic and pathogenic microflora on the surface of fish before stocking ponds. An evaluation of the toxic effects of Betadine (a 10% povidone-iodine solution) on goldfish fry was conducted, and researchers Y.A. Mohamadi *et al.* (2022) found that Betadine has a short half-life in aquatic environments and is non-toxic to fish. Therefore, it can be used for disinfecting closed water systems.

This study aimed to determine the correlation between ectoparasite infestation and bacterial infestations in fish and to investigate the efficacy of an iodine-based agent (active ingredient povidone-iodine) as an antiparasitic and antibacterial treatment.

MATERIALS AND METHODS

Monitoring of fish damage by ectoparasites and bacterial microflora. A study on ectoparasite and bacterial infestations in fish was conducted in fish farms in the Sumy Region, Ukraine: Private Company "Shmatukha" (Solidarne village), Limited Liability Company "Bdzhola" (Kononenkovo village), and Limited Liability Company "Ryasnyanske" (Ryasnyanske village) during the spring-autumn period of 2023. Fish were kept in closed warm-water ponds of up to 10 hectares. These farms follow an intensive commercial fish farming system. The main commercial species was the common carp (*Cyprinus carpio*). Fish were fed balanced compound feed. Ponds were systematically fertilised with organic and mineral fertilisers and subjected to melioration. However, due to military activities, fish farming and melioration measures were not carried out at LLC "Ryasnyanske", leading to a deterioration of the pond's sanitary condition. During a control catch of 100 individuals in each farm, the presence of parasites and bacterial flora was determined. The total number of fish examined across all farms was 300.

Conducting a production study on fish treatment for the prevention of ectoparasites (*Gyrodactylus kobayashii, Lernaea cyprinacea* and *Philometroides lusiana*) *and bacterioses.* One-year-old carp infested with ectoparasites and contaminated with bacterial microflora were placed in 100 dm^3 containers for treatment with Combiiod at concentrations of 0.05%, 0.1%, and 0.2%. The fish were exposed to the treatment solution for 3 hours at a temperature of +14°C. The study was conducted between April and May 2024. Three experimental groups were established (Table 1).

***Table 1**. Study design*

Experiment	Number of fish per group	Concentration of agent
1E	100	0.05 %
2E	100	0.1 %
3E	100	0.2 %

Source: *developed by the authors*

Microorganism swabs and cultivation were carried out at 37°C with a 24-hour exposure period. The experimental iodine-based agent (povidone-iodine 200 mg and sodium selenite 1.2 mg) was provided by the manufacturing company "Brovapharma". The study aimed to conduct a practical trial of fish treatment before their transfer to the pond.

Statistical analysis. The obtained data were processed using Microsoft Excel 2010, alongside statistical analysis employing the Fisher-Student method, accounting for statistical errors and a significance level greater than 95% ($p < 0.05$). The research conducted at the fish farms adhered to the standards of DSTU EN ISO/IEC 17025:2019 (2019) and complied with bioethics rules and the humane treatment of vertebrate animals, as per 2010/63/EU (Hartung, 2010), the European Convention (1986), and the Law of Ukraine No. 249 (2012).

RESULTS

Results of monitoring fish damage by ectoparasites. At the beginning of the study, the degree of ectoparasite infestation in fish was determined in the ponds of PC "Shmatukha" (Solidarne village), LLC "Bdzhola" (Kononenkovo village), and LLC "Ryasnyanske" (Ryasnyanske village) during the autumn-spring period (Fig. 1).

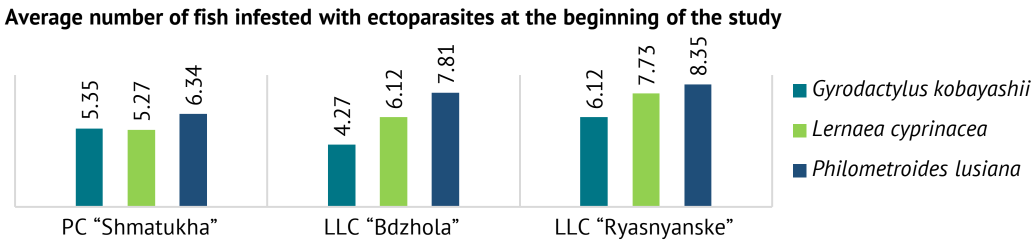


***Figure 1**. Monitoring of ectoparasite pathogens in fish at farms in the Sumy Region*
***Source:** developed by the authors*

Infestation of carp by ectoparasites was notably higher at LLC "Ryasnyanske", with *Gyrodactylus kobayashii* at 43.32%, *Lernaea cyprinacea* at 46.67%, and *Philometroides lusiana* at 31.71%, compared to the lowest rates recorded in other farms. The study revealed breaches in sanitary conditions at LLC "Ryasnyanske". Disinfection of the pond is a labour-intensive and costly process. A large quantity of disinfectant is required, and it is difficult to accurately calculate the concentration of the active substance in the water or whether it will be sufficient to eliminate the parasites. A more effective and sustainable method for maintaining water quality is regular water exchange and mechanical cleaning, which reduces the risk of parasite and microorganism accumulation in the water. Additionally, to prevent the transmission of fish parasites to workers, personal hygiene must be maintained. Additionally, treatment of infested fish is necessary to prevent the spread and reinfestation of fish in the main pond where cultivation occurs.

Conducting a production study on the treatment of fish against ectoparasites. The next stage of the study involved treating the fish with a 0.05% solution of treatment before stocking the ponds (Fig. 2). It was found that the level of infestation by gill flukes decreased after treatment by 4.29% at PC "Shmatukha", 1.63% at LLC "Bdzhola", and 12.58% at LLC "Ryasnyanske", compared to the initial results. *Gyrodactylus spp.* are flatworms that infest bony fish, feeding on mucus and epithelial cells. Damage to the epidermis promotes the development of secondary infestations, increasing the risk of mass fish mortality.

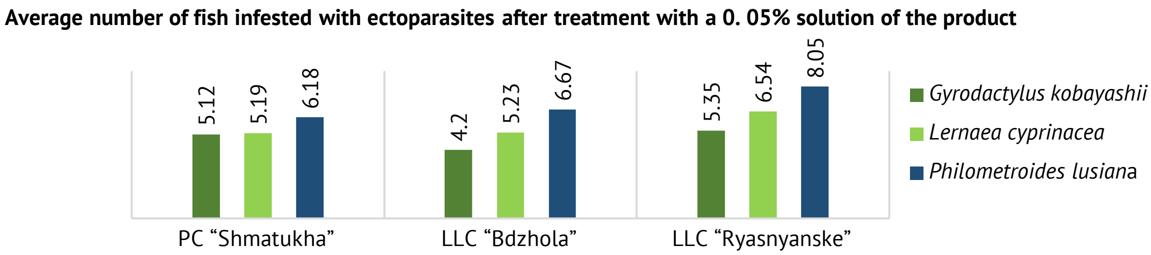


***Figure 2**. Extensiveness of ectoparasite infestation in fish after treatment with a 0.05% iodine-based solution*
***Source:** developed by the authors*

The level of fish infestation by lernaeosis following treatment with Combiiod decreased by 1.51% at PC "Shmatukha", 14.54% at LLC "Bdzhola", and 15.39% at LLC "Ryasnyanske". The number of fish with philometroidosis decreased by 2.52% at PC "Shmatukha", 14.59% at LLC "Bdzhola", and 3.59% at LLC "Ryasnyanske" compared to the results before treatment. Treatment of fish with a 0.05% solution of the agent showed low efficacy. Therefore, in subsequent experiments, the concentration of the iodine-based agent was increased to 0.1% to eliminate ectoparasites on fish (Fig. 3).

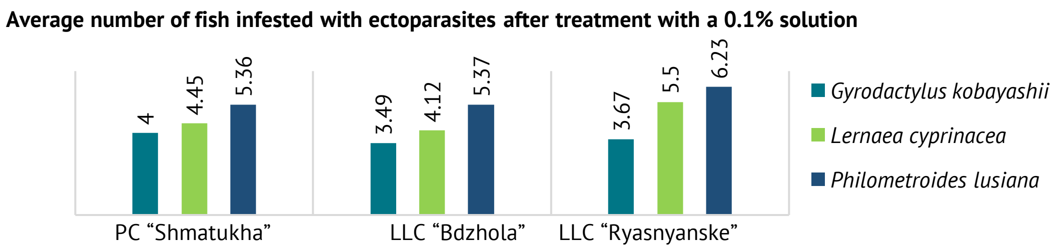


***Figure 3**. Extensiveness of ectoparasite infestation in fish after treatment with a 0.1% iodine-based solution*
***Source:** developed by the authors*

Following treatment with a 0.1% solution, the efficacy against gyrodactylosis was 25.23% at PC "Shmatukha", 42.97% at LLC "Bdzhola", and 40.03% at LLC "Ryasnyanske" compared to the beginning of the experiment. The parasites *Gyrodactylus kobayashii* exhibit a direct life cycle and a short generation time, allowing them to rapidly infest a significant number of fish. The infestation of fish by the parasite *Lernaea cyprinacea* decreased by 15.55% at PC "Shmatukha", 32.67% at LLC "Bdzhola", and 28.84% at LLC "Ryasnyanske". The parasite *Lernaea cyprinacea* is highly invasive and infects freshwater fish in large numbers. After treatment with the iodine-based agent the number of fish affected by philometroidosis decreased by 15.45% at PC "Shmatukha", 31.24% at LLC "Bdzhola", and 25.38% at LLC "Ryasnyanske" compared to the beginning of the experiment. Philometroidosis in carp is caused by the nematode *Philometroides lusiana* from the family *Philimetridae*. The disease is severe and involves the liver, kidneys, and swim bladder. Against a background of pronounced general intoxication, the fish initially lose weight, which gradually leads to emaciation and death. To achieve maximum efficacy in eliminating ectoparasites, the concentration of the agent was increased to 0.2% (Fig. 4).

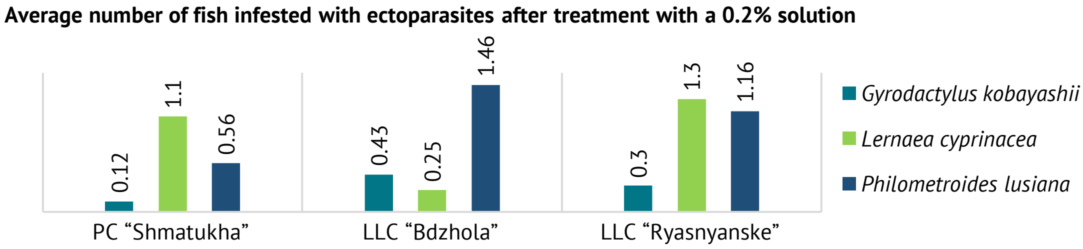


***Figure 4**. Extensiveness of ectoparasite infestation in fish after treatment with a 0.1% iodine-based solution*
***Source:** developed by the authors*

Treatment with a 0.2% iodine-based solution significantly reduced gyrodactylosis at PC "Shmatukha" by 97.35%, at LLC "Bdzhola" by 89.92%, and at LLC "Ryasnyanske" by 95.09%, compared to the initial data. Lernaeosis was reduced by 79.13% at PC "Shmatukha", 95.91% at LLC "Bdzhola", and 83.18% at LLC "Ryasnyanske". The percentage of fish with philometroidosis decreased by 91.16% at PC "Shmatukha", 81.30% at LLC "Bdzhola", and 86.11% at LLC "Ryasnyanske" compared to the beginning of the study.

Results of monitoring fish damage by ectoparasites and bacterial microflora. The degree of fish infestation by parasites, in turn, contributes to the development of bacterial infestations and the death of a significant number of fish. Therefore, parallel monitoring of fish infestation by opportunistic bacterial microflora was carried out in fish farms in the Sumy Region (Fig. 5).

Most fish zoonoses are caused by bacteria. The prevalence of bacterial infestations in carp is constantly changing and needs to be monitored to detect infestation in both wild populations and aquaculture. The results of the study show the degree of bacterial infestation, which, against a background of ectoparasite infestation, poses a threat to both fish and human health. Contamination of carp with *Escherichia coli* was higher at PC "Shmatukha" by 8.0% compared to the lowest value. At LLC "Ryasnyanske", fish infestation with *Aeromonas hydrophila* was higher by 47.97%, *Aeromonas salmonicida* by 31.39%, *Pseudomonas anguilliseptica* by 19.48%, *Streptococcus iniae* by 13.27%, and *Micrococcus spp.* by 38.14% compared to the lowest value in other farms. At LLC "Bdzhola", contamination of fish with *Staphylococcus aureus* was higher by 21.37% and *Listeria monocytogenes* by 11.43%.

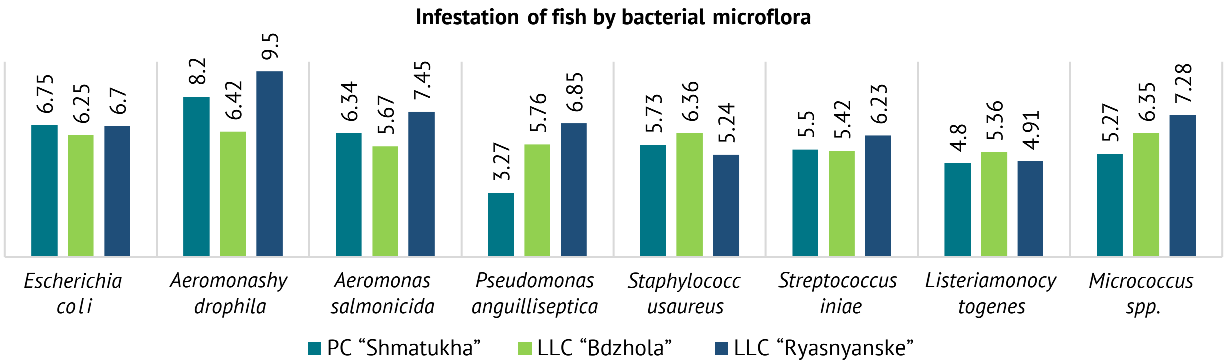


***Figure 5**. Monitoring of fish infestation by opportunistic bacterial microflora in farms of the Sumy Region*
***Source:** developed by the authors*

Conducting a production study on fish processing to prevent bacterial microflora.Fish infested with ectoparasites have a weakened immune system, making them more susceptible to bacterial infestations.To reduce the risk of infectious diseases in fish, the level of bacterial contamination was determined after treatment with a 0.05% solution (Fig. 6). Bacterial infestations in fish cultured in open water bodies can lead to significant economic losses due to disease and mortality. Therefore, finding effective solutions for the prevention and control of major bacterial diseases in fish is crucial. Studies have shown that after treatment with a 0.05% iodine-based solution, the number of fish infested with *Escherichia coli* decreased by 11.11% at PC "Shmatukha", 18.08% at LLC "Bdzhola", and 18.50% at LLC "Ryasnyanske" compared to the initial data. While *Escherichia coli* is not a specific pathogen of fish bacterial infestations, it is a zoonosis that can cause human disease. Therefore, determining the contamination of fish with *E. coli* is important for product safety and also indicates the sanitary condition of the water bodies where the fish is kept.

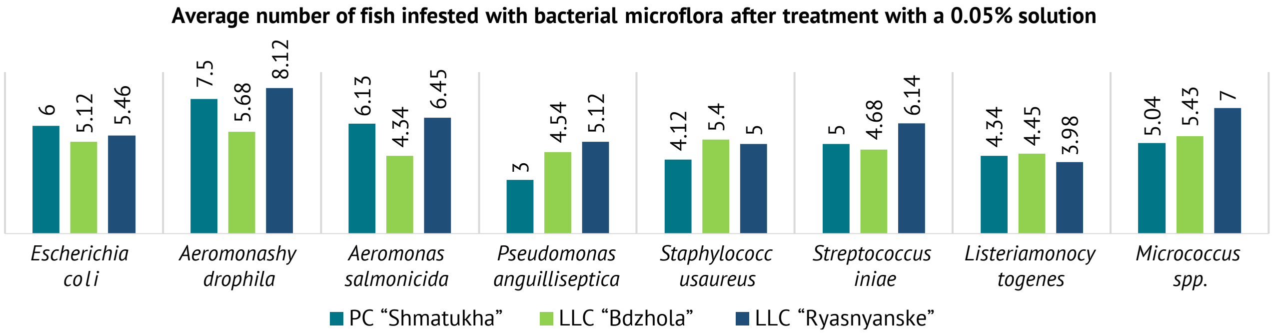


Figure 6. *Infestation of fish with opportunistic microflora after treatment with 0.05 % iodine-based solution*
Source: *developed by the authors*

Aeromonosis in fish is a common cause of fish mortality due to damage to internal organs, especially the hematopoietic system. Infestations with *Aeromonas hydrophila* decreased by 8.53% at PC "Shmatukha", 11.52% at LLC "Bdzhola", and 14.52% at LLC "Ryasnyanske". The percentage of fish infested with *Aeromonas salmonicida* was lower by 3.31% at PC "Shmatukha", 23.45% at LLC "Bdzhola", and 13.42% at LLC "Ryasnyanske". *Pseudomonas anguilliseptica* is a conditionally pathogenic microorganism that affects various fish species. *Pseudomonas* manifests as haemorrhages, damage to internal organs, and mortality. Infestations with *Pseudomonas anguilliseptica* decreased by 8.53% at PC "Shmatukha", 21.18% at LLC "Bdzhola", and 25.26% at LLC "Ryasnyanske" after treatment with a 0.05% solution, compared to monitoring data.

A decrease in staphylococcal infestation was observed at PC "Shmatukha" by 28.09%, at LLC "Bdzhola" by 17.61%, and at LLC "Ryasnyanske" by 4.58%. *Staphylococcus aureus* is a conditionally pathogenic microorganism and is an indicator of the sanitary condition of water bodies where fish are farmed. Reducing the number of staphylococci on the fish surface is important for ensuring food safety. *S. iniae* is a major causative agent of streptococcosis in wild and farmed fish worldwide. The level of *Streptococcus iniae* decreased after treatment with the agent by 9.09% at PC "Shmatukha", 13.65% at LLC "Bdzhola", and 1.44% at LLC "Ryasnyanske", compared to the initial results.

Listeria monocytogenes, a frequent pathogen in fish, can cause enterotoxemia in humans. After treatment, the incidence of this pathogen decreased by 9.77% at PC "Shmatukha", 16.97% at LLC "Bdzhola", and 17.25% at LLC "Ryasnyanske". The content of *Micrococcus spp.* on the fish surface decreased by 4.36% at PC "Shmatukha", 14.48% at LLC "Bdzhola", and 3.84% at LLC "Ryasnyanske", compared to the previous monitoring. The results of fish treatment with a 0.05% iodine-based solution suggest the possibility of increasing the concentration of the agent (Fig. 7).

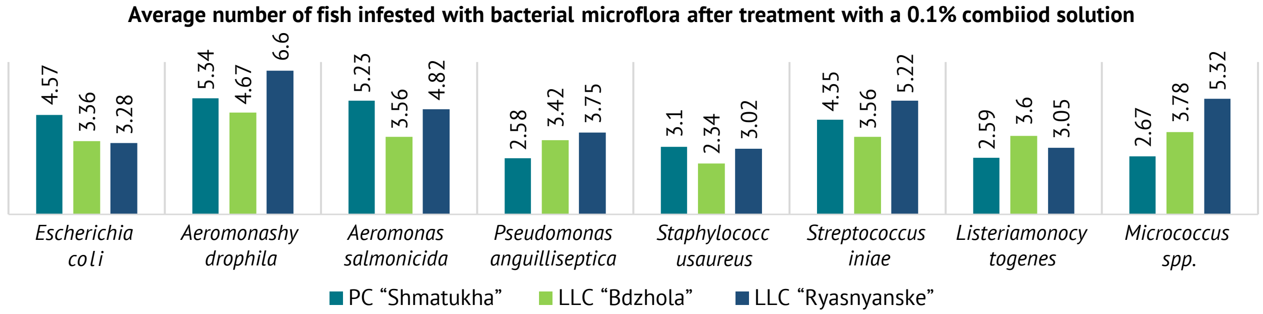


Figure 7. *Infestation of fish with opportunistic microflora after treatment with 0.1% solution of iodine-containing solution*
Source: *developed by the authors*

The percentage of fish infested with *Escherichia coli* decreased by 32.29% at PC "Shmatukha", 46.24% at LLC "Bdzhola", and 51.04% at LLC "Ryasnyanske" after treatment. The contamination of fish with *A. hydrophila* decreased by 34.87% at PC "Shmatukha", 50.84% at LLC "Bdzhola", and 30.52% at LLC "Ryasnyanske". Fish during cultivation undergo significant stress, which reduces immunity and resistance to bacterial infestations. *Aeromonas salmonicida* causes furunculosis and severe septicaemia, leading to fish mortality. Infestations with *A. salmonicida* decreased by 17.50% at PC "Shmatukha", 37.21% at LLC "Bdzhola", and 35.30% at LLC "Ryasnyanske" compared to the monitoring results.

The number of *Pseudomonas* on the fish surface decreased by 28.10% at PC "Shmatukha", 40.62% at LLC "Bdzhola", and 45.25% at LLC "Ryasnyanske". The contamination of fish with the sanitary indicator microorganism *S. aureus* decreased by 45.89% at PC "Shmatukha", 63.20% at LLC "Bdzhola", and 42.36% at LLC "Ryasnyanske" compared to the initial data. The content of streptococci decreased after treatment by 20.90% at PC "Shmatukha", 34.31% at LLC "Bdzhola", and 16.21% at LLC "Ryasnyanske". Infestations with *Listeria* decreased by 46.15% at PC "Shmatukha", 32.84% at LLC "Bdzhola", and 36.59% at LLC "Ryasnyanske" compared to the monitoring results. The level of *Micrococcus spp.* decreased after treatment with the agent by 46.15% at PC "Shmatukha", 32.84% at LLC "Bdzhola", and 36.59% at LLC "Ryasnyanske". To achieve maximum effectiveness in eliminating microorganisms, the concentration of the agent was increased to 0.2% (Fig. 8).

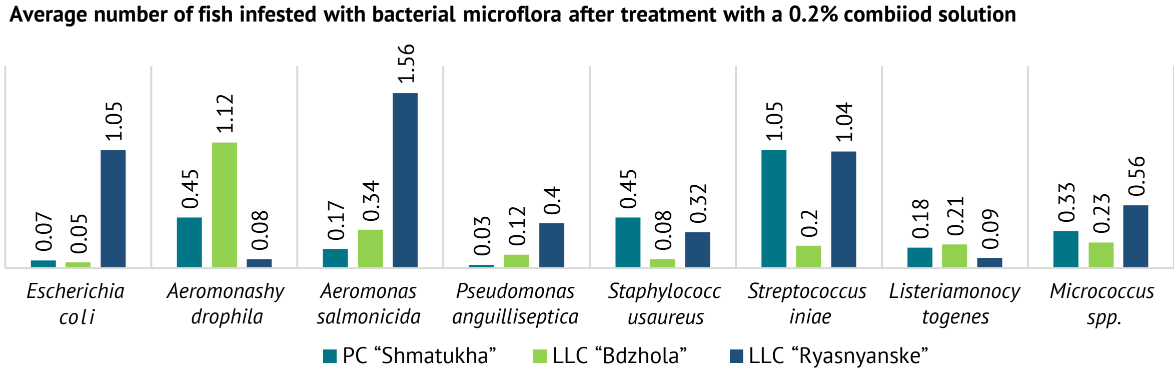


Figure 8. *Infestation of fish with opportunistic microflora after treatment with 0.2 % iodine-containing solution*
Source: *developed by the authors*

As a result of the treatment, the content of *Escherichia coli* in carp decreased by 98.96% at PC "Shmatukha", 99.2% at LLC "Bdzhola", and 84.32% at LLC "Ryasnyanske", compared to the beginning of the experiment. Infestations with *A. hydrophila* decreased by 94.51% at PC "Shmatukha", 80.28% at LLC "Bdzhola", and 99.15% at LLC "Ryasnyanske" after treatment. The contamination of carp with *A. salmonicida* decreased by 97.23% at PC "Shmatukha", 94.00% at LLC "Bdzhola", and 79.06% at LLC "Ryasnyanske" after treatment with a 0.2% agent, compared to the monitoring results. Opportunistic infestations that can affect humans include *Pseudomonas spp., Micrococcus spp.., E. coli, S. aureus* and *Streptococcus spp*. The level of contamination of fish with *P. anguilliseptica* decreased by 99.08% at PC "Shmatukha", 97.91% at LLC "Bdzhola", and 99.41% at LLC "Ryasnyanske".

Infestations with *S. aureus* in carp decreased by 92.15% at PC "Shmatukha", 98.74% at LLC "Bdzhola", and 93.89% at LLC "Ryasnyanske" after treatment with the iodine-based agent compared to the initial data. The level of *Streptococcus iniae* decreased by 80.90% at PC "Shmatukha", 99.63% at LLC "Bdzhola", and 83.30% at LLC "Ryasnyanske". The number of *L. monocytogenes* decreased by 96.25% at PC "Shmatukha", 96.08% at LLC "Bdzhola", and 98.13% at LLC "Ryasnyanske" compared to the monitoring results. Infestations with *Micrococcus spp.* in carp decreased by 93.74% at PC "Shmatukha", 96.37% at LLC "Bdzhola", and 92.26% after treatment with the agent. As a result of the conducted test, the destruction of ectoparasites and bacterial microflora on fish (carp) using the Combiiod agent at different concentrations before stocking in the pond, it was established that treatment with a 0.2% solution had the most pronounced effect.

DISCUSSION

Carp is one of the most widely consumed fish species globally and is frequently contaminated with parasites. Many of these parasites can pose a serious threat to human health. Researchers S. Shamsi (2019) and N. Dyshliuk *et al.* (2023) have found that fish parasites often remain unidentified and lead to zoonotic diseases. Protocols and standards for testing food products for pathogens vary across countries (Williams *et al.,* 2020) and even within developed countries (Franceschini *et al.,* 2023). Scientists W. Saijuntha *et al.* (2021) have determined that the increasing demand for raw and undercooked fish as a human food product, as well as climate change, contributes to the rise of zoonoses.

Infestations of fish with the ectoparasite *Gyrodactylus* cause a sharp decline in freshwater fish production. Researchers E.D. Renner and I.C. Duggan (2024) confirmed in their studies that the prevalence of gyrodactylosis is influenced by season and temperature. As a result of the monitoring of fish infestations with ectoparasites in fish farms, the pathogens *Gyrodactylus kobayashii, Lernaea cyprinacea* and *Philometroides lusiana* were identified. Of the three experimental farms, the highest percentage of infestations was recorded at LLC "Ryasnyanske". The obtained result is associated with the sanitary condition of the pond. Due to the hostilities in the area, it was not cleaned for a long time. The bottom of the water body has a significant layer of silt and clay. The increased amount of soil particles in the water and low transparency prevent sunlight from destroying microorganisms and parasite larvae in the water at a significant depth. To prevent the introduction of infested individuals into the water bodies, the fish were pre-treated with an agent containing active iodine in different concentrations.

After treating carp with a 0.05% solution of the agent, the infestation of fish with gyrodactylosis (12.58%) and lernaeosis (15.39%) decreased significantly at LLC "Ryasnyanske" compared to other farms. However, the destruction of the parasite *Philometroides lusiana* (14.59%) on the fish surface was most observed at LLC "Bdzhola". Treatment of fish with a 0.05% iodine-based solution demonstrated low efficacy in terms of extent. It was established that the infestation of carp with gyrodactylosis decreased by 4.29% at PC "Shmatukha", 1.63% at LLC "Bdzhola", and 12.58% at LLC "Ryasnyanske" compared to the initial results. *Gyrodactylus spp.* are flatworms that infect bony fish, feeding on mucus and epithelial cells. Damage to the epidermis promotes the development of secondary infestations, which increases the risk of death of a large number of fish. Studies by S. Zhou *et al.* (2022) in vivo and in vitro confirm that the antiparasitic efficacy of palm oil against *G. kobayashii* depends on the time of application and dose.

Increasing the concentration of the agent to 0.1% for treating fish against ectoparasites showed a decrease in the maximum number of parasites *G. kobayashii* and *L.cyprinacea* at LLC "Bdzhola" by 42.97% and 32.67%, respectively, compared to other fish farms. Studies on the infestation of carp with the parasite *Lernaea cyprinacea* are of great importance. Scientists H. Rahmati-Holasoo *et al.* (2023) studied this problem and found that it is necessary to consider the direct and indirect impact of various environmental factors on the occurrence and spread of the disease. The infestation of carp with *Philometroides lusiana* decreased significantly in the fish farm LLC "Ryasnyanske" by 25.38%. In the article of F. Moravec *et al.* (2019), representatives of the species *Philometridae* were studied, which represent a group of dracunculoid nematodes parasitising fish. Researchers believe that this species is so widespread on most continents that it needs to be studied in detail to increase the possibilities of developing preventive measures.

Increasing the concentration of the solution to 0.2% enabled the achievement of maximum extensity effectiveness. The destruction of gyrodactylosis in farms on the fish surface was 89.92-97.35%; lernaeosis – 79.13-95.91%; philometroidosis – 81.30-91.16%, compared to the monitoring results. Scientists A. Hedayati *et al.* (2018), and N. Holembovska *et al.* (2024) proved the antiparasitic efficacy of povidone-iodine at 200 mg/m^3 for 1 hour in the destruction of *Pseudocapillaria tomentosa* in danio fish. The contamination of fish by bacterial microflora, alongside the presence of ectoparasites, was high, which further reduced productivity and posed a threat to carp health. Research indicated that the proportion of contaminated fish included *Escherichia coli* (6.25-6.75%), *Aeromonas hydrophila* (6.42-9.50%), *Aeromonas salmonicida* (5.67-7.45%) *Pseudomonas anguilliseptica* (3.27-6.85%) *Staphylococcus aureus* (5.24-6.36%), *Streptococcus iniae* (5.42-6.23%), *Listeria monocytogenes* (4.80-5.36%), *Micrococcus spp.* (5.27-7.28%) out of 100 experimental carp.

Research by F.I. Magouz *et al.* (2024) confirms the contamination of fish with bacteria such as *Aeromonas*, *Vibrio*, *Streptococcus*, *Pseudomonas, Enterococcus* and *Edwardsiella* spp., especially at elevated water temperatures. Furthermore, an analysis of bacteria isolated from fish by researchers P. Nicholson *et al.* (2020) showed a high level of infestation with *A. hydrophila* concurrently with *Aeromonas spp.,* demonstrating their synergy. The obtained results provide a basis for the development and implementation of more effective strategies for the prevention and treatment of diseases.

Treatment of carp with a 0.05% iodine-based solution significantly reduced the number of fish infested with *Escherichia coli*, *Aeromonas hydrophila*, and *Pseudomonas anguilliseptica* at LLC "Ryasnyanske". The number of fish contaminated with *Aeromonas salmonicida, Listeria monocytogenes* and *Micrococcus spp.* decreased significantly at LLC "Bdzhola". Results obtained by X. Chen *et al.* (2018) showed that povidone-iodine eliminates *Micropterus salmoides rhabdovirus (MSRV)A. hydrophila* in closed water bodies and prevents fish contamination. The maximum reduction in staphylococcal colonisation of fish was observed at PC "Shmatukha". Scientists P. Xu *et al.* (2021) confirmed in their studies that *Staphylococcus aureus* forms a biofilm, making it difficult to eliminate. The level of *Streptococcus iniae* contamination decreased after treatment with the experimental 0.05% agent at LLC "Bdzhola". Scientists N. Mon-On *et al.* (2018) proved in their studies the high efficacy of povidone-iodine in inactivating *Streptococcus spp.*

Increasing the concentration of the experimental agent to 0.1% had a positive impact on reducing bacterial contamination of carp: *E. coli* by 46.24%, *A. hydrophila* by 50.84%, *A. salmonicida* by 37.21%, *P. anguilliseptica* by 45.25%, *S. aureus* by 63.20%, *S. iniae* by 34.31%, *L. monocytogenes* by 46.15%, and *Micrococcus spp*. by 46.15%. The obtained results are confirmed by the experiment of Q. Ma *et al.* (2024) where they recommend treating fish embryos for 5-20 minutes with a povidone-iodine buffer solution to eliminate *Micropterus salmoides rhabdovirus* at a concentration of 5 mg/L.

To achieve maximum efficacy in reducing bacterial contamination, the concentration of the experimental agent was increased to 0.2%. As a result of the experiment, a reduction in fish contamination was observed: *E. coli* by 99.2%, *A. hydrophila* by 99.15%, *A. salmonicida* by 97.23%, *P. anguilliseptica* by 99.08%, *S. aureus* by 98.74%, *S. iniae* by 99.63%, *L. monocytogenes* by 98.13%, and *Micrococcus spp*. by 46.15%. The maximum values obtained in the experimental farms were considered. The results of the study by R. He *et al.* (2024) confirm the possibility of using iodine-based preparations to develop a method for controlling the transmission of infestation in closed-water bodies. As a result of the experiment, the most effective concentration of the experimental agent was determined, namely 0.2%, for the destruction of ectoparasites and bacterial microflora on the surface of carp before stocking in ponds.

CONCLUSIONS

Carp infestation with ectoparasites *G. kobayashii* was found to be 43.32%, *L. cyprinacea* – 46.67%, and *P. lusiana* – 31.71% in fish farms. The use of a 0.2% iodine-based agent enabled the destruction of gyrodactylosis by 89.92-97.35%; lernaeosis by 79.13-95.91%; and philometroidosis by 81.30-91.16%, compared to monitoring results. As a result of the treatment of carp with the experimental agent at a concentration of 0.2%, the content of *Escherichia coli* decreased at PC "Shmatukha" by 98.96%, at LLC "Bdzhola" by 99.2%, and at LLC "Ryasnyanske" by 84.32%, compared to the beginning of the experiment. The infestation with *A. hydrophila* decreased after treatment at PC "Shmatukha" by 94.51%, at LLC "Bdzhola" by 80.28%, and at LLC "Ryasnyanske" by 99.15%, compared to monitoring.

Contamination of carp with *A. salmonicida* decreased after treatment with the experimental agent at a concentration of 0.2% at PC "Shmatukha" by 97.23%, at LLC "Bdzhola" by 94.00%, and at LLC "Ryasnyanske" by 79.06%, compared to monitoring results. The level of *P. anguilliseptica* colonisation decreased at PC "Shmatukha" by 99.08%, at LLC "Bdzhola" by 97.91%, and at LLC "Ryasnyanske" by 99.41%. Carp infestation with *S. aureus* decreased after treatment with the iodine-based agent at PC "Shmatukha" by 92.15%, at LLC "Bdzhola" by 98.74%, and at LLC "Ryasnyanske" by 93.89%, compared to initial data. The level of *Streptococcus iniae* decreased at PC "Shmatukha" by 80.90%, at LLC "Bdzhola" by 99.63%, and at LLC "Ryasnyanske" by 83.30%.

The number of *L. monocytogenes* decreased at PC "Shmatukha" by 96.25%, at LLC "Bdzhola" by 96.08%, and at LLC "Ryasnyanske" by 98.13%, compared to monitoring results. Carp infestation with *Micrococcus spp.* decreased after treatment with the experimental agent at PC "Shmatukha" by 93.74%, at LLC "Bdzhola" by 96.37%, and at LLC "Ryasnyanske" by 92.26%. It was established that the use of a 0.2% iodine-based agent eliminates ectoparasites *G. kobayashii*, *L. cyprinacea. P. lusiana*, and bacterial microflora *E. coli, A. hydrophila, A. salmonicida, P. anguilliseptica*, *S. aureus, S. iniae, L. monocytogenes,* and *Micrococcus spp.* on the surface of carp. The perspective of further research is to determine the level of infestation of carp with ectoparasites and bacterial infestations one year after stocking in a pond.

ACKNOWLEDGEMENTS

The authors express their gratitude for the support provided during the research to the Chairman of the Board of Brovapharma LLC, Doctor of Veterinary Sciences, Professor A.V. Berezovsky. The research was carried out as part of the R&D project (0121U109563) "Scientifically substantiated concept of prevention of epidemiologically significant bacterial diseases of animals on the basis of use of innovative technologies".

CONFLICT OF INTEREST

None.

REFERENCES

[1] Barreto, R., Barrois, B., Lambert, J., Malhotra-Kumar, S., Santos-Fernandes, V., & Monstrey, S. (2020). Addressing the challenges in antisepsis: focus on povidone iodine. *International Journal of Antimicrobial Agents,* 56(3), article number 106064. doi: 10.1016/j.ijantimicag.2020.106064.

[2] Buchmann, K. (2022). Control of parasitic diseases in aquaculture. *Parasitology,* 149(14), 1985-1997. doi: 10.1017/S0031182022001093.

[3] Chen, X., Lai, C., Wang, Y., Wei, L., & Zhong, Q. (2018). Disinfection effect of povidone-iodine in aquaculture water of swamp eel (*Monopterus albus*). *PeerJ*, 6, article number e5523. doi: 10.7717/peerj.5523.

[4] Dyshliuk, N., Usenko, S., Slobodyanyuk, N., Mazurkevych, T., & Stehnei, Zh. (2023). Microstructural analysis of frozen and salted fish and seafood meat. *Ukrainian Journal of Veterinary Sciences,* 14(1), 26-38. doi: 10.31548/veterinary1.2023.26.

[5] European convention for the protection of vertebrate animals used for experimental and other scientific purposes. (1986). Retrieved from https://rm.coe.int/168007a67b.
[6] Fetherman, E.R., Neuschwanger, B., Praamsma, C., & Davis, T. (2023). Concentration, life stage, feeding, density, flow, and strain effects on formalin sensitivity in rainbow trout (*Oncorhynchus mykiss*). *Animals,* 13(15), article number 2425. doi: 10.3390/ani13152425.
[7] Franceschini, R., Valiani, A., Ranucci, D., Roila, R., Palma, G., Agnetti, F., Di Giacinto, G., & Branciari, R. (2023). Eustrongylides spp. parasite risk management in *Atherina boyeri* from Lake Trasimeno. *Italian Journal of Food Safety*, 12(3), article number 11338. doi: 10.4081/ijfs.2023.11338.
[8] Harmansa Yilmaz, B., & Yavuzcan Yildiz, H. (2023). Anthelmintic effects of peppermint (*Mentha piperita*), lemon (*Citrus limon*), and tea tree (*Melaleuca alternifolia*) essential oils against Monogenean parasite (*Dactylogyrus* sp.) on carp (*Cyprinus carpio*). *Helminthologia,* 60(2), 125-133. doi: 10.2478/helm-2023-0019.
[9] Hartung, T. (2010). Comparative analysis of the revised Directive 2010/63/EU for the protection of laboratory animals with its predecessor 86/609/EEC – a t4 report. *ALTEX*, 27(4), 285-303. doi: 10.14573/altex.2010.4.285.
[10] He, R., Zhu, N., Chen, X., Liang, Q., Yao, G., Tian, Q., Zhou, F., & Ding, X. (2024). Experimental evidence of effective disinfectant to control the transmission of Micropterus salmoides rhabdovirus. *Journal of Fish Diseases*, 47(2), article number e13891. doi: 10.1111/jfd.13891.
[11] Hedayati, A., Darabitabar, F., Bagheri, T., Hedayati, E., & Van Doan, H. (2018). Histopathological impairment of common carp (*Cyprinus carpio*) induced through povidone-iodine exposure. *Microscopy Research and Technique*, 81(11), 1257-1260. doi: 10.1002/jemt.23131.
[12] Holembovska, N., Slobodianiuk, N., Israelian, V., Androshchiuk, O., & Maceyko, V. (2024). Influence of organic acids on organoleptic and structural and mechanical properties of freshwater hydrobiont meat. *Animal Science and Food Technology*, 15(1), 9-28. doi: 10.31548/animal.1.2024.09.
[13] Islam, S.I., Mahfuj, S., Baqar, Z., Asadujjaman, M., Islam, MJ., Alsiwiehri, N., Almehmadi, M., Sanjida, S., & Ahammad, F. (2024). Bacterial diseases of Asian sea bass (*Lates calcarifer*): A review for health management strategies and future aquaculture sustainability. *Heliyon,* 10(9), article number e29793. doi: 10.1016/j.heliyon.2024.e29793.
[14] Kochmann, J., Laier, M., Klimpel, S., Wick, A., Kunkel, U., Oehlmann, J., & Jourdan, J. (2023). Infection with acanthocephalans increases tolerance of Gammarus roeselii (*Crustacea: Amphipoda*) to pyrethroid insecticide deltamethrin. *Environmental Science and Pollution Research International,* 30, 55582-55595. doi: 10.1007/s11356-023-26193-0.
[15] Law of Ukraine No. 249 "On the Procedure for Carrying out Experiments and Experiments on Animals by Scientific Institutions". (2012, March). Retrieved from https://zakon.rada.gov.ua/laws/show/z0416-12#Text.
[16] Ma, Q., Zhao, G., Liu, J., Chen, I.T., Wei, Y., Liang, M., Dai, P., Nuez-Ortin, W.G., & Xu, H. (2024). Effects of a phytobiotic-based additive on the growth, hepatopancreas health, intestinal microbiota, and Vibrio parahaemolyticus resistance of Pacific white shrimp, Litopenaeus vannamei. *Frontiers in Immunology*, 15, article number 1368444. doi: 10.3389/fimmu.2024.1368444.
[17] Magouz, F.I., Moustafa, E.M., Abo-Remela, E.M., Halawa, M.R., Barakaat, P.M., & Omar, A.A. (2024). Summer mortality syndrome bacterial pathogens in farmed Nile tilapia (*Oreochromis niloticus*). *Open Veterinary Journal*, 14(1), 53-69. doi: 10.5455/OVJ.2024.v14.i1.7.
[18] Mohamadi Yalsuyi, A., Forouhar Vajargah, M., Hajimoradloo, A., Mohammadi Galangash, M., Prokić, M.D., & Faggio, C. (2022). Can Betadine (10% povidone-iodine solution) act on the survival rate and gill tissue structure of Oranda goldfish (*Carassius auratus*)? *Veterinary Research Communications*, 46, 389-396. doi: 10.1007/s11259-021-09862-8.
[19] Mon-On, N., Surachetpong, W., Mongkolsuk, S., & Sirikanchana, K. (2018). Roles of water quality and disinfectant application on inactivation of fish pathogenic *Streptococcus agalactiae* with povidone iodine, quaternary ammonium compounds and glutaraldehyde. *Journal of Fish Diseases*, 41(5), 783-789. doi: 10.1111/jfd.12776.
[20] Moravec, F., Nagasawa, K., Nitta, M., & Tawa, A. (2019). New records of philometrids (*Nematoda: Philometridae*) from marine fishes off Japan, including description of *Philometra kidakoi* sp. n. and *Congerinema japonicum* gen. et sp. n. *Folia Parasitologica*, 66, article number 021. doi: 10.14411/fp.2019.021.
[21] Nicholson, P., Mon-On, N., Jaemwimol, P., Tattiyapong, P., & Surachetpong, W. (2020). Coinfection of tilapia lake virus and *Aeromonas hydrophila* synergistically increased mortality and worsened the disease severity in tilapia (*Oreochromis* spp.). *Aquaculture,* 520, article number 734746. doi: 10.1016/j.aquaculture.2019.734746.
[22] Othmen, Z.O., Jerbi, M.A., Timoumi, R., Besbes, R., Haouas, Z., Achour, L., Elazomi, A., Zaet, A., Zourgui, L., & Kacem, A. (2024). Liver histopathological and oxidative stress assessment by a combination of formaldehyde and oxytetracycline in sea bass (*Dicentrarchuslabrax* L). *Open Veterinary Journal*, 14(2), 630-639. doi: 10.5455/OVJ.2024.v14.i2.3.

[23] Peter, N., Dörge, D.D., Cunze, S., Schantz, A.V., Skaljic, A., Rueckert, S., & Klimpel, S. (2023). Raccoons contraband – The metazoan parasite fauna of free-ranging raccoons in central Europe. *International Journal for Parasitology: Parasites and Wildlife*, 20, 79-88 doi: 10.1016/j.ijppaw.2023.01.003.
[24] Pravdová, M., Kolářová, J., Grabicová, K., Janáč, M., Randák, T., & Ondračková, M. (2023). Response of parasite community composition to aquatic pollution in common carp (*Cyprinus carpio* L.): A semi-experimental study. *Animals,* 13(9), article number 1464. doi: 10.3390/ani13091464.
[25] Rahmati-Holasoo, H., Marandi, A., Shokrpoor, S., Goodarzi, T., Ziafati Kafi, Z., Ashrafi Tamai, I., & Ebrahimzadeh Mousavi, H. (2023). Clinico-histopathological and phylogenetic analysis of protozoan epibiont Epistylis wuhanensis associated with crustacean parasite *Lernaea cyprinacea* from ornamental fish in Iran. *Scientific Reports*, 13, article number 14065. doi: 10.1038/s41598-023-41368-y.
[26] Renner, E.D., & Duggan, I.C. (2024). Season, size, and sex: factors influencing monogenean prevalence and intensity on *Gambusia affinis* in New Zealand. *Parasitology Research,* 123, article number 228. doi: 10.1007/s00436-024-08241-x.
[27] Rigos, G., Padrós, F., Golomazou, E., & Zarza, C. (2024). Antiparasitic approaches and strategies in European aquaculture, with emphasis on Mediterranean marine finfish farming: Present scenarios and future visions. *Reviews in Aquaculture*, 16(2), 622-643. doi: 10.1111/raq.12857.
[28] Saijuntha, W., Sithithaworn, P., Petney, T.N., & Andrews, R.H. (2021). Foodborne zoonotic parasites of the family *Opisthorchiidae*. *Research in Veterinary Science*, 135, 404-411. doi: 10.1016/j.rvsc.2020.10.024.
[29] Shamsi, S. (2019). Seafood-borne parasitic diseases: A "one-health" approach is needed. *Fishes,* 4(1), article number 9. doi: 10.3390/fishes4010009.
[30] Szentmáry, N., Shi, L., Daas, L., & Seitz, B. (2020). Diagnostics and management approaches for *Acanthamoeba keratitis*. *Expert Opinion on Orphan Drugs*, 8(7), 227-236. doi: 10.1080/21678707.2020.1791081.
[31] Umasuthan, N., Xue, X., Caballero-Solares, A., Kumar, S., Westcott, J.D., Chen, Z., Fast, M.D., Skugor, S., Nowak, B.F., Taylor, R.G., & Rise, M.L. (2020). Transcriptomic profiling in fins of atlantic salmon parasitized with sea lice: Evidence for an early imbalance between chalimus-induced immunomodulation and the host's defense response. *International Journal of Molecular Sciences*, 21(7), article number 2417. doi: 10.3390/ijms21072417.
[32] Williams, M., Hernandez-Jover, M., & Shamsi, S. (2020). A Critical appraisal of global testing protocols for zoonotic parasites in imported seafood applied to seafood safety in Australia. *Foods*, 9(4), article number 448. doi: 10.3390/foods9040448.
[33] Xu, P., Xu, X.B., Khan, A., Fotina, T., & Wang, S.H. (2021). Antibiofilm activity against *Staphylococcus aureus* and content analysis of *Taraxacum Officinale* phenolic extract. *Polish Journal of Veterinary Sciences,* 24(2), 243-251. doi: 10.24425/pjvs.2021.137659.
[34] Zhou, S., Dong, J., Liu, Y., Yang, Q., Xu, N., Yang, Y., & Ai, X. (2021). Antiparasitic efficacy of herbal extracts and active compound against *Gyrodactylus kobayashii* in *Carassius auratus*. *Frontiers in Veterinary Science*, 8, article number 665072. doi: 10.3389/fvets.2021.665072.
[35] Zhou, S., Yang, Q., Dong, J., Liu, Y., Xu, N., Yang, Y., & Ai, X. (2022). Anthelmintic efficacy of palmarosa oil and curcuma oil against the fish *Ectoparasite Gyrodactylus kobayashii* (monogenean). *Animals,* 12(13), article number 1685. doi: 10.3390/ani12131685.

Результати застосування йодмісткого засобу при вирощуванні коропових риби у закритих водоймах

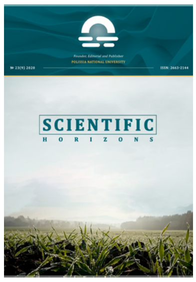
Тетяна Фотіна
Доктор ветеринарних наук, професор
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-5079-2390
Юрій Ярмошенко
Аспірант
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0003-2108-2431
Євгенія Дудник
Доктор філософії
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0002-0735-3779
Лідія Коваленко
Кандидат ветеринарних наук, доцент
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0002-4350-2284
Юлія Негреба
Старший викладач
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-8437-9617

Анотація. Метою дослідження було провести моніторинг ураження риби ектопаразитами та бактеріальними інфекціями та встановити ефективні дози нового йодмісткого засобу з метою профілактики хвороб риби. Дослідженнями встановлено ураження коропа ектопаразитами *G. kobayashii* на 43,32 %, *L. cyprinacea* – на 46,67 %, *P. lusiana* – на 31,71 % у рибних господарствах Сумської області. Обробка йодмістким засобом дала можливість знизити ступень ураження до 0,2 % в тому числі на гіродактильоз – 89,92-97,35 %; лерніозу – 79,13-95,91 %, філометроїдозу – 81,30-91,16 %, порівняно з моніторинговими результатами. При дослідженні на бактеріальні інфекції виявлено, що контамінація коропа була більше *E. coli* у ПП «Шматуха» на 8,0 %; *Aeromonas hydrophila* на 47,97 % та *Aeromonas salmonicida* – на 31,39 %, *Pseudomonas anguilliseptica* – на 19,48 %, *Streptococcus iniae* – на 13,27 %, *Micrococcus spp.* – на 38,14 % у ТОВ «Ряснянське»; *Staphylococcus aureus*– на 21,37 %, *Listeria monocytogenes* – на 11,43 % у ТОВ «Бджола» ці показники були менше ніж в інших господарствах. Після обробки йодмістким засобом контамінація риби *E. coli* знизилась у ПП «Шматуха» на 98,96 %, у ТОВ «Бджола» – на 99,2 %, у ТОВ «Ряснянське» – на 84,32 %. Обсіменіння коропа *A. hydrophila* знизилось у ПП «Шматуха» на 94,51 %, у ТОВ «Бджола» – на 80,28 %, у ТОВ «Ряснянське» – на 99,15 %; *A. salmonicida* у ПП «Шматуха» на 97,23 %, у ТОВ «Бджола» – на 94,00 %, у ТОВ «Ряснянське» – на 79,06 %; *S. aureus* у ПП «Шматуха» на 92,15 %, у ТОВ «Бджола» – на 98,74 %, у ТОВ «Ряснянське» – на 93,89 %; *S. iniae* у ПП «Шматуха» на 80,90 %, у ТОВ «Бджола» – на 99,63 %, у ТОВ «Ряснянське» – на 83,30 %; *L. monocytogenes* зменшилась у ПП «Шматуха» на 96,25 %, у ТОВ «Бджола» – на 96,08 %, у ТОВ «Ряснянське» – на 98,13 %; *Micrococcus spp.* у ПП «Шматуха» на 93,74 %, у ТОВ «Бджола» – на 96,37 %, у ТОВ «Ряснянське» – на 92,26 % порівняно з результатами моніторингу. Практичною цінністю роботи є контроль поширення та розробка профілактичних заходів для знищення ектопаразитів та бактеріальних інфекцій коропа перед висадкою у водойми

Ключові слова: ектопаразити риби; екстенсивність інвазії; бактеріальна мікрофлора; контроль; профілактика

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 32-41



UDC 636.5
Doi: 10.48077/scihor9.2024.32

Effect of feed with extruded components and phytobiotics on quail

Yuriy Balji
PhD in Veterinary Sciences, Acting Professor
S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
https://orcid.org/0000-0002-5006-3224
Dinara Zhanabayeva*
Doctor of Veterinary Sciences, Acting Associate Professor
S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
https://orcid.org/0000-0001-7499-347X
Leila Sultanayeva
Master in Veterinary Sciences, Researcher
S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
https://orcid.org/0000-0003-2774-9575
Gulzhan Yeszhanova
PhD in Veterinary Sciences, Associate Professor
S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
https://orcid.org/0000-0001-8411-466X
Danara Mussagiyeva
Master in Veterinary Sciences, Researcher
S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
https://orcid.org/0000-0001-5605-9552

Article's History:
Received: 10.02.2024
Revised: 21.07.2024
Accepted: 28.08.2024

Abstract. Quails are a valuable type of poultry, as their eggs and meat have high nutritional value. Moreover, quails are distinguished by early sexual maturity, high egg production and small body size. These unique characteristics make them an attractive object for breeding and scientific research. The purpose of the study was to investigate the effect of feed with extruded components and phytobiotics on the meat productivity and blood biochemistry of Texas quails. The methodology involved dividing 200 quails into experimental and control groups, feeding them different diets

Suggested Citation:
Balji, Yu., Zhanabayeva, D., Sultanayeva, L., Yeszhanova, G., & Mussagiyeva, D. (2024). Effect of feed with extruded components and phytobiotics on quail. *Scientific Horizons*, 27(9), 32-41. doi: 10.48077/scihor9.2024.32.

*Corresponding author

over a 60-day period, and analysing their growth performance, meat yield, and biochemical blood parameters using statistical analysis tools. As a result of the research, it was revealed that feed produced according to the developed recipe has a positive effect on the weight gain of quails. In the experimental group (EG), the absolute increase was 313.7 ± 4.34 g, in the control group (CG) – 275.9 ± 2.89 g (not significant difference, $P > 0.05$). Furthermore, the feed with extruded components and phytobiotics led to improved feed conversion ratio in the EG compared to the control. The birds in the EG also demonstrated higher carcass weight and yield. The experimental diet also appeared to have a positive influence on the immune status of the quails. The results demonstrate the potential benefits of incorporating extruded components and phytobiotics into quail feed to improve growth performance and maintain healthy physiological parameters. Evaluating the biochemical blood test results, it can be indicated that no significant changes in the blood composition were detected, which may indicate the absence of a negative effect of the developed feed on the body of birds. The results obtained may be of practical importance for developing optimal diets for meat quails and improving the quality and safety of their products

Keywords: extrusion; blood biochemistry; homeostasis; diet; protein

INTRODUCTION

The relevance of this study lies in addressing the critical issues surrounding quail farming, which has gained popularity due to its economic advantages, such as low maintenance costs, short generation intervals, disease resistance, and high egg production. Two key factors that limit poultry production are energy and protein, traditionally sourced from plant-based ingredients like grains and beans. Although, competition for these resources, along with challenges such as global warming and rising costs, has raised concerns about the sustainability of using conventional feed ingredients. This highlights the importance of developing alternative feeding solutions, such as balanced diets supplemented with animal proteins or essential amino acids, to ensure sustainable and productive quail farming.

There is no direct ban on the use of meat and bone meal (MBM) in animal diets in the Republic of Kazakhstan, however, the Veterinary (Veterinary and Sanitary) Rules dated August 25, 2015 (as amended and supplemented as of July 11, 2023) provide recommendations not to allow the use of MBM for cattle feed and ruminant processing waste to prevent bovine spongiform encephalopathy. In this regard, when developing their own feed recipes, the authors have used fishmeal in the feed compositions.

Feed additives are used to replenish missing dietary elements. The increasing demand for natural feed additives in poultry farming is due to the ban on the use of antibiotics as feed additives. The feed industry is now focusing on a new category of additives called phytogenic feed additives or phytobiotics, which are made from herbs, aromatic plants and spices. The successful use of phytogenic growth promoters brings greater benefits to the poultry industry through increased feed efficiency and improved health status (Alagawany *et al.*, 2022; Abd Elzaher *et al.*, 2023). Therefore, in this study, the authors used a mixed feed that included extruded components and was enriched with BioFeed-P phytobiotic, which is a natural immunostimulant (Sultanayeva *et al.*, 2023).

G. Kanbur *et al.* (2023) examined the effects of adding dried banana leaves with or without a multienzyme complex to the diets of laying quails. The results showed that it increased egg production and weight, improved yolk colour, and affected egg quality, while the multienzyme addition had minimal effects on laying performance. This lack of any benefits from adding multienzymes leaves room for further exploration into optimal dietary supplementation strategies.

C.E. Stanquevis *et al.* (2022) focused on evaluating the effects of different levels of vitamin A supplementation in the diets of meat-type quails (Coturnix coturnix sp) from 1 to 35 days of age. The research finds that vitamin A supplementation has a significant impact on body weight, weight gain, and feed efficiency, although its effect on immune parameters was limited. A critical analysis of the work reveals its focus on immunity was somewhat narrow, only examining a few immune-related factors like heterophil/lymphocyte ratio and organ weights. The lack of significant findings in immunity could indicate either that vitamin A does not strongly influence early immune development or that more comprehensive immunological markers need to be assessed.

In their study A. Ansaripoor *et al.* (2020) examined the improvement of the growth and production of Japanese quail breeders and their offspring. Using the Taguchi method, the researchers measured egg production, feed intake, and hatchability in 630 quails. And while the study provides valuable data on the optimisation of quail diets, it is limited by its relatively short timeframe and does not explore potential long-term impacts on reproductive performance or health. E.A. Ashour *et al.* (2024) also investigated the productive performance, egg quality, and digestibility of laying Japanese quails. They found that the best egg weight and mass were achieved with a diet containing 20% crude protein and 2,900 kcal/kg metabolised energy. However, the study was conducted only in the summer season, which might limit the generalizability of the findings to other seasons.

The aim of this study was to assess the effects of feeding Texas quails with extruded parts and phytobiotics on their physiological parameters and meat productivity. By focusing on alternative feed solutions, the study address concerns about the sustainability and efficiency of traditional poultry diets. It determines whether these dietary enhancements can improve quail growth performance, carcass characteristics, and biochemical blood markers.

MATERIALS AND METHODS

The experiment was carried out in the base farm (Akmola-Phoenix Farm) in Akmola region, Kazakhstan. The experiment period was 60 days, starting feeding from the 7th day of life until the poultry reached the slaughter age. The experimental part of the research was approved by the local ethical commission on biological and medical ethics (for research involving animals) of the S. Seifullin Kazakh Agro Technical Research University, Minutes of the Meeting No. 2 dated December 14, 2021. All procedures performed in studies involving animals were in accordance with the ethical standards of the institutional and national research committee and with the Basel Declaration (Animal Research Tomorrow, 2010) and its later amendments or comparable ethical standards.

Diets were formulated according to the recommendations of the Nutrient Requirements of Ring-Necked Pheasants, Japanese Quail, and Bobwhite Quail (National Research Council, 1994). Compound feed for quails for meat production was produced in the production and testing workshop of "NFT-KATU" Limited Liability Partnership on the basis of S. Seifullin Kazakh Agro Technical Research University. The composition included extruded corn, wheat, soybean meal/cake, fish meal, tricalcium phosphate (TCP), feed yeast, crushed shell rock and chalk, table salt, activated carbon, and BioFeed-P phytobiotic feed additive developed by the authors.

The chemical composition of feed for quails for meat production (content of "crude" protein, "crude" ash, "crude" fat, Ca, P, carotene) was determined using NIRS DS2500 infrared feed analyser (Foss Analytical A/S, Denmark). Feed components were purchased from local producers in Kazakhstan. The chemical composition of meat and eggs was determined by the permanganometric method. The experiment used 200 birds of the Texas breed to determine the effect of the developed recipe on meat productivity, the chemical composition of meat, and biochemical blood parameters, reflecting a complete picture of the body state.

The birds were divided into 2 groups: control and experimental. Until the 7th day of age, the chicks were fed commercial feed used in the base farm. The maintenance of two groups of birds is generally accepted according to zootechnical standards, depending on the age of the birds. The experimental group and the control group were housed in identical settings, guaranteeing uniformity in environmental elements including humidity, illumination, and temperature. The amount of feed was adjusted as the birds matured to meet their changing nutritional requirements. To support healthy growth and reduce stress, age-appropriate guidelines for general care and space allocation were closely followed, guaranteeing that every bird enjoyed ideal living conditions for the duration of the trial. Feed was given to quails during the fattening period in the amount of 42 g/bird per day with two feedings a day. Daily feed intake was measured by subtracting the remaining feed from the feed offered. The feed conversion ratio was calculated by dividing feed intake by weight gain *100. The control group (CG) ate feed previously used on the base farm. The experimental group (EG) was fed according to three recipes: "Start" (from the 7th to 21st days), "Grower" (from 21 to 42 days), "Finish" (from the 42nd to 63rd days), differing in the percentage of components, however, the data on the "Finish" recipe was important in authors' research and is shown in Table 1.

***Table 1**. Feed composition for the EG of quails*

Feed component	Percentage, %
Wheat	39.54
Soybean meal/cake	33
Fish meal	13
Extruded corn	10
Feed yeast	2
TCP	1
Crushed shell rock and chalk – 1%	1
BioFeed-P phytobiotic feed additive	0.06
Common salt (NaCl)	0.4

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

To assess the effect of the developed feed on metabolic processes in the blood of quails, the following indicators were studied: total protein (TP), albumin and globulins, total bilirubin, urea, calcium, glucose, amylase activity, alanine aminotransferase (ALT), aspartate aminotransferase (AST). Meat productivity was determined by conducting weekly individual weighing and slaughter with the study of meat productivity indicators. For that, 100 quails (50 quails from each group) were sent for slaughter. Due to the fact that sexual maturity in quails occurs in approximately 6-7 weeks and blood parameters change quickly accordingly, it is methodically incorrect to compare them at the beginning and after the experiment. Therefore, the blood parameters of the EG were compared with the parameters of the CG of poultry at the end of the experiment at the age of 60 days. The blood test was carried out on SMT-120V biochemical veterinary analyser (Chengdu Seamaty Technology Co., China, Sichuan), the operation of which is based on absorption spectroscopy and transmission turbidimetry. Blood samples were collected by decapitation using a simple random sampling method. Before blood sampling, the birds were on a 6-hour starvation diet. After slaughter of poultry, blood samples for biochemical analysis were collected in 1.5 ml testing tubes with an activator and gel, followed by centrifugation at 3,000 rpm during 10 minutes on a CM-6M centrifuge (Sia "Elmi", Latvia, Riga). Statistical analysis was performed using SPSS 25.0 application.

RESULTS

To optimise feeding patterns, it is important to determine the energy content of feeds and also establish the poultry ideal energy intake to ensure maximum economic return. The chemical composition of the diets of the EGs is presented in Table 2.

***Table 2**. Chemical composition of quail diets in EGs*

Group	Humidity (%)	DM (%)	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Ash	Starch (%)	ME (poultry), Kcal
CG	9.3	90.7	25.3	6.9	3.88	6.57	28.83	3,309
EG	8.3	91.7	27.6	5	3.49	5.38	32.79	3,357

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

As can be seen from Table 2, the metabolic energy of the mixed feed of the EG was 3,357 Kcal/1,000 g, while in the commercial feed of the CG the level of metabolic energy was lower by 48 Kcal, but in both groups the indicator was at a high level. According to the Manual for working with meat quails, the metabolic energy should be 3,100 Kcal/1,000 g, protein in the feed should be 20%. Due to the fact that the components of the feed are subjected to extrusion processing, its moisture content is reduced, which makes it possible to prolong the shelf life, reducing the risk of the development of microorganisms and molds. In the mixed feed of the EG the moisture content was 8.3%, in the CG – 9.3%.

An important indicator of the nutritional and energy value of feed is dry matter. Dry matter content indicates the actual amount of various nutrients available to the poultry consuming the feed. Dry matter contains inorganic (raw ash) and organic components. Organic matter in feed consists of crude protein, crude fat, and carbohydrates. The feed according to the recipe authors developed contained 91.7% of dry matter, while the CG contained 90.7%. The percentage of protein in the feed of the EG was 27.6%, in the CG – 25.3%, which indicates a sufficient supply of protein to the poultry's body and satisfies their needs. Fiber in the feed is digested in the poultry body in the cecum, where there are microorganisms that secrete enzymes that can decompose from 10 to 30% of the fiber. The crude fiber content should be at the level of 4.0-5.0%, in authors' case this figure is slightly reduced and amounts to 3.49% in the EG and 3.88% in the CG.

Carbohydrates – starchy polysaccharides (starch, sugar) are the main sources of energy for poultry. The percentage of starch in the feed of the EG was slightly higher than in the CG and amounted to 32.79% and 28.83%, respectively. Ash content is generally recognized as the most important indicator for assessing the mineral composition of a product. The feed of the EG contained 5.38% of ash, and the CG – 6.57%. The results of the weight gain of the EGs of quail are shown in Table 3.

***Table 3**. Dynamics of growth of quails from the 7th day to the 63rd day of life using the developed recipes*

Age, days	Average weight, g	
	CG	EG
7	56.7 ± 1.22	60.1 ± 0.88
14	105.8 ± 1.54	106.1 ± 1.56
21	147.7 ± 2.22	170.8 ± 1.98
28	220.6 ± 2.93	233.3 ± 2.48
35	267.9 ± 3.02	278.3 ± 2.7
42	306.2 ± 4.03	314.7 ± 3.62
49	319.6 ± 4.4	342.7 ± 3.58
56	331.4 ± 4.74	360.3 ± 4.35
63	333.2 ± 4.53	373.7 ± 4.28

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

From Table 3 it can be seen that during all periods of quail growth, the EG had a greater weight gain. Live weight when feeding birds according to the Start recipe (from the 7th to 21st days) in the CG by the 21st day was 147.7 ± 2.22 g, and in the EG – 170.8 ± 1.98 g, which is 15.6% higher or 23.1 g. Live weight when feeding birds according to the Grower recipe (from 21st to 42nd days) on the 42nd day in the EG is 2.7% higher than in the CG. The weight of birds fed with the Finish recipe (from the 42nd to 63rd days) in the EG increased every week, while in the CG from the 56th to 63rd days there was practically no increase. So, by the end of the fattening period, the EG poultry weighed 373.7 ± 4.28 g, while the poultry in the EG weighed 333.2 ± 4.53 g, which is 12.15% lower than the EG level or less than 40.5 g. The dynamics of growth in live weight of quails is presented by indicators of absolute and relative growth. The growth rates (absolute, average daily) of quail in groups are shown in Table 4.

***Table 4**. The Contribution of agroforestry practice to pesanggem household income*

Group	Absolute weight gain, g	Average daily weight gain, g
CG	275.9 ± 2.89	5.11
EG	313.7 ± 4.34	5.81

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

Calculation of absolute weight gain revealed that the difference between the groups amounted to 37.8 g. Absolute gain in the EG amounted to 313.7 ± 4.34 g, in the CG – 275.9 ± 2.89 g. Average daily gain in the CG – 5.11 g, in EG – 5.81 g. The EGs ate almost the same amount of feed on average per day in the EG – 32.1 ± 0.97 g, in the CG – 31.9 ± 0.99 g, or per 1 g of gain in the EG 5.53 g of feed was spent, while in the CG – 6.24 g, i.e. in the EG feed conversion was 13% higher. The results of meat productivity indices are shown in Table 5.

***Table 5**. Meat productivity indices*

Indicator	Group (n = 30)	
	1st group (EG) M ± m, g	2nd group (CG) M ± m, g
Pre-slaughter weight, g	370.1 ± 24.05	294 ± 14.9
Weight of semi-gutted carcass, g	331.3 ± 16.9	240.6 ± 13.01
Weight of gutted carcass, g	287 ± 17.4	219.3 ± 16.4
Slaughter yield, %	78%	75%
Weight of skin and subcutaneous fat, g	37.1 ± 2.3*	13.5 ± 5.99
Pectoral muscles, g	93.1 ± 5.7	51.6 ± 4.8
Leg muscles, g	49.3 ± 4.9	34.85 ± 13.1
Weight of internal organs, g		
Muscle stomach, g	4.1 ± 0.73	3.65 ± 0.3
Heart, g	3.25 ± 0.21	2.8 ± 0.47
Liver, g	6.12 ± 1.48	4.07 ± 0.12

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

According to Table 5, it can be concluded that the slaughter yield of quails in the EG is 4% higher than in the CG. The best results were obtained in the EG, which received Finish enriched feed. Live weight in the EG was 370.1 ± 24.05 g, which was higher than in the CG by 76.1 g or 26%, in the CG live weight index was less by 21%. According to the table in the EG the weight of half-gutted (331.3 ± 16.9) and gutted (287 ± 17.4) carcasses was 30.6-37.7% ahead of the corresponding indicators of the CG, while in the CG the indicators were lower by 67.7-90.7 g or 27.38-23.6%, which indicates the effectiveness of the developed enriched feed.

Also, according to the results obtained in the EG an increase in the weight of skin and subcutaneous fat was noted, which gives the meat juiciness, tenderness and peculiar taste. According to the results of the study in the EG this indicator was equal to 37.1 ± 6.8 g, which was an increase of 174%, as well as pectoral muscles – 93.1 ± 5.7 g or 80.4%, leg muscles – 49.3 ± 4.9 g or 41.46% were more in comparison with the index of the CG. At the same time in the CG the mass of skin and subcutaneous fat amounted to 13.5 ± 5.99 g, pectoral muscles – 51.6 ± 4.8 g, leg muscles – 34.85 ± 13.1 g. Thus, analysing the obtained data, it can be noted that meat productivity of quails increases with the introduction of “Finish” enriched feed into the main diet.

In the EGs, the weight of internal organs such as muscular stomach, heart and liver surpassed the values of the CG. It is important to develop heart, liver and muscular stomach as human food organs. The mass of muscular stomach of the EG was 4.1 ± 0.73 g, which was 12.33% higher than of the CG. The EG was superior to the CG in heart weight by 16.08%. Liver weight in the EG was 6.12 ± 1.48 g or more by 50.7% compared to the CG. Thus, relative to live weight, internal organs of experimental birds in the EG had a better index, which indicates the positive effect of "Finish" enriched feed. When analysing the results of chemical composition of quail meat, 4.70 ± 1.74% of fat was found in the CG, while in the EG this index was 2.79 ± 0.89% (Table 6).

***Table 6**. Chemical composition of quail meat*

Name of indicators, units of measurement	Results of the EG	CG results
1	2	3
Physical and chemical indicators:		
Mass fraction of protein, %	21.12 ± 0.36	20.82 ± 0.08
Mass fraction of fat, %	2.79 ± 0.89	4.7 ± 1.74
Mass fraction of carbohydrates, %	Not detected	Not detected
Mass fraction of ash content, %	1.18 ± 0.03	1.27 ± 0.06

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

Protein level in the EG was equal to 21.12 ± 0.36%, in the CG – 20.82 ± 0.08%. Mass fraction of ash content in the EG was slightly lower than in the CG and amounted to 1.18%. Thus, enriched feeds with the use of highly nutritious, highly digestible and natural plant components according to the Start, Grower and Finish formulation had a positive effect on the growth and development of Texas quail. The used enriched feeds allow obtaining the weight of quails at 63 days of age within the physiological norm, while the feed used on the farm showed lower efficiency. The results obtained from the assessment of the developed feed are shown in Table 7.

***Table 7**. Assess the effect of the developed feed on metabolic processes in the blood of quails*

Indicator	Actual result of EG	Actual result of CG	Unit
Albumin	13.67 ± 0.48	12.23 ± 2.93	g/L
TP	27.8 ± 1.11	27.33 ± 8.94	g/L
Globulin	14.32 ± 0.89	18 ± 21.35	g/L
Total bilirubin	2.75 ± 0.84	3.5 ± 0.99	umol/L
AST	403 ± 44.95	382 ± 42.75	U/L
ALT	11.67 ± 1.8	11.67 ± 3.34	U/L
Amylase			
Glucose	15.49 ± 0.48	16.68 ± 0.8	mmol/L
Calcium (Ca)	2.31 ± 0.11	2.39 ± 0.09	mmol/L
Urea	1.93 ± 0.24	2.48 ± 0.72	mmol/L

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

According to the results of the research of protein metabolism in quails of the EG at the age of 60 days, the content of TP was 1.7% higher than in the CG. The content of globulin fractions in experimental birds was 20.44% lower than in control birds. Most likely the decrease was due to alpha and beta-globulin fractions, which indicates the absence of intoxication and inflammatory processes in the body of experimental birds. Authors found that the combined feeds do not have a significant effect on the level of urea in the blood of quails, which is associated with a stable level of TP and albumin. Urea content in the blood of the EG was lower by 22.17% than in control quails, and both values were within physiological values. Both increase and decrease of urea content in blood are fraught with consequences for the organism of birds. Urea and creatinine are indicators of normal renal function and their increase in serum indicates renal dysfunction or protein overfeeding. Decreased plasma/serum urea levels are less common and usually have less clinical significance than increased plasma/serum urea levels (Mamoulakis *et al.*, 2024). Decreased blood urea is associated with prolonged protein malnutrition and impaired urea-forming function of the liver.

Healthy poultry have higher glucose levels. For quail, as for other small birds, decrease in blood glucose below 8.25 mmol/L is considered life-threatening. In authors' studies, the blood glucose level in experimental and CGs was at a fairly high level, ranging from 15.49-16.68 mmol/L. The concentration of bilirubin in the blood serum of quails did not exceed the physiological values in poultry of both groups, however, in experimental quails this indicator in the blood was 21.42% lower than in the control ones. Calcium is one of the most important chemical elements necessary to ensure the basic life processes of quails. The concentration of calcium in the blood serum is a fairly constant value. However, its content may vary depending on the level of its intake from feed and the clinical condition of the bird's body. The calcium content in the blood of quails of the experimental and CGs, although it was within the standard values, 2.31 and 2.39 mmol/l, with a minimum reference value of 2 mmol/l.

The most valuable information about the functioning of the organs of the digestive system of birds is provided by the activity of enzymes such as ALT and AST. All enzymes provide metabolic fluxes along with enzymatic activity, and there is a metabolic relationship between nonspecific biochemical changes. The research results showed that when feeding extruded feed to growing quails, there is a significant fourfold increase in AST, while ALT activity remains within normal limits, and amylase activity shows a distinct decreasing tendency. It was also found that in quails of the EG, amylase activity was 50% lower than in the CG. Such changes can be explained by the fact that this age period is associated with intensive growth of the poultry and its puberty. The function of the pancreas reflects the characteristics of the poultry species nutrition. The content of enzymes in the pancreatic juice of the gland reflects its adaptation to the quality of food and its digestibility. The decrease in amylase activity is apparently associated with a decrease in metabolism, as well as with the emergence of new highly digestible feeds.

DISCUSSION

In the course of this study, significant advantages of the EG over the CG in terms of meat productivity were revealed. This trend can be explained by the completeness of the feed composition of EG, which included extruded components and the phytobiotic feed additive BioFeed-P, which contains more than 250 biologically active components. Research results by A.M. Khalifah *et al.* (2021) showed that growth performance was positively affected by the addition of lemongrass essential oil ($P \leqslant 0.01$) at a dose of 0.4 g/kg compared to the CG. In addition, the additive improved meat quality as it significantly improved ($P \leqslant 0.01$) water holding capacity of thigh meat and pH values. Blood characteristics showed a significant decrease ($P \leqslant 0.01$) in lipid profile, AST, ALT, and malondialdehyde under the influence of additives.

In the scientific discourse, the position is spreading that the use of natural feed additives as growth promoters in poultry diets has a positive effect on egg production, meat production, reproduction and health and minimizes the use of antibiotics as growth promoters. In the course of this research, a phytobiotic additive BioFeed-P was developed for animals and poultry, which was used as a plant feed additive. Corn, wheat, and soybean meal are the main components of poultry diets, providing a significant portion of energy and protein. Traditional sources of fiber-rich byproducts include wheat bran, sunflower meal, cottonseed, oat bran, soybean bran, and pea bran (Jha & Mishra, 2021).

M.T. Sisay *et al.* (2018) reported that wheat-based extruded products are relatively low in protein and high in gluten, and have a high glycemic index. Due to the high protein content in legumes, they are considered crops that satisfy the need for plant protein in poultry diets (Nalluri & Karri, 2021). The extruded components used by the authors also improve the safety performance of the feed, reducing the risk of contamination by microorganisms and fungi. According to D.D. Loy and E.L. Lundy (2019), corn starch is almost 100% digestible and its content can be increased during grain processing. M.M. Rahman *et al.* (2024) found that groups of quails receiving specific combinations of olive oil and key lime juice showed improved weight gain and feed conversion ratio. F.M. Reda *et al.* (2024) examined the effects of naringenin, a natural feed additive, on the growth performance, carcass traits, blood biochemistry, immunity, antioxidant responses, and cecal microbiota of Japanese quails. The results showed that naringenin improved quail growth, feed conversion ratio, blood biochemistry, and immune responses, while also reducing harmful microbial populations in the quails' cecum.

K. Wengerska *et al.* (2022) believe that with proper enrichment, soybean meal fully meets the requirements for essential amino acids. According to S.A. Lee *et al.* (2023), TCP is obtained by reaction of phosphoric acid with carbonate, followed by calcination at temperatures above 900°C. TCP, intended for feeding, is used in diets for poultry. TCP is able to provide unique properties of a filler agent to powder mixtures. According to C.H. Kim *et al.* (2023) premixes and minerals such as copper, iron, zinc, magnesium are important nutrients that directly or indirectly contribute to biochemical processes in the body. The authors included 1% premix to the developed feed to enrich the diet with minerals.

Enrichment of the diet of quails with extruded components and the phytobiotic additive BioFeed-P demonstrated a positive effect on the main zootechnical indicators. Thus, the absolute increase in live weight of quails in EG was 313.7 ± 4.34 g, while in CG – 275.9 ± 2.89 g (the difference is not significant, $P > 0.05$). This indicates an increase in the energy of growth and the efficiency of the use of feed by quails when using the developed diet. In addition, the EG bird had a higher slaughter weight and meat yield in the carcass. The analysis of biochemical indicators of blood did not reveal significant differences between the groups, which may indicate the absence of a negative effect of the developed feed on the bird's body. TP, albumin, and globulin levels were within the normal range for both groups, indicating adequate nutritional support and absence of inflammation. Also, no significant differences were found in the activity of liver enzymes, which indicates the absence of a negative effect on the function of the organ.

A positive effect of the experimental diet was also observed on the immune status of quails. The stability of the indicators of protein metabolism and the absence of signs of liver damage can indicate the maintenance of the homeostasis of the body and the preservation of the health of the bird when using the developed feed. As for the study of quail homeostasis, it should be noted that this indicator is significantly influenced by the egg production of birds, as well as the quality and hatchability of eggs. This indicates the additional advantages of using extruded components and phytobiotic additives in feeding meat quails and the need to involve them in the development of optimal schemes for increasing productivity and product quality. The results obtained by the authors regarding the use of extruded components in diets in combination with a phytobiotic feed additive are consistent with the above data of foreign authors, and the authors consider their use in the production of compound feed for quail to be promising.

CONCLUSIONS

As a result of the conducted research, the specifics of the use of extruded components in quail diets were analysed in order to increase meat productivity. The basis of the study was the problem of antibiotic resistance, in particular, effective ways of replacing antimicrobial agents with safe natural herbal alternatives were considered. It has been established that they can be phytobiotics that have similar properties, without having a negative effect on the bird's body, and, on the contrary, stimulating metabolic processes. The results obtained during the research confirm the high efficiency of the use of extruded components and the phytobiotic additive BioFeed-P in quail diets for the meat sector. Poultry feeding according to the specially developed "Start", "Growth" and "Finish" recipes ensured an increase in live weight indicators, better slaughter characteristics and quality indicators of meat compared to the CG.

It was established that the introduction of extruded components and phytobiotics into the compound feed contributed to a significant increase in the absolute and average daily weight gain of the quails of the EG. In addition, the poultry of the EG had a higher slaughter weight by 26%, a higher yield of semi-eviscerated and gutted carcasses by 30.6-37.7%, a greater mass of skin, subcutaneous fat, pectoral and tender muscles compared to the CG. The analysis of biochemical blood parameters conducted during the study did not reveal significant deviations from the norm, which indicated the absence of a negative effect of the developed compound feed on the physiological state of the bird. At the same time, a decrease in amylase activity was observed, which is probably associated with a decrease in the intensity of metabolism against the background of the use of easily digestible feed components. In general, the results obtained in this study prove the expediency of using extruded components and phytobiotic additives in feeding quails of the meat production sector to increase their productivity, preserve health and improve the quality of meat products. The obtained data can be used in the development of complete balanced diets for industrial quail breeding. Further research is required to better understand the mechanisms underlying these changes and determine homeostasis for quail. Additional studies could also explore the impact of the experimental diet on egg production, quality and hatchability.

ACKNOWLEDGEMENTS

Financial support for this project was provided by the Ministry of Science and Higher Education of the Republic of Kazakhstan (project number – AP13068280 "Development of enriched feed using highly nutritious, easily digestible and natural plant components to obtain high-quality and safe quail products").

CONFLICT OF INTEREST

None.

REFERENCES

[1] Abd Elzaher, H.A., Ibrahim, Z.A., Ahmed, S.A., Salah, A.S., Osman, A., Swelum, A.A., Suliman, G.M., Tellez-Isaias, G., Alagawany, M., & Abd El-Hack, M.E. (2023). Growth, carcass criteria, and blood biochemical parameters of growing quails fed Arthrospira platensis as a feed additive. *Poultry Science*, 102(12), article number 103205. doi: 10.1016/j.psj.2023.103205.

[2] Alagawany, M., El-Hindawy, M.M., Mohamed, L.A., Bilal, R.M., & Soomro, J. (2022). The use of cold pressed oils as eco-friendly alternatives for antibiotics in high and low-CP diets of laying Japanese quail. *Animal Biotechnology*, 33(5), 816-823. doi: 10.1080/10495398.2020.1837846.

[3] Animal Research Tomorrow. (2010). *Basel Declaration*. Retrieved from https://animalresearchtomorrow.org/en/basel-declaration.

[4] Ansaripoor, A., Sedghi, M., Sadeghi-Sefidmazgi, A., & Pilevar, M. (2020). Optimization of growth performance responses of Japanese quail with different concentrations of metabolizable energy, lysine, and sulfur amino acids using Taguchi method. *Livestock Science*, 241, article number 104234. doi: 10.1016/j.livsci.2020.104234.

[5] Ashour, E.A., Kamal, M., Altaie, H.A., Swelum, A.A., Gamaleldin, M.S., Tellez-Isaias, G., & El-Hack, M.E. (2024). Effect of different energy, protein levels and their interaction on productive performance, egg quality, digestibility coefficient of laying Japanese quails. *Poultry Science*, 103(1), article number 103170. doi: 10.1016/j.psj.2023.103170.

[6] Jha, R., & Mishra, P. (2021). Dietary fiber in poultry nutrition and their effects on nutrient utilization, performance, gut health, and on the environment: A review. *Journal of Animal Science and Biotechnology*, 12(1), article number 51. doi: 10.1186/s40104-021-00576-0.
[7] Kanbur, G., Göçmen, R., & Cufadar, Y. (2023). Effect of dietary banana leaves (*Musa acuminata*) with multienzyme complex supplementation on intestinal content, serum biochemicals, egg production, and egg quality in laying quail. *Livestock Science*, 277, article number 105249. doi: 10.1016/j.livsci.2023.105249.
[8] Khalifah, A.M., Abdalla, S.A., Dosoky, W.M., Shehata, M.G., & Khalifah, M.M. (2021). Utilization of lemongrass essential oil supplementation on growth performance, meat quality, blood traits and caecum microflora of growing quails. *Annals of Agricultural Sciences*, 66(2), 169-175. doi: 10.1016/j.aoas.2021.12.001.
[9] Kim, C.H., Yang, K., Lim, S.J., Jeon, J.H., Kim, K.H., Chun, J.L., & Lee, M.Y. (2023). The effect of inorganic and organic mineral premix in broiler diets on growth performance, and fecal mineral excretion. *Journal of the Korea Academia – Industrial Cooperation Society*, 24(8), 484-493. doi: 10.5762/KAIS.2023.24.8.484.
[10] Lee, S.A., Lopez, D.A., & Stein, H.H. (2023). Mineral composition and phosphorus digestibility in feed phosphates fed to pigs and poultry. *Animal Bioscience*, 36(2), 167-174. doi: 10.5713/ab.22.0322.
[11] Loy, D.D., & Lundy, E.L. (2019). Chapter 23 – Nutritional properties and feeding value of corn and its coproducts. In S.O. Serna-Saldivar (Ed.), *Corn (Third Edition)* (pp. 633-659). London: AACC International Press. doi: 10.1016/B978-0-12-811971-6.00023-1.
[12] Mamoulakis, C., Georgiadis, G., & Fragkiadoulaki, E. (2024). Urea. *Encyclopedia of Toxicology (Fourth Edition)*, 9, 685-692. doi: 10.1016/B978-0-12-824315-2.00759-4.
[13] Nalluri, N., & Karri, V.R. (2021). Grain legumes and their by-products: As a nutrient rich feed supplement in the sustainable intensification of commercial poultry industry. In P. Guleria, V. Kumar & E. Lichtfouse (Eds.), *Sustainable Agriculture Reviews 51* (pp. 51-96). Cham: Springer. doi: 10.1007/978-3-030-68828-8_3.
[14] National Research Council. (1994). *Nutrient requirements of poultry*. Washington: The National Academies Press.
[15] Rahman, M.M., Sukor, S.A., Umami, N., & Sukri, S.A.M. (2024). Effects of olive oil-treated diet and key lime juice-treated drinking water on intake and growth performance of quail. *Veterinary Integrative Sciences*, 23(1), article number e2025022. doi: 10.12982/VIS.2025.022.
[16] Reda, F.M., Alagawany, M., Mahmoud, H.K., Aldawood, N., Alkahtani, A.M., Alhasaniah, A.H., Mahmoud, M.A., El-Saadony, M.T., & El-Kassas, S. (2024). Application of naringenin as a natural feed additive for improving quail performance and health. *Journal of Applied Poultry Research*, 33(3), article number 100446. doi: 10.1016/j.japr.2024.100446.
[17] Sisay, M.T., Emire, S.A., Ramaswamy, H.S., & Workneh, T.S. (2018). Effect of feed components on quality parameters of wheat-tef-sesame-tomato based extruded products. *Journal of Food Science and Technology*, 55(7), 2649-2660. doi: 10.1007/s13197-018-3187-x.
[18] Stanquevis, C.E., de Paula, V.R., Zancanela, V.T., Benites, M.I., Finco, E.M., de Aquino, D.R., Rodrigues, T.P., & Marcato, S.M. (2022). Levels of vitamin A supplementation for growing meat-type quails. *Emerging Animal Species*, 4, article number 100008. doi: 10.1016/j.eas.2022.100008.
[19] Sultanayeva, L., Karkehabadi, S., Zamaratskaia, G., & Balji, Y. (2023). Tannins and flavonoids as feed additives in the diet of ruminants to improve performance and quality of the derived products. A review. *Bulgarian Journal of Agricultural Science*, 29(3), 522-530.
[20] Wengerska, K., Czech, A., Knaga, S., Drabik, K., Próchniak, T., Bagrowski, R., Gryta, A., & Batkowska, J. (2022). The quality of eggs derived from Japanese quail fed with the fermented and non-fermented rapeseed meal. *Foods*, 11(16), article number 2492. doi: 10.3390/foods11162492.

Вплив комбікорму з екструдованими компонентами та фітобіотиками на організм перепелів

Юрій Бальджи
Кандидат ветеринарних наук, в.о. професора
Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Женіса, 62, м. Астана, Республіка Казахстан
https://orcid.org/0000-0002-5006-3224

Дінара Жанабаєва
Доктор ветеринарних наук, в.о. доцента
Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Женіса, 62, м. Астана, Республіка Казахстан
https://orcid.org/0000-0001-7499-347X

Лейла Султанаєва
Магістр ветеринарних наук, дослідник
Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Женіса, 62, м. Астана, Республіка Казахстан
https://orcid.org/0000-0003-2774-9575

Гульжан Єсжанова
Кандидат ветеринарних наук, доцент
Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Женіса, 62, м. Астана, Республіка Казахстан
https://orcid.org/0000-0001-8411-466X

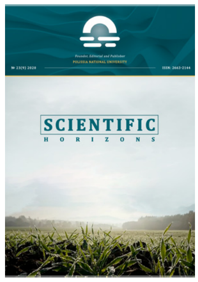
Данара Мусагієва
Магістр ветеринарних наук, дослідник
Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Женіса, 62, м. Астана, Республіка Казахстан
https://orcid.org/0000-0001-5605-9552

Анотація. Перепели є цінним видом домашньої птиці, оскільки їхні яйця та м'ясо мають високу поживну цінність. Крім того, перепели відрізняються ранньою статевою зрілістю, високою несучістю і невеликими розмірами тіла. Ці унікальні характеристики роблять їх привабливим об'єктом для селекції та наукових досліджень. Метою роботи було дослідити вплив комбікорму з екструдованими компонентами та фітобіотиками на м'ясну продуктивність і біохімічні показники крові техаських перепелів. Методологія дослідження передбачала розподіл 200 перепелів на дослідну та контрольну групи, згодовування їм різних раціонів протягом 60 днів та аналіз показників росту, м'ясної продуктивності та біохімічних показників крові за допомогою інструментів статистичного аналізу. У результаті досліджень було виявлено, що комбікорм, виготовлений за розробленою рецептурою, позитивно впливає на приріст маси тіла перепелів. У дослідній групі (ЕГ) абсолютний приріст склав 313,7 ± 4,34 г, у контрольній групі (КГ) – 275,9 ± 2,89 г (різниця не вірогідна, $P > 0,05$). Крім того, комбікорм з екструдованими компонентами та фітобіотиками призвів до покращення коефіцієнту конверсії корму в ЕГ порівняно з контролем. Птахи в ЕГ також продемонстрували вищу масу тушки та виходи. Експериментальний раціон також позитивно вплинув на імунний статус перепелів. Отримані результати демонструють потенційні переваги включення екструдованих компонентів та фітобіотиків у корм перепелів для покращення показників росту та підтримання здорових фізіологічних параметрів. Оцінюючи результати біохімічного аналізу крові, можна зазначити, що суттєвих змін у складі крові не виявлено, що може свідчити про відсутність негативного впливу розробленого комбікорму на організм птиці. Отримані результати можуть мати практичне значення для розробки оптимальних раціонів для м'ясних перепелів та підвищення якості і безпечності їх продукції

Ключові слова: екструзія; біохімія крові; гомеостаз; дієта; білок

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 42-53



UDC 639.371.1
Doi: 10.48077/scihor9.2024.42

Technology for the production of extruded starter feed for juvenile fish

Maya Bektursunova*
Doctoral Student, Senior Researcher
Kazakh Research Institute of Processing and Food Industry
050060, 238 G Gagarin Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-5105-4864
Valentina Sidorova
Leading Researcher
Kazakh Research Institute of Processing and Food Industry
050060, 238 G Gagarin Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0001-6244-0691
Saule Zhiyenbayeva
Doctor of Technical Sciences, Associate Professor
Almaty Technological University
050012, 100 Tole bi Str., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-2003-8909
Alyona Mukhramova
Chief Scientific Secretary
Fisheries Research and Production Center
050016, 89 A Suyunbai Ave., Almaty, Republic of Kazakhstan
Doctoral Student
Kazakh National Agrarian Research University
050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-4701-6195
Saule Assylbekova
Doctor of Biological Sciences, Deputy Director
Fisheries Research and Production Center
050016, 89 A Suyunbai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-6648-4744

Article's History:
Received: 18.03.2024
Revised: 03.08.2024
Accepted: 28.08.2024

Abstract. The latest advances in science, combined with the growing possibilities of modern technology, contributed to the improvement of fish feeding technology and fish farming in general. It is obvious that the expansion of the species composition of cultivated fish farming objects will continue, and the importance of feed and fish feeding technology will steadily increase. The developed recipes of starter feeds for

Suggested Citation:
Bektursunova, M., Sidorova, V., Zhiyenbayeva, S., Mukhramova, A., & Assylbekova, S. (2024). Technology for the production of extruded starter feed for juvenile fish. *Scientific Horizons*, 27(9), 42-53 doi: 10.48077/scihor9.2024.42.

**Corresponding author*

juvenile fish and the technology of their production would make it possible to establish the production of these feeds for fish farms in Kazakhstan, as a result, the survival rate and growth rate of juvenile fish grown in industrial conditions would increase. The aim of the work was to develop recipes for starter feeds for pikeperch fry and technology for their production by extrusion, the development of these feeds to improve the efficiency of growing pikeperch in industrial conditions. According to the developed recipe, a starter feed for zander juveniles, balanced in terms of basic nutrients, was developed, a study was made of the effect of this feed on the efficiency and speed of growing zander juveniles. The dynamics of rearing juvenile pikeperch was studied when feeding the starter feed developed by the Kazakh Research Institute of Processing and Food Industry, with a feed coefficient of 1.28 and as a control foreign starter feed for trout "Aller Aqua" – 1.2. The materials of the article are of practical importance and the need for further research, they will help replenish the formulas of compound feed for the industrial cultivation of juvenile pike perch in fish farms of the Republic of Kazakhstan

Keywords: pike perch; fish fry; extrusion; starter diet; feed ratio

INTRODUCTION

Pike perch *Sander lucioperca* is a promising object of aquaculture – it is a valuable fast-growing fish that matures well and spawns well in cage conditions, lives well in cages, corresponds to the temperature optimum of nutrition and the temperature regime of reservoirs in Kazakhstan. According to V. Zyabrev *et al.* (2019), farmed pike perch remains one of the most difficult species to breed, given that aquaculture techniques are not fully developed. The difficulty in working with this species lies in raising the larvae and providing them with sufficient food. The need to grow pike perch is determined by a number of reasons: due to high nutritional qualities – an increase in demand, an increase in productivity, use in inland waters and the restoration of industrial fish stocks. The main problem in the development of aquaculture is the organization of a food base for fish of different breeds and at all stages of cultivation: starter feed for fry, production feed for fingerlings and breeding stock, mixed feed for adults and breeding stock.

Á. Hernández-Contreras *et al.* (2023) investigated how varying temperatures and fish sizes affect juvenile wolffish growth rates and feeding efficiency. They discovered that juvenile spotted wolffish had the highest growth rates at moderate temperatures, with growth efficiency decreasing at both higher and lower temperatures. The feed conversion ratio (FCR), an important metric of feed efficiency, was shown to improve as fish size rose, particularly at lower temperatures. This meant that as the fish mature, they will be able to better use feed in colder settings. Furthermore, the study found that temperature had a greater impact on growth performance than fish size alone, emphasising the necessity of maintaining ideal environmental conditions in aquaculture to maximise development efficiency. As noted by M.J. Bektursunova *et al.* (2021), in the Kazakh market of mixed feed raw materials there was a number of advanced technologies for the rational use of feed resources, which were mainly characterized by the feed extrusion method, consisting in a balanced diet of at least 20 different ingredients, combined depending on the chemical composition, type and method production, as well as the physiological needs of fish.

According to Aquatic Sciences and Fisheries Abstracts, the total volume of fishery and aquaculture production reached 214 million tons, including 178 million tons of aquatic animals and 36 million tons of algae. At the same time, according to forecasts, until 2030, the volumes of production, consumption and marketing of aquaculture products will grow at a low pace. Annual fish consumption should be at least 15 kg per capita, but today the figure does not exceed 5 kg per year, in contrast to developed countries where Japan consumes 70 kg of fish per capita per year, Spain – 43 kg, Norway – 53 kg. Given the statements of J. Wan *et al.* (2022), the production of fish feed is currently the most expensive in comparison with prescription feed for other types of farm animals. This is due to the fact that the fish has a short digestive system and needs easily digestible food. For optimal consumption, feed should be as free of various contaminants as possible. The shape and size of the food should match the preferences of the fish. Depending on the size of the fish and the density of the food that can sink or float on the surface of the water, pellets of different diameters should be made.

According to Z. Koshak (2022), at present, the variety of fish feed offered by domestic producers is limited, and this leads to a decrease in the development of industrial aquaculture in Kazakhstan, as enterprises use outdated dry pressing technology. Modern realities in the feed production system require theoretical understanding and identification of technological conditions, they can ensure the sustainable use of granulation and extrusion technologies, which are widely used in the production of feed for the world's aquaculture.

The development of starter rations was of particular importance, as it will increase the efficiency of growing pike perch fry, given the critical period of exotrophy of larvae to an acceptable stage, and expand the possibilities for breeding these fish species in Kazakhstani aquaculture. Extrusion will allow feed manufacturers to select suitable processing temperatures that affect the density of feed raw materials, structural changes, nutritional and physiological properties of feed, improve digestibility and nutritional value of feed ingredients. The purpose of this study was to develop and evaluate a specialised starter feed for juvenile pike perch (Sander lucioperca), and to compare its effectiveness to that of a commercial trout feed manufactured by Aller Aqua. It was to see if the newly created feed could adequately meet the nutritional needs and development of pike perch fry, a species noted for its aquaculture problems. The study looked at the feed's physical and chemical properties, tested fish growth and survival rates, and estimated the FCR.

LITERATURE REVIEW

The general pattern of obtaining functional fish feeds is poorly understood, and modern technology for the processing of feeds for valuable fish species is based on the use of extrusion processes of multicomponent mixtures to obtain various buoyancy values and control the sinking rate. Extruded products are resistant to water and retain their shape, and in combination with vacuum liquid emulsification and deeper hydrothermal processing of ingredients, it is possible to create compound feeds with programmable characteristics, maximally adapted to various breeds of valuable fish. According to X. Zhao *et al*. (2021), the formation of fish is accompanied by the development of its digestive system; therefore, starter diets should contain easily digestible carbohydrate and high-protein ingredients, the presence of which is possible by converting the nutrients of feed raw materials using static extrusion conditions: dynamic effects of temperature, osmotic pressure, and water exchange. A. Martin *et al*. (2019), in his work evaluated the high density, dry matter content, long shelf life of extruded feed raw materials. The main difference between pellets and extruded foods is that the pellets sink while the extrudates have controlled buoyancy in the water. The settling rate of pellets for fish such as pike perch, sturgeon, catfish, tilapia should be as low as possible to allow enough time for product consumption, so producing feed with a density adapted to the way the fish eat is a prerequisite for efficient fish farming.

The extrusion parameters of starter feed raw materials are set within the temperature range of 110-138°C and steam pressure of 4-6 MPa. At temperatures above 140°C, sugar caramelization occurs and the extruded granules become too strong, and their swelling is 30-40 minutes. The extrusion conditions promote gelatinisation of the starch upon deformation of the outer layer of the granules formed by amylopectin. M.O. Oke *et al*. (2012) stated that after extrusion, the rate of starch hydrolysis increased the activity of α-amylase by 6 times, and in corn – by 8 times, in glucose – by 15 times, before that the enzyme acted only on the amylase of starch granules. N.P. Mishurov *et al*. (2019), reported that extrusion increases the dextrin content in grain ingredients by 2-4 times, due to the solubility of non-starch polysaccharides or crude fibre. As far as feed ingredients are concerned, water is activated by binders and forms a film on the feed components: starch, protein, fibre and fat, affecting the hardness, durability and expansion of the granules. Vegetable oils and fats are rapidly oxidised, reducing the shelf life of compound feed, so they are introduced into the composition by spraying at a temperature of 50°C, its amount should be up to 35-40% to achieve 100% starch degradation.

Z. Koshak (2022) stated that proteins are one of the most important nutrients that affect growth and all physiological systems of the body, which play an important role in the energy metabolism of fish, since nitrogen consumption by fish is 3-5 times higher than that of warm-blooded animals. The high protein level contributes to a low feed ratio and rapid fry growth. Extrusion changes the protein portion of the feed and protein solubility may vary depending on the type of product due to denaturation. Due to the research of E. Skarbøvik *et al*. (2014), it was noted that during extrusion at a temperature of 110°C and a pressure of 6 MPa, proteins are denatured and most of the anti-nutritional components are destroyed. The unfolding of the polypeptide chain facilitates the contact of digestive enzymes with the active site of the protein molecule, thereby facilitating hydrolysis, but the reverse process can also occur in parallel. At high temperature and pressure, additional bonds are formed between the polypeptide chains with the formation of protein complexes of glycoconjugates.

In blends, the overall increase in protein content of the starch recovered from the extrudates is accompanied by a significant decrease in starch solubility. When studying the properties of extrudates from starch-containing and protein-containing raw materials, it was found that with an increase in the protein content in the formulation up to 50%, feeds with the lowest moisture-absorbing capacity are obtained. J. Wan *et al*. (2022) found that an optimal diet would require additional amino acids and lipids to reduce starch conversion during extrusion and prevent mechanical degradation of the granules and prevent water uptake. The practice of L. Horváth *et al*. (2008) has shown that extrusion almost completely disinfects feed from fungal and bacterial microflora. For example, extruding soy and peas reduces the total bacteria count by 67-100% and completely inactivates E. coli. Extrusion is an effective means of suppressing the activity of protease inhibitors, trypsin amylases. After extrusion, nutrients are more easily absorbed, especially in predatory fish species. A.K. Imsland *et al*. (2006) noted that fish feeding includes more than a hundred different feeds and feed additives made from food industry waste, including products of microbial synthesis, various salts, vitamins, enzymes and amino acids, polyunsaturated fatty acids, antibiotics, adsorbents, antioxidants and flavours.

MATERIALS AND METHODS

The starter feed for pike perch juveniles was produced strictly according to the recipe developed under the production conditions of the Kazakh Research Institute of Processing and Food Industry, on a professional extruder OEE 25 NG. The new generation of extruders is based on the Amandus Kahl, crushed feed raw materials with a moisture content of 12-16% were fed into the system, the mass was heated to 120-150°C at a high pressure of 2.8-3.8 MPa. Then the process quickly passed from the area of high pressure to the area of ambient pressure, the homogeneous mass expanded, resulting in the formation of a product of a porous structure.

The proportions of the ingredients created a complete biological complex that ideally meets the physiological requirements of juvenile fish, allowing to balance the diet in terms of nutritional value, digestible protein, limiting amino acids, vitamins and minerals. Starter feed for pike perch fry mixed well, had a coarse-grained texture from dark brown to light brown. The technology for the production of microgranules with a size of 0.1-0.5 mm was not available, it was used only at some feed mills with world brands. Therefore, the starter feed was made with a granule size of 2 mm, which was subsequently crushed and sieved into grain fractions of 0.2-0.5 mm, which are dense multifaceted particles of crushed granules without impurities, with the original color and smell preserved. The technical parameters of the compound feed were determined in accordance with the current ISO 12875:2011 (2011).

The preparation of the test samples of the starter feed for juvenile fish was carried out in accordance with ISO 6498:2012 (2012), while the weight of the experimental feed sample for physical and chemical studies was taken at least 600 g. During the research, the experiments were carried out in triplicate, after which the average was calculated. Friability of feed pellets of starter feed for fish was determined in accordance with ISO 12099:2017 (2017). The water resistance and swelling capacity of starter compound feed granules was determined according to ISO 6495-1:2015 (2015). Chemical study of starter feed for fish was carried out according to ISO 6496:1999 (1999) for moisture content, ISO 5983-2:2009 (2009) – crude protein, ISO 6865:2000 (2000) – crude fiber, ISO 6492:1999 (1999) – crude fat, ISO 5984:2002 (2002) – raw ash, the content of nitrogen-free extractive (NFE) and nutritional value was determined by the calculation method.

A scientific experiment on the productivity of the starter feed was carried out in cage-grown production cooperative (PC) "Zhambyl" for 30 days. During the experiment, the hydrochemical regime in cages was optimal. Feeding was done by hand six times a day. The fry was stocked in cages at a density of 10,000 larvae per cubic meter. The feeding regime consisted of manual feeding six times a day, with control fishing conducted every 10 days to monitor progress. The experiment involved the control group, and the experimental group. The control group was fed the commercially available Aller Aqua starting feed, which is primarily intended for trout but was employed in comparative research due to its nutritional profile. The choice to utilise this feed in the control group enabled researchers to establish a baseline for growth, survival, and feed efficiency. The experimental group was fed a starter meal prepared by the Kazakh Research Institute of Processing and Food Industry particularly for pike perch juveniles. The goal was to compare the performance of the newly formulated feed with the widely used trout feed. The Aller Aqua feed was compared to a pike perch-specific feed to guarantee that the new feed meets or surpasses industry requirements, indicating possible improvements. Based on the results obtained, the growth rate of zander fry was determined and the daily feeding rate was calculated. Upon completion of the experimental work, the theoretical and practical conclusions were refined, the results obtained were summarised and systematised. All procedures performed using animals were revised and approved by the Scientific Committee of Ethics of the Kazakh Research Institute of Processing and Food Industry, Almaty. AuthoriSation No. 68-15.

The feeding efficiency of pike perch fry was evaluated according to the feeding coefficient, growth rate, survival rate, and physiological state. The experiment assessed feeding efficiency by measuring the FCR, which compared the amount of feed given to fry to the total weight gained by the fish. A lower ratio suggested improved feed conversion into body mass, as measured by experimental analysis of feed inputs and fish weight outputs. The study measured pike perch fry's weight at the beginning and the end of a 30-day experiment, utilising absolute growth rate and specific growth rate as direct and percentage increases, gathered at regular intervals. The survival rate of fry was assessed by counting them at the beginning and end of the experiment, yielding a percentage-based survival rate that reflects their adaptation to the feed and conditions, allowing for a quantitative analysis of mortality or survival trends. The study assessed the fry's physiological health using both qualitative and quantitative methodologies. Researchers employed the condition factor to assess general body health, visual inspections to detect symptoms of sickness, deformities, or stress, and behavioural observations to identify anomalies in swimming or feeding behaviour, offering a full picture of the fry's well-being. The hydrochemical parameters in the cages were monitored throughout the experiment to provide a favourable environment for pike perch development. Water factors such as dissolved oxygen (5.8-8.3 mg/l), pH (6-8), and temperature were maintained at ideal levels for juvenile fish growth. Regular checks guaranteed that the water quality remained appropriate for the fry's development and survival.

All experiments were performed in triplicate, and the average results were calculated for each parameter. Statistical analysis was used to compare the performance of the control and experimental groups in terms of FCR, growth rates, and survival rates. The significance of differences between the groups was assessed, and conclusions were drawn based on the results.

RESULTS

Starter feed for pikeperch juveniles is not industrially produced, so it is necessary to study the parameters of the manufacturing processes of the extruded product, the porous structure and expanded volume, moisture content, granulometric and chemical composition (crude protein, crude fat, carbohydrates). According to the organoleptic and physico-mechanical properties of the starter feed, a dark brown color and a fishy smell were established. The features of the use of the studied feed are that, when feeding, the granules are introduced into the water, where they float on the surface, sink at a certain speed, or remain intact for a given period of time. For aquafeeds, "water properties" are of paramount importance: bulk density, 880.3 kg/m^3; water resistance (swelling), 165 min; crumbling – 1.1%, moisture absorption coefficients – 0.002 g/min, granule size – 0.1-0.2 mm.

The assessment of the chemical composition of water is important for rearing juvenile pike perch, and the natural state of pond water, which is determined by physical and chemical properties, determines whether it is suitable for fish farming. Water has a high solubility and contains minerals, organic substances, gases, therefore it is extremely important for the development of phytoplankton and zooplankton. Minerals dissolved in water are used by bacteria, lower and higher aquatic plants, which are used as food for fish. The content of dissolved oxygen in water varies from 5.8 mg/l to 8.3 mg/l, and the saturation of water with oxygen from 58.7% to 88.7%. An important aspect of fish breeding is the active reaction of the water. It can be acidic (pH less than 6), slightly acidic (pH 6-7), neutral (pH 7) or slightly alkaline (pH 6-8). In order for gas exchange between blood and water to be efficient, the pH of the blood must be adjusted to the pH of the water. The biomass of zooplankton is represented by three groups of organisms: Rotatoria, Copepoda, and Cladocera; also, planktonic forms of chironomid larvae and other insects were found in small quantities in the samples. Fish food is produced in the form of grains and granules, differing in diameter, and as the fish move from one age group to another, the size increases accordingly, as noted in Table 1.

***Table 1**. Diameter of starter feed for fish depending on weight*

Diameter, mm	Weight of fish, g	Feeding period, days
Up to 0.2 – nibs	Up to 0.1	1-10
0.2-0.4 – nibs	0.1-0.3	10-20
0.4-0.6 – nibs	0.3-1	20-45
0.6-1 – nibs	1-2	45-60

***Source:** compiled by the authors based on M. Bektursunova et al. (2022)*

Pike perch is a predatory fish by its nature. therefore, feed of animal origin prevails in the diet: fish 50-60%, meat and bone and meat 10-20% meal. Vegetable feed proteins: soybean meal – 20%, soy isolate – 15%, are similar in terms of crude protein content, however, the growth rate of zander fry is much lower. Table 2 shows the physico-chemical parameters of feed according to the current ISO 12875:2011 (2011) and its comparison with the chemical quality indicators of the experimental starter feed for fish juveniles after extrusion. The extrusion parameters required to obtain the specific physical qualities of pike perch feed must be based on an accurate chemical analysis of each ingredient.

***Table 2**. Physical and chemical parameters of the starter feed for juvenile pike perch*

Components	Starter feed for pike perch	According to ISO 12875:2011
Moisture, %	8.55	no more 10
Crude protein, %	53.66	at least 52
Crude lipid, %	12.02	at least 11
Crude fiber, %	0.74	no more 1.5
Raw ash, %	10.17	no more 11
Linoleic acid, %	2.13	-
NFE, %	13.39	-
Lysine, %	4.03	at least 3
Methionine, %	1.18	at least 1.6

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

Table 2. Continued

Components	Starter feed for pike perch	According to ISO 12875:2011
Methionine + cystine, %	1.75	-
Tryptophan, %	0.68	-
Carbohydrate, %	0.41	-
Starch, %	4.57	-
Phosphorus, %	1.68	at least 0.6
Calcium, %	2.51	-
Gross energy, MJ/kg	20.78	-
Exchange energy MJ/kg	17.45	at least 17

Source: *compiled by the authors*

Evaluating the data, it was found that it was possible to obtain food with a sufficiently high energy, nutritional and biological value, which can be suitable for the industrial production of feed oriented towards feeding larvae and juvenile pike perch. The carbohydrates that make up the diet are the cheapest source of food and energy, quantitatively the largest component of the diet is 40-55%, including them in the diet can save on expensive food proteins and get more energy. The main sources of carbohydrates in the diet of fish are grains (wheat, oats, corn, etc.) and legumes (soybeans, chickpeas, peas), but their digestibility and the ability of the digestive system to break them down should be taken into account. The experimental extruded diet for pikeperch fry in terms of nutrient content included 53.7% crude protein, 12% crude lipid, 0.7% crude fiber, 10.2% crude ash, 13.4% NFE, 4% lysine, 1.2% methionine, 1.8% methionine and cystine. According to the established physiological needs of fish and the technology for the production of feed by extrusion, the appropriate norms for introducing components into starter and production compound feeds for pikeperch juveniles are used, shown in detail in Table 3.

Table 3*. Norms for adding components to starter and production feeds for fish, %*

Components	Starter feed for pike perch
Wheat	0-15
Wheat bran	0-5
Soybean meal	0-20
Sunflower meal	0-10
Gluten corn	0-15
Meat and bone meal	0-15
Meat meal	0-10
Blood meal	0-15
Fish meal	0-60
Feed yeast	0-20
Casein	0-15
Bentonite	0-1
Soy isolate	0-15
Wheat gluten	0-4
Soybean oil	0-10
Sunflower oil	0-3
Linseed oil	0-4
Fish oil	0-8

Source: *compiled by the authors based on E. Puzevich (2021)*

Feed protein can fully perform its function if all components are present in the required amount. Due to the growing shortage of fishmeal, in recent years, feeds containing raw materials of plant origin have become widespread. To develop the formulation of the starter compound feed, a chemical analysis of feed raw materials was carried out, which included: fish meal, blood meal, meat and bone meal; gluten and corn germ; fodder yeast; meal, isolate and soybean oil; corn, wheat germ, bran and gluten; fish oil; as a mineral additive – bentonite. Table 4 shows the ingredients that were used in the calculation of the diet, their quality indicators and the value of satisfying the physiological requirements of juvenile pike perch, since the composition of the extruded mixture is an important condition for obtaining high-quality feed.

***Table 4**. Chemical composition of the ingredients of the starter feed ration for pike perc*

Diet Ingredients	Indicators											
	crude protein	crude lipid	crude fiber	raw ash	NFE	starch	total carbohydrate	lysine	methionine	methionine + cystine	phosphorus	calcium
Fish meal	56.2	8.9	-	17.9	6.4	-	-	4.5	1.6	2.2	3.1	4.8
Blood meal	75.2	1.1	-	5.6	9.3	-	-	6.4	0.9	1.8	0.4	0.4
Meat and bone meal	48	20.3	-	23	11.3	-	-	1.7	0.5	0.8	4.8	9
Corn gluten	51.1	5.0	5	2	17.2	13.8	1.4	1.3	1.5	2.6	0.5	0.4
Corn germ	18.2	46	3.3	5.8	24.9	10.1	-	0.6	0.3	0.4	0.3	0.2
Feed yeast	41.5	1.2	1.6	4.7	46	-	1.5	2.6	0.4	0.8	1.4	0.8
Soybean meal	41.9	1.2	7.7	7.4	32.9	1.8	4.8	2.5	0.5	1.1	0.7	0.4
Soy isolate	86.6	4	-	5	-	-	-	6.9	1.9	2.8	0.3	0.4
Wheat	11.6	1.62	2.73	1.8	72.8	54.9	2.4	0.3	0.2	0.3	0.3	0.1
Wheat germ	28.4	11	3	5.8	37	-	-	1.4	0.7	0.8	0.4	0.3
Wheat gluten	75	1.2	0.8	-	14.2	-	-	6.2	0.9	1.9	0.3	0.4
Wheat bran	14.4	4.1	9.6	4.7	54.6	-	4.7	0.5	0.16	0.33	1	0.22
Fish oil	-	98.1	-	-	-	-	-	-	-	-	-	-
Soybean oil	-	99.9	-	-	-	-	-	-	-	-	-	-
Bentonite	-	-	-	-	-	-	-	-	-	-	2.3	-

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

Before the extrusion process, the feed ingredients were separately crushed in a crusher and screened through a set of sieves according to TU 25.06.1250-77. In the production of waterproof floating feed pellets, the optimal temperature range is 100-110°C and humidity 30% and steam pressure 4-6 MPa. The starter compound feed developed and produced for juvenile pike perch Kazakh Research Institute of Processing and Food Industry from ingredients of local origin differed from that produced by the popular Aller Aqua brand in terms of physicochemical, nutritional and energy properties. Kazakh Research Institute of Processing and Food Industry starting compound feed in terms of crude protein content was 53.7%, crude lipid – 12.0%, NFE – 13.4%, with an energy value of 496.8 kcal, and digestible energy of 417.3 kcal.

The starter feed intended for trout fry "Aller Aqua" had a content of crude protein 64%, crude lipid – 18%, NFE – 6%, with an energy value of 472.3 kcal, digestible energy of 396.7 kcal. It has been established that the starter compound feed developed by Kazakh Research Institute of Processing and Food Industry is physiologically ideal for pike perch, however, when formulating compound feeds, it is not recommended to exceed the level of crude lipid content tested for this age category, as well as to comply with the energy value of the feed. The productivity of feeding the starter compound feed on the fish-breeding and biological parameters of juvenile zander was studied using two groups of control and experimental. Foreign starter trout feed "Aller Aqua" was fed to the control group of juvenile pike perch, the second experimental group was the studied feed developed by Kazakh Research Institute of Processing and Food Industry. The study of the productivity of juvenile zander was carried out in the cages of the PC "Zhambyl", when feeding starter compound feeds. When feeding starter artificial feeds, the results presented in Table 5 were obtained.

***Table 5**. Productivity of juvenile pike perch*

Indicators	Groups	
	1-control	2-experienced
Growing period, days	30	30
Planting density, thousand pieces/m^3	10	10
Initial weight, mg	1 ± 0.1	1 ± 0.1
Final weight, mg	93 ± 5.8	88 ± 6.2
Absolute gain, mg	92	87
Average daily gain, mg	3.06	2.9
Survival of juveniles, %	55	52
Feed ratio, units	1.2	1.28

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

According to the results of the experiment, both starter feeds had a positive productive effect on pikeperch fry, due to the same values of feed units, which differed by 0.06 units, high normative indicators of absolute and average daily gain were observed, differing by insignificant ones by 5 mg and 0.16 mg, respectively. Also, during the experiment, the following pattern was established: the survival rate of pike perch was maximum – 55% and 52%. The results of rearing pikeperch larvae in cages showed the possibility of effective use of the domestic artificial feed Kazakh Research Institute of Processing and Food Industry for pikeperch fry, therefore it is recommended for use in the conditions of fish farms in Kazakhstan.

DISCUSSION

In Kazakhstan, scientific research was being carried out related to feeding issues in three areas: the development of rations for the production of starter feed, the cultivation of live food organisms (microorganisms, algae, invertebrates) or by adding high-protein meat or fish meal, as well as the search for the optimal ratio of dry combined and live feed. Given the scientific research of G.I. Zhelyzakov (2018), in the production of starter feeds for juvenile pike perch, it has not yet been possible to create artificial mixed feeds that would fully satisfy the nutritional needs at the early stages of postembryonic development. Undernourished juvenile pike perch lag behind in growth, and with prolonged starvation, the larvae even change body proportions and appearance. An emaciated larva has a deformed body and a degenerated intestine, so subsequently the digestive tract is destroyed, and digestion of food becomes impossible.

The artificial habitat of fish in intensive aquaculture, in contrast to the natural one, can be significant enough to cause an imbalance in genetically based metabolic systems, pathology and a decrease in vitality (Bal *et al.*, 2023). Rational feeding of animals is based on physiologically based diets, optimal feeding methods and components. Knowledge of the age characteristics of the formation of the digestive system is an important biological factor necessary for the development and survival of fish in the aquatic ecosystem, the rationing and quality of feed consumed (Alexyuk *et al.*, 2021). The initial weight of pike perch fry was 1 mg. The optimal conditions for the metabolic life of fish in the early stages of development are formed according to the amount of food that is favourable for the species of a certain type of fish (Shumka & Apostolou, 2018). The quality of fish food is influenced by: bulk density, water absorption, solubility, hardness, colour, size and shape of granules, elasticity, buoyancy. Starter compound feeds for fish, with efficient production, are fed in strict dependence on the diameter of the grains on the weight of the fish (Kondratiuk *et al.*, 2023). In the process of rearing juvenile pike perch, there is a transition from endogenous nutrition to external food. In other words, the forms of metabolism are replaced one after another, due to the restructuring of the integration mechanism both in the whole organism and in its individual parts and organs. When feeding fish, the daily rate of feed feeding is of great importance, depending on the age and growing conditions (Voronetska & Yurchuk, 2023). With an increase in the mass of fish, the relative value of the diet decreases, and with an increase in water temperature to the optimum, it increases. The development and growth of juvenile zander can occur if the diet exceeds the nutritional requirements.

The experiment showed that the digestibility of dry matter, nutrients and total energy of the experimental diets is affected by the presence of selected ingredients, since an irrational starter diet leads to significant weight loss in pikeperch juveniles. For the production of a mixture of extruded feed, particles of small diameter up to 0.1 mm were burnt to the screw in the centre of the working chamber, rotating the resulting plug in one place, laying the outlet of the matrix, which resulted in a sharp pressure pulsation, and subsequently to an unstable extrusion process. With a particle size of 0.2-0.5 mm of the extruded mixture, the extrusion process was stable at low pulsations, while the extrudate was granules with fine porosity, this particle diameter is the most effective and was recommended for the production of starter feed. Also, when extruding the feed mixture with a particle size of 0.5-1 mm, the process was stable at low pressure fluctuations, however, the resulting feed had unground grains, which led to heterogeneity in mixing the feed. Subsequently, components with a particle size of 0.2-0.5 mm were loaded into the mixer, mixed, maintaining moisture content up to 28-30%. E. Delgado *et al.* (2021) give an example of extruded shrimp food, where the optimal cooking conditions are noted at extrusion parameters: temperature 130°C, humidity 14%, and screw speed 180 rpm. M. Kumar *et al.* (2018) note that the extrusion of the production method for preparing the most versatile fish food is the chosen way of feeding fish, which has multiple positive effects. Extrusion occurs: heat treatment, gelatinization, protein denaturation, hydration, texture change, partial dehydration and destruction of microorganisms and toxic compounds, it is also considered environmentally friendly because it improves the preservation and compactness of the feed in the aquatic environment.

A.G.J. Tacon (2019) noted that pike perch is a carnivorous fish, so the percentage of high-protein ingredients of animal origin in their diet was about 70%, and the percentage of vegetable ingredients is 30%. It is very important to take into account the ratio of digestible protein and digestible non-nitrogen component of the feed. The starter diet ingredients tested in this experiment showed good digestibility. Therefore, components such as soy protein isolate, soybean meal, corn and wheat germ, corn gluten can be used as alternative sources of vegetable protein in this recipe (Grayson & Dabrowski, 2022). However, further experimentation is needed, especially with regard to the digestibility and bioavailability of the amino acids contained in the studied ingredients. This will allow us to fully understand the nutritional value of the starter diet for pike perch juveniles. An experimental goal of many scientists in the development of diets for carnivorous fish is alternative, sustainable protein sources that can replace fishmeal and ensure high fish productivity. For example, H. Dadras *et al*. (2022) cited a method of replacing fishmeal in the diet with up to 30% cottonseed and soymeal, and this research was supported by the findings of other studies reporting increased water tolerance of feeds.

The transition of zander fry to active feeding is determined by the change in their swimming behaviour. They stop floating vertically upwards, sink head down, rest against the bottom, and then begin to swim horizontally, always remaining in the water column. They switch to gill breathing, inflate their swim bladder and feed first on rotifers and then on crustaceans such as cyclops. Juvenile pike-perch tolerate transportation in plastic bags especially well during the transition to active feeding. As zander fry are small, they should be kept in cages with a No. 16 during the transition to active feeding and transfer to delicacy cages only when they grow up. Also, zander fry feed on plankton and prefer crustaceans, and they also grow poorly in cages, reaching 0.5 g at 1 month and 2 g at 4 months.

The results showed that the conditions for rearing early juvenile pike perch and the amount of feed used were close to optimal, and the artificial feed developed was adapted to the requirements of the given rearing period. The results obtained can help to increase the potential of fish farms that do not have the technical base for aquaculture. Further research is needed to determine the optimal minimum weight. It has been established that from the results of the quality indicators of feed for juvenile fish, it follows that the studies carried out on the development of a starter feed recipe and technological modes for the production of extruded feed made it possible to create a starter feed with a sufficiently high energy, nutritional and biological value. Kazakh Research Institute of Processing and Food Industry starter compound feed can be recommended for feed production and is focused on feeding juvenile pike perch.

CONCLUSIONS

The aquaculture feed market is represented by a wide range of special extruded and granulated compound feeds for fish of different species and ages (for juveniles, marketable fish, carp, salmon, sturgeon, catfish spawners) with a grain size of 0.1 to 2 mm and a granule diameter of 1 mm to 12 mm. Given Kazakhstan's growing demand for aquaculture products, the study underlined the importance of ongoing scientific research and practical support to develop fish feed recipes. Current feed choices included extruded and granulated compound feeds for a variety of fish species, but customising them to individual species, such as pike perch, posed distinct growth and feeding issues.

Chemical examination revealed that the meal comprised 53.7% crude protein, 12% crude protein, and 13.4% NFE, which contributed to its high energy value of 496.8 kcal. These nutritional qualities make the meal ideal for stimulating the growth of juvenile pike perch and facilitating effective feed conversion. The feed's composition guarantees that vital nutrients are accessible to promote healthy fish growth. It has been established that a larger amount of vegetable protein can be introduced into the diet using extrusion technology. Furthermore, the capacity to include a greater quantity of vegetable protein into the feed using extrusion technology, along with physiologically active compounds like amino acids, phytase, probiotics, and immunostimulants, improved the feed's efficacy. This guarantees that young pike perch get all of the nutrients they need to prosper, while also minimising dependency on more expensive animal protein sources.

When using two starter feeds developed by Kazakh Research Institute of Processing and Food Industry and foreign starter trout "Aller Aqua", good productivity was obtained. When growing juvenile zander, the effective consumption of nutrients of the extruded starter ration for absolute growth was established, which amounted to 87 mg, while in the group fed with "Aller Aqua" compound feed, the increase was 5 mg more. The feed coefficient of the experimental compound feed for the study period, on average for all size groups, was 1.28, in contrast to the control compound feed "Aller Aqua", which was 0.06 units less. But this difference was not large enough to negatively affect overall growth performance. It has been established that the process of extrusion is an effective way to obtain feed for starter diets of pikeperch fry, and the technology and developed recipes will make it possible to establish the production of grits with a grain diameter of 1 mm, accelerate the growth rate of juvenile fish, increasing the productivity of fish farming in industrial conditions. The survival rates of juvenile pike perch in both the control and experimental groups were similar (55% and 52%, respectively), indicating that the new diet is equally effective in enhancing the health and well-being of pike perch fry. These findings suggested that the locally created starting feed is a viable alternative to traditional commercial feeds. The study also revealed that the extrusion processes are effective methods for producing high-quality feed for pike perch fry. The new recipe and production method enabled the creation of feed with grain diameters as small as 1 mm, which is acceptable for juvenile fish. This results in quicker development and increased yield in fish farming operations.

Ongoing research will help feed companies that produce fish feed make optimal use of extrusion technology, obtaining feed with high nutritional value and strong physical and chemical properties, contributing to the development of waste-free technologies for processing food raw materials to obtain high-tech domestically produced feed products. Extruded complete feed for aquaculture is a promising direction that requires: additional scientific research that determines the parameters of processing processes, evaluation of various types of plant and animal raw materials and their compositions, analysis of finished extrudates with a detailed comparative description of their properties.

ACKNOWLEDGEMENTS

This research has is funded by the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan (Grant No. BP10264236).

CONFLICT OF INTEREST

None.

REFERENCES

[1] Alexyuk, M., Bogoyavlenskiy, A., Alexyuk, P., Moldakhanov, Y., Berezin, V., & Digel, I. (2021). Epipelagic microbiome of the Small Aral Sea: Metagenomic structure and ecological diversity. *MicrobiologyOpen*, 10(1), article number e1142. doi: 10.1002/mbo3.1142.

[2] Bal, I., Lebsky, S., Tolok, G., Ustymenko, I., & Kyslytsia, Ya. (2023). State and prospects of fish processing technologies. *Animal Science and Food Technology*, 14(4), 9-25. doi: 10.31548/animal.4.2023.09.

[3] Bektursunova, M., Ospanov, A., Sidorova, V., Yanvareva, N., Zhiyenbayeva, S., Assylbekova, S., & Mukhramova, A. (2022). Changes in the quality indicators of extruded starter compound food for fish during storage. *The Journal of Almaty Technological University*, 3, 161-168. doi: 10.48184/2304-568X-2022-3-161-168.

[4] Bektursunova, M.J., Zhiyenbayeva, S.T., Sidorova, V.I., & Yanvareva, N.I. (2021). Development of production technology for extruded starter compound feedsfor juvenile fish. *The Journal of Almaty Technological University*, 4, 10-16. doi: 10.48184/2304-568X-2021-4-10-16.

[5] Dadras, H., Chupani, L., Imentai, A., Malinovskyi, O., Esteban, M.A., Penka, T., Kolářová, J., Rahimnejad, S., & Policar, T. (2022). Partial replacement of fish meal by soybean meal supplemented with inulin and oligofructose in the diet of pikeperch (*Sander lucioperca*): Effect on growth and health status. *Frontiers in Marine Science*, 9, article number 1009357. doi: 10.3389/fmars.2022.1009357.

[6] Delgado, E., Valles-Rosales, D.J., Flores, N.C., & Reyes-Jáquez, D. (2021). Evaluation of fish oil content and cottonseed meal with ultralow gossypol content on the functional properties of an extruded shrimp feed. *Aquaculture Reports*, 19, article number 100588. doi: 10.1016/j.aqrep.2021.100588.

[7] Grayson, J.D., & Dabrowski, K. (2022). Utilization of live-food enrichment with polyunsaturated fatty acids (PUFA) for the intensive culture of yellow perch larvae. *North American Journal of Aquaculture*, 84(2), 131-148. doi: 10.1002/naaq.10227.

[8] Hernández-Contreras, Á., Teles, A., Salas-Leiva, J.S., Chaves-Pozo, E., & Tovar-Ramírez, D. (2023). Feed additives in aquaculture. In *Sustainable use of feed additives in livestock* (pp. 811-846). Cham: Springer. doi: 10.1007/978-3-031-42855-5_28.

[9] Horváth, L., Tamás, G., & Seagrave, C. (2008). *Carp and pond fish culture: Including Chinese herbivorous species, pike, tench, zander, wels catfish, goldfish, African catfish and sterlet.* Hoboken: John Wiley & Sons.

[10] Imsland, A.K., Foss, A., Sparboe, L.O., & Sigurdsson, S. (2006). The effect of temperature and fish size on growth and feed efficiency ratio of juvenile spotted wolffish Anarhichas minor. *Journal of Fish Biology*, 68, 1107-1122. doi: 10.1111/j.0022-1112.2006.00989.x.

[11] ISO 12099:2017. (2017). *Animal feeding stuffs, cereals and milled cereal products – Guidelines for the application of near infrared spectrometry.* Retrieved from https://www.iso.org/standard/67352.html.

[12] ISO 12875:2011. (2011). *Traceability of finfish products – Specification on the information to be recorded in captured finfish distribution chains*. Retrieved from https://www.iso.org/standard/52084.html.

[13] ISO 5983-2:2009. (2009). *Animal feeding stuffs – Determination of nitrogen content and calculation of crude protein content.* Retrieved from https://www.iso.org/standard/52199.html.

[14] ISO 5984:2002. (2002). *Animal feeding stuffs – Determination of crude ash*. Retrieved from https://www.iso.org/standard/77807.html.

[15] ISO 6492:1999. (1999). *Animal feeding stuffs – Determination of fat content*. Retrieved from https://www.iso.org/standard/12865.html.

[16] ISO 6495-1:2015. (2015). *Animal feeding stuffs – Determination of water-soluble chlorides content.* Retrieved from https://www.iso.org/standard/60533.html#:~:text=ISO%206495-1%3A2015%20specifies%20a%20method%20for%20the%20determination,chloride%20content%2C%20expressed%20as%20sodium%20chloride%2C%20%E2%89%A50%2C05%20%25.

[17] ISO 6496:1999. (1999). *Animal feeding stuffs – Determination of moisture and other volatile matter content*. Retrieved from https://www.iso.org/standard/12871.html.
[18] ISO 6498:2012. (2012). *Animal feeding stuffs – Guidelines for sample preparation*. Retrieved from https://www.iso.org/standard/52285.html.
[19] ISO 6865:2000. (2000). *Animal feeding stuffs – Determination of crude fibre content – Method with intermediate filtration*. Retrieved from https://www.iso.org/standard/13377.html.
[20] Kondratiuk, V., Sychov, M., Ilchuk, I., Umanets, D., Balanchuk, I., & Holubieva, T. (2023). Growth of rainbow trout fingerling at different levels and ratios of lysine and arginine in combined feed. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 19(2), 1-12. doi: 10.31548/dopovidi2(102).2023.007.
[21] Koshak, Z. (2022). Problems of quality of raw materials in fodder for fish mixed fodder. *Belarus Fish Industry Problems*, 1(33), 144-155.
[22] Kumar, M., Patel, A.B., Keer, N.R., Mandal, S.C., Biswas, P., & Das, S. (2018). Utilization of unconventional dietary energy source of local origin in aquaculture: Impact of replacement of dietary corn with tapioca on physical properties of extruded fish feed. *Journal of Entomology and Zoology Studies*, 6(2), 2324-2329.
[23] Martin, A., Osen, R., Greiling, A., Karbstein, H.P., & Emin, A. (2019). Effect of rapeseed press cake and peel on the extruder response and physical pellet quality in extruded fish feed. *Aquaculture,* 512, article number 734316. doi: 10.1016/j.aquaculture.2019.734316.
[24] Mishurov, N.P., Davydova, S.A., & Davydov, A.A. (2019). Promising technologies for combined feed quality improving. *Bulletin of the All-Russian Scientific Research Institute of Animal Husbandry Mechanization*, 3(35), 4-11.
[25] Mukhramova, A., Assylbekova, S., Sambetbaev, A., Policar, T., Isbekov, K., Koishybayeva, S., & Badryzlova, N. (2020). Use of domestic starter feeds for culturing clarid catfish and tilapia. *EurAsian Journal of BioSciences*, 14(1), 453-458.
[26] Oke, M.O., Awonorin, S.O., Sanni, L.O., Asiedu, R., & Aiyedun, P.O. (2012). Effect of extru on variables on extrudates properties of water yam flour – A response surface analysis. *Journal of Food Processing and Preservation,* 37(5), 456-473. doi: 10.1111/j.1745-4549.2011.00661.x.
[27] Puzevich, E. (2021). Feed production in the context of modern equipment and technologies. *Efficient Animal Husbandry*, 3(169), 64-69.
[28] Shumka, S., & Apostolou, A. (2018). Current knowledge on the status of the most common non-indigenous fish species in the transboundary greater Prespa Lake (Albanian side). *Acta Zoologica Bulgarica*, 70(2), 203-209.
[29] Skarbøvik, E., Perovic, A., Shumka, S., & Nagothu, U.S. (2014). Nutrient inputs, trophic status and water management challenges in the transboundary lake skadar/shkodra, western balkans. *Archives of Biological Sciences*, 66(2), 667-681. doi: 10.2298/ABS1402667S.
[30] Tacon, A.G.J. (2019). Trends in global aquaculture and aquafeed production: 2000-2017. *Reviews in Fisheries Science & Aquaculture*, 28(1), 43-56. doi: 10.1080/23308249.2019.1649634.
[31] Voronetska, I., & Yurchuk, N. (2023). Fodder production in Ukraine: Trends, problems and prospects. *Ukrainian Black Sea Region Agrarian Science*, 27(2), 51-62. doi: 10.56407/bs.agrarian/2.2023.51.
[32] Wan, J., Xi, Q., Tang, J., Liu, T., Liu, C., Li, H., Gu, X., Shen, M., Zhang, M., Fang, J., & Meng, X. (2022). Effects of pelleted and extruded feed on growth performance, intestinal histology and microbiota of juvenile red swamp crayfish (*Procambarus clarkii*). *Animals*, 12(17), article number 2252. doi: 10.3390/ani12172252.
[33] Zhao, X., Wang, Y., Wang, X., & Ye, J. (2021). Growth performance, plasma components, and intestinal barrier in grouper (*Epinephelus coioides*) are altered by dietary fish meal replacement with extruded soybean meal. *Aquaculture Reports*, 21, article number 100863. doi: 10.1016/j.aqrep.2021.100863.
[34] Zhelyzakov, G.I. (2018). Effect of different diets on growth performance and survival of european perch (*Perca fluviatilis L.*) cultivated in recirculating system during transition from live food to formulated feed. *Aquatic Research*, 1(1), 12-17. doi: 10.3153/AR18002.
[35] Zyabrev, V., Dolud, M., & Lukht, Kh.V. (2019). Stern. Aquaculture: Optimal production technologies. *Sphere "Fish"*, 1(22), 17-20.

Технологія виробництва екструдованих стартових комбікормів для молоді риб

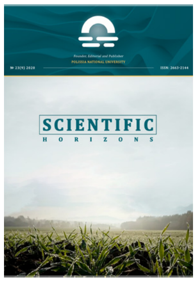
Мая Бектурсунова
Докторант, старший дослідник
Казахський науково-дослідний інститут переробної та харчової промисловості
050060, просп. Гагаріна, 238 Г, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-5105-4864
Валентина Сидорова
Провідний дослідник
Казахський науково-дослідний інститут переробної та харчової промисловості
050060, просп. Гагаріна, 238 Г, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0001-6244-0691
Сауле Жиєнбаєва
Доктор технічних наук, доцент
Алматинський технологічний університет
050012, вул. Толе бі, 100, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-2003-8909
Альона Мухрамова
Головний вчений секретар
Науково-виробничий центр рибного господарства
050016, просп. Суюнбая, 89А, м. Алмати, Республіка Казахстан
Докторант
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-4701-6195
Сауле Асилбекова
Доктор біологічних наук, заступник директора
Науково-виробничий центр рибного господарства
050016, просп. Суюнбая, 89А, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-6648-4744

Анотація. Новітні досягнення науки в поєднанні зі зростаючими можливостями сучасної технології сприяють удосконаленню технологій годівлі риби та рибництва в цілому. Очевидно, що розширення видового складу культивованих об'єктів рибництва буде продовжуватися, а значення кормів і технології годівлі риб неухильно зростатиме. Розроблені рецептури стартових комбікормів для молоді риб і технологія їх виробництва дозволять налагодити випуск цих кормів для рибницьких господарств Казахстану, в результаті чого підвищиться виживаність і швидкість росту молоді риб, вирощуваної в індустріальних умовах. Метою роботи була розробка рецептур стартових комбікормів для мальків судака та технології їх виробництва методом екструзії, освоєння цих комбікормів для підвищення ефективності вирощування судака в індустріальних умовах. За розробленою рецептурою було розроблено збалансований за основними поживними речовинами стартовий комбікорм для молоді судака і було проведено дослідження впливу цього комбікорму на ефективність та швидкість вирощування молоді судака. Вивчалась динаміка вирощування молоді судака при згодовуванні стартового комбікорму, розробленого Казахським НДІ переробної і харчової промисловості, з кормовим коефіцієнтом 1,28 і в якості контролю закордонного стартового комбікорму для форелі "Aller Aqua" – 1,2. Матеріали статті мають практичне значення і необхідність подальших досліджень, вони сприятимуть поповненню рецептур комбікормів для індустріального вирощування молоді судака в рибницьких господарствах Республіки Казахстан

Ключові слова: судак; мальки; екструзія; стартовий раціон; співвідношення кормів

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 54-63



UDC 635.654:631.53.048:581.15
Doi: 10.48077/scihor9.2024.54

Research on the impact of planting schemes on the trait variability of *Vigna* varieties (*Vigna unguiculata* (L.) Walp. *subsp. sesquipedalis* (L.) Verdc.)

Iryna Bobos
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-5193-7192

Oleksandr Komar*
PhD in Agricultural Sciences
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-7511-4190

Ivan Fedosiy
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-5044-9960

Ivanna Havrys
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-5965-9916

Mykhailo Retman
PhD in Agricultural Sciences, Senior Researcher
Institute of Water Problems and Land Reclamation
of the National Academy of Agrarian Sciences of Ukraine
03022, 37 Vasylkivska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-6972-2410

Article's History:
Received: 19.04.2024
Revised: 03.08.2024
Accepted: 28.08.2024

Abstract. This research aimed to study the formation of asparagus bean yield, taking into account the influence of technological factors, including testing specific varieties based on changes in stand density. Among the primary methods used to investigate this issue were field experiments to examine the cultivation techniques and statistical

Suggested Citation:
Bobos, I., Komar, O., Fedosiy, I., Havrys, I., & Retman, M. (2024). Research on the impact of planting schemes on the trait variability of *Vigna* varieties (*Vigna unguiculata* (L.) Walp. *subsp. sesquipedalis* (L.) Verdc.). *Scientific Horizons*, 27(9), 54-63. doi: 10.48077/scihor9.2024.54.

**Corresponding author*

analysis to assess the reliability of the results. This article presents the results of studies on sowing patterns: 70×10 cm, 70×25 cm (control), 70×40 cm, and 70×50 cm, on bush asparagus bean varieties Kafedralna (Ukraine) and U-Cha-Kontou (China) (control). Stand density significantly influenced the morphometric characteristics and productivity of the studied varieties. Increasing plant density to 143,000 plants/ha led to a significant increase (by 2-3 t/ha) in the yield of flat pods in both cultivars compared to the control (70×25 cm). The highest yield of flat pods (7.7-10.4 t/ha) was obtained for varieties at a density of 143,000 plants/ha. This is related to the optimal provision of plants with moisture, light, and nutrients at a given stand density. The Kafedralna variety generally exhibited a higher yield of flat pods than the U-Cha-Kontou variety. At lower seeding densities (29,000 plants/ha), the beans had a greater mass (120.5-152.0 g), but their number per plant was lower. Reducing stand density to 29,000 plants/ha led to an increase in the beans' dry matter, sugars, and vitamin C content. The Kafedralna variety had a higher content of these components under all sowing patterns. A strong correlation was found between biochemical indicators and stand density. The optimal sowing pattern for cowpeas to obtain flat pods in the Forest-Steppe zone of Ukraine can be considered 70×10 cm and 70×25 cm. The Kafedralna variety is recommended for open-field cultivation to obtain flat pods. The materials presented in the article have practical value for developing effective technologies for growing bush varieties of asparagus beans in the Forest-Steppe zone of Ukraine for vegetable production

Keywords: bush asparagus bean; variety; flat pods; planting scheme; plant density; yield; biochemical indicators

INTRODUCTION

Addressing the issue of providing the population with high-quality food products is a pressing concern worldwide. These products are primarily valued for their balanced content of nutrients, vitamins, and mineral salts such as iron, calcium, and phosphorus. However, no single crop can fully supply all the necessary nutrients for human consumption. Furthermore, there is a significant deficit of both animal and plant-based proteins. Therefore, it is essential to provide the population with high-protein foods. Plant-based proteins can be effectively obtained from legumes, a diverse group of crops cultivated globally. Authors S. Dhaliwal *et al.* (2020), D. Punniyamoorthy and S. Jegadeesan (2023) assert that cowpea is a valuable legume crop, serving as a readily accessible source of protein, vitamins, and mineral salts. Moreover, a key advantage of this crop is its high heat and drought tolerance, making it suitable for cultivation worldwide in the face of global warming. The significance of *Vigna* as a vegetable crop cannot be overstated. It is harvested at the technical maturity stage, specifically for its immature seeds and green beans. In the USA, high-quality sprouts are produced from the seeds of small-seeded varieties (Paraschivu *et al.,* 2021).

K. Akasapu and R. Uppaluri (2022) note that green beans reaching a length of 10-20 cm are primarily used in the preparation of frozen soup mixes. Beans up to 100 cm in length are bundled for market sale, which significantly enhances their commercial appeal. *Vigna unguiculata* L. exhibits a vast genetic diversity, as evidenced by the International Institute of Tropical Agriculture in Nigeria, where a genetic repository of 15,000 accessions is maintained (Boukar *et al.,* 2020). Although not as extensively documented in literature as other legumes, *Vigna* is often mistakenly identified as common beans. However, in terms of valuable properties, it is comparable to both beans and peas.

Asparagus bean is a subspecies resulting from a mutation in China. It is an ancient vegetable crop, cultivated in the Mediterranean, India, and Japan. The immature beans, often exceeding 90 cm in length, are consumed (Verma *et al.,* 2022). In Ukrainian markets, *Vigna* seeds can be found under the names "Chinese pea" or "lentil" (Bondarchuk *et al.,* 2022). Asparagus bean, or Cuban black-eyed pea, belongs to the vegetable variety of cowpea, *Vigna sesquipedalis* (L.) W.S. Wight. Asparagus bean is most widely cultivated in China, India, and African countries, where the mutation that led to the absence of the parchment layer in young beans likely occurred. This mutation gave rise to the vegetable variety (Kebede & Bekeko, 2020; Panzeri *et al.,* 2022).

The authors P. Vyshnivskyi and O. Furman (2020), and I. Fedosiy *et al.* (2022) highlight that this crop is promising for cultivation in Ukraine due to the sufficient amount of effective temperatures. At the National University of Life and Environmental Sciences of Ukraine, the Department of Vegetable Crops and Greenhouse conducted the first studies on *Vigna* between 2008 and 2011 in the northern part of the Forest-Steppe region. These studies assessed *Vigna* samples based on their morphological characteristics, maturity, and yield. A promising bush *Vigna* specimen was obtained, which was later used as a parental form in breeding programmes. As a result, the first bush *Vigna* vegetable variety, Kafedralna, was developed. This variety passed qualification examinations in 2023 and was granted a patent. In 2024, Kafedralna was included in the State Register of Plant Varieties of Ukraine (Patent No. 230332, 2023).

Considering the botanical and biological characteristics of the crop, it is possible to generate profit by cultivating it for flat pods and seed production. At the same time, the need arose to investigate planting schemes and compare varieties in terms of productivity and biochemical traits of the beans, considering changing climatic conditions. Photosynthesis is a key process in the plant organism, influenced by various factors, with plant density and uniform distribution per unit area being the most significant. By optimally combining these factors, favourable conditions are created, ensuring equal access to light, moisture, and nutrients for each plant. This improves the phytosanitary condition of the agroecosystem, reducing the risk of diseases and pests.

Therefore, this research aimed to study the characteristics of yield formation in asparagus beans, considering the impact of technological elements, particularly testing different varieties based on changes in stand density of crops.

MATERIALS AND METHODS

Between 2014 and 2016, a research study was conducted at the National University of Life and Environmental Sciences of Ukraine (NULES) on the collection plots of the educational laboratory "Fruit and Vegetable Garden", located in the Kyiv Region without irrigation. The research was carried out in three replications using a two-factor experimental design (Bondarenko & Yakovenko, 2001). The planting schemes of the bush varieties Kafedralna (Ukraine) and U-Cha-Kontou (China) were studied, specifically: 70×10 (143), 70×25 (57), 70×40 (36), and 70×50 cm (29,000 plants/ha). The 70×25 cm pattern was used as a control. The total plot size was 75 m^2, and each individual plot was 5 m^2. Data was collected from 30 plants – 10 from each replication.

Previous research at the Department of Vegetable Crops, NULES Ukraine, identified the adaptive and high-yielding Chinese variety U-Cha-Kontou, which was used as a control. In addition, promising bush asparagus bean specimens studied between 2008 and 2011 were utilised in breeding programmes. As a result of this breeding work, the first bush variety in Ukraine, Kafedralna, was developed and included in studies to optimise plant density (Bobos *et al.,* 2022). The cultivation technology for bush asparagus beans is standard in production conditions. Seeds of the studied varieties were sown on 27 April across all variants simultaneously during 2014-2016. The sowing depth was 2.0-3.0 cm. Crop care included inter-row loosening, weed control, and protection against diseases and pests. During the initial growth period, a combination of high temperatures and low humidity led to the active spread of the common spider mite (Tetranuchis *trticeae* Kosh.) on plants. Significant damage was caused by aphids (*Aphidoidea*), which proliferated on all plants throughout the growing season. The pesticide Aktofit was applied (50 ml per 6-12 litres of water). Treatment with this biopesticide was conducted during the evening hours when the air temperature ranged from 15 to 25°C. The level of pest infestation was found to be similar across all varieties and sowing patterns.

Common bacterial blight (*Xanthomonas campestres pv. phaseoli* (Smith) Dye) was detected on the asparagus bean plants. The disease began to manifest in the second half of the growing season (July) following a decrease in temperature and an increase in soil and air humidity due to rainfall. The biopesticide Fitocid (10 ml per 10 litres of water) was applied. The plants were sprayed three times during the growing season: the first time when the disease first appeared on July 17th, and subsequently every 10 days. Flat pods (at technical maturity) were harvested simultaneously in all experimental variants weekly at the same time. Before harvesting, biometric measurements were taken. The number of beans and their weight per plant, as well as the length and number of seeds per pod, were counted during the harvesting process. Simultaneously with the yield calculation, a combined sample was taken for each variant to determine the "1,000-seed weight" index.

Biochemical analyses of the flat pods were conducted at the Laboratory of Biochemical and Technological Quality Indicators at the Ukrainian Institute of Plant Variety Examination using standard methods. Samples were collected at the stage of technical maturity. The collection plot is located in the Forest-Steppe zone with a moderately continental climate, characterised by mild winters. The average long-term temperature in January, the coldest month, is – 6.5°C, and in July, the warmest month, is +19.8°C. According to long-term observations, the lowest recorded temperature was -36°C and the highest was +39°C. The total sum of active temperatures is 2440-2700°C. Overall, the combination of temperatures, moisture conditions, and necessary irrigation during the research years was favourable for the growth and development of asparagus beans, allowing for the observation of flat pod formation in the different varieties.

The soil in the area is dark grey, moderately podsolised, and consists of light loam, with a slightly acidic reaction. The thickness of the humus horizon measures 24-28 cm. The experimental site is characterised by a low humus content of 1.5-2.2%, a moderate level of hydrolysable nitrogen at 26-38 mg/kg, and available phosphorus and potassium levels of 43-61 mg/kg and 28-34 mg/kg, respectively. The depth of the plough layer was 20-22 cm. The crop rotation included cucumber in 2014, tomato in 2015, and white cabbage in 2016. In autumn, the plant residues from the preceding crop and weeds were destroyed, followed by deep autumn ploughing. Seven days before sowing, a fertiliser mix of $N_{60}P_{40}K_{90}$ (ammonium nitrate, superphosphate, and potassium chloride) was applied. During the first ten days of April, before sowing, the experimental area was cultivated to a depth of 12-15 cm using the KPSP-4 cultivator.

Statistical analysis, specifically analysis of variance (ANOVA) and correlation analysis was performed using the XLSTAT add-in for Microsoft Excel. Differences were considered statistically significant at the $\alpha = 0.95$ level

(Rao, 2018). The authors adhered to the standards set by the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

During the years of research, it was found that the yield of *Vigna* was significantly influenced by the varietal characteristics of the plants and their density per unit area. Varieties sown at a density of 143,000 plants per hectare yielded significantly higher bean crops – 7.7-10.4 tonnes per hectare, which is 2-3 tonnes per hectare more than the control (Table 1). One of the most important characteristics of *Vigna* flat pods is the absence of a parchment layer and fibres. It is widely accepted that the highest quality varieties are those whose flat pods do not thicken over a long period and do not form a parchment layer or fibres throughout the entire harvest period. The variety Kafedralna was characterised by the formation of a weak parchment layer and fibres in the flat pods under conditions of high air temperature, despite delayed harvesting.

***Table 1**. Productivity indicators of asparagus bean varieties at different plant stand densities (average for 2014-2016)*

Experimental variant (factor B)	Plant density, thousand plants/ha	The average weight of beans in the phase of technical maturity, g	Average number of beans per plant, pcs.	Weight of beans per plant at the stage of technical maturity, g	Yields of commercial flat pods, t/ha
U-Cha-Kontou (control) (*factor A*)					
70×10 cm	143	5.7	9.6	53.7	7,7
70×25 cm (control)	57	6.0	16.8	100.2	5,7
70×40 cm	36	6.5	17.3	109.8	3,9
70×50 cm	29	6.7	18.5	120.5	3,5
Kafedralna					
70×10 cm	143	7.1	10.2	72.4	10,4
70×25 cm (control)	57	7.4	17.5	129.5	7,4
70×40 cm	36	7.7	17.8	137.1	4,9
70×50 cm	29	8.3	18.3	152.0	4,4
LSD_{05}		1.92	1.82	32.60	1.49
factor A		0.96	0.91	16.30	0.74
factor B		1.36	1.29	23.05	1.05

***Source:** developed by the authors based on the conducted research*

Heavier beans were obtained from *Vigna* varieties planted at the lowest density of 29,000 plants per hectare. For the U-Cha-Kontou variety, the average pod weight was 120.5 g, and for Kafedralna, it was 152.0 g. This represents an increase of 20.3-22.2 g compared to the control. At the same time, the sparser plantings resulted in a greater number of flat pods formed: 18.3-18.5 per plant, with an average bean weight of 6.7-8.3 g. Despite these higher metrics, the average yield of flat pods in the *Vigna* varieties was found to be higher at a density of 143,000 plants per hectare, ranging from 7.7 to 10.4 tonnes per hectare. This is attributed to the greater number of plants per unit area.

Lower yields of flat pods were obtained at a plant density of 29,000 plants per hectare for the U-Cha-Kontou variety (3.5 t/ha) and the Kafedralna variety (4.4 t/ha), which is 2.2-3.0 t/ha less than the control. Additionally, the U-Cha-Kontou variety consistently produced lower yields of flat pods compared to the Kafedralna variety across all planting patterns (Fig. 1). Despite higher productivity and a greater number of beans per plant, the lower bean yield in *Vigna* varieties was attributed to the lower plant density per unit area. Significant differences were found for factor B in all economic and valuable traits studied.

The productivity of asparagus bean plants influenced their average yield of flat pods. Due to the non-simultaneous ripening of beans at different plant densities, the crop was harvested weekly for each cultivar (Fig. 2). Consequently, the yield increased with the number of plants per unit area. At a plant density of 29,000 plants per hectare, the lowest yield was observed at 3.5-4.4 t/ha. This trend could be attributed to the lower plant density per plot, while the average number of beans per plant and their weight were higher.

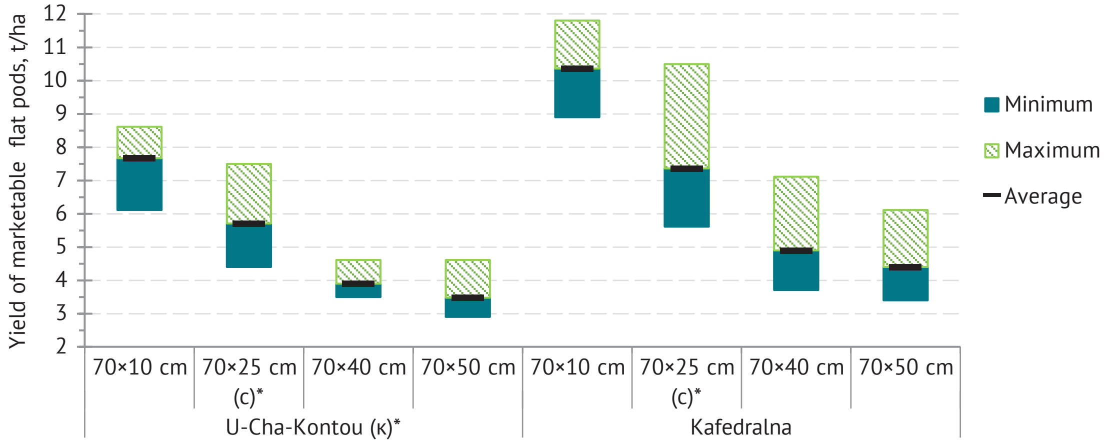


Figure 1. *The impact of plant density of bush Vigna varieties on the yield of marketable flat pods, t/ha (2014-2016)*
Note: *(c)* – control*
Source: *developed by the authors based on the conducted research Yield of marketable flat pods, t/ha*

Figure 2. *Non-simultaneous ripening of beans in the Kafedralna variety*
Source: *developed by the authors based on the conducted research*

The results obtained indicate that varying plant density has a significant impact on economic and valuable traits, as plants are in constant competition with each other for light, water, and nutrients throughout their life cycle. Consequently, with less dense plantings, plants receive better lighting, more favourable conditions for nutrition, and there is a better sanitary condition of the plot, which in turn contributes to higher yields. However, the yield of *Vigna* varieties was higher in denser plantings due to the greater number of plants, which affected the overall output per unit area. The optimal plant density for bush *Vigna* varieties in open ground for obtaining flat pods can be considered to be from 57 to 143 thousand plants per hectare, at which the marketable yield of flat pods for the U-Cha-Kontou and Kafedralna varieties was, respectively, 5.7-7.7 and 7.4-10.4 t/ha.

The accumulation and formation of organic matter by plants is a completely autonomous process that does not require human intervention. However, the intensity of dry organic matter accumulation in plant product organs and their quality indicators are variable, as their magnitude is determined by the influence of both organised and unorganised environmental factors. Research has established that the biochemical indicators of asparagus beans at technical maturity depend on plant density (Fig. 3).

Based on the biochemical analysis of the studied varieties, at lower plant densities (29,000 plants/ha), the quality indicators of the beans improved, specifically: the dry matter content was between 13.1-13.4%, sugars at 3.6-4.0%, vitamin C at 32.8-37.1 mg/100 g of fresh weight, and crude protein at 3.4-3.5 mg/100 g of fresh weight. Due to the fact that plants in sparse plantings receive sufficient light, their nutrient uptake and microclimate are improved, which contributed to the formation of beans with higher biochemical indicators. As the plant density approached 143,000 plants/ha, there was a significant decrease in the quality indicators of the beans. In this case, the dry matter content varied between varieties from 12.5 to 12.7%, sugars from 2.9 to 3.0%, vitamin C from 30.4 to 33.6 mg/100 g fresh weight, and crude protein from 3.2 to 3.4 mg/100 g fresh weight.

Among the varieties, the Kafedralna variety stood out as having the most valuable biochemical indicators. Regardless of plant density, this variety consistently exhibited a dry matter content of 12.7-13.4%, sugars of 3.0-4.0%, vitamin C of 33.6-37.1 mg/100g fresh weight, and crude protein of 3.2-3.7%. Correlational analysis for the U-Cha-Kontou (control) variety revealed a strong positive correlation between dry matter and total sugars (r = 0.98), crude protein (r = 0.99), and vitamin C (r = 0.93); between total sugars and crude protein (r = 0.95), and vitamin C (r = 0.97); and between crude protein and vitamin C (r = 0.87) (Table 2). A strong negative correlation was also found between plant density and dry matter (r = -0.91), total sugars (r = -0.93), crude protein (r = -0.90), and vitamin C (r = -0.84).

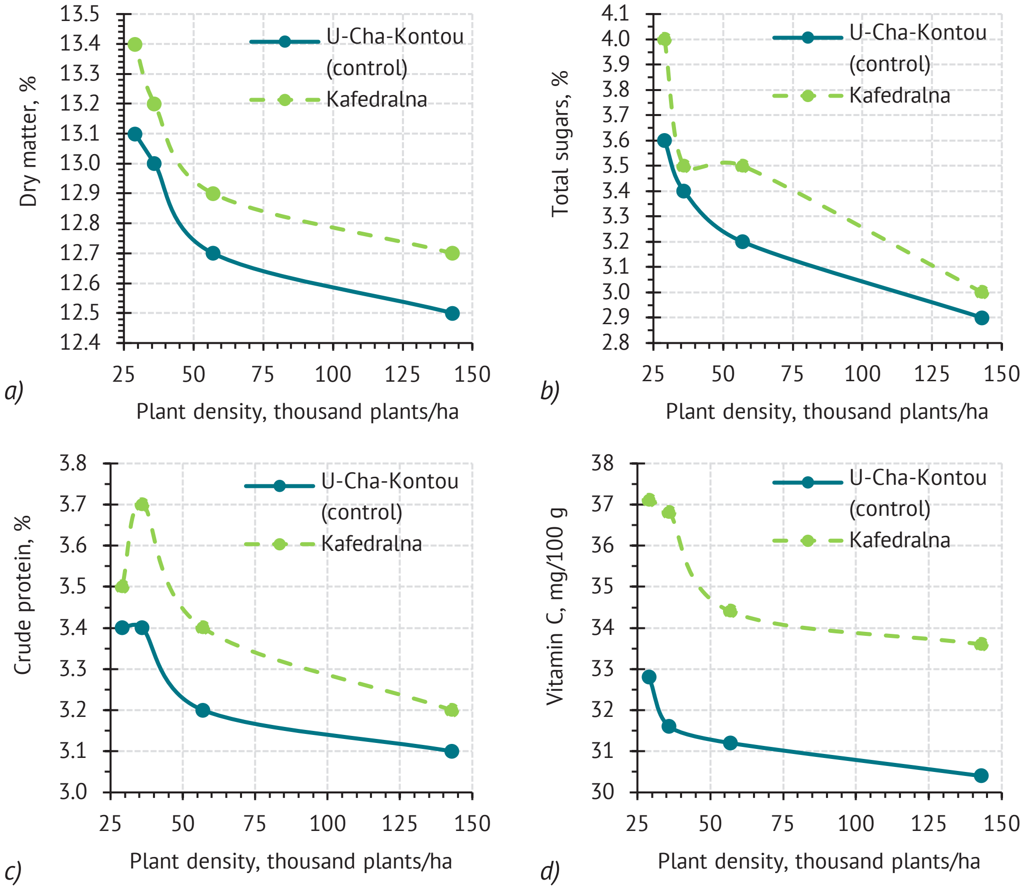


Figure 3*. Biochemical indicators of asparagus bean flat pods at technical maturity at different plant densities (average for 2014-2016)*

Note: *a) dry matter, % ((LSD_{05} 0.23; factor A (LSD_{05} 0.11; factor B (LSD_{05} 0.16); b) total sugars, % ((LSD_{05} 0.19; factor A (LSD_{05} 0.09; factor B (LSD_{05} 0.13); c) crude protein, % ((LSD_{05} 0.17; factor A (LSD_{05} 0.09; factor B (LSD_{05} 0.12); d) vitamin C, mg/100g (LSD_{05} 1.55; factor A (LSD_{05} 0.77; factor B (LSD_{05} 1.10)*

Source: *developed by the authors based on the conducted research*

Table 2*. Correlation matrix between the biochemical composition of asparagus bean flat pods (average for 2014-2016)*

Variety	Parameter	Plant density, thousand units/ha	Dry matter, %	Total sugars, %	Crude protein, %	Vitamin C, mg/100g
U-Cha-Kontou (control)	Plant density, thousand units/ha	1				
	Dry matter, %	-0.91	1			
	Total sugars, %	-0.93	0.98	1		
	Crude protein, %	-0.90	0.99	0.95	1	
	Vitamin C, mg/100 g	-0.84	0.93	0.97	0.87	1
Kafedralna	Plant density, thousand units/ha	1				
	Dry matter, %	-0.88	1			
	Total sugars, %	-0.89	0.92	1		
	Crude protein, %	-0.74	0.93	0.71	1	
	Vitamin C, mg/100 g	-0.67	0.49	0.79	0.14	1

Source: *developed by the authors based on the conducted research*

A strong positive correlation was observed in the Kafedralna variety between dry matter and total sugars (r = 0.92), crude protein (r = 0.93); between total sugars and crude protein (r = 0.71), and vitamin C (r = 0.79). Additionally, a moderate positive correlation was found between dry matter and vitamin C (r = 0.49). There was also a strong negative correlation between plant density and dry matter (r = -0.88), total sugars (r = -0.89), crude protein (r = -0.74), and vitamin C (r = -0.67). However, the Kafedralna variety proved to be more adaptable to growing conditions with high biochemical indicators of beans at technical maturity. *Vigna* yields are low in dense plantings, especially in the African region (0.025-0.3 t/ha). This is due to the widespread prevalence of pests, plant diseases, reduced soil fertility, drought, improper cultivation techniques, unsuitable varieties, unprofessional seed systems, and various socioeconomic constraints.

Sowing density needs to be regulated to achieve maximum yield, as competition between plants exists after emergence. For the growth and development of leguminous crops such as *Vigna*, sowing density is of particular importance. The results obtained in the studies are consistent with L. Bastos *et al.* (2020), who state that seed weight decreases with increasing sowing rates of *Vigna*. This response is due to competition for light and mineral nutrients, as high plant density reduces the distribution of assimilates. At the same time, varieties with lower plant density formed greater biomass and allocated more assimilate to seeds, leading to higher plant productivity. The obtained results agree with the data of B. Abebe and M. Alemayehu (2022). They argue that a plant spacing of 40×40 cm facilitates light circulation for better photochemical processes, while at high-density plants shade each other. Thus, light slowly disperses to all parts of the plant, especially to the leaves located in the lower part.

It was established that lower plant density increased the number of shoots and beans per plant. These results confirm the findings of N. Tehulie *et al.* (2021). At the same time, studies conducted on soybeans indicate that a high seeding rate delays flowering and reduces the number of shoots (Nleya *et al.,* 2020). Additionally, excessive narrowing or widening of row spacing also leads to a decrease in soybean grain yield. Optimal plant density can vary significantly between regions. For *Vigna* varieties with different morphological plant structures, different optimal densities are required to ensure high seed and bean yields with high-quality indicators. Also, the sowing density of *Vigna* affects the yield of varieties with different maturity groups. Very early maturing varieties such as IT99K573-2-1 and IT98K-205-8 are recommended for the Sahel and semi-arid regions, which helps to avoid the negative consequences of drought (Senyk, 2020).

Plantings with high densities of 62.5 thousand plants/ha (40×40 cm) and 125 thousand plants/ha (40×20 cm) proved to be the most effective for increasing *Vigna* yield in West Africa (Ishikawa *et al.,* 2022). According to the results of the economic efficiency of *Vigna* production in India, it was found that growing the Yardlong variety in open fields at a plant density of 74 thousand plants/ha (45 cm×30 cm) was more profitable (Manjesh *et al.,* 2019). The results of this study showed that at plant densities ranging from 57 to 143 thousand plants/ha, the maximum marketable yield of flat pods was formed in both studied varieties.

Plant density can be regulated not only by the sowing pattern but also by the number of seeds per planting hole. L. Day *et al.* (2022) argue that when sowing one seed per planting hole, the plant develops optimally and, consequently, yields a higher harvest. Similar results were reported by Y. Gnamien *et al.* (2023). Scientists indicate that at a lower density of 62.5 thousand plants/ha (40 cm×40 cm) with 1 plant per hole, a higher yield was obtained compared to a higher density of 250 thousand plants/ha (20 cm×20 cm) and 2 plants per hole. However, these conclusions diverge from the data of M. Duraipandian *et al.* (2022). According to the research of these authors, *Vigna* yield was higher when sowing three seeds per planting hole. This difference could be due to the varying distance between plants.

A higher incidence of common bacterial blight was observed in denser plantings. A similar trend was observed in the studies of R. Lal (2020) and S. Parveen *et al.* (2022), where more rust infection was found at row widths of 45×30 cm and less at 60×75 cm The study conducted by the authors also found that disease spread was slower in the Kafedralna variety compared to U-Cha-Kontou. The results showed that the biological characteristics of the variety, along with ecological and agronomic factors, influence the dynamics of vegetative mass formation and the intensity of plant photosynthesis, determining the rate of growth and development and assimilation processes of the crop. The higher yield of flat pods at a shorter distance between plants in a row was due to an increase in the number of plants per unit area. At the same time, fewer pods were obtained per plant with a lower average mass. A significant impact of plant density on the biochemical indicators of bean varieties and their interaction was established.

CONCLUSIONS

An optimal plant density for bush asparagus beans grown in open ground can be considered to be between 57,000 and 143,000 plants per hectare, resulting in marketable flat pod yields of 5.7-7.7 and 7.4-10.4 tonnes per hectare for the varieties U-Cha-Kontou and Kafedralna, respectively. The Kafedralna variety exhibited higher biochemical indicators, particularly concerning dry matter content (12.7-13.4%), sugar content (3.0-4.0%), vitamin C content (33.6-36.8 mg/100 g fresh weight), and crude protein content (3.2-3.5%) across different stand densities.

A strong correlation was found between biochemical indicators and plant density in the *Vigna* varieties. The dry matter content of the beans had a strong positive correlation with total sugar content (r = 0.92 – 0.98) and a strong negative correlation with plant density (r = -0.88 – 0.91). There was also a strong negative correlation between plant density and total sugars (r = -0.89 – 0.93), crude protein (r = -0.74 – 0.90), and vitamin C (r = -0.67 – 0.84). Future research should focus on using wild forms in *Vigna* breeding to create cultivars resistant to biotic and abiotic factors.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Abebe, B.K., & Alemayehu, M.T. (2022). A review of the nutritional use of cowpea (*Vigna unguiculata* L. Walp) for human and animal diets. *Journal of Agriculture and Food Research*, 10, article number 100383. doi: 10.1016/j.jafr.2022.100383.
[2] Akasapu, K., & Uppaluri, R.V. (2022). Nutritional efficacy based vegetables selection for the development of ready to cook soup mix formulations. In *Agro and food processing technologies* (pp. 157-192). Singapore: Springer. doi: 10.1007/978-981-19-9704-4_9.
[3] Bastos, L.M., *et al.* (2020). Winter wheat yield response to plant density as a function of yield environment and tillering potential: A review and field studies. *Frontiers in Plant Science*, 11, article number 54. doi: 10.3389/fpls.2020.00054.
[4] Bobos, I., Fedosiy, I., Zavadska, O., Komar, O., Tonkha, O., Furdyha, M., & Rucins, A. (2022). Impact of sowing dates on the variability of different traits of fenugreek. *Rural Sustainability Research*, 47(342), 37-46. doi: 10.2478/plua-2022-0006.
[5] Bondarchuk, O.P., Rakhmetov, D.B., Vergun, O.M., & Rakhmetova, S.O. (2022). Morphological features and productive potential of plants of the genus *Vigna Savi*. in the conditions of the Right-Bank Forest-Steppe of Ukraine. *Plant Varieties Studying and Protection*, 18(1), 4-13. doi: 10.21498/2518-1017.18.1.2022.257582.
[6] Bondarenko, G.L., & Yakovenko, K.I. (2001). *Methodology of experimenting in vegetable farming and melon growing*. Kharkiv: Osnova.
[7] Boukar, O., Abberton, M., Oyatomi, O., Togola, A., Tripathi, L., & Fatokun, C. (2020). Introgression breeding in cowpea [*Vigna unguiculata* (L.) Walp.]. *Frontiers in Plant Science*, 11, article number 567425. doi: 10.3389/fpls.2020.567425.
[8] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.
[9] Convention on International Trade in Endangered Species of Wild Fauna and Flora. (1979, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_129#Text.
[10] Day, L., Cakebread, J.A., & Loveday, S.M. (2022). Food proteins from animals and plants: Differences in the nutritional and functional properties. *Trends in Food Science & Technology*, 119, 428-442. doi: 10.1016/j.tifs.2021.12.020.
[11] Dhaliwal, S.K., Talukdar, A., Gautam, A., Sharma, P., Sharma, V., & Kaushik, P. (2020). Developments and prospects in imperative underexploited vegetable legumes breeding: A review. *International Journal of Molecular Sciences*, 21(24), article number 9615. doi: 10.3390/ijms21249615.
[12] Duraipandian, M., Poorani, K.E., Abirami, H., & Anusha, M.B. (2022). *Vigna unguiculata* (L.) Walp: A strategic crop for nutritional security, well being and environmental protection. *Legumes Research,* 2. doi: 10.5772/intechopen.103025.
[13] Fedosiy, I., Bobos, I., Zavadska, O., Komar, O., Tonkha, O., Furdyha, M., Polishchuk, S., Arak, M., & Olt, J. (2022). Research into properties of blue melilot and fenugreek cultivated using different sowing times. *Agronomy Research*, 20(1), 103-123. doi: 10.15159/AR.22.005.
[14] Gnamien, Y.G., Nanti, B.T.J.I., Kouassi, N.J., Kouame, N., Ayolié, K., & Kouadio, Y.J. (2023). Influence of seeding density on agronomic parameters of cowpea (*Vigna unguiculata* L.) accession grown in Daloa, west center of Côte d'Ivoire. *GSC Biological and Pharmaceutical Sciences*, 22(3), 039-048. doi: 10.30574/gscbps.2023.22.3.0102.
[15] Ishikawa, H., Batieno, B.J., Fatokun, C., & Boukar, O. (2022). A high plant density and the split application of chemical fertilizer increased the grain and protein content of cowpea (*Vigna unguiculata*) in Burkina Faso, West Africa. *Agriculture*, 12(2), article number 199. doi: 10.3390/agriculture12020199.
[16] Kebede, E., & Bekeko, Z. (2020). Expounding the production and importance of cowpea (*Vigna unguiculata* (L.) Walp.) in Ethiopia. *Cogent Food & Agriculture*, 6(1), article number 1769805. doi: 10.1080/23311932.2020.1769805.
[17] Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Security*, 12, 871-876. doi: 10.1007/s12571-020-01058-3.

[18] Manjesh, M., Adivappar, N., Srinivasa, V., & Girijesh, G. K. (2019). Effect of plant densities and different environments on productivity and profitability of yardlong bean (*Vigna unguiculata sub sp. sesquipedalis*). *Legume Research-An International Journal*, 42(3), 348-353. doi: 10.18805/LR-3958.

[19] Nleya, T., Schutte, M., Clay, D., Reicks, G., & Mueller, N. (2020). Planting date, cultivar, seed treatment, and seeding rate effects on soybean growth and yield. *Agrosystems, Geosciences & Environment*, 3(1), article number e20045. doi: 10.1002/agg2.20045.

[20] Panzeri, D., Guidi Nissim, W., Labra, M., & Grassi, F. (2022). Revisiting the domestication process of african vigna species (fabaceae): Background, perspectives and challenges. *Plants*, 11(4), article number 532. doi: 10.3390/plants11040532.

[21] Paraschivu, M., Cotuna, O., Sărățeanu, V., Durău, C.C., & Păunescu, R.A. (2021). Microgreens-current status, global market trends and forward statements. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 21(3), 633-639.

[22] Parveen, S., Jamil, A., Pasha, I., & Ahmad, F. (2022). Pulses: A potential source of valuable protein for human diet. *Legumes Research,* 2. doi: 10.5772/intechopen.99980.

[23] Patent No. 230332 "Cowpea *Vigna unguiculata* (L.) *Walp. subsp. sesquipedalis* (L.) Verde.". (2023). Retrieved from http://sort.sops.gov.ua/cultivar/view/20129.

[24] Punniyamoorthy, D., & Jegadeesan, S. (2023). Genetics and genomics of drought and heat tolerance in cowpea, mung bean and black gram. In *Legumes: Physiology and molecular biology of abiotic stress tolerance* (pp. 203-233). *Singapore: Springer*. doi: 10.1007/978-981-19-5817-5_8.

[25] Rao, N.G. (2018). *Statistics for agricultural sciences* (*3rd Ed.*). Hyderabad: BS Publications

[26] Senyk I. I. (2020). Influence of sowing norm and row of row rows on soybean yield in conditions of western forest steppe. *Plant and Soil Science*, 11(3), 43-50. doi: 10.31548/agr2020.03.043.

[27] Tehulie, N.S., Fikadu, T., & Purba, J.H. (2021). Response of mungbean [*Vigna radiata* (L.) Wilczek] varieties to plant spacing under irrigation at Gewane, Northeastern Ethiopia. *Agro Bali: Agricultural Journal*, 4(1), 1-14. doi: 10.37637/ab.v4i1.613.

[28] Verma, S.K., Singh, C.K., Taunk, J., Chandra Joshi, D., Kalia, S., Dey, N., & Singh, A.K. (2022). Vignette of Vigna domestication: From archives to genomics. *Frontiers in Genetics*, 13, article number 960200. doi: 10.3389/fgene.2022.960200.

[29] Vyshnivskyi P. S., & Furman O. V. (2020). Soybean productivity depending on elements of growing technology in the right-bank forest-steppe of Ukraine. *Plant and Soil Science*, 11(1), 13-22. doi: 10.31548/agr2020.01.013.

Дослідження впливу схеми сівби на мінливість ознак сортів вігни спаржевої (*Vigna unguiculata* (L.) Walp. *subsp. sesquipedalis* (L.) Verdc.)

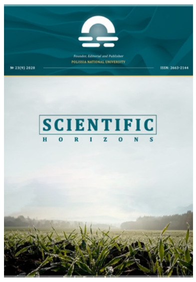
Ірина Бобось
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-5193-7192
Олександр Комар
Кандидат сільськогосподарських наук
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-7511-4190
Іван Федосій
Кандидат сільськогосподарських наук
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-5044-9960
Іванна Гаврись
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-5965-9916
Михайло Ретьман
Кандидат сільськогосподарських наук, старший дослідник
Інститут водних проблем і меліорації Національної академії аграрних наук України
03022, вул. Васильківська, 37, м. Київ, Україна
https://orcid.org/0000-0002-6972-2410

Анотація. Метою досліджень було вивчення особливостей формування врожайності вігни спаржевої з урахуванням впливу елементів технології, що передбачають випробування окремих сортів, на основі зміни густоти стояння посівів. Серед основних методів вивчення даної проблеми є польовий – для дослідження елементів технології вирощування, статистичний – для оцінювання достовірності результатів. У статті представлено результати досліджень схем сівби рослин: 70×10 см, 70×25 см (контроль), 70×40 см, 70×50 см на сортах кущової вігни спаржевої Кафедральна (Україна) та У-тя-Контоу (Китай) (контроль). Густота стояння рослин значно впливає на морфометричні показники та продуктивність досліджуваних сортів. Збільшення густоти посіву до 143 тис. шт./га призвело до значного збільшення (на 2-3 т/га) врожайності бобів-лопаток у обох сортів порівняно з контролем (70×25 см). Найвищу врожайність бобів-лопаток (7,7-10,4 т/га) отримано у сортів за густоти 143 тис. шт./га. Це пов'язано з оптимальним забезпеченням рослин вологою, світлом та поживними речовинами при даній густоті стояння. Сорт Кафедральна загалом характеризувався вищою врожайністю бобів-лопаток, ніж сорт У-тя-Контоу. За меншої густоти посіву (29 тис. шт./га) боби мали більшу масу (120,5-152,0 г), але їх кількість на рослині була меншою. Зменшення густоти стояння до 29 тис. шт./га призводило до збільшення вмісту сухої речовини, цукрів та вітаміну С в бобах. Сорт Кафедральна за всіма схемами сівби мав вищий вміст цих компонентів. Встановлено сильний кореляційний зв'язок між біохімічними показниками та густотою стояння. Оптимальною схемою посіву вігни овочевої для отримання бобів-лопаток в умовах Лісостепу України можна вважати 70×10 см та 70×25 см. Сорт Кафедральна рекомендується для вирощування у відкритому ґрунті з метою отримання бобів-лопаток. Наведені в статті матеріали мають практичну цінність для розробки ефективних технологій вирощування кущових сортів вігни в умовах Лісостепу України для овочевого напрямку

Ключові слова: кущова вігна спаржева; сорт; боби-лопатки; схема сівби; густота рослин; урожайність; біохімічні показники

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 64-72



UDC 635.22:635.032
Doi: 10.48077/scihor9.2024.64

The impact of biologically enhanced fertilisation systems on sweet potato (*Ipomoea batatas*) productivity and quality

Oleksandr Kuts
Doctor of Agricultural Sciences, Senior Research Fellow
State Biotechnological University
61002, 44 Alchevskikh Str., Kharkiv, Ukraine
https://orcid.org/0000-0003-2053-8142

Vasyl Kokoiko*
PhD in Agricultural Sciences, Senior Research Fellow
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences
67667, 24 Mayatska Doroga Str., Khlybodarske Village, Ukraine
https://orcid.org/0000-0002-2528-7920

Svitlana Semenenko
Doctor of Philosophy, Research Associate
Donetsk Research Station of Institute of Vegetable and Melon Growing
of the National Academy of Agrarian Sciences
62478, 5 Prykordonnykiv entry, Selektsiyne Village, Ukraine
https://orcid.org/0000-0002-6606-1151

Ivan Semenenko
PhD in Agricultural Sciences, Senior Researcher
Donetsk Research Station of Institute of Vegetable and Melon Growing
of the National Academy of Agrarian Sciences
62478, 5 Prykordonnykiv entry, Selektsiyne Village, Ukraine
https://orcid.org/0000-0002-6485-0077

Valery Romanov
Postgraduate Student
Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences
62478, 1 Institutska Str., Selektsiyne Village, Ukraine
https://orcid.org/0009-0008-7407-4084

Article's History:
Received: 01.05.2024
Revised: 09.08.2024
Accepted: 28.08.2024

Abstract. The relevance of this research lies in determining the potential use of microbial preparations with varying functionalities to optimise the nutrition and stimulate the growth processes of sweet potato plants, as well as the synergistic effects of different preparations. The developed nutrient optimisation systems are designed to restore soil

Suggested Citation:
Kuts, O., Kokoiko, V., Semenenko, S., Semenenko I., & Romanov, V. (2024). The impact of biologically enhanced fertilisation systems on sweet potato (*Ipomoea batatas*) productivity and quality. *Scientific Horizons*, 27(9), 64-72. doi: 10.48077/scihor9.2024.64.

*Corresponding author

fertility, reduce the anthropogenic load on vegetable agroecosystems, produce high-quality yields, and increase sweet potato productivity without relying on energy-intensive production methods. This study aimed to investigate the impact of biological fertilisation systems on the biometric parameters, yield, and quality of sweet potato tubers. The research programme was implemented through field, statistical, computational-analytical, and laboratory methods. An increase in the number (7.33-9.83 per plant) and length (175.55-184.89 cm) of shoots was observed with the application of the biological preparations "Groundfix" + "Humifriend", "Help-Rost for vegetables", and "Mycofriend". The use of foliar fertilisations in three terms of "Help-Rost for vegetables", both in combination with "Mycofriend" during fertigation and with the foliar fertilisation "Humifriend", resulted in maximal leaf mass formation on the plant (2.41-2.56 m^2/ha in the third decade of June and 23.12-27.45 m^2/ha in the third decade of August). Microbial preparations significantly increased net photosynthetic productivity by 28.9-63.9% during the period from the third decade of June to the third decade of July, especially when "Groundfix" and "Humifriend", or "Humifriend" and "Help-Rost for vegetables" were combined. A substantial commercial yield of tubers (17.4 t/ha) was achieved by applying the mycorrhizal preparation "Humifriend" (1.5 L/ha) in the first fertigation and conducting three foliar applications of "Help-Rost for vegetables" at 2.0 L/ha. Treatments involving biological preparations demonstrated improvements in key biochemical parameters. The use of "Groundfix" + "Humifriend" and "Humifriend" + "Help-Rost for vegetables" resulted in a decrease in nitrate levels in the produce. The authors hypothesise that the optimal supply of micronutrients, particularly iron, manganese, and molybdenum, enhances the transformation of nitrates into organic matter. This research provides valuable insights for the rational application of biologically enhanced fertilisation systems to achieve high yields and quality of sweet potato tubers in various agricultural settings

Keywords: *Ipomoea batatas* L.; biopreparations; irrigation; photosynthetic productivity; yield

INTRODUCTION

Considering the fact that sweet potato tubers are rich in glucose, protein, minerals, and vitamins, making them a valuable product for dietary nutrition (especially for individuals with diabetes), the increase in crop productivity is associated with rising levels of mineral fertilisers and phytopharmacological agents. Such technological approaches, however, can lead to a decline in soil fertility, heightened pollution of agrocenoses, and the introduction of contaminants into agricultural products. As highlighted by K. Nadarajah and N.S.N. Abdul Rahman (2023), in developed countries, despite the use of high levels of mineral fertilisers, a significant direction for the development of the agricultural sector is the biological enhancement of production processes. The biological enhancement of agricultural production is fundamentally more than merely forgoing mineral fertilisers and protective agents; it represents a balanced complex of technological, agrochemical, and biological measures, combined with integrated pest management and scientifically grounded crop rotations.

A key element of biologically enhanced agriculture is the widespread use of microbial preparations to optimise plant nutrition. These preparations activate a range of physiological processes within the soil and plant, such as nitrogen fixation, mobilisation of soil-bound phosphorus and potassium, and growth regulation. Each of these processes has the potential to significantly impact crop yield and quality. For example, according to M. Lopes *et al.* (2021), the use of biopreparations containing associative nitrogen-fixing bacteria can provide plants with an additional 20-50 kg/ha of nitrogen. Nitrogen-fixing microorganisms can fix 40-300 kg/ha of nitrogen annually from the atmosphere, without causing environmental pollution and with minimal energy requirements. Data from R. Gupta *et al.* (2021) reveals that globally, approximately 35 million tonnes of nitrogen are added to soils annually through mineral fertilisers, while plants absorb around 75 million tonnes during the same period. The difference between these figures is largely attributed to the activity of soil nitrogen-fixing microbes.

D. Minemba *et al.* (2020 highlight the potential for improving the phosphorus regime of the soil through the use of microbial preparations containing phosphorus-mobilising microorganisms. These preparations facilitate the conversion of poorly soluble soil phosphates into more soluble forms that are readily available to plants. To transform phosphorus-containing compounds in the soil and release mobile forms of phosphorus, fungi, actinomycetes, and spore-forming bacteria from the genera *Pseudomonas*, Micrococcus, Corinebacterium, and *Alcaligenes* can be effectively utilised.

The primary aim of using microbial preparations in the cultivation of agricultural plants is to establish a specific pool of microorganisms in the soil rhizosphere. According to the opinion of the authors, healthy microflora contributes to the creation of comfortable conditions for plant nutrition and the trophic relationship between soil and plant. According to G. Koskey *et al.* (2021) and P. Trivedi *et al.* (2020), microbial communities facilitate the contact between plant root systems and distant soil aggregates, which contain absorbed nutrient elements. This interaction occurs through chains of bacterial cells, hyphae, and the mycelium of microscopic fungi, among other means. Consequently, the total absorption capacity of microbial-plant associations significantly exceeds that of the plant roots alone. Research by Y. Syromyatnikov *et al.* (2022; 2023) indicate that the quantitative and qualitative composition of soil microbial communities is influenced by various technological practices, particularly irrigation, soil cultivation, and fertiliser use.

An important aspect in recent decades has been the development and implementation of new multifunctional microbial preparations produced from highly effective strains of associative microorganisms that do not adversely affect the natural environment. The use of microbial preparations does not require high energy and material costs, especially when compared to the application of mineral fertilisers or soil cultivation. As noted in the research by L. Gonçalves *et al.* (2023), the productivity of sweet potatoes can be enhanced by using microbial preparations with various functional types of microorganisms to optimise nutrition. According to I. Khan (2023), microbial preparations are effective in combination with both green manures or organic fertilisers and mineral fertilisers. The application of microbial preparations not only increases yield but also improves the quality composition of tubers, including an increase in the dry matter content, β-carotene, and starch levels in the tubers.

Thus, in the context of biological enhancement for sweet potato cultivation, various functional microbial preparations can be utilised to optimise plant nutrition. These preparations enhance processes such as associative nitrogen fixation, phosphorus and potassium mobilisation, the decomposition of plant residues in the soil, and the reduction of pathogenic pressure, among others. This study aimed to establish the impact of different nutrient systems on the biometric parameters of the plants, as well as the yield and quality of sweet potato tubers under irrigation conditions.

MATERIALS AND METHODS

The research was conducted from 2021 to 2023 at the Institute of Vegetable and Melon growing of the National Academy of Agrarian Sciences of Ukraine. The experiments were carried out on a typical low-humus light loamy chernozem (the arable layer contained 4.3% humus, 139 mg/kg of hydrolysable nitrogen, 120 mg/kg of mobile phosphorus, and 93 mg/kg of exchangeable potassium; pH of the salt extract was 5.7; hydrolytic acidity was 2.8 meq per 100 g of soil). The climatic features of the research area include an average annual precipitation of 471 mm, with 57-73 mm of precipitation falling in June and July; relatively dry conditions were formed in early spring and autumn (Archive of meteorological data, n.d.). The research was conducted according to the generally accepted methodology (Bondarenko & Yakovenko, 2001). The total plot area for the experiment was 33.6 m^2, with a plot area of 21 m^2, and the experiments were replicated three times. In the experiments, the sweet potato variety Admiral was grown under drip irrigation and soil mulching with a black polyethene film 120 microns thick, using a planting scheme of (100+40)×25 cm.

The following microbial preparations were used in the study: "Mycofriend" is a microbial preparation containing a complex of agronomically valuable microorganisms, including mycorrhizal fungi such as *Glomus* sp.; rhizospheric microorganisms that enhance mycorrhiza formation (*Trichoderma harzianum, Pseudomonas fluorescens, Streptomyces* sp.); phosphate-mobilising bacteria; and bacteria with fungicidal and bactericidal properties (*Bacillus subtilis, Bacillus megaterium var. phosphaticum, Bacillus muciloginosus, Enterobacter* sp.). The total number of viable cells is not less than 1.0×10^8 CFU/g.

"Humifriend" is a comprehensive fertiliser based on potassium humate, containing microorganisms, humic and fulvic acids, a complex of microorganisms with fungicidal properties, amino acids, peptides, succinic acid, and micronutrients. It accelerates the uptake of nutrients by plants, stimulates the growth and development of the root system and the above-ground parts of the plants, and enhances plant resistance to frost, drought, high temperatures, and moisture deficiency. Additionally, it increases the yield and quality of agricultural products, activates the synthesis of proteins, carbohydrates, and vitamins in plants, improves soil health, and restores its fertility (Brochure about HUMIFRIEND, n.d.).

"Groundfix" is a soil bio-fertiliser that contains cells of the bacteria *Bacillussubtilis, Bacillusmegateriumvar. phosphaticum, Azotobacter chroococcum, Enterobacter,* and *Paenibacillus polymyxa*. The total number of viable cells ranges from (0.5 – 1.5)×10^9 CFU/cm^3. This bio-fertiliser enhances the mobility of phosphorus and the availability of potassium from the soil and mineral fertilisers, prolongs the availability of nutrients, improves the biological activity of the soil, and suppresses the development of phytopathogens (Brochure about GROUNDFIX, n.d.).

"Azotophyt" is a microbial preparation containing cells of the natural nitrogen-fixing bacterium *Azotobacter chroococcum*, along with biologically active products produced by the bacteria (amino acids, vitamins, phytohormones, and fungicidal substances). The total number of viable microorganisms in the product is no less than 1×10^{10} CFU/cm^3 (Brochure about AZOTOPHYT, n.d.).

"Help-Rost for vegetable plants" is used in agriculture for fertilising vegetable crops to improve the yield, marketability, and flavour qualities of the final product. "Help-Rost for vegetable plants" is classified as an organo-mineral fertiliser, containing macro- and micronutrients, amino acids, and more (Brochure about HELP-ROST, n.d.).

Foliar applications of microbial preparations were conducted in three terms: the first treatment was 30 days after transplanting the seedlings, and subsequent treatments were carried out at intervals of 25 days (Table 1).

Table 1. Biometric parameters of sweet potato plants of the Admiral variety

No.	Application of microbial preparations
1	Control (without microbial preparations)
2	Mycofriend application in the first fertigation (1 L/ha)
3	Mycofriend application in the first fertigation (1 L/ha) + Help-Rost for vegetable, foliar application in 3 terms (2 L/ha each)
4	Help-Rost for vegetable, foliar application in 3 terms (2 L/ha each)
5	Groundfix applied in the first fertigation (5 L/ha) + Humifriend, foliar application in 3 terms (1.5 L/ha each)
6	Humifriend, foliar application in 3 terms (1.5 L/ha each) + Help-Rost for vegetables, foliar application in 3 terms (2 L/ha each)

Source: *compiled by the authors*

At the end of the growing season, the content of the following was determined: dry matter according to DSTU 7804:2015 (2016), vitamin C according to DSTU 7803:2015 (2016), total sugar according to DSTU 4954:2008 (2009), nitrates according to DSTU 4948:2008 (2009), and starch (Kucherenko *et al.,* 2002). During the research, the authors adhered to the standards of the Convention on Biological Diversity (n.d.) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (n.d.).

RESULTS AND DISCUSSION

Throughout the years of research, the biometric parameters of the sweet potato plants during the first decade of July did not differ significantly, except for the control variant (without fertilisers), where the lowest number of shoots was recorded at 4.97 shoots per plant, with an average shoot length of 96.2 cm. In the second term (the second decade of August), the most positive impact on the biometric parameters of the sweet potato plants was observed with the application of the preparations "Groundfix" + "Humifriend", which resulted in an average number of shoots per plant of 7.33 and an average shoot length of 184.9 cm. With the preparation of "Help-Rost for vegetables", an increase in the average number of shoots to 9.83 and an average shoot length of 183.6 cm was noted. The variant using "Mycofriend" demonstrated a positive effect as well, with an average of 8.33 shoots and an average shoot length of 175.6 cm (Table 2).

Table 2. Biometric parameters of sweet potato plants of the Admiral variety (average for 2021-2023)

Fertilisation system	First term (1st decade of July)		Second term (1st decade of August)	
	Shoots (pcs)	Length (cm)	Shoots (pcs)	Length (cm)
Control	4.97	96.2	7.58	128.4
Mycofriend (1 L/ha)	5.97	128.5	8.33	175.6
Mycofriend (1 L/ha) + Help-Rost for vegetables (2 L/ha)	6.13	110.2	6.33	133.1
Help-Rost for vegetables (2 L/ha)	6.30	111.7	9.83	183.6
Groundfix (5 L/ha) + Humifriend (1.5 L/ha)	5.63	118.9	7.33	185.0
Humifriend (1.5 L/ha) + Help-Rost for vegetables (2 L/ha)	5.80	100.7	7.83	148.2
$LSD_{0,95}$	0.9	16.7	1.2	24.7

Source: *compiled by the authors*

It has been noted that the maximum impact on leaf formation throughout the entire growing season of sweet potato plants is achieved through the application of foliar fertilisations with "Help-Rost for vegetables" in three terms, both in combination with "Mycofriend" during fertigation and with "Humifriend" for foliar application in three terms (Fig. 1). In this context, the leaf area varied from 2.41 to 2.56 m^2/ha in the third decade of June, from 19.47 to 20.45 m^2/ha in the third decade of July, and from 23.12 to 27.45 m^2/ha in the third decade of August. It is important to note that the use of "Help-Rost for vegetables" alone resulted in significantly lower leaf area values, indicating a certain synergistic effect of the various preparations on this parameter. Mycorrhisation of the sweet potato roots also positively influences the increase in leaf area. Specifically, the application of "Mycofriend" during the first fertigation resulted in a consistent increase in leaf area compared to the control, ranging from 23.5% to 28.5%.

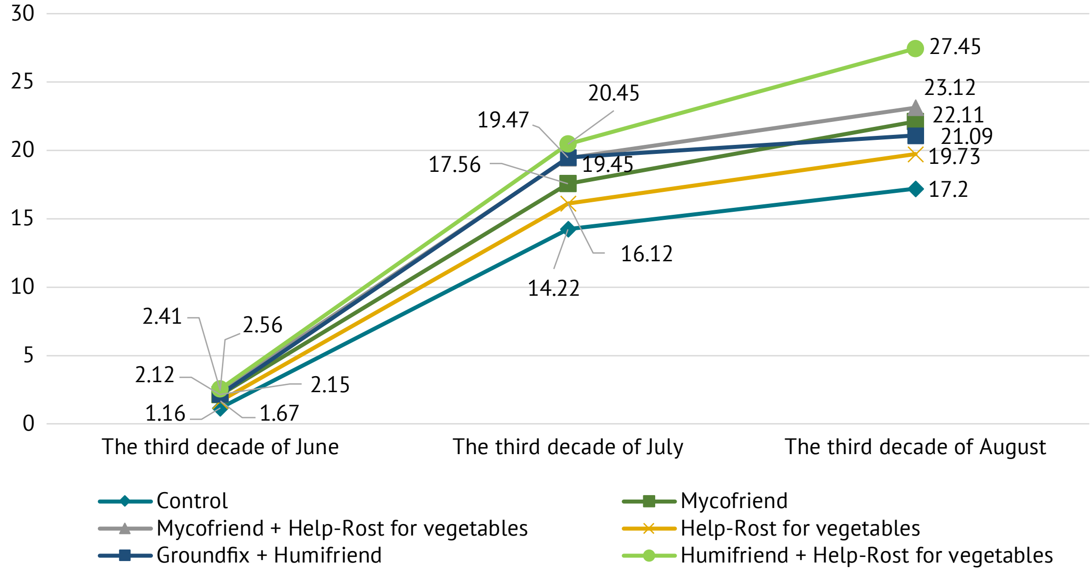


***Figure 1**. Leaf area of sweet potato plants, thousand m²/ha (average for 2021-2023)*
***Source:** compiled by the authors*

The maximum growth of leaf mass was observed in June and July. During the tuber growth period (from the third decade of July to the third decade of August), the increase in leaf area occurs very slowly, which is associated with the redistribution of organic matter synthesised by the plant towards tuber formation. Depending on the rate of leaf development in sweet potato plants, the net productivity of photosynthesis also varies. The parameter of net photosynthetic productivity significantly depends on the level of accumulated dry biomass, which is influenced by technological and agro-meteorological factors, as well as the biological characteristics of the crop and variety.

It has been established that optimising plant nutrition through the use of various types of microbial preparations contributes to an increase in net photosynthetic productivity during the period from the third decade of June to the third decade of July, by 28.9% to 63.9% (Figure 2). The highest levels were observed with the application of "Groundfix" and "Humifriend" (25.8 g/m^2 per day), as well as with "Humifriend" and "Help-Rost for vegetables" (27.2 g/ m^2 per day).

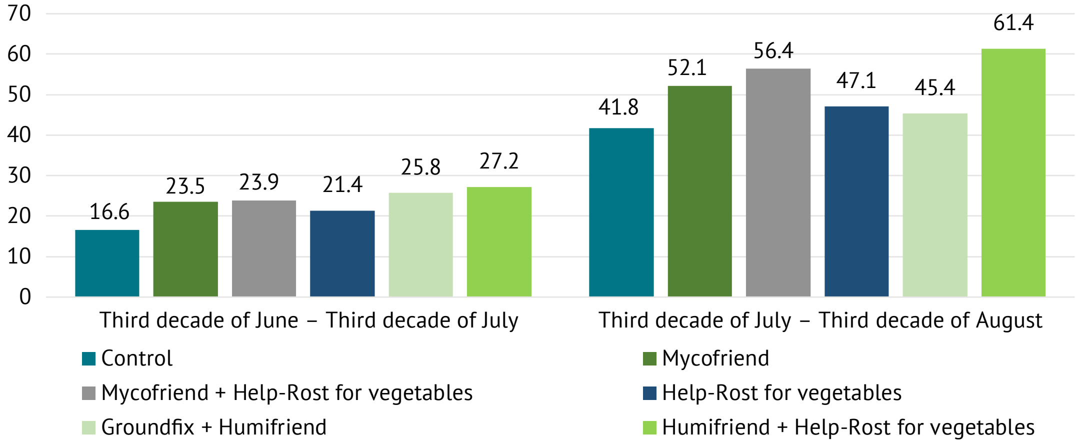


***Figure 2**. Net photosynthetic productivity of sweet potato plants, g/m² per day (average for 2021-2023)*
***Source:** compiled by the authors*

In the later period (from the third decade of July to the third decade of August), the use of microbial preparations resulted in an increase in net photosynthetic productivity by 8.6% to 46.9%. Significantly high values relative to the control group were observed with the application of "Mycofriend" (52.1 g/m^2 per day), "Mycofriend" combined with "Help-Rost for vegetables" (56.4 g/m^2 per day), and "Humifriend" together with "Help-Rost for vegetables" (61.4 g/m^2 per day). Throughout the years of research, microbial preparations for optimising plant nutrition have led to an increase in sweet potato yields (Table 3). The maximum productivity of 17.4 t/ha was achieved with the application of the mycorrhiza-forming preparation "Humifriend" (1.5 L/ha) during the first fertigation, alongside three foliar applications of "Help-Rost for vegetables" at 2.0 L/ha.

***Table 3**. Indicators of marketable yield of sweet potato tubers of the Admiral variety, t/ha*

Fertilisation system	Tuber yield, t/ha			
	2021	2022	2023	Average for 2021-2023
Control	15.9	9.2	8.6	11.2
Mycofriend (1 L/ha)	18.1	9.6	14.7	14.1
Mycofriend (1 L/ha) + Help-Rost for vegetables (2 L/ha)	19.1	10.0	15.4	14.8
Help-Rost for vegetables (2 L/ha)	17.6	10.4	12.2	13.4
Groundfix (5 L/ha) + Humifriend (1.5 L/ha)	18.1	10.7	13.7	14.1
Humifriend (1.5 L/ha) + Help-Rost for vegetables (2 L/ha)	22.7	13.6	16.1	17.4
$LSD_{0.95}$	1.67	0.95	1.21	1.3

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

The high yield of marketable tubers is achieved through the combined use of the preparations "Groundfix" and "Humifriend", resulting in a yield of 14.1 t/ha. The combination of the biological preparations "Mycofriend" and "Help-Rost for vegetables" leads to a sweet potato yield of 14.8 t/ha. It is noted that no synergistic effect from the actions of these preparations was observed, as the differences between the treatments with the individual applications of these microbial preparations were not significant, with no substantial difference compared to the treatment involving only "Help-Rost for vegetables" (13.4 t/ha) and the application of "Mycofriend" at 1 L/ha (14.1 t/ha). Regarding the influence on the biochemical composition of the tubers, the action of microbial preparations was ambiguous (Table 4). A positive trend was observed with the use of "Mycofriend" and the combined application of "Mycofriend" and "Help-Rost for vegetables", which increased the dry matter content in the tubers to 19.07-19.12%.

***Table 4**. Influence of microbial preparations on the quality of sweet potato tubers of the Admiral variety (average for 2021-2023)*

Fertilisation system	The content in tubers:					
	Dry matter (%)	Starch (%)	Total sugar (%)	Vitamin C (mg/100 g)	Carotene (mg/100 g)	Nitrates (mg/kg)
Control	18.66	12.55	3.38	5.51	2.55	165.7
Mycofriend (1 L/ha)	19.07	13.46	3.56	5.27	6.02	101.22
Mycofriend (1 L/ha) + Help-Rost for vegetables (2 L/ha)	19.12	13.97	3.73	4.75	4.09	100.6
Help-Rost for vegetables (2 L/ha)	18.69	13.17	3.65	4.28	5.44	90.3
Groundfix (5 L/ha) + Humifriend (1.5 L/ha)	18.66	12.97	3.85	5.21	5.00	76.0
Humifriend (1.5 L/ha) + Help-Rost for vegetables (2 L/ha)	18.85	14.45	3.90	4.61	4.76	55.5
$LSD_{0.95}$	0.94	0.66	0.18	0.25	0.20	12.81

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

The combined application of "Groundfix" + "Humifriend" and "Humifriend" + "Help-Rost for vegetables" demonstrates a positive trend in the increase of total sugar content in sweet potato tubers, ranging from 3.85% to 3.90%, compared to a control value of 3.38%. A significant increase in starch content in the tubers is achieved with the application of "Groundfix" + "Humifriend" (14.45%), "Mycofriend" (13.46%), and the combined use of "Mycofriend" + "Help-Rost for vegetables" (13.97%). In contrast, a decrease in starch content is noted in the control (12.55%) and with the combined application of "Groundfix" + "Humifriend" (12.97%). Across all variants of microbial preparation applications, an increase in carotene content (4.09-6.02 mg) is observed compared to the control (2.55 mg).

The use of various microbial preparations results in a significant reduction in the nitrate content of sweet potato tubers, bringing levels down to 55.5-101.2 mg/kg of raw mass. Preliminary data indicate a positive effect on reducing nitrate levels in the produce with the application of "Groundfix" + "Humifriend" and "Humifriend" + "Help-Rost for vegetables". The authors believe that the transformation of nitrates into organic matter is enhanced when an optimal level of micronutrient availability is established for the plants, particularly for iron, manganese, and molybdenum.

In conclusion, it is important to note that microbial preparations, within the context of biologically enhanced processes of cultivating crops, provide an effective alternative to the application of mineral fertilizers. They enhance crop yields, improve product quality, and reduce the chemical burden on agrobiocenoses. In this research, the use of microbial preparations with different functional actions proved to be effective for sweet potato cultivation. Thus, with the use of preparations with mycorrhizal-forming agents (Mycofriend), an improvement in the biometric parameters of sweet potato plants, an increase in leaf area and net photosynthetic productivity was noted, which coincides with the results of studies by M. Sakha *et al.* (2019), where the application of preparations with mycorrhizal-forming microorganisms also provided high efficiency on the growth and productivity of sweet potato.

Another key aspect of biologically enhanced sweet potato fertilisation technology is the use of preparations containing rhizospheric microorganisms, whose actions are directed towards various processes: associative nitrogen fixation, mobilisation of readily available forms of phosphorus and potassium in the arable layer of soil, and stimulation of root system development, among others. In the current studies, the application of the microbial preparation Groundfix, which contains both rhizospheric nitrogen-fixing and phosphorus-mobilising microorganisms, combined with the stimulation of growth processes through foliar applications with humic fertilizers, resulted in a 25.9% increase in sweet potato yield, an increase in total sugar content, and a reduction in nitrate levels in the tubers. Similar results were obtained in research conducted by Colombian scientists A. Ariza-Gonzáles *et al.* (2019), where the use of microbial preparations containing *Pseudomonas denitrificans* and *Azotobacter vinelandii* led to increased yields and higher dry matter and sugar content in the tubers. This approach effectively forms a technology that utilises agrocenoses with fully autonomous and regenerative systems for optimising nutrient supply, where a significant portion of the nutrients is supplied to the plants through biological processes such as nitrogen fixation, mineral weathering, and the decomposition of plant residues. These findings align with the practical results of other researchers. According to L. Wang *et al.* (2022), atmospheric nitrogen fixation by free-living diazotrophs can meet 20-40% of the nitrogen requirements of sweet potato plants. Moreover, biological nitrogen fixation is considered more environmentally friendly and economically efficient.

The current research also noted a lack of synergistic effects with certain combinations of preparations. Specifically, no significant increase in yield was observed from the combination of applying "Mycofriend" during fertigation and foliar fertilisation with "Help-Rost for vegetables" compared to the individual use of these preparations. The authors suggest that these products affect the same physiological processes in plants (such as nutrient absorption and growth stimulation), which results in only modest yield increases from their combined application.

CONCLUSIONS

For the Admiral variety of sweet potato, the use of the biological preparations "Groundfix" + "Humifriend", "Help-Rost for vegetables", and "Mycofriend" resulted in an increase in the number of shoots (ranging from 7.33 to 9.83) and their length (from 175.6 to 184.9 cm). The application of foliar fertilisation with "Help-Rost for vegetables" over three terms, both in combination with "Mycofriend" during fertigation and with "Humifriend", maximised leaf mass formation in the plants (measuring 2.41-2.56 m^2/ha in the third decade of June and 23.12-27.45 m^2/ha in the third decade of August). The use of "Mycofriend" during fertigation showed a stable increase in leaf area relative to the control, ranging from 23.5% to 28.5%. Optimising plant nutrition through the use of various microbial preparations contributed to an increase in net photosynthetic productivity during the period from the third decade of June to the third decade of July, achieving an increase of 28.9% to 63.9%, particularly with the use of "Groundfix" and "Humifriend" (25.8 g/ m^2 per day) and "Humifriend" combined with "Help-Rost for vegetables" (27.2 g/m^2 per day).

A significant commercial yield of sweet potato tubers (17.4 t/ha) was achieved through the application of the mycorrhizal-forming preparation "Humifriend" (1.5 L/ha) during the first fertigation, alongside foliar application with "Help-Rost for vegetables" at a rate of 2.0 L/ha over three terms. The use of biological preparations increased key biochemical indicators. Additionally, a positive effect was noted in the reduction of nitrate levels in the produce when using "Groundfix" combined with "Humifriend" and "Humifriend" with "Help-Rost for vegetables". According to the authors of this article, the transformation of nitrates into organic matter is enhanced when the optimal level of plant supply of trace elements (especially iron, manganese, and molybdenum) is formed. Future research in this area will focus on assessing the effectiveness of the comprehensive use of microbial preparations by determining the synergy between their actions, as well as examining the impact of various microbial preparations on the agrochemical and microbiological parameters of the soil.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Archive of meteorological data. (n.d.). Retrieved from https://meteopost.com/weather/archive/.

[2] Ariza-Gonzáles, A., Jarma-Orozco, A., Pérez-Pazos J., & Sánchez-López, D. (2019). Effect of growth promoting bacteria on the fertilization of sweet potatoes (*Ipomoea batatas* Lam). *Revista Temas Agrarios,* 24(2), 147-157. doi: 10.21897/rta.v24i2.2116.

[3] Bondarenko, G.L., & Yakovenko, K.I. (Ed). (2001). *Methodology of research work in vegetable growing and melon growing*. Kharkiv: Osnova.

[4] Brochure about AZOTOPHYT. (n.d.). Retrieved from https://btu-center.com/en/industrial-sector/crop-production/b-oaktivatori/azotofit-r/.

[5] Brochure about GROUNDFIX (n.d.). Retrieved from https://btu-center.com/en/industrial-sector/crop-production/nutrition/groundfix/.

[6] Brochure about HELP-ROST (n.d.). Retrieved from https://btu-center.com/promisloviy-sektor/roslinnitstvo/mikroelementi/helprost-khelprost-dlya-ovochevikh-kultur-/.

[7] Brochure about HUMIFRIEND (n.d.). Retrieved from https://btu-center.com/en/industrial-sector/crop-production/humates/humifriend/.

[8] Convention on Biological Diversity (n.d.). Retrieved from https://www.cbd.int/convention/.

[9] Convention on International Trade in Endangered Species of Wild Fauna and Flora (n.d.). Retrieved from https://cites.org/eng/disc/what.php.

[10] DSTU 4948:2008. (2009). *Fruits, vegetables and their processing products. Methods of determination of nitrate content. With correction*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=83097.

[11] DSTU 4954:2008. (2009). *Products of fruit and vegetable processing. Methods of determination of sugars*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=74270.

[12] DSTU 7803:2015. (2016). *Products of fruit and vegetable processing. Methods of determination of vitamin C*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=80801.

[13] DSTU 7804:2015. (2016). *Fruit and vegetable processing products. Methods of determining dry substances or moisture*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=80802.

[14] Gonçalves, L.F.S., Rossa, Ü.B., Gomes, E.N., Vischetti, C., & Casucci, C (2023). Use of different types of mineral fertilizers in the production of BRS Amélia Ipomoea potatoes in vertical cultivation. *Revista de Ciências Agroveterinárias*, 22(3), 494-503. doi: 10.5965/223811712232023494.

[15] Gupta, R., Anand, G., Gaur, R., & Yadav, D. (2021). Plant-microbiome interactions for sustainable agriculture: A review. *Physiology and Molecular Biology of Plants,* 27, 165-179. doi: 10.1007/s12298-021-00927-1.

[16] Khan, I. (2023). Sweet potato cultivation of a multicomponent microbiological soil inoculant. *Journal of Environmental & Analytical Toxicology*, 13(1), article number 698.

[17] Koskey, G., Mburu, S.W., Awino, R., Njeru, E.M., & Maingi, J.M. (2021). Potential use of beneficial microorganisms for soil amelioration, phytopathogen biocontrol, and sustainable crop production in smallholder agroecosystems. *Frontiers in Sustainable Food Systems*, 5, article number 130. doi: 10.3389/fsufs.2021.606308.

[18] Kucherenko, M.E., Babenyuk, Yu.D., & Voitsitskyi, V.M. (2002). *Modern methods of biochemical research*. Kyiv: Phytosocial Center.

[19] Lopes, M.J.D.S., Dias-Filho, M.B., & Gurgel, E.S.C. (2021). Successful plant growth-promoting microbes: Inoculation methods and abiotic factors. *Frontiers in Sustainable Food Systems*, 5, article number 606454. doi: 10.3389/fsufs.2021.606454.

[20] Minemba, D., Martin, B.C., Ryan, M.H., Veneklaas, E.J., & Gleeson, D.B. (2020). Phosphate fertiliser alters carboxylates and bacterial communities in sweet potato (*Ipomoea batatas* (L.) Lam.) rhizosheaths. *Plant and Soil*, 454, 245-260. doi: 10.1007/s11104-020-04646-6.

[21] Nadarajah, K., & Abdul Rahman, N.S.N. (2023). The microbial connection to sustainable agriculture. *Plants,* 12(12), article number 2307. doi: 10.3390/plants12122307.

[22] Sakha, M.A., Jefwa, J., & Gweyi-Onyango, J.P. (2019). Effects of *Arbuscular Mycorrhizal* fungal inoculation on growth and yield of two sweet potato varieties. *Journal of Agriculture and Ecology Research International*, 18(3), 1-8. doi: 10.9734/jaeri/2019/v18i330063.

[23] Syromyatnikov, Y., Orekhovskaya, A., Klyosov, D., Vodolazskaya, N., Syromyatnikov, P., & Sementsov, V. (2022). Field tests of the experimental installation for soil processing. *Journal of Terramechanics*, 100, 81-86. doi: 10.1016/j.jterra.2022.01.004.

[24] Syromyatnikov, Y., Semenenko, I., Maksimovich, K., Troyanovskaya, I., Karnaukhov, A., Orekhovskaya, A., & Voinash, S. (2023). Influence of agrotechnical practices and sowing time in various weather on soybean yield. *Acta Technologica Agriculturae*, 26(1), 9-16. doi: 10.2478/ata-2023-0002.

[25] Trivedi, P., Leach, J.E., Tringe, S.G., Sa, T., & Singh, B.K. (2020). Plant-microbiome interactions: From community assembly to plant health. *Nature Reviews Microbiology*, 18, 607-621. doi: 10.1038/s41579-020-0412-1.

[26] Wang, L., Zhang, H., Wang, J., & Zhang, Y. (2022). Long-term fertilization with high nitrogen rates decreased diversity and stability of diazotroph communities in soils of sweet potato. *Applied Soil Ecology*, 170, article number 104266. doi: 10.1016/j.apsoil.2021.104266.

Вплив біологізованої системи удобрення на формування продуктивності та якості батату (*Ipomoea batatas*)

Олександр Куц
Доктор сільськогосподарських наук, старший науковий співробітник
Державний біотехнологічний університет
61002, вул. Алчевських, 44, м. Харків, Україна
https://orcid.org/0000-0003-2053-8142

Василь Кокойко
Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут кліматично орієнтованого сільського господарства Національної академії аграрних наук
67667, вул. Маяцька дорога, 24, смт. Хлібодарське, Україна
https://orcid.org/0000-0002-2528-7920

Світлана Семененко
Доктор філософії, науковий співробітник
Донецька дослідна станція Інституту овочівництва і баштанництва Національної академії аграрних наук
62478, в'їзд Прикордонників, 5, с. Селекційне, Україна
https://orcid.org/0000-0002-6606-1151

Іван Семененко
Кандидат сільськогосподарських наук, старший дослідник
Донецька дослідна станція Інституту овочівництва і баштанництва Національної академії аграрних наук
62478, в'їзд Прикордонників, 5, с. Селекційне, Україна
https://orcid.org/0000-0002-6485-0077

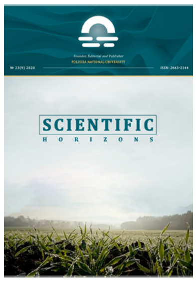
Валерій Романов
Аспірант
Інститут овочівництва і баштанництва Національної академії аграрних наук
62478, вул. Інститутська,1, с. Селекційне, Україна
https://orcid.org/0009-0008-7407-4084

Анотація. Актуальність проведених досліджень полягає у визначенні можливості використання мікробних препаратів різного функціоналу для оптимізації живлення та стимуляції ростових процесів рослин батату, синергізму дії різних препаратів. Розроблені системи оптимізації живлення забезпечать відтворення родючості ґрунту, зниження техногенного навантаження на овочеві агроценози, отримання продукції високої якості, збільшення продуктивності батату без використання високоенергоємних засобів виробництва. Метою проведення дослідження було вивчення впливу біологізованих систем удобрення на біометричні параметри, врожайність та якість бульб батату. Програму досліджень виконано за рахунок проведення польових, статистичних, розрахунково-аналітичних та лабораторних методів. Встановлено збільшення кількості (7,33-9,83 шт.) та довжини (175,55-184,89 см.) пагонів за використання біологічних препаратів «Граундфікс» + «Гуміфренд», «HelpRost для овочевих» та «Мікофренд». Використання позакореневих підживлень в три строки «HelpRost для овочевих» як в поєднанні з використанням «Мікофренду» у фертигацію, так і з позакореневими підживленнями «Гуміфренд» забезпечує максимальне формування маси листків на рослині (2,41-2,56 м^2/га в третій декаді червня та 23,12-27,45 м^2/га , в третій декаді серпня). Мікробні препарати підвищують чисту продуктивність фотосинтезу в період третя декада червня – третя декада липня на 28,9-63,9 %, особливо за використання «Граундфіксу» та «Гуміфренду», «Гуміфренду» та «HelpRost для овочевих». Значну товарну урожайність бульб (17,4 т/га) отримана за внесення в першу фертигацію мікоризоформуючого препарату «Гуміфренд» (1,5 л/га) та проведення позакореневих підживлень в три строки «HelpRost для овочевих» по 2,0 л/га. На варіантах із застосуванням біологічних препаратів відзначено підвищення основних біохімічних показників. Встановлено позитивну дію на зниження рівня нітратів в продукції за використання «Граундфікс» + «Гуміфренд» та «Гуміфренд + «HelpRost для овочевих». На нашу думку, за формування оптимального рівня забезпеченості рослин мікроелементами (в особливості залізо, марганець, молібден) трансформація нітратів в органічну речовину посилюється. Практична цінність полягає у отриманні результатів для раціонального застосування біологізованої системи удобрення для забезпечення високої врожайності та якості бульб батату в господарствах різних форм власності

Ключові слова: *Ipomoea batatas* L; біопрепарати; зрошення; продуктивність фотосинтезу; урожайність

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 73-85



UDC: 633.1:631.54
Doi: 10.48077/scihor9.2024.73

Application of biostimulants in agriculture: Effects on plant growth and yield

Viktoriia Skliar*
Doctor of Biology, Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0002-1301-7384
Kateryna Kyrylchuk
PhD in Biology, Associate Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0001-9968-4833
Inna Zubtsova
PhD in Biology, Associate Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0001-6339-931X
Anna Novikova
PhD in Agriculture, Senior Lecturer
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0003-1515-5593
Svitlana Yaroshchuk
PhD in Agriculture Science, Associate Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0001-6125-1979

Article's History:
Received: 13.03.2024
Revised: 05.08.2024
Accepted: 28.08.2024

Abstract. The study aimed to evaluate the effectiveness of the use of biostimulants, such as humic acid preparation, Seaweed algae extract and microbial preparation Baikal-EM, on plant growth and yield. The impact of biostimulants on plant development and crop yields was studied on sugar beet (*Beta vulgaris*) and maize (*Zea mays*). To achieve this goal, field studies were conducted to compare different biostimulants in terms of germination and yield (total crop weight, weight of a single fruit, sugar, starch and

Suggested Citation:
Skliar, V., Kyrylchuk, K., Zubtsova, I., Novikova, A., & Yaroshchuk, Ya. (2024). Application of biostimulants in agriculture: Effects on plant growth and yield. *Scientific Horizons*, 27(9), 73-85. doi: 10.48077/scihor9.2024.73.

*Corresponding author

protein content). The study was conducted in April-August 2023 in the Sumy district of the Sumy region. Standard agronomic methods, including soil cultivation, measurement of plant growth and yield parameters, and statistical processing of the data were used in the study. The results showed that humic acids and algae extract, when applied separately, provided the highest seed germination and yield. Among all the variants of combined application, the most significant increase in germination rates for beetroot was provided by treatment with a combination of Seaweed and Baikal-EM – 91.7%. For maize, Seaweed with humic acids and Seaweed with Baikal-EM are 92% each. The combination of Seaweed and humic acids had the best effect on the yield of both crops: 460.9 c/ha for beetroot (compared to 325 c/ha without treatment) and 61 c/ha for corn (41.5 c/ha without treatment). The microbial preparation Baikal also demonstrated a positive effect, but its results were lower, and it proved effective in combination with humic acids. The results obtained indicate the feasibility of using humic acids and algae extract to increase plant productivity, while Baikal can be useful for improving the general condition of soil and plants in combination with other fertilisers

Keywords: fertilisation; germination; humic acids; microbial preparations; consortium; algae extract; greening of agriculture

INTRODUCTION

Agriculture is the backbone of the Ukrainian economy and faces many challenges, such as climate change, soil depletion and declining yields, so rationalisation and optimisation are essential. The use of biostimulants is one of the most promising ways to increase crop productivity. These natural or semi-natural substances can activate physiological processes in plants, which in turn has a positive effect on their growth and yield. Among the biostimulants, several groups optimise the plant-soil system and contribute to a more productive use of the natural potential of soils. Algae extracts contain a wide range of bioactive compounds that contribute to the improvement of physiological processes in plants, such as photosynthesis and nutrient assimilation. Humic acids are known for their soil structure improvement, increase in soil fertility and better absorption of nutrients by plants. Microbial preparations activate the beneficial microflora of the soil, which also has a positive effect on plant growth and development.

Among the crops grown in Ukraine, sugar beet and corn are the leading crops. Sugar beet is a key raw material for sugar production; therefore, it is a strategic crop for the food industry (Trembitska & Bohdan, 2023). Ukraine has great potential in growing this crop, but due to imperfect agronomic practices, it lags European countries, despite more favourable climatic conditions. Corn is a multi-purpose crop: a fodder crop for livestock and a raw material for the food industry. It ranks first in the world in terms of gross grain harvest. Reduced planting areas and the need for crop rotation, as well as problems in adapting hybrids, prevent the crop from reaching its potential yield, so optimising the technology for growing these crops is a pressing issue for Ukraine (Donchak & Shkvaruk, 2024). Both crops are sensitive to stress factors, such as insufficient moisture or insufficient mineral nutrition. The use of biostimulants can significantly improve their adaptation to adverse conditions, which is particularly relevant in the context of global climate change (Mokrienko & Kornienko, 2024). It can also solve another global problem faced by humanity – the oversaturation of soil with fertiliser and herbicide residues, which worsens the quality of the soil used for crops.

The feasibility of using biostimulants is widely studied in the world, both in applied and theoretical terms. M. Baltazar *et al.* (2021) present the results of a large-scale review that demonstrates the positive impact of humate-based biostimulants on the productivity of many crops, including corn. The study addressed the molecular mechanisms of biostimulants and proved that they can modify plant metabolism to increase productivity. Y. Yao *et al.* (2020) demonstrated the effect of algal extracts on improving all plant assimilation parameters: photosynthesis, synthesis of sugars, and oils, and activation of defence systems. The beneficial effects of symbiotic microflora are also known, as S. Shirinbayan *et al.* (2019) summarised the results of many studies of microbial preparations, which indicate that they can increase plant resistance and, due to complex mechanisms of action, significantly increase yields. These studies are relevant, but to develop technological schemes for the use of biostimulants, it is necessary to study their effectiveness in the context of certain natural and climatic conditions, considering the characteristics of regional varieties, hence the Ukrainian regional research relevance is determined.

The study of biostimulants in agriculture in Ukraine is becoming more intensive, with many groups of Ukrainian scientists working on their development and testing (Palamarchuk *et al.*, 2021; Prysiazhniuk *et al.*, 2022; Kapitanska, 2022). Research focuses on assessing the impact of various biostimulants on crop productivity, improving their resistance to stress and optimising agronomic practices. M.V. Patyka (2023) highlighted the need to develop and optimise microbial consortia to enhance soil fertility. The author presented author-made developments in the field of microbial biostimulants. O.I. Tsyliuryk *et al.* (2022) studied the effect of different groups of biostimulants on maize growth and showed their effectiveness. Despite the existence of research in the field of corn productivity improvement using biostimulants, no systematic recommendations have been developed yet. The evidence base for the use of biostimulants for sugar beet cultivation in Ukraine is not sufficiently developed, but their wide potential is already well known (Rašovský *et al.*, 2022). The widespread use of biostimulants will improve the economic performance of agricultural production and contribute to the environmental sustainability of the regions. It is necessary to select such biostimulants and their combinations that will ensure maximum productivity and increase the industrial value of crops.

The study aimed to investigate the effect of biostimulants based on algae extract, humic acids and microorganisms, as well as their combinations, on the growth and fertility of sugar beet and corn. Based on the objective, the study set the following tasks: selection of preparations that meet the study criteria; development of preparation application schemes based on manufacturers' recommendations; cultivation of plants with biostimulants and their combinations; evaluation of germination and yield indicators separately for each experimental variant.

MATERIALS AND METHODS

The study was conducted by the method of field experiment, on a field plot located in the central part of the Sumy district of Sumy region. For each treatment option, plots of 10 m^2 were laid out. Crops were sown in mid-April and harvested in early September 2023. Two plant species with different botanical and technical characteristics were used as objects: a representative of dicotyledons – sugar beet (*Beta vulgaris*), hybrid variety Ipel, and a representative of monocotyledons – corn (*Zea mays*), hybrid variety DN Pivyha. Both varieties are listed in the State Register of Varieties and Hybrids. The Ipel beet is a high-sugar beet variety with a yield of 500.9-593.9 c/ha. Sugar content is 17.1-18.0%. Corn variety DN Pivyha, a hybrid of grain, early maturing. Yield: 57.4-84.2 c/ha. Drought resistance 7-9 points. Protein: 9.8-10.3. Starch content 72.7-73.2. The density of beetroot sowing was 10 cm between plants and 50 cm between rows, and corn sowing was 20 cm between plants and 75 cm between rows.

Biostimulants were used as biofertilisers, which affect the root system. Three groups of biostimulants were used: algae extract, humic acids (HA) and microbial preparations. All these biostimulants have a similar direction of action, namely, optimising the plant-soil system, and increasing the availability of nutrients and their absorption by the plant. The aim was to select products containing only the target substances, without additives. The *Ascophyllum* algae extract under the commercial name Seaweed (Terra Aquatica, Ukraine) is a fully organic supplement. The dilution was carried out according to the manufacturer's instructions. It was treated before planting and sprayed at a dose of 2 l/ha three weeks after germination. The preparation based on humic and fulvic acids, commercially known as Humic Acid Concentrate (Organic Group, Ukraine), was applied to the soil before sowing and again 3 weeks after germination at a dose of 3 l/ha. The third preparation was a consortium of microorganisms with the commercial name Baikal-EM (Kisson, Ukraine), containing lactic acid, photosynthesising, nitrogen-fixing bacteria, yeast. It was diluted according to the instructions and tilled before planting, as well as sprayed 4 weeks after the first germination at a dose of 1 litre/ha. The control group of plants was not treated with biologically active substances, instead, it was irrigated with water 3 weeks after germination to simulate the conditions of the experiment.

The square method was used to count seedlings, each plot was divided into 50×50 cm squares, and seedlings were counted in the corners and central square of the plot, and then calculated per hectare. To determine the average weight of the root crop and head of cabbage, 100 fruits were weighed, and the weight was averaged. To calculate the total yield, the entire weight of the harvested crop was converted to a hectare of area. The total carbohydrate content was estimated by the phenol-sulphuric acid method, with glucose as a standard (DuBois *et al.*, 1956). The total protein content was determined by the method of O.H. Lowry *et al.* (1951), using bovine serum albumin as a standard. Statistical analysis was conducted using descriptive statistics, with the F-test used to assess the significance of differences between means. The dependence of the studied indicators on the effect of additives was studied using ANOVA analysis of variance. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

The first stage of the experiment included the study of the effect of biostimulants on the germination rate of the plants studied. The germination of beetroot was determined from the moment the first seedlings appeared on the soil surface, in the conditions of this experiment, they were observed on the 9th day after sowing. Thus, 9 days after sowing is the first day of observations that were carried out for 5 days. Figure 1 shows the dynamics of emergence. As demonstrated in the graph, fertilisers based on algae extract proved to be the most effective in stimulating beet germination, both as a standalone fertiliser and in combination with humic acids and the microbial preparation Baikal-EM. These fertiliser options contributed to a faster and more synchronised emergence of plants. Other combinations were close to the control values. It should be noted that there was no significant synergistic effect from the combination of fertilisers, therefore, it is likely that the leading role at the germination stage belonged to the algae extract.

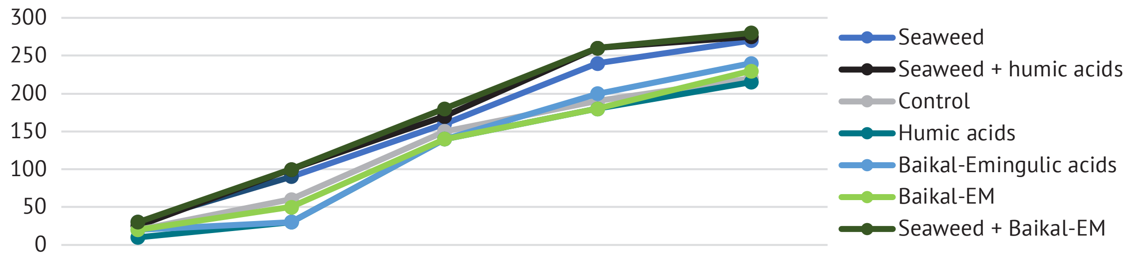


Figure 1. *Germination of Ipel beet seeds under the influence of different biostimulants*
Source: *compiled by the authors*

On the 5th day after the start of the observation, the germination rate of the seeds planted in the soil was calculated. The results were added to Table 1. Notably, the same fertilisers and combinations are used to accelerate germination: Seaweed and its combination with humic acids and Baikal-EM increase the overall germination of beetroot. Treatment with these biostimulants provided germination close to 90%, while without treatment only 73.33% of seeds germinated as seedlings on the 14th day after sowing.

Table 1. *Germination of beetroot seeds of Ipel variety on the 14th day after sowing under the influence of different biostimulants*

Biostimulator	Seaweed	Humic acids	Baikal-EM	Seaweed + humic acids	Baikal-Emingulic acids	Seaweed + Baikal-EM	Control
Similarity, %	90	71.67	76.67	91.67	80	93.33	73.33

Source: *compiled by the authors*

The first sprouts of maize on the soil were observed on the 7th day after sowing the seeds, which was the first day of registration of sprouts. The effect on maize germination was similar, but even more pronounced. The stimulant based on algae extract had the most pronounced positive effect when applied alone. When combined with humic acids and a microbial preparation, a noticeable synergistic effect was observed in each of the variants: the emergence of seedlings on the 3rd day of observation was more intense than in the other variants and control. With a separate application of humic acids, more active germination was observed only on day 3 of the observations, which may indicate different mechanisms of biostimulants' effect (Fig. 2).

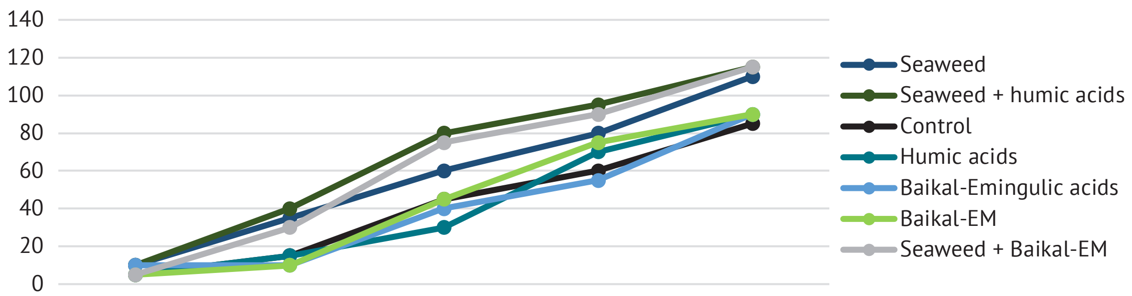


Figure 2. *Germination of maize seeds of DN Pivyha variety under the influence of different biostimulants*
Source: *compiled by the authors*

Total germination at 12 days after sowing is shown in Table 2. It is noticeable that Seaweed and its combinations have a pronounced positive effect on the overall germination of seeds, which, in combination with humic acids, reach more than 88%, while in the control variant without treatment, germination at 12 days was only 68%.

Table 2. *Germination of maize seeds of DN Pivyha variety on the 12th day after sowing under the influence of different biostimulants*

Biostimulator	Seaweed	Humic acids	Baikal-EM	Seaweed + humic acids	Baikal-Emingulic acids	Seaweed + Baikal-EM	Control
Similarity, %	88	72	72	92	72	92	68

Source: *compiled by the authors*

After harvesting, the main characteristics of the crop were analysed. The yield of the studied crops per hectare was calculated. Thus, the yield of beetroot was 325 c/ha, which is lower than the average fertility of this variety, it should be borne in mind that there was no treatment in the experiment, so low yields are quite expected. Treatment with all types of biofertilisers led to an increase in yield. The individual treatments did not reveal any significant difference in yields: treatment with Seaweed algae extract led to an increase in yields of 375 ± 12.2 c/ha, humic acids – up to 394.5 ± 9.2 c/ha, Baikal-EM – 382.9 ± 8.9 c/ha (Fig. 3). Thus, the most effective effect on beetroot yield was the addition of humic acids, although all the results are comparable, the difference between the experimental variants is not significant, and in all variants, the difference is significant compared to the control ($p \leqslant 0.05$). The combination of biofertilisers with each other had an even more pronounced effect compared to individual applications. The combination of algae extracts with humic acids had the most pronounced positive effect on the yield – the weight of harvested roots was 460.9 ± 12.8 c/ha, which brings these indicators closer to the optimal values for this variety. The combination of humic acids with Baikal-EM led to an increase in yield to 426.83 ± 9.2 c/ha. The combination of algae extracts with microbial fertiliser allowed for the harvest of 404.2 ± 8.66 c/ha, i.e. this combination was the least effective in terms of total yield, the indicators did not differ significantly from the individual fertiliser application.

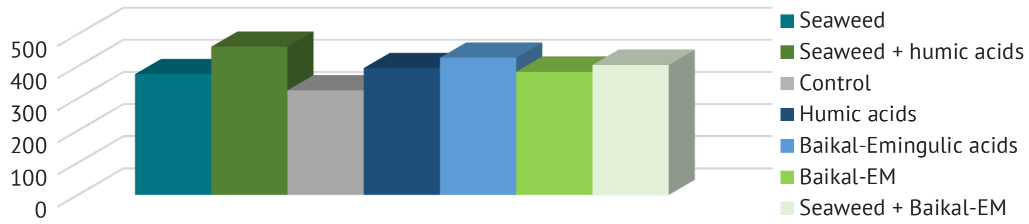


***Figure 3**. Yield of beetroot variety Ipel with the introduction of various biostimulants*
***Source:** compiled by the authors*

A similar trend towards an increase in yield was observed in the study of maize yields when fertilised with all types of biofertilisers compared to the untreated control, in which the yield was 41.5 ± 4.3 c/ha. These figures are too low for this variety; however, the lack of the necessary micronutrient fertiliser was present in the experiment. The introduction of biostimulants caused a significant increase in yield compared to the control in all variants of the experiment ($p \leqslant 0.05$). The use of biostimulants separately provided the following yield indicators: Seaweed – 57.53 ± 5.1 c/ha, humic acids – 54.17 ± 3.9 c/ha, Baikal-EM – 52.67 ± 4.8 c/ha (Fig. 4). The results of using all fertilisers for this indicator are comparable and have no significant difference. The combination of algae-based fertiliser and humic acids again demonstrated the best yield increase: 61 ± 5.86 c/ha. The combination of the microbial preparation with humic acids yielded 58.17 ± 5.8 c/ha and with algae extract – 54.33 ± 5.7 c/ha. As can be seen, these results do not significantly improve compared to the separate use of stimulants but are significantly higher than the results of the control plot.

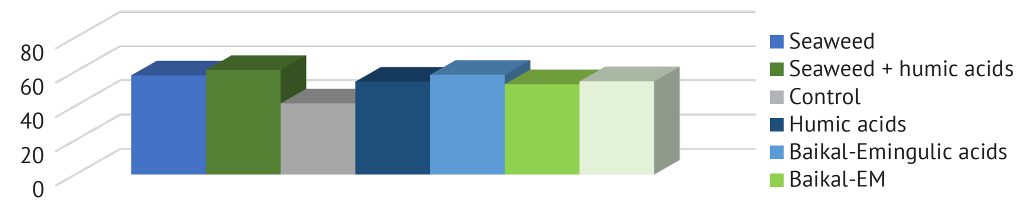


***Figure 4**. The yield of maize variety DN Pivyha with the introduction of various biostimulants*
***Source:** compiled by the authors*

Moreover, the average weight of one fruit was studied separately, since the overall yield can be increased both by increasing the weight of the fruit and by the survival of more beet plants or by increasing the number of ears of corn per stalk. The average weight of one beetroot in the untreated variant was 352 ± 38.7 g (Fig. 5). The best increase in biomass was provided by the introduction of humic acids, both separately – 400 ± 36 g, and in combination with Seaweed algae extract – 425.3 ± 39.5 g. It should be noted that the separate application of Seaweed fertiliser led to a less significant increase in biomass compared to the control – 368 ± 32 g, thus, the synergistic effect of the combination of these two products is observed. In the group with the introduction of the biological product Baikal-EM, the average weight of the root crop was 395 ± 25.2 g, which is significantly higher compared to the control, but its addition in combination with humic acids did not have a significant increase in yield compared to the separate application of acids: 407 ± 39.5 g. The combination of Baikal-EM and Seaweed also had no synergistic effect: 379 ± 31.4 g, which is lower compared to a separate application of microbial fertiliser.

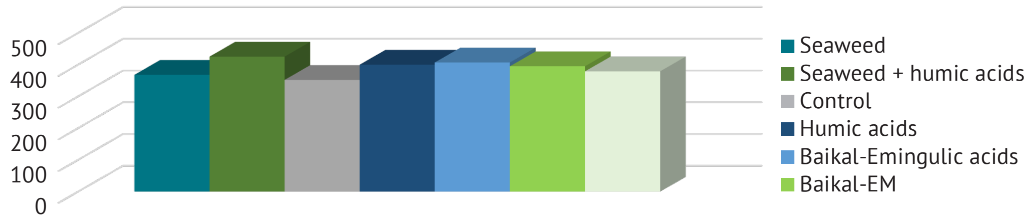


Figure 5*. The average weight of beetroot of Ipel variety under the application of various biostimulants*
Source: *compiled by the authors*

The determination of the weight of corn cobs revealed a slightly different trend in the effect of the preparations. The best performance in a separate application was provided by the preparation based on algae extract: 283 ± 27.6 g, while in the control variant, the average was 216.67 ± 23.4 g (Fig. 6). The use of humic acids and Baikal-EM had a similar effect, the weight of the cob was 255 ± 33.2 and 2596.7 ± 26.1 g, respectively. When these two preparations were combined, a synergistic effect was observed – 298.3 ± 24 g. Furthermore, the weight indicators were quite high when Seaweed and humic acids were combined – 294298.3 ± 29.6 g. The combination of algae extract with a microbial preparation did not lead to an increase in the weight of the head of cabbage compared to a separate application – 260 ± 22.1 g.

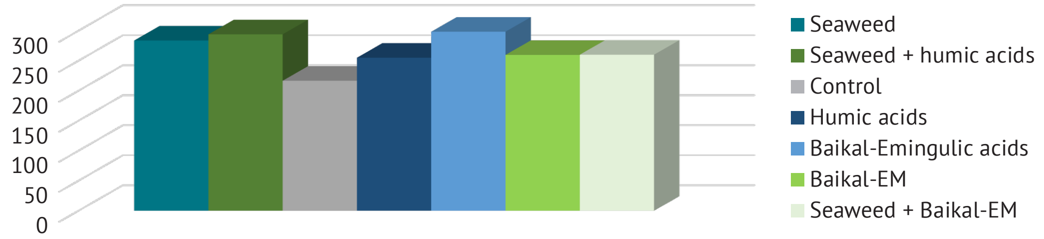


Figure 6*. The average weight of corn cobs of DN Pivyha variety under the application of different biofertilisers and biostimulants*
Source: *compiled by the authors*

To study the qualitative composition of root crops, the amount of sugar in beetroot was determined. The average sugar content in the untreated variant was 10.23 ± 0.25% (Fig. 7), which is quite low for this variety. The introduction of Seaweed biofertiliser led to an increase in this indicator to 15.1 ± 0.36%, which brings them closer to the optimal for this variety. The introduction of humic acids increased the sugar content to 13.3 ± 0.6%, while comparable results were obtained with the addition of Baikal-EM – 12.83 ± 0.3%. Thus, all the preparations had a positive effect on the sugar content of beet, accounting for the increase in total biomass, the preparations significantly increased the productivity of beet. The combination of preparations did not have a significant additive effect on sugar content: Seaweed with humic acids – 15.7 ± 0.3%, Baikal-EM with humic acids – 13.90 ± 0.3%, Seaweed in combination with Baikal-EM – 13.37 ± 0.4%.

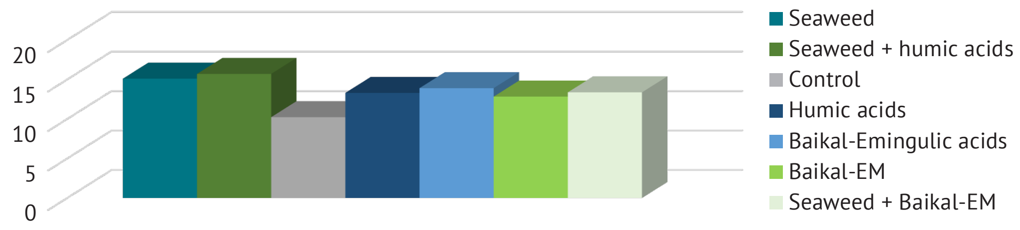


Figure 7*. Sugar content in Ipel beet after treatment with different biostimulants*
Source: *compiled by the authors*

Thus, the sugar content in the root crop increased under the influence of biostimulants, but their combination in the selected combinations does not have a significant impact on productivity compared to a single application. A relevant metric of maize quality is starch content, so this indicator was also studied. In the control group of plants, the average starch content was 66.5 ± 0.5%. All treatments showed a significant positive effect on starch content, and the results were quite homogeneous in all groups. The application of Seaweed provided a starch content of 71.93 ± 0.4%, humic acids – 73.83 ± 0.6%, and Baikal-EM – 72.5 ± 0.5% (Fig. 8). The combination of biofertilisers did not significantly change the indicators compared to the individual application: Seaweed with humic acids – 73.4 ± 0.5%, Baikal-EM with humic acids – 723.9 ± 0.5%, Seaweed in combination with Baikal-EM – 72.5 ± 0.8%.

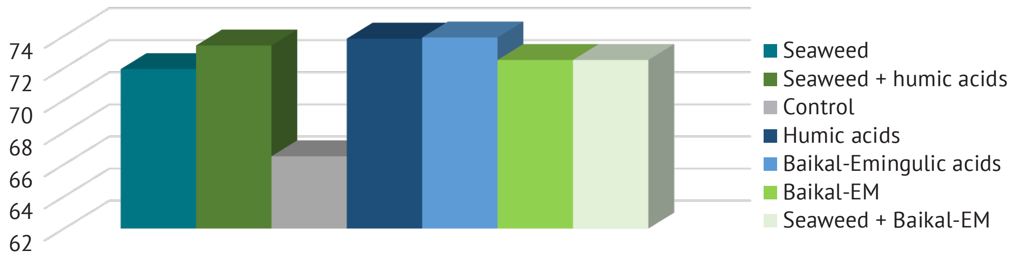


Figure 8*. Starch content in corn variety DN Pivyha after treatment with different biostimulants*
Source: *compiled by the authors*

The protein content of corn can be a relevant metric in the production of oilcake, as it determines its nutritional value. The study of protein content showed that in the control variant, it was at the level of 9.17 ± 0.2% (Fig. 9). The most positive effect when applied separately was demonstrated by a fertiliser based on humic acids – the protein content was 11.27 ± 0.2%. Similar results were obtained with Baikal-EM treatment – 11.03 ± 0.2%. The use of a stimulant based on algae extract had a slightly lower effect – 10.6 ± 0.4%. The combination of Seaweed with Baikal-Em had no synergistic effect, with a protein content of 11.17 ± 0.25%. At the same time, humic acids improved the performance to some extent both in combination with Seaweed – 12.5 ± 0.2%, and with Baikal-EM – 12.2 ± 0.26%. Thus, the combination of fertilisers has a more pronounced effect on the protein content of sugar beet, however, since this indicator is not critical for this crop, the use of such combinations can hardly be considered effective from an economic point of view.

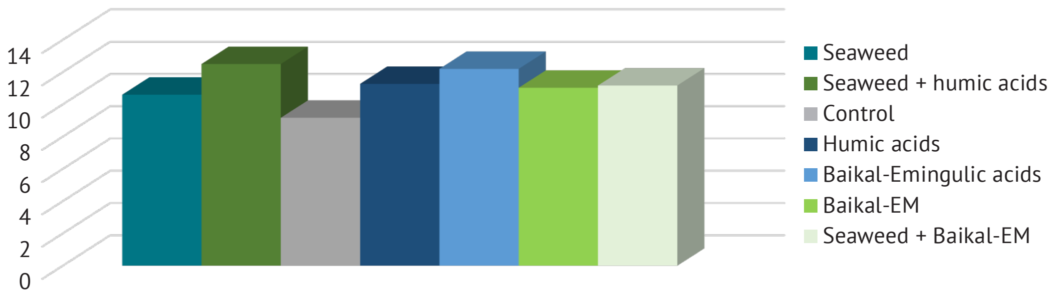


Figure 9*. Protein content in maize variety Ipel after treatment with different biostimulants*
Source: *compiled by the authors*

The protein content of corn is of greater relevance as a technical metric, as it determines its nutritional value, and it also affects the quality of corn flour, which is also produced from this variety. The protein level in corn from the control plot was 8.71 ± 0.15%. The introduction of biostimulants had a positive and equal effect on this indicator: Seaweed provided a protein content of 9.27 ± 0.2%, humic acids – 9.77 ± 0.16%, Baikal-EM – 9.47 ± 0.25% (Fig. 10). The combined use of biofertilisers further improved the results, the most effective was the combination of the microbial preparation extract with humic acids – 11 ± 0.15%, and a slightly lower level – 10.33 ± 0.15% was obtained when processing the combination of humic acids with algae extract. The combination of algae extract with the microbial preparation did not lead to a significant increase in performance compared to the individual application – 9.83 ± 0.16%.

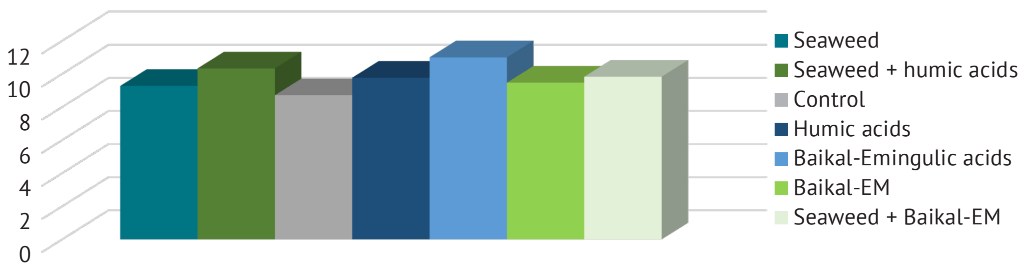


***Figure 10**. Protein content in corn variety DN Pivyha after treatment with different biostimulants*
***Source:** compiled by the authors*

Thus, the effect of treatment with biostimulants on the studied indicators is positive, and the feasibility of using a combination of biofertilisers should be considered in terms of the importance of protein content for the final product. ANOVA analysis of variance revealed a significant effect of biostimulants on all studied parameters. The findings are summarised in Table 3. Data with a significant difference from the control were conditionally marked. The growth of each indicator was estimated using a semi-quantitative method.

***Table 3**. Influence of different biostimulants and their combinations on germination and yield of beetroot variety Ipel*

Type of stimulant	Similarities	Berry mass	Yields, hwt/ha	Sugar contents	Protein content
Seaweed	++	-	+	++	+
Humic acids	-	++	+	+	+
Baikal-EM	-	+	+	+	+
Seaweed + humic acids	++	++	++	++	++
Baikal-Emingulic acids	+	++	++	+	++
Seaweed + Baikal-EM	++	+	++	+	+
Control	-	-	-	-	-

***Note:** "-" – increase is not statistically significant; "+" – increase in the indicator within 15%; "++" – increase in the indicator over 15%*
***Source:** compiled by the authors*

Table 3 shows that the use of biostimulants had a positive impact on almost all of the identified indicators. It can also be noted that the level of effect of different types of fertilisers is not the same for different indicators, which is due to different mechanisms of influence. It is also noticeable that the combined use of biofertilisers is advisable, as it has a synergistic effect on some of the studied indicators. The best combination for Ipel beet among the studied ones is the combination of algae extract with humic acids, which had a pronounced positive effect on all studied parameters. Comparative data on the effect of biofertilisers on the growth and yield of maize variety DN Pivyha are shown in Table 4. The symbols correspond to those described above. The table shows that the use of all types of biofertilisers led to an increase in the studied indicators, so their application is advisable for increasing yields. The best combination was a combination of stimulants based on algae extract and Baikal-EM. Although the effect on starch and protein content was not very significant, germination and total yield were significantly higher than in the untreated variant.

***Table 4**. Influence of different biostimulants and their combinations on germination and yield of maize variety DN Pivyha*

Type of stimulant	Similarities	Cob fruit weight	Yields, hwt/ha	Starch content	Protein content
Seaweed	+	++	++	+	+
Humic acids	-	+	+	+	+
Baikal-EM	-	++	+	+	+
Seaweed + humic acids	++	++	++	+	+
Baikal-Emingulic acids	+	++	++	+	+
Seaweed + Baikal-EM	++	+	+	+	+
Control	-	-	-	-	-

***Note:** "-" – increase is not statistically significant; "+" – increase in the indicator within 15%; "++" – increase in the indicator over 15%*
***Source:** compiled by the authors*

Thus, based on the generalisation of the data obtained, it is possible to propose the studied types of fertilisers to increase the germination and yield of sugar beet and corn.

DISCUSSION

This study focused on the effects of biostimulants on plant nutrient uptake. All three types of preparations studied – algae extract, humic acids and microbial consortium – contribute to the enhancement of mineral nutrition of the plant, but in different ways: through the influence on the soil structure, root system or rhizosphere. Hence, all methods of influence are effective in improving the indicators selected for observation. The best indicators of beetroot germination and sugar content, as well as increased corn yields, were obtained using Seaweed algae extract and combinations with it. The product under study contains an extract of the algae *Ascophyllum nodosum*. This seaweed is one of the most popular sources of raw materials for biostimulants. P.S. Shukla *et al.* (2019) describe the composition of the algae, it is a source of various bioactive phenolic compounds, including flortanins, and unique polysaccharides: alginic acid (28%), fucoidans (11.6%), mannitol (7.5%), laminarin (4.5%). It is the high content of phenolic compounds that makes this species different from most algae used to produce biostimulants. These substances help improve the absorption of nutrients from the soil, which leads to increased growth and productivity of many plants, including corn. A. Ertani *et al.* (2018) showed the positive effect of algae extract-based biostimulants on improving the morphology of maize root system and enhancing nutrition.

Numerous studies have also attributed the effect of algae to the content of natural hormones, including auxins, cytokinins and gibberellins, which regulate plant growth and development (Panfilova *et al.*, 2019). Their composition increases plant resistance to stressful conditions (drought, disease) by activating antioxidant systems. They also stimulate the processes responsible for seed germination. T. Arioli *et al.* (2023) studied the increase in the number of generative organs (flowers and ovaries) in different crops, which leads to an increase in yield. This study also noted the most pronounced positive effect of algae extract on the rate of seedling formation and germination of corn and beet seeds. R.A. Hamouda *et al.* (2022) demonstrated that the polysaccharide fraction isolated from algae stimulates an increase in carbohydrate and protein content, as well as enhances antioxidant activity, which is consistent with the data obtained in this study on increasing plant sugar content. P.S. Shukla and B. Prithiviraj (2021) studied in detail the mechanisms of algae extract effect on maize metabolism under phosphorus deficiency. It was shown that the addition of the extract increased the content of chlorophyll and carotenoids, as well as had a positive effect on sugar metabolism, which led to an increase in yield and total amino acid content.

The use of humic acids (HAs) is important for improving mineral nutrition, especially in conditions of deficiencies, as they increase the absorption of substances from the soil (Jindo *et al.*, 2020), in this study, no additional mineral nutrition was applied, so the plants did not receive enough of the necessary macro- and microelements. S. Nardi *et al.* (2021) in their meta-review indicate that the size of humic substances affects the sugar content and the intensity of root formation. D.G. Popa *et al.* (2022) indicate that strengthening the root system is a direct mechanism for increasing yields. Substances with a lower molecular weight penetrate the root and affect plant metabolism, while high molecular weight substances contribute to soil structuring in the root zone, the presence of an aromatic ring in the structure of HAs makes them resistant to biodegradation and promotes the formation of complex molecular structures with minerals (Lipczynska-Kochany, 2018).

One of the ways humates affect the soil is by improving its structure, they contribute to the formation of soil aggregates, which increases aeration and water retention capacity. They also affect the absorption of nutrients, increasing the bioavailability of macro- and microelements, and activating the processes of their absorption by the root system (Bulgakov *et al.*, 2017). M. Olaetxea *et al.* (2016) described the mechanism of humic acids' effect on the roots, which enhances the ability to absorb substances and distribute them in the stem, associated with increased ATPase activity, enzyme activation and increased absorption of nitrates and other minerals from the soil. Increased root hair activity leads to better water and nutrient absorption. The result is an activation of metabolism: HAs stimulate photosynthesis, respiration and protein synthesis, which leads to an increase in the energy potential of plants. In addition, they can activate hormonal processes, which promote shoot and leaf growth.

A.C. Souza *et al.* (2022) demonstrated in a study on maize that HA treatment regulates the activity of enzymes – kinases and phosphatases. Genes related to hormones (auxins, gibberellins, cytokinin, ethylene, abscisic acid, brassinoids, jasmonic and salicylic acids), as well as many other transcription factors, are also activated. M. Baltazar *et al.* (2021) review indicates that despite the simple chemical composition of humic acids, they can regulate the activity of thousands of genes in plants that regulate all metabolic pathways, including respiration, photosynthesis, and phytohormone activity. A. Godara and M. Bakshi (2021) focus on increasing the yield value of various fruit and vegetable crops when treated with humic acids, which is due to an increase in the content of sugars, proteins and oils, due to the activation of assimilation processes. HAs are commonly used in combination with fulvic acids, similar to the present study. One of the important effects observed with the addition of HAs in this study was an increase in the sugar content of beetroot. These findings are consistent with those of the review by J. Hudda *et al.* (2020), which showed an increase in sugar content after HA treatment in different crops within 20%. Z. Braziene *et al.* (2021) showed a positive effect of fulvic acids on seed germination and an increase in the overall yield of various crops, including sugar beet.

The microbiological preparation Baikal-EM contains a consortium of microorganisms that increase the microbiological activity of the soil. It consists of several groups of microorganisms, including lactobacilli (*Lactobacillus* spp.), yeasts (*Saccharomyces* spp.), cyanobacteria (*Nostoc* spp.), and bacteria of the Bacillus genus. This consortium has a balanced composition of microorganisms normally found in soils, so it does not disturb natural biomes, but can only enrich them (Burdina & Priss, 2016). S. Shirinbayan *et al.* (2019) in their review describe numerous mechanisms of influence exerted by symbiotic organisms. Cyanobacteria, including Nostoc, are active producers of auxin. Bacteria of the Bacillus genus are producers of auxins, gibberellins, and cytokines. They also have antagonistic effects against many groups of pathogens. W.F. Viera-Arroyo (2020) pointed out the following mechanisms of the symbiotic effect of Bacillus bacteria: antagonistic inhibition of pathogenic microflora of the rhizosphere, stimulation of root biomass growth and stimulation of microelements absorption. The average positive effect on crop productivity reaches 20%. R. Singh *et al.* (2023) in their review of microbial stimulants provide evidence that beneficial bacteria can increase the productivity of many crops, including corn, by up to 25% and reduce the need for mineral fertilisers by up to 50%.

S. Shirinbayan *et al.* (2019) showed the effectiveness of Azotobacter bacteria in increasing growth and potassium and phosphorus uptake by maize under drought conditions. L. Nephali *et al.* (2021) studied the mechanisms of maize fertility improvement in response to microbial consortium treatment. An increase in the main components of the tricarboxylic acid cycle changes in the profile of phenols and lipids were recorded, and at the cellular level, this was manifested in cell wall thickening, membrane remodelling, and improved osmoregulation, which increased drought resistance. M.E.-S. Shalaby and M.F. Shalaby (2008) present the results of a study on the effectiveness against Fusarium infection of sugar beet and, as a result, increase in crop productivity. Thus, consortia of microorganisms contribute to improving the microbiological composition of the soil, increase the availability of nutrients and activate fermentation processes, help protect plants from pathogens and increase their resistance to stress. These data are supported by the results of this study, which demonstrated improved germination and plant productivity under the influence of a consortium of microorganisms.

The study demonstrated a synergistic effect on the germination and yield of both crops. The interaction between HAs and microbial consortia has been confirmed in many studies, and attention has also been paid to the study of mechanisms of interaction. E. Di Iorio *et al.* (2022) point to the interaction between humic acids and rhizosphere microorganisms, which can lead to an increase in the yield of various crops. Several aspects of synergistic interaction have been identified: HAs can be metabolised by microorganisms to release biologically active substances, and they can serve as substrates and adaptogens for microbial survival. Moreover, HAs are involved in redox reactions as an electron acceptor, thus changing the buffering properties of the soil (Xi *et al.*, 2016), which creates a favourable environment for the development of many beneficial microorganisms. M. Rašovský *et al.* (2022) demonstrated the positive effect of microbial biostimulants on sugar content, while the combination of soil bacteria with humic acids proved to be the most effective for increasing the overall yield of root crops. Thus, numerous scientific data from other researchers confirm the effectiveness of the studied groups of biostimulants in increasing plant resistance, growth and yield, which is consistent with the results of the current study.

CONCLUSIONS

The use of fertilisers contributed to a faster and more synchronised emergence of plants. The best results were obtained with the use of a biostimulants based on Seaweed algae extract. In particular, in the case of beetroot, seed germination exceeded 90% when treated with algae extract, while the control group showed only 73.33%. Similar results were observed for maize, where the maximum germination rate reached 88% with the treatment and 68% in the control group. The yield data were also significant compared to the untreated control. The treatment with humic acids increased the yield of beetroot to 394.5 c/ha, and with algae extract to 375 c/ha, while the yield was 325 c/ha in the control variant. The corn yield had the highest increase when treated with algae extract – 57.53 c/ha, while the control value was 41.5 c/ha. Among the combinations of biostimulants, the most effective was the combination of algae extract and humic acids, which increased the yield of beet up to 460.9 c/ha and corn up to 61 c/ha, thus achieving optimal values for these varieties. Another important effect of the treatment with these stimulants was an increase in the sugar content of beet, which significantly increases its commercial value. It is possible to state of a pronounced synergistic effect of fertilisers that exceeds the benefits of individual applications.

Baikal-EM demonstrated good results in terms of seed germination, although the yield was lower compared to humic acids and algae extract. It has proven itself well in combination with humic acids, which may indicate that it is advisable to use it in combination with other fertilisers to achieve maximum results, and the product expands the potential for improving the overall condition of plants. The data obtained are particularly important as the treatment with other types of fertilisers and herbicides was limited in the experimental conditions. It should be noted that the potential of using bio-fertilisers can be much higher when combining them with other types of fertilisers. Biostimulants can be useful in reducing the cost of mineral and organic fertilisers, and herbicides, and increase plant resistance to water shortages. This opens up opportunities for further research to find optimal combinations of biostimulants and their dosage to achieve maximum effect.

The use of only two hybrids of the studied crops, cultivation within one experimental field plot and the lack of standard mineral nutrition led to the limitation of the results of this study. To verify the reproducibility of the data, it is necessary to continue research with other varieties and hybrids, as well as in areas with different agronomic and climatic characteristics. In the future, it is also recommended to investigate the effect of different growing conditions on the effectiveness of biostimulants, as well as their long-term impact on soil fertility. Further research in this area could lead to a significant improvement in the results and efficiency of agronomic practices.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Arioli, T., Mattner, S.W., Islam, M.T., Tran, T.L.C., Weisser, M., Winberg, P., & Cahill, D.M. (2023). Applications of seaweed extracts in agriculture: An Australian perspective. *Journal of Applied Phycology*, 36(2), 713-726. doi: 10.1007/s10811-023-03120-x.

[2] Baltazar, M., Correia, S., Guinan, K.J., Sujeeth, N., Bragança, R., & Gonçalves, B. (2021). Recent advances in the molecular effects of biostimulants in plants: An overview. *Biomolecules*, 11(8), article number 1096. doi: 10.3390/biom11081096.

[3] Braziene, Z., Paltanavicius, V., & Avizienytė, D. (2021). The influence of fulvic acid on spring cereals and sugar beets seed germination and plant productivity. *Environmental Research*, 195, article number 110824. doi: 10.1016/j.envres.2021.110824.

[4] Bulgakov, V., Adamchuk, V., Nozdrovický, L., & Ihnatiev, Y. (2017). Theory of vibrations of sugar beet leaf harvester front-mounted on universal tractor. *Acta Technologica Agriculturae*, 20(4), 96-103. doi: 10.1515/ata-2017-0019.

[5] Burdina, I., & Priss, O. (2016). Effect of the substrate composition on yield and quality of basil (*Ocimum basilicum* L.). *Journal of Horticultural Research*, 24(2), 109-118. doi: 10.1515/johr-2016-0027.

[6] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[7] Convention on International Trade in Endangered Species of Wild Fauna and Flora. (1979, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_129#Text.

[8] Di Iorio, E., Circelli, L., Angelico, R., Torrent, J., Tan, W., & Colombo, C. (2022). Environmental implications of interaction between humic substances and iron oxide nanoparticles: A review. *Chemosphere*, 303, article number 135172. doi: 10.1016/j.chemosphere.2022.135172.

[9] Donchak, L., & Shkvaruk, D. (2024). Current state and prospects for the development of agriculture in the Vinnytsia region. *Ekonomika APK*, 31(2), 23-31. doi: 10.32317/2221-1055.202402023.

[10] DuBois, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, 28(3), 350-356. doi: 10.1021/ac60111a017.

[11] Ertani, A., Francioso, O., Tinti, A., Schiavon, M., Pizzeghello, D., & Nardi, S. (2018). Evaluation of seaweed extracts from *Laminaria* and *Ascophyllum nodosum* spp. as biostimulants in *Zea mays* L. using a combination of chemical, biochemical and morphological approaches. *Frontiers in Plant Science*, 9, article number 00428. doi: 10.3389/fpls.2018.00428.

[12] Godara, A., & Bakshi, M. (2021). Effect of application of bio stimulants like humic acid and vermiwash on the growth, quality and yield of plant – A review. *Plant Cell Biotechnology and Molecular Biology*, 22(19-20), 22-30.

[13] Hamouda, R.A., Hussein, M.H., El-Naggar, N.E., Karim-Eldeen, M.A., Alamer, K.H., Saleh, M.A., Al Masoudi, L.M., Sharaf, E.M., & El-Azeem, R.M.A. (2022). Promoting effect of soluble polysaccharides extracted from *Ulva* spp. on *Zea mays* L. Growth. *Molecules*, 27(4), article number 1394. doi: 10.3390/molecules27041394.

[14] Hudda, J., Godara, A., & Kukreja, S. (2020). Effect of application of humic acid and vermiwash on the growth, quality and yield of plants: A review. *International Journal of Current Microbiology and Applied Sciences*, 9(11), 1277-1284. doi: 10.20546/ijcmas.2020.911.149.

[15] Jindo, K., Canellas, L., Albacete, A., dos Santos, L.F., Rocha, R.L.F., Baia, D.C., Canellas, N.O.A., Goron, T.L., & Olivares, F.L. (2020). Interaction between humic substances and plant hormones for phosphorous acquisition. *Agronomy*, 10(5), article number 640. doi: 10.3390/agronomy10050640.

[16] Kapitanska, O. (2022). *Plant biostimulants. State of the market, types and features of application*. Retrieved from https://www.agronom.com.ua/biostymulyatory-roslyn-stan-rynku-vydy-ta-osoblyvosti-zastosuvannya/.
[17] Lipczynska-Kochany, E. (2018). Humic substances, their microbial interactions and effects on biological transformations of organic pollutants in water and soil: A review. *Chemosphere*, 202, 420-437. doi: 10.1016/j.chemosphere.2018.03.104.
[18] Lowry, O.H., Rosebrough, N.J., Farr, A.L., & Randall, R.J. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry*, 193(1), 265-275. doi: 10.1016/S0021-9258(19)52451-6.
[19] Mokrienko, V., & Kornienko, T. (2024). Formation of productivity of maize hybrids of different ripening groups in the Forest-Steppe region. *Plant and Soil Science*, 15(1), 52-62. doi: 10.31548/plant1.2024.52.
[20] Nardi, S., Schiavon, M., & Francioso, O. (2021). Chemical structure and biological activity of humic substances define their role as plant growth promoters. *Molecules*, 26(8), article number 2256. doi: 10.3390/molecules26082256.
[21] Nephali, L., Moodley, V., Piater, L., Steenkamp, P., Buthelezi, N., Dubery, I., Burgess, K., Huyser, J., & Tugizimana, F. (2021). A metabolomic landscape of maize plants treated with a microbial biostimulant under well-watered and drought conditions. *Frontiers in Plant Science*, 12, article number 676632. doi: 10.3389/fpls.2021.676632.
[22] Olaetxea, M., Mora, V., García, A.C., Santos, L.A., Baigorri, R., Fuentes, M., Garnica, M., Berbara, R.L.L., Zamarreño, A.M., & Garcia-Mina, J.M. (2016). Root-shoot signaling crosstalk involved in the shoot growth promoting action of rhizospheric humic acids. *Plant Signaling & Behavior*, 11(4), article number e1161878. doi: 10.1080/15592324.2016.1161878.
[23] Palamarchuk, V.D., Vinnik, O.V., & Kovalenko, O.A. (2021). Starch content in corn grain and bioethanol yield depending on vegetation conditions and factors of cultivation technology. *Agrarian Innovations*, 5, 143-156. doi: 10.32848/agrar.innov.2021.5.23.
[24] Panfilova, A., Korkhova, M., Gamayunova, V., Fedorchuk, M., Drobitko, A., Nikonchuk, N., & Kovalenko, O. (2019). Formation of photosynthetic and grain yield of spring barley (*Hordeum vulgare* L.) depend on varietal characteristics and plant growth regulators. *Agronomy Research*, 17(2), 608-620. doi: 10.15159/AR.19.099.
[25] Patyka, M.V. (2023). Formation of the microbial biome of soils and systems based on it as a key basis for balanced agricultural production. In *Materials of the IV All-Ukrainian scientific and practical conference "Scientific and innovative development of agricultural production as a guarantee of food security of Ukraine: Yesterday, today, tomorrow"* (pp. 282-284). Kyiv: National Academy of Agrarian Sciences, National Research Library of Ukraine, Institute of History of Agrarian Science, Education and Technology, Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine.
[26] Popa, D.G., Lupu, C., Constantinescu-Aruxandei, D., & Oancea, F. (2022). Humic substances as microalgal biostimulants-implications for microalgal biotechnology. *Marine Drugs*, 20(5), article number 327. doi: 10.3390/md20050327.
[27] Prysiazhniuk, O.I., Prysiazhniuk, L.M., Melnyk, S.I., & Hryniv, S.M. (2022). *Sugar beet – Breeding, seed production and cultivation technology*. Vinnytsia: Tovory LLC.
[28] Rašovský, M., Pačuta, V., Ducsay, L., & Lenická, D. (2022). Quantity and quality changes in sugar beet (*Beta vulgaris* Provar. Altissima Doel) induced by different sources of biostimulants. *Plants*, 11(17), article number 2222. doi: 10.3390/plants11172222.
[29] Shalaby, M.E.-S., & El-Nady, M.F. (2008). Application of *Saccharomyces cerevisiae* as a biocontrol agent against *Fusarium* infection of sugar beet plants. *Acta Biologica Szegediensis*, 52(2), 271-275.
[30] Shirinbayan, S., Khosravi, H., & Malakouti, M.J. (2019). Alleviation of drought stress in maize (*Zea mays*) by inoculation with *Azotobacter* strains isolated from semi-arid regions. *Applied Soil Ecology*, 133, 138-145. doi: 10.1016/j.apsoil.2018.09.015.
[31] Shukla, P.S., & Prithiviraj, B. (2021). *Ascophyllum nodosum* biostimulant improves the growth of *Zea mays* grown under phosphorus impoverished conditions. *Frontiers in Plant Science*, 11, article number 601843. doi: 10.3389/fpls.2020.601843.
[32] Shukla, P.S., Mantin, E.G., Adil, M., Bajpai, S., Critchley, A.T., & Prithiviraj, B. (2019). *Ascophyllum nodosum*-based biostimulants: Sustainable applications in agriculture for the stimulation of plant growth, stress tolerance, and disease management. *Frontiers in Plant Science*, 10, article number 00655. doi: 10.3389/fpls.2019.00655.
[33] Singh, R., Kaur, S., Bhullar, S.S., Singh, H., & Sharma, L.K. (2023). Bacterial biostimulants for climate smart agriculture practices: Mode of action, effect on plant growth and roadmap for commercial products. *Journal of Sustainable Agriculture and Environment*, 3(1), article number e12085. doi: 10.1002/sae2.12085.
[34] Souza, A.C., Olivares, F.L., Peres, L.E.P., Piccolo, A., & Canellas, L.P. (2022). Plant hormone crosstalk mediated by humic acids. *Chemical and Biological Technologies in Agriculture*, 9, article number 29. doi: 10.1186/s40538-022-00295-2.
[35] Trembitska, O., & Bohdan, S. (2023). Evaluation of the effect of sugar mud and organic fertilizers on the productivity of sugar beets in the conditions of Podillia. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 90-98. doi: 10.56407/bs.agrarian/4.2023.90.

[36] Tsyliuryk, O.I., Izhboldin, O.O., & Sologub, I.M. (2022). Effect of plant growth stimulants on biometric parameters and yield of corn in the Northern Steppe. *Agrarian Innovations*, 15, 59-66. doi: 10.32848/agrar.innov.2022.15.9.
[37] Viera-Arroyo, W.F. (2020). Role of beneficial microorganisms in sustainable agriculture. *Journal of the Selva Andina Biosphere*, 8(2), 67-68. doi: 10.36610/j.jsab.2020.080200067x.
[38] Xi, B., Zhao, X., He, X., Huang, C., Tan, W., Gao, R., Zhang, H., & Li, D. (2016). Successions and diversity of humic-reducing microorganisms and their association with physical-chemical parameters during composting. *Bioresource Technology*, 219, 204-211. doi: 10.1016/j.biortech.2016.07.120.
[39] Yao, Y., Wang, X., Chen, B., Zhang, M., & Ma, J. (2020). Seaweed extract improved yields, leaf photosynthesis, ripening time, and net returns of tomato (*Solanum lycopersicum* Mill.). *ACS Omega*, 5(8), 4242-4249. doi: 10.1021/acsomega.9b04155.

Використання біостимуляторів у сільському господарстві: ефекти на ріст та врожайність рослин

Вікторія Скляр
Доктор біологічних наук, професор
Сумський національний аграрний університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0002-1301-7384

Катерина Кирильчук
Кандидат біологічних наук, доцент
Сумський національний аграрний університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-9968-4833

Інна Зубцова
Кандидат біологічних наук, доцент
Сумський національний аграрний університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-6339-931X

Анна Новікова
Кандидат сільськогосподарських наук, старший викладач
Сумський національний аграрний університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0003-1515-5593

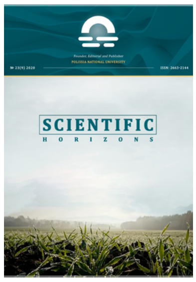
Світлана Ярощук
Кандидат сільськогосподарських наук, доцент
Сумський національний аграрний університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-6125-1979

Анотація. Метою роботи була оцінка ефективності використання біостимуляторів, таких як препарат гумінових кислот, екстракт водоростей Seaweed та мікробний препарат Байкал-ЕМ, на показники росту та врожайності рослин. Досліджувався вплив біостимуляторів на розвиток рослин та врожайність сільськогосподарських культур: цукрового буряка (*Beta vulgaris*) та кукурудзи (*Zea mays*). Для досягнення мети були проведені польові дослідження, в яких порівнювалися різні біостимулятори за показниками схожості та врожайності (загальна маса врожаю, вага окремого плоду, вміст цукру, крохмалю та білка). Дослідження проведене в період квітня-серпня 2023 року в Сумському районі Сумської області. У дослідженні використовувалися стандартні агрономічні методи, включаючи обробку ґрунту, вимірювання параметрів росту та врожайності рослин та статистичну обробку отриманих даних. Результати показали, що гумінові кислоти та екстракт водоростей при окремому внесенні забезпечили найвищі показники схожості насіння та врожайності. Серед усіх варіантів комбінованого внесення, для буряка найбільш суттєвий ріст показників схожості забезпечила обробка комбінацією Seaweed з Байкал-ЕМ – 91,7 %. Для кукурудзи – Seaweed з гуміновими кислотами та Seaweed з Байкал-ЕМ – по 92 %. Комбінація Seaweed з гуміновими кислотами найкраще вплинули на врожайність обох культур: 460,9 ц/га для буряка (порівняно з 325 ц/га без обробки) та 61 ц/га для кукурудзи (41,5 ц/га без обробки). Мікробний препарат Байкал також продемонстрував позитивний вплив, але його результати були дещо нижчими, ефективно показав себе в комбінації з гуміновими кислотами. Отримані результати свідчать про доцільність використання гумінових кислот і екстракту водоростей для підвищення продуктивності рослин, тоді як препарат Байкал може бути корисним для покращення загального стану ґрунту та рослин у комплексі з іншими добривами

Ключові слова: удобрення; схожість; гумінові кислоти; мікробні препарати; консорціум; екстракт водоростей; екологізація агросфери

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 86-97



UDC 631.461:631.811
Doi: 10.48077/scihor9.2024.86

The role of mycorrhizal fungi in enhancing fertiliser efficiency in agriculture

Olena Koberniuk*
PhD in Agricultural Sciences, Associate Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-1380-7976
Vasyl Hryhoriev
PhD in Agricultural Sciences, Associate Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-8567-5466
Kateryna Nebaba
PhD in Agricultural Sciences, Assistant
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-4529-3623
Ruslan Havrylianchyk
PhD in Agricultural Sciences, Associate Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-7609-1039
Danylo Plahtiy
PhD in Agricultural Sciences, Associate Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-2014-9748

Article's History:
Received: 19.02.2024
Revised: 21.07.2024
Accepted: 28.08.2024

Abstract. The study was conducted to evaluate the impact of mycorrhizal fungi on the yield, biomass and quality of cereals (wheat and maize) in the South of Ukraine. For the experiment, control and experimental plots were selected where mycorrhizal fungi were used to improve plant nutrient uptake. The research process included detailed measurements of yields, biomass and uptake of nutrients such as phosphorus, nitrogen and potassium at different stages of the growing season. The results showed that the use of mycorrhizal fungi increased wheat yields by 15% and corn yields by 18% in the experimental plots compared to the control plots, which was achieved through

Suggested Citation:
Koberniuk, O., Hryhoriev, V., Nebaba, K., Havrylianchyk, R., & Plahtiy, D. (2024). The role of mycorrhizal fungi in enhancing fertiliser efficiency in agriculture. *Scientific Horizons*, 27(9), 86-97. doi: 10.48077/scihor9.2024.86.

*Corresponding author

increased nutrient uptake from deeper soil layers. Wheat biomass increased by 12% and corn biomass by 14%, indicating a positive impact of mycorrhiza on plant development. Phosphorus uptake at a depth of 20-30 cm increased by 50%, which contributed to better root development and the supply of available elements to plants. In addition, we recorded a 7% increase in protein content in wheat grain and a 9% increase in corn, which indicates an improvement in the nutritional and feed value of the products. The analysis also showed a 4% increase in the oil content of corn grain, which increases its economic value. Another important result was a 15% reduction in mineral fertiliser costs due to improved nutrient use efficiency, which reduces the need for additional fertiliser. The results confirm that the use of mycorrhizal fungi is an effective method for increasing yields, product quality and economic efficiency of agricultural production

Keywords: agrotechnology; cereal crops; *Glomus*; yield; biomass; nutrient uptake

INTRODUCTION

The relevance of this research is driven by the need to enhance agricultural productivity in Ukraine amidst climate change and deteriorating soil conditions. The depletion of soil fertility due to the intensive use of chemical fertilisers and the increasing impact of droughts necessitates the search for alternative methods to ensure stable yields and improve product quality. One promising avenue is the utilisation of biotechnology, specifically mycorrhizal fungi, which facilitate improved nutrient uptake by plants, allowing for a reduction in mineral fertiliser requirements and increased plant resilience to adverse conditions. In Ukraine, the application of mycorrhizal fungi remains understudied, despite significant interest from the global scientific community in exploring the potential of this technology.

One of the primary challenges facing Ukrainian agriculture is soil degradation resulting from the excessive use of chemical fertilisers, leading to soil depletion and reduced fertility (Burdina & Priss, 2016). W. Sun and M.H. Shahrajabian (2023) and S. Shahini *et al.* (2023) in their studies focused on examining the impact of mineral fertilisers on soil structure and their influence on agroecosystems. Their research demonstrated that the systematic application of mineral fertilisers without adequate control results in the loss of organic matter and soil structure degradation, reducing its ability to retain moisture and nutrients. However, their studies were limited to short-term analysis without considering long-term ecological consequences and potential biological alternatives, such as mycorrhizal fungi, for restoring natural soil fertility.

Another significant issue is the accumulation of toxic elements in the soil due to the application of chemical fertilisers and pesticides (Ivanova *et al.*, 2022). V. Oliferchuk *et al.* (2023) investigated the impact of such agricultural practices on heavy metal accumulation in soils and found that the prolonged use of chemicals leads to increased concentrations of toxic elements, negatively affecting soil fertility and reducing crop yields. Despite the importance of these findings, the study did not consider alternative methods, particularly biological solutions, that could help reduce the accumulation of toxic substances in the soil. Mycorrhizal fungi could be a potential solution to this problem as they contribute to improving soil structure and its ecological stability.

D. Mitra *et al.* (2023) conducted research focused on enhancing nutrient use efficiency in plants. They highlighted the ability of mycorrhizal fungi to improve the uptake of essential elements such as phosphorus and potassium, which is crucial for boosting plant productivity. However, their experiments were conducted on a limited scale and under specific agroclimatic conditions, which does not allow for a comprehensive assessment of the technology's potential across various regions of Ukraine with diverse soil and climatic conditions. The need for a broader analysis of the effectiveness of mycorrhizal fungi in other regions remains a significant research challenge.

Another crucial area of research is exploring the impact of mycorrhizal fungi on reducing the demand for mineral fertilisers. S. Qian *et al.* (2024) investigated how mycorrhizal fungi can decrease fertiliser requirements while simultaneously increasing cereal crop yields. Their experiments demonstrated that the use of mycorrhizal fungi can reduce fertiliser costs by 15-20% while promoting plant productivity. However, their studies were conducted on small-scale plots, which limits the ability to draw conclusions about the application of this technology on large-scale farms, where environmental factors can be significantly more complex.

Meanwhile, J. Franczuk *et al.* (2023) in their studies examined the impact of mycorrhizal fungi on soil structure and water-holding capacity. They demonstrated that the application of mycorrhiza contributes to improved soil properties and increased drought resistance. However, the research was short-term and did not encompass an analysis of the long-term impact of mycorrhizal fungi on the soil ecosystem. To fully understand the long-term effects of mycorrhiza on restoring natural soil fertility, additional experiments with longer timeframes and on various soil types are necessary.

Consequently, there is a need for a comprehensive study to assess the impact of mycorrhizal fungi on agricultural crop productivity across various agroclimatic conditions in Ukraine. The current study aimed to determine how mycorrhizal fungi affect crop yields and product quality, as well as to evaluate their potential to reduce reliance on mineral fertilisers and improve the ecological sustainability of agroecosystems. The objectives of the study included assessing the effectiveness of mycorrhizal fungi in enhancing nutrient absorption by plants, analysing the economic feasibility of using this technology in real agricultural production conditions, and comparing the yield and quality of cereal crops on plots with and without mycorrhizal application.

MATERIALS AND METHODS

The research was conducted in the experimental field of Mykolaiv National Agrarian University, located in the southern region of Ukraine. The sowing of agricultural crops, specifically wheat cultivar "Smuglyanka" and maize hybrid "Dniprovskyi 181 SV", was carried out in early April 2022, when weather conditions favoured the active development of mycorrhizal fungi. The study covered the entire annual crop growing cycle and concluded in April 2023 after collecting all necessary data. Two groups of plots, each consisting of 50 areas measuring 10 m^2 were prepared for the experiment. In the control group, fertilisers were applied following a standard scheme, which included the base application of nitrogen, phosphorus, and potassium fertilisers in proportions of $N_{60}P_{60}K_{60}$ per hectare. In the experimental group, these fertilisers were also used, but additionally, a mycorrhizal preparation based on fungi of the genus *Glomus* was applied. This preparation was produced in the university laboratory using a specialised method for cultivating mycorrhizal fungi under sterile conditions on the roots of donor plants (carrots and Sudan grass). This method ensured a high concentration of mycorrhizal spores, which were used for subsequent application.

The application of the preparation was carried out prior to sowing using equipment designed for uniform fertiliser distribution, specifically the Kverneland Accord rotary seeder, which enabled precise dosing of both fertilisers and the preparation at a depth of 5 cm. The mycorrhizal fungi preparation was applied at a rate of 20 g per plot, ensuring a sufficient concentration for effective colonisation of the plant root system. Fertilisers for the crops were applied following a three-stage scheme: the first nitrogen application took place at the three-leaf stage, the second during the onset of heading, and the third at the grain filling stage. For this purpose, a drip irrigation system was utilised, ensuring the uniform application of liquid complex fertilisers of the "Kristalon" brand (NPK 18-18-18). The irrigation system was controlled by an automated Netafim installation, which allowed for precise regulation of water and fertiliser consumption.

Soil condition monitoring was conducted at various stages of the growing season by analysing soil samples collected from each plot before sowing, at the beginning of growth, in the middle of the vegetation period, and during crop maturation. Samples were analysed for nitrogen, phosphorus, and potassium content using an Agilent 7500 ICP-MS spectrometer, which allowed for the highly accurate determination of element concentrations in the soil. To assess plant growth, measurements of biomass and height were taken for each plant on a monthly basis. After harvest in autumn, a detailed yield analysis was conducted, taking into account the quantity of grain harvested, its mass, and quality. The grain was processed and weighed using a Sartorius Quintix 5102-1S weighing system, which provided a measurement accuracy of 0.01 g.

The root systems of the plants were subjected to microscopic analysis to assess the level of colonisation by mycorrhizal fungi. Roots were excavated and cleaned of soil, then stained with a trypan blue solution to reveal mycorrhizal structures. Root system analysis was conducted using a Leica DM750 microscope, allowing for the determination of the number of infected root sections. For each plant, the proportion of root hairs colonised by mycorrhiza was calculated and compared to similar indicators in the control group. Statistical analysis of the results was conducted using IBM SPSS Statistics and R software. The primary analytical methods employed were Student's t-test for comparing mean values between the experimental and control groups, and analysis of variance to determine the impact of mycorrhizal fungi on various growth stages and yield. The following parameters were evaluated: biomass growth, grain yield and quality, and nutrient uptake. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

The research results demonstrated a significant increase in wheat and maize yield and biomass on plots where mycorrhizal fungi were used (Table 1). This increase is attributed to a more effective symbiotic interaction between plants and mycorrhizal fungi, leading to improved nutrient uptake at various soil depths. Due to the expanded root zone and more efficient resource acquisition, plants in the experimental plots exhibited more stable growth and development.

***Table 1**. Yield and biomass indicators of wheat and maize in control and experimental plots in 2023*

Indicator	Crop	Control group, t/ha	Experimental group, t/ha	Increase (%)
Yield (t/ha)	Wheat	4.5	5.2	+15%
Yield (t/ha)	Maize	6.8	8.0	+18%

Table 1. Continued

Indicator	Crop	Control group, t/ha	Experimental group, t/ha	Increase (%)
Biomass (t/ha)	Wheat	10	11.2	+12%
Biomass (t/ha)	Maize	12.5	14.3	+14%

Source: *developed by the authors*

In the plots with wheat, the average yield was 5.2 t/ha, which is 15% higher compared to the control plots, where this figure was 4.5 t/ha. In maize, the yield increased by 18% and amounted to 8 t/ha compared to 6.8 t/ha in the control plots. This difference is primarily explained by the increased availability of nutrients, especially phosphorus and nitrogen, which are critical for the formation of ears and cobs. Specifically, it was recorded that at a depth of 20-30 cm in the soil, the concentration of available forms of phosphorus in plots with mycorrhizal fungi increased by 15% compared to control plots. This facilitated more efficient uptake of phosphorus by wheat and maize plants, especially at the early stages of development when plants require phosphorus to form a strong root system. Additionally, mycorrhizal fungi actively increased the root surface area, allowing plants to acquire more phosphorus from inaccessible soil layers where its uptake would be impossible without symbiosis.

Similar changes were observed with nitrogen uptake. In plots with mycorrhizal fungi, the concentration of plant-available nitrogen at a depth of 10-20 cm increased by 12% compared to control plots. This increase provided plants in the experimental plots with better stem and leaf growth, which was particularly important for wheat during the formation of reproductive organs. The increase in nitrogen concentration at these depths was due to mycorrhizal fungi facilitating plant access to organic forms of nitrogen, which were less accessible without symbiotic associations. Regarding biomass, its increase was also significant: in wheat, the average biomass on experimental plots was 11.2 t/ha, which is 12% higher compared to the control plots, where this figure was 10 t/ha. In maize, this figure was 14.3 t/ha, which is 14% higher than in the control plots (12.5 t/ha). The increase in biomass is explained by the increased activity of photosynthetic processes due to better provision of plants with water and nutrients. Plants in plots with mycorrhizal fungi demonstrated a better ability to retain water, which was particularly important in conditions of temporary rainfall deficits during the growing season.

It is also worth noting that the growth uniformity of plants in the experimental plots was higher compared to the controls. Plants in plots with mycorrhizal fungi demonstrated stable growth throughout the entire growing season. This can be explained by the fact that mycorrhizal fungi provided plants with a constant supply of nutrients, even during periods when their availability in the soil decreased due to adverse conditions, such as reduced moisture levels. In the control plots, where symbiotic relationships were absent, uneven nutrient uptake was observed, leading to fluctuations in growth rates. One of the key findings of the study was a significant increase in the colonisation of wheat and maize root systems by mycorrhizal fungi in experimental plots compared to control plots (Table 2). It is known that mycorrhizal fungi form symbiotic relationships with plant roots, providing them with better access to nutrients, especially in hard-to-reach soil layers, thanks to the development of hyphae that penetrate microscopic soil pores. This allows plants to obtain more nutrients, such as phosphorus, potassium, nitrogen, and other micronutrients, which are usually unavailable in natural conditions without symbiosis with fungi.

Table 2*. Level of root system colonisation by mycorrhizal fungi and nutrient uptake at various growth stages and soil depths*

Indicator	Crop	Growth stage	Soil depth (cm)	Control group	Experimental group	Increase (%)
Root colonisation (%)	Wheat	Three-leaf stage	10-20	15%	80%	+65%
	Wheat	Heading stage	20-30	25%	85%	+60%
Phosphorus uptake (mg/g root)	Wheat	Three-leaf stage	20-30	0.12	0.18	+50%
Nitrogen uptake (mg/g root)	Wheat	Heading stage	10-20	0.22	0.29	+31.8%
Potassium uptake (mg/g root)	Wheat	Grain filling stage	30-40	0.15	0.22	+46.7%

Table 2. Continued

Indicator	Crop	Growth stage	Soil depth (cm)	Control group	Experimental group	Increase (%)
Root colonisation (%)	Maize	Intensive stem growth stage	10-20	12%	78%	+66%
Root colonisation (%)	Maize	Cob formation stage	20-30	18%	82%	+64%
Phosphorus uptake (mg/g root)	Maize	Intensive stem growth stage	20-30	0.14	0.21	+50%
Nitrogen uptake (mg/g root)	Maize	Grain filling stage	10-20	0.2	0.28	+40%
Potassium uptake (mg/g root)	Maize	Cob formation stage	30-40	0.17	0.26	+52.9%

Source: *developed by the authors*

Based on the conducted analysis, it was established that in wheat, the level of root system colonisation by mycorrhizal fungi reached 85% in the experimental plots, while in the control plots, this figure did not exceed 20%. Similar results were obtained for maize, where colonisation was 82% in the experimental group and 18% in the control group. This indicates that the application of the mycorrhizal product significantly improved the symbiotic relationships between fungi and plants, which in turn improved their nutrition and ability to adapt to stressful environmental conditions. Analysis of root colonisation revealed that mycorrhizal fungi most actively colonised roots during the early stages of plant vegetation. Specifically, in wheat, the highest colonisation was observed during the period of intensive root growth, at the three-leaf stage, when fungi entered into an active symbiosis with young root hairs. This allowed plants to access nutrients, especially phosphorus, at depths of 20-30 cm. At this depth, the concentration of phosphorus available to plants in the experimental group increased by 15% compared to the control group. This value indicates the ability of fungi to assimilate phosphorus in less accessible forms and provide it to plants.

Root colonisation in maize was most active during the stage of intensive stem development when plants required a significant amount of nitrogen to build up vegetative mass. At depths of 10-20 cm, a 12% increase in available nitrogen was recorded in the experimental plots compared to the control plots, which can be explained by the activity of mycorrhizal fungi in breaking down organic nitrogen compounds and converting them into accessible forms. Such a high concentration of nitrogen had a positive impact on the growth of maize stems and leaf mass, providing plants with better conditions for subsequent ear formation. The symbiosis with mycorrhizal fungi also positively influenced the plants' ability to absorb potassium from deeper soil layers. At depths of 30-40 cm, a 9% increase in available potassium was observed in the experimental group compared to the control. Potassium is an important element that regulates plant water relations and is responsible for stress resistance, such as drought (Myronycheva *et al.*, 2017). This allowed plants in the experimental plots to retain water in their cells better, reducing the risk of water loss through transpiration and increasing overall resistance to water shortages during critical growth stages.

Furthermore, the high level of colonisation by mycorrhizal fungi contributed to an improved root system structure. Under experimental conditions, it was observed that the root systems of wheat and maize had more branched root hairs, allowing plants to absorb nutrients and water from the soil more efficiently. In the control plots, where there was no symbiosis with mycorrhizal fungi, the root systems were less developed, significantly limiting the plants' ability to obtain resources from deeper soil layers. Another crucial aspect is that mycorrhizal fungi facilitate the uptake of micronutrients such as zinc, copper, and iron, which are essential for the functioning of various plant enzyme systems (Dymytrov *et al.*, 2023). In the experimental plots, an 11% increase in zinc concentration in the root system was recorded, significantly improving the activity of enzymes responsible for respiration and protein synthesis. This contributed to increased plant productivity in the experimental plots.

Thus, the results of the study clearly demonstrate that mycorrhizal fungi significantly enhance the colonisation of the root systems of wheat and maize, which in turn ensures more efficient nutrient and water absorption by the plants. This positively impacts their growth, resilience to stress and overall productivity. The uptake of nutrients in plants that formed symbiotic relationships with mycorrhizal fungi was significantly more effective than in the control groups. This can be attributed to several key factors, including the increased surface area of the root system and the fungi's ability to mobilise hard-to-access elements in the soil (Table 3). The expanded root system formed through mycorrhizal hyphae enables plants to absorb nutrients from a larger volume of soil, including hard-to-reach elements that exist in bound or organic forms.

***Table 3**. Uptake of micronutrients (magnesium, calcium, zinc, copper, and iron) at various soil depths in control and experimental plots*

Indicator	Crop	Growth stage	Soil depth (cm)	Control group (mg/g root)	Experimental group (mg/g root)	Increase (%)
Magnesium uptake	Wheat	Intensive root growth stage	10-20	0.08	0.12	+17%
	Maize	Intensive stem growth stage	10-20	0.09	0.13	+17%
Calcium uptake	Wheat	Heading stage	20-30	0.1	0.14	+14%
	Maize	Grain filling stage	20-30	0.11	0.15	+14%
Zinc uptake	Wheat	Intensive root growth stage	10-20	0.06	0.09	+20%
	Maize	Intensive stem growth stage	10-20	0.07	0.1	+22%
Copper uptake	Wheat	Grain filling stage	10-20	0.05	0.07	+18%
	Maize	Cob formation stage	10-20	0.06	0.08	+19%
Iron uptake	Wheat	Grain filling stage	20-30	0.1	0.13	+15%
	Maize	Grain filling stage	20-30	0.11	0.14	+17%

***Source:** developed by the authors*

In particular, the study showed a 17% increase in magnesium uptake at depths of 10-20 cm in the experimental plants. This can be explained by the active interaction of mycorrhizal fungi with soil mineral particles, where magnesium can be bound in an unavailable form. Mycorrhizal fungi release organic acids and enzymes that dissolve these particles, making magnesium available to the root system. Experimental plants, receiving magnesium from greater depths and in higher concentrations, demonstrated more stable growth and accumulated more biomass throughout the growing season, which ensured increased photosynthetic activity and overall physiological plant resistance. A similar trend was observed with calcium, where a 14% increase in uptake was recorded at depths of 20-30 cm in the experimental plants. Calcium is often found bound to soil particles, but thanks to the symbiotic interactions of mycorrhizal fungi with soil minerals, its availability is significantly increased. In the experimental plants, improved calcium uptake ensured the stability of cellular processes and tissue structure, providing plants with greater resistance to mechanical damage and stressful conditions such as drought or nutrient deficiency.

Regarding micronutrients such as zinc and copper, their uptake was also significantly improved in the experimental groups. Zinc uptake at a depth of 10-20 cm increased by 20% for wheat and 22% for maize in the experimental plants. This effect is linked to the ability of mycorrhizal fungi to mobilise less accessible forms of zinc from organic compounds in the soil, significantly increasing its availability to plants. Importantly, zinc uptake became possible even at greater depths due to the expanded root system formed by fungal hyphae. As a result, plants had better conditions for respiration and protein synthesis, leading to more stable growth throughout the growing season. Copper uptake increased by 18% in wheat and 19% in maize in the experimental plants, which can also be attributed to the ability of mycorrhizal fungi to release organic acids that dissolve bound forms of copper in the soil, making them available to plants. This improved copper availability ensured more efficient functioning of plant enzyme systems, especially during periods of stress when enzymatic activity is critical for plant adaptation to changes in the environment. In the control group plants, where symbiotic relationships did not form, a lower ability to absorb copper was observed, leading to decreased stress resistance and less efficient growth.

Iron uptake was also significantly improved in the experimental plants, particularly at depths of 20-30 cm, where uptake levels increased by 15% in wheat and 17% in maize. This increase can be attributed to the ability of mycorrhizal fungi to convert iron from oxide forms into soluble forms, making this element available to plants even in hard-to-reach parts of the soil. Improved iron uptake facilitated more efficient chlorophyll synthesis, which contributed to increased rates of photosynthesis and, consequently, improved overall plant productivity. The research results clearly demonstrated that the use of mycorrhizal fungi not only increased crop yield and biomass but also significantly improved the quality of the harvested produce (Table 4). The improvement in product quality is of great significance for agricultural production, as it affects not only the quantity but also the market value of the crop, its nutritional value, and its competitiveness in both domestic and international markets.

***Table 4**. Quality of wheat and maize grain in control and experimental plots*

Indicator	Crop	Control group	Experimental group	Increase (%)
Protein content (%)	Wheat	12.5	13.4	+7%
Protein content (%)	Maize	9.2	10.0	+9%
Carbohydrate content (%)	Wheat	67.0	70.4	+5%
Carbohydrate content (%)	Maize	73.0	77.4	+6%
Amino acid content (%)	Wheat	5.5	5.9	+8%
Amino acid content (%)	Maize	4.8	5.3	+10%
Oil content (%)	Maize	3.5	3.7	+4%
Reduction in fertiliser costs (%)	Wheat	-	-	-15%
Reduction in fertiliser costs (%)	Maize	-	-	-15%
Increase in sales revenue (%)	Wheat	-	-	+20%
Increase in sales revenue (%)	Maize	-	-	+20%

***Source:** developed by the authors*

An analysis of wheat and maize grain from the experimental plots revealed a 7% increase in protein content in wheat compared to the control plots. In maize, this figure increased by 9%. This increase in protein content is directly linked to better nitrogen uptake, which is critical for protein synthesis. Experimental plants in plots with mycorrhizal fungi had access to a greater amount of nitrogen due to the expanded root system and the ability of mycorrhizal fungi to mobilise nitrogen from organic forms. This allowed plants to accumulate more protein in the grain, which in turn increased its nutritional value. In addition to the increased protein content, grains from the experimental plots had higher levels of carbohydrates and fats, which are also important indicators of product quality. In wheat, the total carbohydrate content increased by 5%, while in maize this figure increased by 6%. This growth can be explained by the improved photosynthetic process in plants that receive more nutrients and water. A more efficient photosynthetic process allowed plants to produce more assimilates, which directly affected the formation of carbohydrates and fats.

The significant improvement in grain quality is also supported by data on amino acid composition. In wheat from the experimental plots, an 8% increase in essential amino acids was recorded, while in maize, this figure increased by 10%. This indicator is extremely important for assessing the nutritional value of grain, as essential amino acids are not synthesised in the human or animal body, and therefore their quantity in grain directly affects its nutritional value for food and feed (Andreychenko *et al.*, 2024). Analysis of the oil content in maize grain also revealed a 4% increase. This is a significant aspect, as oil content is one of the key parameters for determining the quality of maize, especially in the context of its use in feed production or the food industry. The increased oil content of maize from the experimental plots suggests that mycorrhizal fungi also contributed to the accumulation of fats in the grain.

In addition to improving product quality, the use of mycorrhizal fungi also had a significant economic impact. Since mycorrhizal fungi promote more efficient uptake of nutrients from the soil, this allows for a reduction in the need for mineral fertilisers. According to calculations, fertiliser costs on the experimental plots were reduced by 15% compared to the controls, which allowed for a reduction in overall crop production costs. This is because mycorrhizal fungi provide more efficient uptake of macro- and micronutrients, such as phosphorus, nitrogen, potassium, magnesium, and calcium, from smaller amounts of fertilisers, which would otherwise be unavailable to plants. The economic benefits of using mycorrhizal fungi also include increased yields and improved product quality, which directly impacts increased revenue from product sales. According to calculations, the total revenue from the sale of wheat and maize on the experimental plots increased by 20% compared to the control plots. This is due not only to increased crop yields but also to improved grain quality, which has a higher market value due to increased protein, carbohydrate, and other nutrient content.

In conclusion, the use of mycorrhizal fungi has a significant impact on improving product quality and the economic efficiency of agricultural production. Improved grain quality, higher yields, and reduced fertiliser costs make mycorrhizal fungi a promising element of agricultural technologies for increasing crop productivity.

DISCUSSION

The results obtained demonstrate a significant impact of mycorrhizal fungi on increasing yield, biomass, improving product quality, and the economic efficiency of wheat and maize cultivation. These data are of significant importance as they confirm the high efficiency of mycorrhizal fungi in the context of modern agricultural technologies, as well as their ability to improve the availability of nutrients and water for plants. However, it is important to analyse the significance of the results obtained and their correspondence with the research of other scientists.

The results obtained regarding the increase in yield and improvement of grain quality using mycorrhizal fungi are consistent with numerous studies conducted in various countries worldwide. In particular, the increase in wheat and maize yields on experimental plots confirms the effectiveness of mycorrhiza as a key element for improving agricultural technologies. Importantly, similar results have been obtained in the work of other researchers. For example, H. Yang *et al.* (2022) in their study also found a significant increase in maize yield under drought conditions through the use of mycorrhizal fungi. These data are also supported by the results of studies by A. Fall *et al.* (2023) and W. Chafai *et al.* (2023), who demonstrated similar trends in different regions with arid climates. This is consistent with results indicating the positive impact of mycorrhiza on root system development and improved water uptake from deep soil layers.

However, some discrepancies can be explained by differences in research methodologies or specific soil and climatic conditions. For instance, C. Ngosong *et al.* (2022) noted that excessive soil moisture can reduce the effectiveness of mycorrhiza due to a lack of aeration. This indicates that the activity of mycorrhizal fungi is dependent on environmental conditions, particularly soil moisture and structure. Similar conclusions were drawn by F. Buzo *et al.* (2022), who investigated the effectiveness of mycorrhiza under conditions of high soil moisture. The study conducted in the Mykolaiv Region did not include extreme moisture conditions, so these results may differ in regions with higher rainfall or waterlogged soils. This highlights the need for further research aimed at assessing the impact of different moisture levels on the symbiosis between mycorrhizal fungi and plants.

Another crucial aspect for comparison is the study of the impact of mycorrhizal fungi on wheat and maize biomass. According to the presented results, wheat biomass increased by 12%, and maize biomass by 14% in plots where mycorrhizal fungi were applied. This corresponds to the results of the study by A. Feilinezhad *et al.* (2022), which indicated that mycorrhizal fungi not only improve nutrient uptake but also intensify photosynthetic processes, directly affecting vegetative mass growth. This trend is also confirmed by studies by Z. Hazzoumi *et al.* (2022), which revealed a similar impact of mycorrhiza on increasing overall plant productivity in various climatic conditions. Although Z. Peng *et al.* (2023) focused on more southern regions with tropical climates, the results obtained demonstrate that the effect of mycorrhiza on increasing plant biomass is universal and depends less on climatic conditions than on the ability of fungi to provide plants with additional nutrients.

In the context of maize grain quality, it is also important to note a 4% increase in oil content as a result of the experiment. This aligns with the research of M. Dhiman *et al.* (2022), which showed that mycorrhizal fungi can influence lipid metabolism in plants, leading to increased fat accumulation in grain. Similar results were obtained by Z. Felföldi *et al.* (2022), who found that mycorrhiza improves lipid metabolism in oilseed crops, which may affect the increase in fat content in maize grain. Although authors studied this phenomenon in oilseed crops such as sunflower, similar processes can occur in cereal crops, as confirmed by the results obtained for maize in the Mykolaiv Region. This highlights the importance of further research into the impact of mycorrhizal fungi on various aspects of product quality, particularly fat and protein content.

The research of M. Sheikh-Assadi *et al.* (2023) also confirms that mycorrhizal fungi significantly improve phosphorus uptake by plants, especially under conditions of phosphorus deficiency in the soil. Similar results were obtained by A. Khaliq *et al.* (2022), who investigated the effectiveness of mycorrhiza in moderately enriched soils, confirming the overall improvement in nutrient uptake in plants. This correlates with the results where a 50% increase in phosphorus uptake was recorded at a depth of 20-30 cm. However, in the article of A. Khaliq *et al.* (2022), focus was on poor soils with a phosphorus deficit, while the soils in the Mykolaiv Region were characterised by a moderate content of this element. Thus, the obtained results demonstrate that mycorrhizal fungi are effective not only under conditions of critical nutrient deficiency but also in moderately enriched soils, making them a universal tool for increasing crop productivity.

Regarding the improvement of product quality, the results also confirm the conclusions of previous studies. For instance, the increase in protein content in wheat by 7% and in maize by 9% aligns with the research of W. Benaffari *et al.* (2022), who found similar changes when applying mycorrhizal fungi in cereal cultivation. Similar conclusions were drawn by A. Wahab *et al.* (2023), who also observed an increase in protein content in plants due to improved nitrogen uptake. Their studies showed that the improved nitrogen uptake, provided by mycorrhizal fungi, leads to an increase in protein synthesis in plants, which increases the nutritional and feed value of the product. It is important to note that this study also observed an increase in the content of amino acids and carbohydrates, indicating a general improvement in plant metabolic processes.

Comparisons with the research of other scientists also indicate general trends regarding the use of mycorrhizal fungi in modern agriculture. Y. Khan *et al.* (2022) also noted a decreased reliance on mineral fertilisers when using mycorrhizal fungi in organic farming systems. The presented study in the Mykolaiv Region showed a similar result – a 15% reduction in fertiliser costs. This indicates a significant economic effect, especially for small and medium-sized agricultural enterprises that seek to reduce fertiliser costs without lowering yields.

A more in-depth analysis should also be conducted in the context of the environmental sustainability that mycorrhizal fungi provide. The presented results regarding a 15% reduction in the need for mineral fertilisers coincide with the research of J. Sun *et al*. (2022) and K. Anand *et al*. (2022), who note that mycorrhizal fungi can significantly reduce the chemical load on the soil. Similar results are presented in the studies of D. Beslemes *et al*. (2023) and R. Kalamulla *et al*. (2022), where it was established that mycorrhiza can contribute to the restoration of soil ecosystems through reduced use of chemical fertilisers. This not only allows for a reduction in fertiliser costs but also promotes the restoration of natural soil fertility, which is critically important in the context of ecosystem conservation. A comparison of the results of the study in the Mykolaiv Region and other regions of the world suggests that mycorrhizal fungi can be an important element of sustainable agriculture, regardless of specific climatic and soil conditions.

Another crucial aspect deserving attention is the impact of mycorrhizal fungi on plant resilience to stress factors such as drought and nutrient deficiencies. The results obtained confirmed that plants in plots with mycorrhizal fungi demonstrated greater resistance to temporary droughts and a better ability to maintain growth under adverse conditions. This aligns with the research of S. Ettlili *et al*. (2022), who found that mycorrhizal fungi promote better water use under limited moisture conditions, providing plants with access to deeper soil layers. Similar results were obtained in studies by H. Tang *et al*. (2022) and F. Soussani *et al*. (2023), which confirmed the effectiveness of mycorrhiza in improving plant water balance. In the study conducted in the Mykolaiv Region, this effect was noticeable due to improved water absorption from a depth of up to 30 cm, allowing plants to maintain stable growth even with a lack of moisture in the upper soil layers. Importantly, this effect was also observed in other regions with different climatic conditions, emphasising the universality of the mechanism of action of mycorrhizal fungi in increasing plant stress resistance (Donchak & Shkvaruk, 2024).

In summarising the analysis results, it can be concluded that the data obtained regarding the impact of mycorrhizal fungi on yield, product quality, and economic efficiency corroborate trends noted in other studies. Nevertheless, certain aspects of the interaction between mycorrhizal fungi and plants remain open for further investigation, particularly concerning the influence of various ecological conditions on the effectiveness of the symbiosis.

CONCLUSIONS

The research conducted demonstrated that the application of mycorrhizal fungi significantly increased the yield and quality of cereal crops, such as wheat and maize, in the Mykolaiv Region. In particular, a 15% and 18% increase in yield was recorded for wheat and maize, respectively, on experimental plots compared to control plots. This increase is associated with improved uptake of nutrients from the soil by plants, including phosphorus, nitrogen, and potassium. Specifically, phosphorus uptake increased by 50% at a depth of 20-30 cm, which contributed to the development of a more robust root system, ensuring a stable supply of nutrients to plants throughout the growing season. This, in turn, led to a 12% increase in wheat biomass and a 14% increase in maize biomass, indicating a positive impact of mycorrhizal fungi on overall plant growth.

Another significant outcome of the study was an improvement in the quality of the harvested grain. The protein content in wheat increased by 7%, and in maize by 9%, indicating a higher nutritional value for both human consumption and animal feed. This aspect is crucial for the agricultural industry, as products with higher protein content are in greater demand on the market. Additionally, the oil content in maize grain increased by 4%, which enhances its value and attractiveness to the processing industry. The increase in these quality indicators of the grain confirms that the application of mycorrhizal fungi is an effective technology not only for increasing production volumes but also for improving economic performance in the agricultural sector. The economic benefits of using mycorrhizal fungi were also evident in reduced costs of mineral fertilisers. Due to improved efficiency in nutrient uptake from the soil, the need for additional fertilisation decreased by 15%, allowing for a reduction in reliance on mineral fertilisers and a decrease in the chemical load on soils. This is a significant step towards sustainable agriculture, which considers environmental aspects and contributes to preserving natural soil fertility.

However, it is important to note that the study had certain limitations. Specifically, the experiment was conducted in only one region – the Mykolaiv Region – which may influence the overall conclusions regarding the application of mycorrhizae in different climatic and soil conditions. Therefore, the results may vary in other regions where climatic conditions and soil composition differ. This underscores the necessity for further research in various climatic zones, as well as on other crops, to broaden the applicability of the findings in agricultural production. The study also did not include an analysis of the long-term effects of mycorrhizae on soil ecosystems and plant resilience to stress factors such as drought or excessive moisture, which could serve as a direction for future experimental work.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Anand, K., Pandey, G., Kaur, T., Pericak, O., Olson, C., Mohan, R., Akansha, K., Yadav, A., Devi, R., Kour, D., Rai, A., Kumar, M., & Yadav, A. (2022). Arbuscular mycorrhizal fungi as a potential biofertilizers for agricultural sustainability. *Journal of Applied Biology & Biotechnology*, 10(1), 90-107. doi: 10.7324/jabb.2022.10s111.

[2] Andreychenko, S., Kurchii, B., & Klepko, A. (2024). Ethylene and fatty acids as markers of stress resistance in winter wheat. *Biological Systems: Theory and Innovation*, 15(1), 84-90. doi: 10.31548/biologiya15(1).2024.007.

[3] Benaffari, W., Boutasknit, A., Anli, M., Ait-El-Mokhtar, M., Ait-Rahou, Y., Ben-Laouane, R., Ahmed, H., Mitsui, T., Baslam, M., & Meddich, A. (2022). The native arbuscular mycorrhizal fungi and vermicompost-based organic amendments enhance soil fertility, growth performance, and the drought stress tolerance of quinoa. *Plants*, 11(3), article number 393. doi: 10.3390/plants11030393.

[4] Beslemes, D., Tigka, E., Roussis, I., Kakabouki, I., Mavroeidis, A., & Vlachostergios, D. (2023). Effect of arbuscular mycorrhizal fungi on nitrogen and phosphorus uptake efficiency and crop productivity of two-rowed barley under different crop production systems. *Plants*, 12(9), article number 1908. doi: 10.3390/plants12091908.

[5] Burdina, I., & Priss, O. (2016). Effect of the substrate composition on yield and quality of basil (*Ocimum basilicum* L.). *Journal of Horticultural Research*, 24(2), 109-118. doi: 10.1515/johr-2016-0027.

[6] Buzo, F., Mortinho, E., Santana, T., Garcia, I., Carvalho, C., & Filho, M. (2022). Bean nutrition and development in the function of reduced phosphorus doses and inoculation with arbuscular mycorrhizal fungus. *Journal of Plant Nutrition*, 45, 1942-1952. doi: 10.1080/01904167.2022.2043372.

[7] Chafai, W., Haddioui, K., Serghini-Caid, H., Labazi, H., AlZain, M., Noman, O., Parvez, M., Addi, M., & Khalid, A. (2023). Impact of *Arbuscular mycorrhizal* fungal strains isolated from soil on the growth, yield, and fruit quality of tomato plants under different fertilization regimens. *Horticulturae*, 9(9), article number 973. doi: 10.3390/horticulturae9090973.

[8] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[9] Convention on International Trade in Endangered Species of Wild Fauna and Flora. (1979, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_129#Text.

[10] Dhiman, M., Sharma, L., Kaushik, P., Singh, A., & Sharma, M. (2022). Mycorrhiza: An ecofriendly bio-tool for better survival of plants in nature. *Sustainability*, 14(16), article number 10220. doi: 10.3390/su141610220.

[11] Donchak, L., & Shkvaruk, D. (2024). Current state and prospects for the development of agriculture in the Vinnytsia region. *Ekonomika APK*, 31(2), 23-31. doi: 10.32317/2221-1055.202402023.

[12] Dymytrov, S., Sabluk, V., & Humentyk, M. (2023). Formation of productivity of giant miscanthus (Miscanthus×giganteus) under symbiosis of its root system with fungi and bacteria. *Plant and Soil Science*, 14(2), 46-56. doi: 10.31548/plant2.2023.46.

[13] Ettlili, S., Labidi, S., Khiari, B., Jerbi, M., Alaya, A.B., Djébali, N., & Faysal, B.J. (2022). Reduced nitrogen and phosphorus fertilization combined with mycorrhizal inoculation enhance potato yield and soil mineral fertility. *Journal of Oasis Agriculture and Sustainable Development*, 4(4), 20-29. doi: 10.56027/joasd.212022.

[14] Fall, A., Nakabonge, G., Ssekandi, J., Founoune-Mboup, H., Badji, A., Ndiaye, A., Ndiaye, M., Kyakuwa, P., Anyoni, O., Kabaseke, C., Ronoh, A., & Ekwangu, J. (2023). Combined effects of indigenous arbuscular mycorrhizal fungi (AMF) and NPK fertilizer on growth and yields of maize and soil nutrient availability. *Sustainability*, 15(3), article number 2243. doi: 10.3390/su15032243.

[15] Feilinezhad, A., Mirzaeiheydari, M., Babaei, F., Maleki, A., & Rostaminya, M. (2022). The effect of tillage, organic matter and mycorrhizal fungi on efficiency and productivity use of nutrients in maize. *Communications in Soil Science and Plant Analysis*, 53(20), 2719-2733. doi: 10.1080/00103624.2022.2072869.

[16] Felföldi, Z., Vidican, R., Stoian, V., Roman, I., Sestras, A., Rusu, T., & Sestras, R. (2022). Arbuscular mycorrhizal fungi and fertilization influence yield, growth and root colonization of different tomato genotype. *Plants*, 11(13), article number 1743. doi: 10.3390/plants11131743.

[17] Franczuk, J., Tartanus, M., Rosa, R., Zaniewicz-Bajkowska, A., Dębski, H., Andrejiová, A., & Dydiv, A. (2023). The effect of mycorrhiza fungi and various mineral fertilizer levels on the growth, yield, and nutritional value of sweet pepper (*Capsicum annuum* L.). *Agriculture*, 13(4), article number 857. doi: 10.3390/agriculture13040857.

[18] Hazzoumi, Z., Azaroual, S., Mernissi, N., Zaroual, Y., Duponnois, R., Bouizgarne, B., & Kadmiri, I. (2022). Effect of arbuscular mycorrhizal fungi isolated from rock phosphate mine and agricultural soil on the improvement of wheat plant growth. *Frontiers in Microbiology*, 13, article number 881442. doi: 10.3389/fmicb.2022.881442.

[19] Ivanova, I., Serdyuk, M., Malkina, V., Tonkha, O., Tsyz, O., Mazur, B., Shkinder-Barmina, A., Herasko, T., & Havryliuk, O. (2022). Cultivar features of polyphenolic compounds and ascorbic acid accumulation in the cherry fruits (*Prunus cerasus* L.) in the Southern Steppe of Ukraine. *Agronomy Research*, 20(3), 588-602. doi: 10.15159/AR.22.065.
[20] Kalamulla, R., Karunarathna, S., Tibpromma, S., Galappaththi, M., Suwannarach, N., Stephenson, S., Asad, S., Salem, Z., & Yapa, N. (2022). Arbuscular mycorrhizal fungi in sustainable agriculture. *Sustainability*, 14(19), article number 12250. doi: 10.3390/su141912250.
[21] Khaliq, A., Perveen, S., Alamer, K., Haq, M., Rafique, Z., Alsudays, I., Althobaiti, A., Saleh, M., Hussain, S., & Attia, H. (2022). Arbuscular mycorrhizal fungi symbiosis to enhance plant-soil interaction. *Sustainability*, 14(13), article number 7840. doi: 10.3390/su14137840.
[22] Khan, Y., Shah, S., & Hui, T. (2022). The roles of arbuscular mycorrhizal fungi in influencing plant nutrients, photosynthesis, and metabolites of cereal crops – A review. *Agronomy*, 12(9), article number 2191. doi: 10.3390/agronomy12092191.
[23] Mitra, D., Nayeri, F.D., Sansinenea, E., Ortiz, A., Bhatta, B.B., Adeyemi, N.O., Janeeshma, E., Al-Ani, L.K., Sharma, S.B., Boutaj, H., Priyadarshini, A., Chakroborty, D., Senapati, A., Sierra, G., Chidambaranathan, P., Das Mohapatra, P.K., & Panneerselvam, P. (2023). Unraveling arbuscular mycorrhizal fungi interaction in rice for plant growth development and enhancing phosphorus use efficiency through recent development of regulatory genes. *Journal of Plant Nutrition*, 46(13), 3184-3220. doi: 10.1080/01904167.2023.2191638.
[24] Myronycheva, O., Bandura, I., Bisko, N., Gryganskyi, A.P., & Karlsson, O. (2017). Assessment of the growth and fruiting of 19 oyster mushroom strains for indoor cultivation on lignocellulosic wastes. *BioResources*, 12(3), 4606-4626. doi: 10.15376/biores.12.3.4606-4626.
[25] Ngosong, C., Tatah, B., Olougou, M., Suh, C., Nkongho, R., Ngone, M., Achiri, D., Tchakounté, G., & Ruppel, S. (2022). Inoculating plant growth-promoting bacteria and arbuscular mycorrhiza fungi modulates rhizosphere acid phosphatase and nodulation activities and enhance the productivity of soybean (*Glycine max*). *Frontiers in Plant Science*, 13, article number 934339. doi: 10.3389/fpls.2022.934339.
[26] Oliferchuk, V., Kendzora, N., Shukel, I., Samarska, M., & Olejniuk-Puchniak, O. (2023). The role of V-strategist endophytes in stimulating the formation of mycorrhizal interactions and soil regeneration. doi: 10.5772/intechopen.109912.
[27] Peng, Z., Johnson, N., Jansa, J., Han, J., Fang, Z., Zhang, Y., Jiang, S., Xi, H., Mao, L., Pan, J., Zhang, Q., Feng, H., Fan, T., Zhang, J., & Liu, Y. (2023). Mycorrhizal effects on crop yield and soil ecosystem functions in a long-term tillage and fertilization experiment. *New Phytologist*, 242(4), 1798-1813. doi: 10.1111/nph.19493.
[28] Qian, S., Xu, Y., Zhang, Y., Wang, X., Niu, X., & Wang, P. (2024). Effect of AMF inoculation on reducing excessive fertilizer use. *Microorganisms*, 12(8), article number 1550. doi: 10.3390/microorganisms12081550.
[29] Shahini, S., Kachanova, T., Manushkina, T., Petrova, O., & Shevchuk, N. (2023). Using organic nitrogen fertilisers to improve soil health and increase yields. *International Journal of Environmental Studies*, 80(2), 433-441. doi: 10.1080/00207233.2023.2174739.
[30] Sheikh-Assadi, M., Khandan-Mirkohi, A., Taheri, M., Babalar, M., Sheikhi, H., & Nicola, S. (2023). Arbuscular mycorrhizae contribute to growth, nutrient uptake, and ornamental characteristics of statice (*Limonium sinuatum* [L.] Mill.) subject to appropriate inoculum and optimal phosphorus. *Horticulturae*, 9(5), article number 564. doi: 10.3390/horticulturae9050564.
[31] Soussani, F., Boutasknit, A., Ben-Laouane, R., Benkirane, R., Baslam, M., & Meddich, A. (2023). Arbuscular mycorrhizal fungi and compost-based biostimulants enhance fitness, physiological responses, yield, and quality traits of drought-stressed tomato plants. *Plants*, 12(9), article number 1856. doi: 10.3390/plants12091856.
[32] Sun, J., Jia, Q., Li, Y., Zhang, T., Chen, J., Ren, Y., Dong, K., Xu, S., Shi, N., & Fu, S. (2022). Effects of arbuscular mycorrhizal fungi and biochar on growth, nutrient absorption, and physiological properties of maize (*Zea mays L.*). *Journal of Fungi*, 8(12), article number 1275. doi: 10.3390/jof8121275.
[33] Sun, W., & Shahrajabian, M.H. (2023). The application of arbuscular mycorrhizal fungi as microbial biostimulant: Sustainable approaches in modern agriculture. *Plants*, 12(17), article number 3101. doi: 10.3390/plants12173101.
[34] Tang, H., Hassan, M., Feng, L., Nawaz, M., Shah, A., Qari, S., Liu, Y., & Miao, J. (2022). The critical role of arbuscular mycorrhizal fungi to improve drought tolerance and nitrogen use efficiency in crops. *Frontiers in Plant Science*, 13, article number 919166. doi: 10.3389/fpls.2022.919166.
[35] Wahab, A., Muhammad, M., Munir, A., Abdi, G., Zaman, W., Ayaz, A., Khizar, C., & Reddy, S.P. (2023). Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. *Plants*, 12(17), article number 3102. doi: 10.3390/plants12173102.
[36] Yang, H., Fang, C., Li, Y., Wu, Y., Fransson, P., Rillig, M., Zhai, S., Xie, J., Tong, Z., Zhang, Q., Sheteiwy, M., Li, F., & Weih, M. (2022). Temporal complementarity between roots and mycorrhizal fungi drives wheat nitrogen use efficiency. *New Phytologist*, 263(3), 1168-1181. doi: 10.1111/nph.18419.

Роль мікоризних грибів у підвищенні ефективності використання добрив в сільському господарстві

Олена Кобернюк
Кандидат сільськогосподарських наук, доцент
Заклад вищої освіти "Подільський державний університет"
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-1380-7976

Василь Григор'єв
Кандидат сільськогосподарських наук, доцент
Заклад вищої освіти "Подільський державний університет"
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-8567-5466

Катерина Небаба
Кандидат сільськогосподарських наук, асистент
Заклад вищої освіти "Подільський державний університет"
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-4529-3623

Руслан Гаврилянчик
Кандидат сільськогосподарських наук, доцент
Заклад вищої освіти "Подільський державний університет"
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-7609-1039

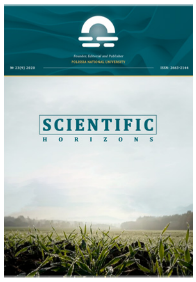
Данило Плахтій
Кандидат сільськогосподарських наук, доцент
Заклад вищої освіти "Подільський державний університет"
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-2014-9748

Анотація. Дослідження було проведене з метою оцінки впливу мікоризних грибів на врожайність, біомасу та якість зернових культур (пшениці та кукурудзи) в умовах Півдня України. Для експерименту були відібрані контрольні та експериментальні ділянки, на яких застосовувалися мікоризні гриби для покращення засвоєння поживних речовин рослинами. Процес дослідження включав детальне вимірювання врожайності, біомаси та поглинання таких поживних елементів, як фосфор, азот і калій, на різних етапах вегетації. Результати показали, що застосування мікоризних грибів забезпечило збільшення врожайності пшениці на 15 % і кукурудзи на 18 % на експериментальних ділянках у порівнянні з контрольними, що було досягнуто завдяки підвищеному рівню поглинання поживних речовин із глибших шарів ґрунту. Біомаса пшениці зросла на 12 %, а кукурудзи на 14 %, що свідчить про позитивний вплив мікоризи на розвиток рослин. Поглинання фосфору на глибині 20-30 см збільшилося на 50 %, що сприяло кращому розвитку кореневої системи та забезпеченню рослин доступними елементами. Крім того, було зафіксовано підвищення вмісту білка в зерні пшениці на 7 %, а в кукурудзи на 9 %, що свідчить про покращення харчової та кормової цінності продукції. Аналіз показав також підвищення рівня олійності зерна кукурудзи на 4 %, що підвищує її економічну цінність. Важливим результатом стало зниження витрат на мінеральні добрива на 15 % завдяки покращенню ефективності використання поживних речовин, що зменшує потребу в додатковому підживленні. Отримані результати підтверджують, що використання мікоризних грибів є ефективним методом для підвищення врожайності, якості продукції та економічної ефективності сільськогосподарського виробництва

Ключові слова: агротехнології; зернові культури; *Glomus*; врожайність; біомаса; поглинання поживних елементів

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 98-109



UDC 663.86:634.7
Doi: 10.48077/scihor9.2024.98

Assessment of nutritional value and safety of soft drinks enriched with berries growing in the Republic of Azerbaijan in comparison with traditional drinks

Sevinj Maharramova*
Doctor of Philosophy, Associate Professor
Azerbaijan State University of Economics
AZ1001, 6 Istiqlaliyyat Str., Baku, Azerbaijan
https://orcid.org/0000-0002-1599-7013

Maryam Mammadaliyeva
PhD in Biology, Teacher
Azerbaijan State University of Economics
AZ1001, 6 Istiqlaliyyat Str., Baku, Azerbaijan
https://orcid.org/0000-0002-4351-8286

Gunash Nasrullayeva
PhD in Economics, Associate Professor
Azerbaijan State University of Economics
AZ1001, 6 Istiqlaliyyat Str., Baku, Azerbaijan
https://orcid.org/0000-0003-2661-8354

Mehriban Maharramova
PhD in Biology, Associate Professor
Azerbaijan State University of Economics
AZ1001, 6 Istiqlaliyyat Str., Baku, Azerbaijan
https://orcid.org/0000-0002-8359-5112

Mehriban Yusifova
PhD in Biology, Associate Professor
Azerbaijan State University of Economics
AZ1001, 6 Istiqlaliyyat Str., Baku, Azerbaijan
https://orcid.org/0000-0001-7608-5950

Article's History:
Received: 11.04.2024
Revised: 06.08.2024
Accepted: 28.08.2024

Abstract. The study used modified formulations of traditional drinks to enrich them with several nutrients and microelements. Berries selected for the study, namely: dogwood, pomegranate, persimmon, blueberry, and raspberry, demonstrated high antioxidant activity and rich vitamin composition. The study revealed a significant increase in the antioxidant activity of traditional Azerbaijani drinks when enriched with berry extracts. The antioxidant activity of arrowroot increased by 20 mg GAE/100

Suggested Citation:
Maharramova, S., Mammadaliyeva, M., Nasrullayeva, G., Maharramova, M., & Yusifova, M. (2024). Assessment of nutritional value and safety of soft drinks enriched with berries growing in the Republic of Azerbaijan in comparison with traditional drinks. *Scientific Horizons*, 27(9), 98-109. doi: 10.48077/scihor9.2024.98.

*Corresponding author

ml after dogwood enrichment. Sherbet showed an increase in activity of 22.5 mg GAE/100 ml with the addition of raspberries. Tea enriched with persimmon increased its antioxidant activity by 125%. The pomegranate-enriched compote increased its activity by 24 mg GAE/100 ml. Blueberry pekmez showed average results, although due to the high level of nutritional properties of blueberries, it was also a promising research object. The study also analysed the selected berries, further evaluating potential changes in the vitamin composition, antioxidant activity, and organoleptic properties of the beverages after adding the berries. The most significant improvement in taste, aroma, colour and texture of the drinks was observed in persimmon extract-enriched tea and blueberry pekmez, which received the highest scores for all parameters after enrichment. The antioxidant activity of the drinks also increased significantly after adding berry extracts. The microbiological and chemical risks associated with the use of fresh berries and the proposed measures to ensure the safety of beverages helped to shape the further vector of research in this area

Keywords: antioxidant activity; healthy food; functional foods; microbiological analysis; formulations

INTRODUCTION

In the modern world, the consumption of various soft drinks is an important part of everyday life for millions of people. However, the growing interest in healthy lifestyles is driving consumers to look for healthier alternatives to traditional beverages, which often contain high levels of sugar and artificial additives. In this regard, the use of natural ingredients to enrich beverages is becoming increasingly popular. Berries are high in antioxidants, vitamins, minerals and biologically active compounds. Antioxidants are crucial in protecting the body from oxidative stress, which is one of the causes of chronic diseases such as cardiovascular disease, diabetes and cancer. Azerbaijani berries are a source of flavonoids, anthocyanins and antioxidants, which makes them promising components of functional foods.

Recent studies show that berries can not only supplement the diet but also have a positive impact on the health of patients with iron deficiency anaemia, diabetes or obesity (Hameed *et al*., 2020; Pourhakim *et al*., 2024). Details of the pharmacological properties of chemical compounds in berries were also reported in a recent review in 2024, where O. Golovinskaia and C.-K. Wang (2021) identified the main components that affect the usefulness of berries, which, in addition to the above effects, can be used in the treatment of cardiovascular diseases to slow platelet aggregation. On the other hand, there is the problem of consuming large quantities of stimulating sweetened beverages that can cause food addiction in consumers, with further negative health consequences (Loiko *et al.*, 2024). A Romanian research team, together with M. Mititelu *et al.* (2023), noted correlations between the growing popularity of coffee-sweetened drinks and the deterioration of the psycho-emotional state and a decrease in physical activity among the population. Moreover, in the work of T.C. Gheonea *et al.* (2023), a negative trend can be noted on the general impact of a high-calorie, but not particularly nutritious diet on human social activity.

Scientists highlight the benefits of blueberries and raspberries on the gastrointestinal tract. For instance, a group of scientists from China, when studying the antioxidant properties of berries using four chemical methods of analysis, noted that the results for each sample may differ depending on the chosen method of analysis (Chen *et al*., 2022). To obtain a more accurate overall picture, they needed data from both *in vitro* and *in vivo* experiments, which revealed that the addition of berries to the diet inhibits the growth of pathogenic bacteria and, on the contrary, promotes the growth of *Bifidobacterium* and *Lactobacillus*. At the same time, a combination of drinks already containing phenolic compounds, anthocyanins and vitamins with berry extracts can have a more nutritious and balanced composition (Bogoyavlenskiy *et al.*, 2022).

Among the popular berries in Azerbaijan, pomegranate is also of particular interest due to the presence of several polyphenolic compounds with pronounced anti-inflammatory properties (Habib *et al*., 2023). In addition, T. Bozkurt and Z. Ergun (2021) emphasised that even the seeds of pomegranate are rich in fatty acids and should be included in the daily diet. *Diospyros kaki* is another source of antioxidants in the Republic of Azerbaijan; adding persimmon extract to tea can enrich the beverage with several bioactive substances and fruit flavours (Hossain & Shahidi, 2023). It is also worth noting that for Azerbaijan, the culture of tea drinking occupies a special place in everyday life and is an important part of national identity. Tea is traditionally served at significant events, such as holidays, family gatherings or even business negotiations (Isaxanli, 2023). Thus, the enrichment of traditional Azerbaijani tea with persimmon extract is a rational and useful addition that can not only preserve cultural heritage but also become part of an innovative technology in the food industry.

The search for an alternative to modern beverages is not only a promising area of research but also a necessity for broad social groups. For instance, for children, the availability of alternatives to consuming large amounts of sugar and replacing it with natural sweeteners, as well as the promotion of traditional drinks, will prevent several acute and chronic diseases in adulthood (Dudarev, 2024). Research by other authors highlighted the importance of using natural ingredients, such as berries, to enrich soft drinks to improve their functionality and health benefits. Antioxidants, flavonoids and other biologically active compounds contained in berries have a positive effect on the body, helping to prevent and treat chronic diseases. This data confirms the promise of the fortified beverage business. The study aimed to evaluate the effect of adding extracts of Azerbaijani berries (pomegranate, dogwood, persimmon, raspberry and blueberry) on the nutritional value and organoleptic properties of traditional drinks.

MATERIALS AND METHODS

The study was conducted in the spring-summer period of 2024 in the food technology laboratory of Azerbaijan State University of Economics (Baku) and Lankaran State University (Lankaran). The laboratory was selected due to the availability of the necessary equipment and qualified personnel to carry out biochemical, toxicological, microbiological and organoleptic analysis of soft drinks enriched with Azerbaijani berry extracts. For the analysis of beverages enriched with extracts of Azerbaijani berries and fruits, the study required various reagents used in spectrophotometry, chromatography, assessment of antioxidant activity, and microbiological analysis. All chemicals were of analytical purity and were purchased from Sigma (St Louis, Missouri, USA), among them Methanol (CH_3OH), chloride acid (HCl, 1%), rutin, cyanidin-3-rutinoside, tannic acid, acetonitrile (CH_3CN), phosphate buffer (pH 3-5), distilled water (H_2O), 2,2-diphenyl-1-picrylhydrazyl (DPPH), Trolox, sodium hydroxide (NaOH, 0.1 N), phenolphthalein, nitric acid (HNO_3), metal standard solutions (for ICP-OES calibration), ethyl alcohol (70%), H_2O_2.

The following equipment was used in the study: a blender (Philips HR3652/00, Netherlands), a spectrophotometer for the determination of phenolic compounds and anthocyanins (Shimadzu UV-1800, Japan), chromatography for the determination of vitamins and flavonoids (Shimadzu LC-2030, Japan), inductively coupled plasma with optical emission spectrometry (ICP-OES) on an Agilent 5100 instrument with Agilent Vapor Generation Accessory VGA 77 (USA), pH meter (Mettler Toledo SevenCompact S210, Switzerland). Regulatory standards were complied with according to local requirements according to the State Standard of Azerbaijan (AZS) 731-2018 (standard establishing requirements for the quality of drinking water and beverages, including methods of their analysis and control of safety indicators), AZS 249-2001 (standard for methods of determining physical and chemical indicators of beverages, including measurement of acidity, sugars and other indicators), AZS 441-2014 (normative document determining methods of organoleptic evaluation of food and beverages, as well as requirements for qualification of members of the tasting commission). All equipment was purchased through official distributors and suppliers in Azerbaijan, which guaranteed the authenticity and reliability of the equipment. Laboratory equipment and reagents were supplied through Interlab LTD, one of the leading suppliers of scientific equipment and reagents in the region.

The following Azerbaijani berries and fruits were used in the experiment: raspberries (*Rubus idaeus*), blueberries (*Vaccinium myrtillus*) collected in mountainous regions of Azerbaijan, peeled pomegranate (*Punica granatum*), pitted dogwood (*Cornus mas*), and persimmon (*Diospyros kaki*), peeled and pitted. To prepare the extracts, the berries and fruits were ground in a blender and filtered through cheesecloth to remove solid particles. The extracts were stored at +4°C until use. The study objects were purchased from a local manufacturer or prepared according to standard recipes, including ayran (AZS 119-2002), sherbet made from fruit juice and sugar syrup following AZS 562-2012, black Azerbaijani tea brewed in the traditional way following AZS 574-2016, compote made from boiled fruit without added sugar following AZS 762-2014 and pekmez, a thick juice obtained from grapes by AZS 744-2012. Each traditional drink was divided into two parts: control and experimental. The experimental samples of beverages were enriched with the respective extracts in the ratio of 10% of the total volume of the beverage. Enriched drinks were stored at +4°C before analysis. The antioxidant activity of drinks and berry extracts was determined by the DPPH method. The sample (0.1 ml) was added to 3.9 ml of DPPH solution (0.1 mM) in methanol. The mixture was left at room temperature for 30 minutes, after which the absorbance at 517 nm was measured using a spectrophotometer. The antioxidant activity was expressed in trolox equivalents (mg TE/100 ml for beverages and mg TE/100 g for berries). The decrease in absorbance compared to the control DPPH solution without the addition of the extract was calculated using the formula (1):

$$\text{Antioxidant activity(\% inhibition)} = \\ = A_{control} - A_{sample}/A_{control} \times 100, \quad (1)$$

where $A_{control}$ – absorbance of the DPPH control solution; A_{sample} – absorbance of the sample with the extract.

The choice of the DPPH method for determining the antioxidant activity of fortified beverages is based on its simplicity, reliability and availability, which allows for an effective and accurate assessment of the contribution of Azerbaijani berries to improving the functional properties of beverages. The organoleptic analysis was carried out with the participation of 20 trained tasters. The following characteristics were evaluated: taste, aroma, colour and overall impression. The scores were based on a 5-point scale, where 1 is very poor and 5 is excellent. The general requirements for this analysis were conducted following O'z DST 2004:2008 and O'z DST 2765:2013 (standard governing the quality and safety of dairy products, including their organoleptic evaluation). The study complied with all the necessary ethical standards, and the participants agreed to the publication of the study results. All measurements were made in triplicate. Data are presented as mean values ± standard deviation. Statistical analysis was performed using ANOVA followed by Tukey's test to determine the significance of differences ($p < 0.05$).

RESULTS

Azerbaijan, with its rich natural resources and favourable climate, is one of the main producers of a variety of berries and fruits that can be used to make functional drinks. Known for their health benefits, berries such as pomegranate, persimmon, blueberry, raspberry and dogwood are rich in vitamins, minerals and antioxidants. The addition of these berries in soft drinks can not only improve their nutritional value but also give them unique organoleptic properties.

Before preparing the extracts for the subsequent enrichment of the drinks, the berries themselves were analysed, as their chemical composition can vary both due to climatic conditions and the location of the plantation. Blueberries demonstrated the highest antioxidant activity, while the conclusion about the benefits of new functional drinks should be made by comparing a range of metrics of the finished product with its classical analogue (Table 1).

***Table 1**. Antioxidant activity of Azerbaijani berries (mg GAE/100 g)*

Berry	Antioxidant activity (mg GAE/100 g)
Pomegranate	2,340
Persimmon	1,440
Raspberries	2,700
Dogwood	1,210
Blueberries	4,000

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

The choice of traditional drinks for this study was based on their importance in the culture of Azerbaijan and the unique properties they can acquire when enriched with berry extracts. Immediately before the enrichment, a detailed analysis of the selected control samples was also carried out, among which pekmez showed the highest antioxidant activity, while ayran had much lower values. At the same time, this drink contained more animal fats and proteins, which also affected its beneficial properties. The literature analysis was used to identify the most successful combinations of traditional drinks with each of the berries. The addition of dogwood extract to ayran significantly enriched the organoleptic properties of the drink, giving it a characteristic sourness and refreshing taste. On the other hand, raspberries were used in sherbet, a traditional sweet drink made from fruit juice (Table 2). Raspberries were chosen as an enriching ingredient due to their high content of antioxidants, in particular anthocyanins and vitamin C, as well as their distinct berry aroma and sweet taste, which perfectly complemented the basic characteristics of sorbet.

***Table 2**. Changes to traditional formulations*

Drink	Enriching berry	Reason for the choice
Ayran	Dogwood	Increase in antioxidant activity and vitamin C
Sherbet	Raspberries	Improved flavour and increased antioxidant activity
Compote	Pomegranate	Increased antioxidant and vitamin content
Pekmez	Blueberries	Improved flavour and increased antioxidant activity
Tea	Persimmon	Increase in antioxidant activity and vitamins

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

According to the recipe, sugar was dissolved in water and brought to a boil, after which it was simmered until a thick syrup was obtained. This stage ensured the necessary sweetness and thickness of the drink. Thus, before being enriched with raspberries, sherbet was a refreshing sweet drink with a light fruity taste that was common to the locals. The enrichment process involved adding concentrated raspberry extract at the stage of cooling the drink. This preserved the maximum beneficial properties of raspberries while avoiding changes in the texture and taste of traditional sherbet. The extract was added in the proportion that ensured the best combination of taste and functional characteristics.

The antioxidant activity was assessed using the DPPH test, which is based on measuring the ability of antioxidants to reduce the DPPH free radical, which has an intense purple colour. As the radical reacts with the antioxidants, the colour changes to yellow, which can be measured spectrophotometrically. To obtain the results, 0.025 g of DPPH was initially prepared in 100 ml of methanol, and then 1 ml of the sample was added to 2 ml of the DPPH solution. Incubated in the dark at room temperature for 30 minutes, the absorbance of the solutions was measured at 517 nm using a spectrophotometer (Table 3).

***Table 3**. Antioxidant activity of beverages (mg TE/100 g)*

Drink	Before enrichment	Raspberries	Blueberries	Pomegranate	Dogwood	Persimmon
Ayran	15 ± 0.5	45 ± 0.7	50 ± 0.8	55 ± 0.6	52 ± 0.5	48 ± 0.7
Sherbet	20 ± 0.6	50 ± 0.9	55 ± 0.7	60 ± 0.8	58 ± 0.6	53 ± 0.8
Tea	30 ± 0.4	60 ± 0.8	65 ± 0.6	70 ± 0.7	68 ± 0.7	64 ± 0.6
Pekmez	25 ± 0.7	55 ± 0.8	60 ± 0.9	65 ± 0.6	63 ± 0.8	59 ± 0.7
Compote	18 ± 0.5	48 ± 0.6	53 ± 0.7	58 ± 0.7	56 ± 0.5	51 ± 0.8

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

These tests were chosen due to their simple practicality, but moderate sensitivity to some components of the resulting mixtures. The antioxidant activity of the beverages increased significantly after enrichment with selected berry extracts. The highest increase was observed in tea and Pekmez, which indicated a high content of antioxidants in the added berry extracts (Table 4).

***Table 4**. Antioxidant activity of beverages before and after enrichment (mg TE/l)*

Drink	Before enrichment	After enrichment
Ayran	2.5	6.3
Compote	3	7
Sherbet	4.2	8.5
Tea	3.8	9
Pekmez	5	10.2

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

A factor of 1.5 was used to convert the antioxidant activity of the drinks from milligrams of Trolox equivalent (mg TE/100 ml) to milligrams of gallic acid equivalent (mg GAE/100 ml). Dogwood ayran demonstrated the greatest increase in antioxidant activity, which amounted to 20 mg GAE/100 ml, equivalent to a 200% increase. This indicates the high efficiency of dogwood in improving the antioxidant properties of the drink. Before conducting the organoleptic evaluation, it was also crucial to analyse the toxicity of the beverages, and for this purpose, their composition was studied, and the data was summarised in Tables 5-7. These are particularly important in the context of beverage production, as any violations of sanitary standards or the presence of toxic substances can harm consumer health.

***Table 5**. Content of phenolic compounds and anthocyanins in beverages before enrichment (mg/l)*

Drink	Phenol compounds	Anthocyanins
Ayran	150	50
Sherbet	200	70
Tea	160	55
Pekmez	220	75
Compote	14 ± 0.3	7 ± 0.3

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

***Table 6**. Biochemical contents of beverages (mg/100 g)*

Drink	Phenol compounds	Flavonoids	Anthocyanins	Vitamin C
Ayran	12 ± 0.3	8 ± 0.2	6 ± 0.3	4 ± 0.2
Sherbet	15 ± 0.4	10 ± 0.3	8 ± 0.4	5 ± 0.3
Tea	20 ± 0.5	12 ± 0.4	10 ± 0.5	6 ± 0.4
Pekmez	18 ± 0.4	11 ± 0.3	9 ± 0.4	5.5 ± 0.3
Compote	14 ± 0.3	9 ± 0.2	7 ± 0.3	4.5 ± 0.2

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

Table 7. Heavy metal content in beverages (μg/l)

Drink	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	Arsenic (As)
Ayran	2.1 ± 0.1	0.05 ± 0.01	0.02 ± 0.01	0.5 ± 0.02
Sherbet	1.8 ± 0.1	0.04 ± 0.01	0.01 ± 0.01	0.4 ± 0.01
Tea	2.5 ± 0.2	0.06 ± 0.01	0.03 ± 0.01	0.6 ± 0.03
Pekmez	2.2 ± 0.1	0.05 ± 0.01	0.02 ± 0.01	0.5 ± 0.02
Compote	2 ± 0.1	0.04 ± 0.01	0.02 ± 0.01	0.4 ± 0.01

Source: *compiled by the authors*

During the chemical analysis of the berry-enriched beverages, some particularly important compounds that directly affected the healthiness of the resulting formulations were identified. For ayran, it was epicatechin and gallic acid, which have anti-inflammatory properties and prevent lipid oxidation in cells. At the same time, the combination of quercetin and rutin in the compote demonstrated its ability to improve capillary strength. Due to its high content of phenolic compounds, tea could be considered a medicinal drink. On the other hand, the content of heavy metals in all beverages was well below the permissible limits set by national safety standards. This indicated that fortification of the beverages with berry extracts does not adversely affect their safety for consumption. These data indicate that there is no risk of toxic effects on consumers when consuming these beverages. It is worth noting that control of heavy metal content should be an integral part of the production process, especially when using herbal ingredients, as their concentration can vary depending on environmental conditions.

The test for pathogens and general microbiological activity of the samples showed their compliance with the established standards, with a slight decrease in the concentration of bacterial organisms, which was caused by the high content of phenolic compounds in the components of the drinks (Table 8). The microbiological analysis was aimed at determining the presence of pathogenic microorganisms in the beverages before and after enrichment with berry extracts. The main purpose of this analysis was to identify possible microbiological risks associated with the use of fresh berries, as well as to confirm the safety of the final product.

Table 8. Microbiological analysis of beverages

Metric	Total number of aerobic microorganisms (CFU/ml)	*Escherichia coli*	*Salmonella* spp.	Yeast and mould (CFU/ml)	*Staphylococcus aureus*
Permissible level (CFU/ml)	⩽10^3	None	None	⩽100	None
Ayran (before enrichment)	120	Not detected	Not detected	10	Not detected
Ayran (after dogwood enrichment)	100	Not detected	Not detected	12	Not detected
Compote (before enrichment)	95	Not detected	Not detected	9	Not detected
Compote (after enrichment with pomegranate)	90	Not detected	Not detected	8	Not detected
Sherbet (before enrichment)	110	Not detected	Not detected	11	Not detected
Sherbet (after enrichment with raspberries)	105	Not detected	Not detected	10	Not detected
Tea (before enrichment)	125	Not detected	Not detected	14	Not detected
Tea (after enrichment with persimmons)	110	Not detected	Not detected	12	Not detected
Pekmez (before enrichment)	130	Not detected	Not detected	15	Not detected
Pekmez (after enrichment with blueberries)	115	Not detected	Not detected	13	Not detected

Source: *compiled by the authors*

For microbiological analysis, standard methods were used, including cultures on nutrient media to identify pathogens such as *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus*, as well as yeast and mould. In addition, the total number of aerobic microorganisms was analysed to assess the overall microbiological purity of the beverages. The results of the microbiological analysis showed that all beverage samples met the established microbiological safety standards. Pathogenic microorganisms such as *Escherichia coli* and *Salmonella* spp., were not detected in any of the samples. The total level of aerobic microorganisms was within the permissible limits, which indicates a high level of hygiene at all stages of beverage production and processing.

Yeast and mould content was also analysed, which is particularly important for beverages containing fruit ingredients, as they can contribute to the development of such microorganisms. In this study, the levels of yeast and mould were minimal and did not exceed the permissible values, which confirms that the berry extracts were stored and processed properly. An important aspect of microbiological safety is the control of the pasteurisation or heat treatment process that can be applied to beverages to kill pathogens. This study confirmed that the fortified beverages underwent the necessary heat treatment to ensure their microbiological purity.

The organoleptic properties of beverages, such as taste, aroma, colour and texture, are inextricably linked to their biochemical composition. Thus, enrichment with berry extracts significantly improved all these parameters, which was confirmed by the results of the questionnaire survey of the participants of the tasting group. During organoleptic analysis, firstly, each recipient was offered to taste drinks with traditional formulations and evaluate them on a five-point scale. The tasters described ayran as slightly sour and it was rated 3.8 points. Sherbet was rated slightly higher because of its sweetish flavour, namely 4 points. The highest scores were given to pekmez, its syrupy structure was particularly liked by the focus group participants (4.2 points). Tea and compote were rated at 3.7 and 4.1 points. After the control samples, the tasters were asked to rate the beverages with extracts. The results of the survey were averaged and summarised in a table (Table 9).

***Table 9**. Organoleptic evaluation of fortified beverages (points, mean value)*

Drink	Taste	Aroma	Colour	Overall assessment
Ayran	4.2	4.3	4.1	4.2
Sherbet	4.5	4.4	4.6	4.5
Tea	4.8	4.7	4.9	4.8
Pekmez	4.4	4.5	4.3	4.4
Compote	4.3	4.2	4.4	4.3

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

The organoleptic evaluation showed a high acceptability of the drinks enriched with berries. Their flavour was quite different from the traditional parental prototypes and depended on the combination of sweetness, acidity, tartness and bitterness, as well as the texture of the product. Dogwood and pomegranate extracts added the necessary sourness to the ayran and compote, respectively, which improved their flavour characteristics. The raspberries added to the sherbet brought sweetness and a light fruity note, softening the bitterness sometimes present in the traditional version of the drink. Persimmon tea added a fruity flavour that harmoniously complemented its original taste, while blueberries gave the pekmez a slight tartness and intensity of flavour. The most preferred tea in terms of taste was persimmon-enriched tea, which received high marks in all parameters.

The texture of the drinks has also changed as a result of the enrichment. The introduction of berry extracts, especially raspberries and blueberries, added density to the drinks, which was noted by the tasting panel. These changes in texture could be due to the presence of pectin and other polysaccharides in the berries, which affected the viscosity and mouthfeel of the drink. On the other hand, the change in flavours as a result of enrichment with berry extracts was due to the content of various volatile compounds in their composition, which gave them a characteristic smell. Pomegranates and raspberries were known for their intense aroma, which was reflected in the results of the compote and sherbet tasting. After enrichment, these drinks became more flavourful and attractive to consumers. These changes were attributed to the increased content of aromatic compounds such as esters and aldehydes, which enhanced the pleasant fruity smell. Anthocyanins had a direct impact on the colour of the drinks due to their pigment properties. The tea enriched with persimmon extract acquired a richer hue, which also affected its perception in the organoleptic analysis. Colour, along with aroma, was one of the first indicators perceived by tasters, and it had a significant impact on the overall impression of the product. In the present study, the colour of the beverages after fortification was highly appreciated, indicating a positive effect of anthocyanins on the visual properties of the beverages.

The results of the study show that the enrichment of traditional drinks with Azerbaijani berries significantly increases their nutritional value, antioxidant activity and organoleptic properties. All enriched beverages showed improvement over their traditional counterparts, making them more attractive to health-conscious consumers.

DISCUSSION

Sweet soft drinks in the modern world are used not only to quench thirst but have long been part of the cultural heritage. At the same time, their prevalence does not indicate the dynamics of improving the chemical composition and healthiness of such drinks. Every day, while shopping, a wide variety of sugary drinks with synthetic flavours that do more harm than good to the body are readily available. Due to their low cost and high glucose content, children are the main consumers of such drinks, which can later provoke diseases of the cardiovascular, digestive and other body systems (Calvano *et al*., 2019).

There are controversial opinions on this topic. For instance, Korean scientists state that unhealthy eating habits have a worse impact on women's health than men's. J.-M. Kim and E. Lee (2021) link the onset of depression in Korean women to their consumption of sugary soft drinks. On the other hand, in South America, C. Campos-Ramírez *et al.* (2020) argued that men consume significantly more sugary drinks than women, which can lead to the development of obesity and diabetes. In any case, the popularity of sweeteners does not contribute to the quick quenching of thirst and the health of soft drink consumers. Therefore, improving the chemical composition of well-known beverages can act not only as a disease prevention measure but also contribute to the nation's health (Byeon *et al.*, 2024).

R. Yeniçağ and N. Rakıcıoğlu (2024) studied the antioxidant activity of Turkish beverages, among 394 samples, the highest results were observed in tea of different brewing methods and the lowest in sodas. They argued that climate change, along with increased environmental awareness among both governments and consumers, has led to a significant increase in demand for plant-based products, suggesting the relevance of this trend in the context of the study. In addition, the review by H.E. Khoo *et al.* (2023) analysed plant-based sweeteners, which were considered as an alternative to synthetic sweeteners, which are often carcinogenic. Traditional Azerbaijani beverages are composed of natural ingredients, and they also need to be modernised to improve their nutritional value and market appeal.

Many literature sources suggest that berries rich in anthocyanins and phenolic compounds may have a therapeutic effect on people with anaemia, type 2 diabetes or high cholesterol (Jara Palacios *et al*., 2019). Food safety is an important aspect that cannot be ignored when developing new products. In this work, all risks associated with the potential toxicity of beverages were addressed. Thus, a comprehensive study of the heavy metal content in samples and raw materials showed that the metal content was well below the permissible limits set by national standards (Maharramova & Maharramov, 2023; Wale, 2023). This indicated that the fortification of beverages with berry extracts does not lead to the accumulation of potentially hazardous substances, which is important for consumer safety. It is worth noting that the use of berries grown in the Republic of Azerbaijan for beverage enrichment can help support local producers and develop the agricultural sector. This will create new jobs and stimulate economic development in the regions where these berries are grown. In addition, it will draw attention to the preservation and revival of traditional berry processing and beverage production technologies.

In previous studies, ayran enriched with dogwood extract was determined to have an increase in antioxidant activity, which is associated with the high content of phenolic compounds in dogwood (Maharramova, 2023). These compounds were found to be effective free radical inhibitors, confirming their significant contribution to the overall antioxidant activity of the beverage (Aurori *et al*., 2023). In addition, ayran itself contains unsaturated fatty acids and can be further enriched with beneficial bacterial cultures, which also makes it an almost ideal traditional beverage (Shalabi *et al*., 2024). Similarly, pomegranate-enriched compote showed a significant increase in antioxidant content due to the presence of active compounds such as punicalagin and anthocyanins, which contributed to the protection of body cells from oxidative stress. Pomegranate juice is mostly used as a stand-alone product, but not everyone can enjoy such an acidic drink, with pomegranate seeds containing many beneficial substances (Zeynalova-Husuyeva *et al*., 2019). A scientific group led by I.D. Bobayev *et al.* (2022) analysed 69 species of pomegranates that grow in Azerbaijan and found high levels of vitamins, minerals, and phenolic compounds, but they advise diluting it with water. Therefore, the use of pomegranate extract for compote enrichment can be called a promising solution.

Another interesting combination was the enrichment of the classic sherbet with raspberries, which is characterised by a high content of vitamins and flavonoids, making it attractive in terms of strengthening the immune system and preventing inflammation (Marcetic & Arsenijević, 2023). The presence of raspberries in the drink also improved its organoleptic properties, giving the sherbet a fresh and rich flavour that was highly appreciated by the tasting panel. In the study, pekmez enriched with blueberries was characterised by an increased concentration of anthocyanins (Zhou *et al*., 2019). Anthocyanins, which are powerful antioxidants, can effectively protect cells from damage caused by free radicals, which underlines the importance of using blueberries in this product.

Tea enriched with persimmon also demonstrated an improvement in its sensory characteristics and bioactive substance content (Zaychenko *et al.*, 2019). Persimmon, being a source of antioxidants such as catechins and flavonoids, contributed to the antioxidant potential of tea, which confirmed its functional value (Choudhary *et al*., 2022). At the same time, B vitamins, as well as essential amino acids and sugars in their composition, were supposed to add sweetness to the drink. The change in the recipe resulted in a sample with a more pronounced taste and aroma, which were positively evaluated in the organoleptic analysis. The microbiological safety of beverages was also one of the main challenges identified in previous studies (Hellström *et al*., 2013). The use of fresh berries as raw materials posed a potential risk of microbiological contamination, which required careful consideration of processing and sterilisation methods (Shevchuk *et al.*, 2023). Studies noted that the lack of proper pasteurisation or other processing methods could lead to the development of pathogenic microflora in beverages, which could jeopardise consumer safety.

A comparative analysis of the antioxidant activity of beverages before and after enrichment showed that the addition of berry extracts led to a significant increase in the antioxidant content of the finished products. This underlined the prospects of using local berries to create beverages with increased functional value that meet modern consumer requirements for a healthy diet. The difficulties noted in previous studies were also addressed. The focus was on controlling storage conditions and processing methods for berry raw materials to preserve their bioactive properties. The enrichment process was standardised to minimise variations in the composition of the final products.

CONCLUSIONS

The results of this study could have a major impact on the food industry, opening new opportunities to produce healthy and natural drinks. They also help to promote Azerbaijani berries on the international market, increasing their value and contributing to the economic development of the region. The berries chosen were pomegranate, persimmon, raspberry, dogwood and blueberry. The nutritional value of the drinks was assessed by the content of vitamins, minerals, antioxidants and acidity. The safety of the drinks was determined using chemical tests. The results showed that the soft drinks enriched with berries grown in Azerbaijan have a high nutritional value and are safe for consumption. Fortified drinks contain more antioxidants and vitamins than traditional drinks, which makes them promise for introduction into the diet of the public. This study can be used as a basis for further developments in the field of functional drinks and the food industry.

On the other hand, the study has high scientific significance and practical value. First and foremost, the study aimed to improve traditional drinks that are deeply rooted in the culture of Azerbaijan, making the results important for a wide audience. Despite the positive results, this study had several limitations. Firstly, the study was limited to the selection of five specific berry extracts, and the effects of other potentially beneficial berries such as blackberries, currants, kinkans, barberries, cherries, etc. were not considered. Secondly, the studies were conducted in a laboratory environment, which may not fully reflect the actual industrial environment of beverage production.

Seasonal and regional variations in the composition of berries should also be addressed, which may affect their antioxidant activity and biochemical composition. Consequently, changes in the quality of the raw materials may affect the reproducibility of the results in the future. Further research may include clinical evaluations of the impact of regular consumption of fortified beverages on human health, including their effect on the antioxidant status of the body and the prevention of chronic diseases. Taken together, these results show that the enrichment of traditional Azerbaijani beverages with berry extracts not only improves their functional properties but also maintains or even enhances their safety and organoleptic qualities, making them promising products for consumer health.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Aurori, M., Niculae, M., Hanganu, D., Pall, E., Cenariu, M., Vodnar, D.C., Bunea, A., Fiţ, N., & Andrei, S. (2023). Phytochemical profile, antioxidant, antimicrobial and cytoprotective effects of cornelian cherry (*Cornus mas* L.) fruit extracts. *Pharmaceuticals*, 16(3), article number 420. doi: 10.3390/ph16030420.

[2] Bobayev, I.D., Niyozov, X.N., Maxmadqulova, K.F., O'rinboyev, J.J., & Xakimov, A.I. (2022). Biological and chemical composition of pomegranate fruit grown in Azerbaijan and Uzbekistan. *Texas Journal of Agriculture and Biological Sciences*, 3, 70-74.

[3] Bogoyavlenskiy, A., Alexyuk, M., Alexyuk, P., Amanbayeva, M., Anarkulova, E., Imangazy, A., Bektuganova, A., & Berezin, V. (2022). Metagenomic exploration of koumiss from Kazakhstan. *Microbiology Resource Announcements*, 11(1), article number e01082-21. doi: 10.1128/mra.01082-21.

[4] Bozkurt, T., & Ergun, Z. (2021). Fatty acid composition and antioxidant capacity of pomegranate seed oil. *GSC Biological and Pharmaceutical Sciences*, 15(2), 103-110. doi: 10.30574/gscbps.2021.15.2.0126.

[5] Byeon, H., Shabaz, M., Ramesh, J.V.N., Dutta, A.K., Vijay, R., Soni, M., Patni, J.C., Rusho, M.A., & Singh, P.P. (2024). Feature fusion-based food protein subcellular prediction for drug composition. *Food Chemistry*, 454, article number 139747. doi: 10.1016/j.foodchem.2024.139747.

[6] Calvano, A., Izuora, K., Oh, E.C., Ebersole, J.L., Lyons, T.J., & Basu, A. (2019). Dietary berries, insulin resistance and type 2 diabetes: An overview of human feeding trials. *Food & Function*, 10(10), 6227-6243. doi: 10.1039/c9fo01426h.

[7] Campos-Ramírez, C., Ramírez-Amaya, V., Olalde-Mendoza, L., Palacios-Delgado, J., & Anaya-Loyola, M.A. (2020). Soft drink consumption in young Mexican adults is associated with higher total body fat percentage in men but not in women. *Foods*, 9(12), article number 1760. doi: 10.3390/foods9121760.
[8] Chen, J., Shu, Y., Chen, Y., Ge, Z., Zhang, C., Cao, J., Li, X., Wang, Y., & Sun, C. (2022). Evaluation of antioxidant capacity and gut microbiota modulatory effects of different kinds of berries. *Antioxidants*, 11(5), article number 1020. doi: 10.3390/antiox11051020.
[9] Choudhary, R., Singh, A., Upadhyay, A., Singh, R., Thangalakshmi, S., Dar, A.H., Bajpai, V.K., & Shukla, S. (2022). Exotic god fruit, persimmon (*Diospyros kaki*): Pharmacological importance and human health aspects. *eFood*, 4(1), article number e52. doi: 10.1002/efd2.52.
[10] Dudarev, I. (2024). Development of craft drinks with oat milk and fruit and berry powders. *Commodity Bulletin*, 17(1), 105-115. doi: 10.62763/ef/1.2024.105.
[11] Gheonea, T.C., Oancea, C.-N., Mititelu, M., Lupu, E.C., Ioniță-Mîndrican, C.-B., & Rogoveanu, I. (2023). Nutrition and mental well-being: Exploring connections and holistic approaches. *Journal of Clinical Medicine*, 12(22), article number 7180. doi: 10.3390/jcm12227180.
[12] Golovinskaia, O., & Wang, C.-K. (2021). Review of functional and pharmacological activities of berries. *Molecules*, 26(13), article number 3904. doi: 10.3390/molecules26133904.
[13] Habib, H.M., El-Gendi, H., El-Fakharany, E.M., El-Ziney, M.G., El-Yazbi, A.F., Al Meqbaali, F.T., & Ibrahim, W.H. (2023). Antioxidant, anti-inflammatory, antimicrobial, and anticancer activities of pomegranate juice concentrate. *Nutrients*, 15(12), article number 2709. doi: 10.3390/nu15122709.
[14] Hameed, A., Galli, M., Adamska-Patruno, E., Krętowski, A., & Ciborowski, M. (2020). Select polyphenol-rich berry consumption to defer or deter diabetes and diabetes-related complications. *Nutrients*, 12(9), article number 2538. doi: 10.3390/nu12092538.
[15] Hellström, J., Mattila, P., & Karjalainen, R. (2013). Stability of anthocyanins in berry juices stored at different temperatures. *Journal of Food Composition and Analysis*, 31(1), 12-19. doi: 10.1016/j.jfca.2013.02.010.
[16] Hossain, A., & Shahidi, F. (2023). Persimmon leaves: Nutritional, pharmaceutical, and industrial potential – a review. *Plants*, 12(4), article number 937. doi: 10.3390/plants12040937.
[17] Isaxanli, H. (2023). Tea, coffee and cocoa – a cultural phenomenon in Azerbaijan. *Khazar Journal of Humanities and Social Sciences*, 26(4), 100-118. doi: 10.5782/2223-2621.2023.26.4.100.
[18] Jara Palacios, M., Santisteban, A., Gordillo, B., Hernanz, D., Heredia, F.J., & Escudero-Gilete, M.L. (2019). Comparative study of red berry pomaces (blueberry, red raspberry, red currant and blackberry) as source of antioxidants and pigments. *European Food Research and Technology*, 245, 1-9. doi: 10.1007/s00217-018-3135-z.
[19] Khoo, H.E., Chen, B.J., Li, J., Li, X., Cheng, S.H., & Azlan, A. (2023). Emerging natural and high-phenolic sweet substances: A review. *International Food Research Journal*, 30(2), 303-323. doi: 10.47836/ifrj.30.2.03.
[20] Kim, J.-M., & Lee, E. (2021). Association between soft-drink intake and obesity, depression, and subjective health status of male and female adults. *International Journal of Environmental Research and Public Health*, 18(19), article number 10415. doi: 10.3390/ijerph181910415.
[21] Loiko, S., Romanova, Z., Zheplinska, M., Romanov, M., & Vasyliv, V. (2024). Use of unmalted cereals with enzyme preparations in brewing. *Animal Science and Food Technology*, 15(1), 55-73. doi: 10.31548/animal.1.2024.55.
[22] Maharramova, S. (2023). Changes in the chemical composition of extracts of wild berries growing in the Republic of Azerbaijan during enzimatic pretreatment of their pulp. *Ukrainian Food Journal*, 12(4), 542-555. doi: 10.24263/2304-974X-2023-12-4-5.
[23] Maharramova, S., & Maharramov, M. (2023). Use of Azerbaijan-grown berries to improve nutritional value and reduce toxic metals in soft drinks (including energy drinks). *Innovaciencia*, 11(1). doi: 10.15649/2346075X.3538.
[24] Marcetic, M., & Arsenijević, J. (2023). Antioxidant activity of plant secondary metabolites. *Arhiv za Farmaciju*, 73(4), 264-277. doi: 10.5937/arhfarm73-45560.
[25] Mititelu, M., Oancea, C.N., Neacșu, S.M., Olteanu, G., Cîrțu, A.T., Hîncu, L., Gheonea, T.C., Stanciu, T.I., Rogoveanu, I., Hashemi, F., Stanciu, G., Ioniță-Mîndrican, C.B., Angelica, C., Măru, N., Lupu, S., & Lupu, C.E. (2023). Evaluation of non-alcoholic beverages and the risk related to consumer health among the Romanian population. *Nutrients*, 15(17), article number 3841. doi: 10.3390/nu15173841.
[26] Pourhakim, R., Emadi, F., Razavi Dizaji, S., Talei, D., Esmaeili Saber, S.S., & Iranzadasl, M. (2024). Evaluating the effect of grape syrup on iron deficiency anemia in women: A randomized clinical trial. *Food Science & Nutrition*, 12(8), 5473-5479. doi: 10.1002/fsn3.4185.
[27] Shalabi, O.M., Hassan, A.M., Ismail, M.M., & El-Menawy, R.K. (2024). Characterization of the Ayran made with commercial probiotic cultures for fatty acids, cholesterol, folic acid levels, and anti-oxidative potential. *Probiotics Antimicrob Proteins*, 16(3), 1065-1075. doi: 10.1007/s12602-023-10100-7.

[28] Shevchuk, L., Vintskovska, Y., Levchuk, L., Babenko, A., & Hrynyk, R. (2023). Sensory and bioactive quality indicators of fresh and dried blue honeysuckle fruits (*Lonícera caeruléa* L.). *Plant and Soil Science*, 14(4), 98-110. doi: 10.31548/plant4.2023.98.
[29] Wale, K. (2023). An overview of the level of heavy metals concentration in fruits and vegetables. *International Journal of Food Science and Biotechnology*, 8(2), 23-25. doi: 10.11648/j.ijfsb.20230802.12.
[30] Yeniçağ, R., & Rakıcıoğlu, N. (2024). Assessing the antioxidant potential of soft beverages in the Turkish market: A comprehensive study. *International Journal of Food Properties*, 27(1), 478-492. doi: 10.1080/10942912.2024.2322160.
[31] Zaychenko, G., Mishchenko, O., Sharifov, Ch., Gordienko, A., Tkachova, O., Sinitsyna, O., Laryanovska, Yu., & Khalieieva, O. (2019). Influence of extract of peach ordinary (*Persica vulgaris*) leaves on the state of the Hypothalamic-pituitary-adrenal system of rats in conditions of chronic immobilization stress. *Problemi Endokrinnoi Patologii*, 2, 89-97. doi: 10.21856/j-PEP.2019.2.13.
[32] Zeynalova-Husuyeva, A., Novruzov, E.N., & Maserti, B. (2019). Studies on the physico-chemical characteristics, antioxidant activity and juice organic compound composition in Azerbaijan wild pomegranate fruits. *Plant & Fungal Research*, 2(1), 40-46. doi: 10.29228/plantfungalres.48.
[33] Zhou, L., Xie, M., Yang, F., & Liu, J. (2019). Antioxidant activity of high purity blueberry anthocyanins and the effects on human intestinal microbiota. *LWT*, 117, article number 108621. doi: 10.1016/j.lwt.2019.108621.

Оцінка харчової цінності та безпечності безалкогольних напоїв, збагачених ягодами, що ростуть в Азербайджанській Республіці, порівняно з традиційними напоями

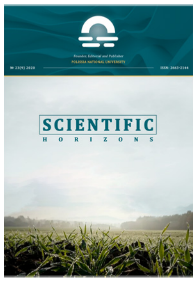
Севіндж Махаррамова
Доктор філософії, доцент
Азербайджанський державний економічний університет
AZ1001, вул. Істікляліят, 6, м. Баку, Азербайджан
https://orcid.org/0000-0002-1599-7013
Мар'ям Мамедалієва
Кандидат біологічних наук, викладач
Азербайджанський державний економічний університет
AZ1001, вул. Істікляліят, 6, м. Баку, Азербайджан
https://orcid.org/0000-0002-4351-8286
Гюнаш Насруллаєва
Кандидат економічних наук, доцент
Азербайджанський державний економічний університет
AZ1001, вул. Істікляліят, 6, м. Баку, Азербайджан
https://orcid.org/0000-0003-2661-8354
Мехрібан Махаррамова
Кандидат біологічних наук, доцент
Азербайджанський державний економічний університет
AZ1001, вул. Істікляліят, 6, м. Баку, Азербайджан
https://orcid.org/0000-0002-8359-5112
Мехрібан Юсіфова
Кандидат біологічних наук, доцент
Азербайджанський державний економічний університет
AZ1001, вул. Істікляліят, 6, м. Баку, Азербайджан
https://orcid.org/0000-0001-7608-5950

Анотація. У дослідженні використовувалися модифіковані рецептури традиційних напоїв з метою збагачення їх низкою поживних речовин і мікроелементів. Відібрані для дослідження ягоди, а саме: кизил, гранат, хурма, чорниця, малина, продемонстрували високу антиоксидантну активність та багатий вітамінний склад. У результаті дослідження було виявлено значне підвищення антиоксидантної активності традиційних азербайджанських напоїв у разі збагачення їх ягідними екстрактами. Антиоксидантна активність айрану збільшилася на 20 мг GAE/100 мл після збагачення кизилом. Шербет показав зростання активності на 22,5 мг GAE/100 мл при додаванні малини. Чай, збагачений хурмою, збільшив свою антиоксидантну активність на 125 %. Компот, збагачений гранатом, збільшив свою активність на 24 мг GAE/100 мл. Дошаб із чорницею продемонстрував середні результати, хоча за рахунок високого рівня поживних властивостей у чорниці був також перспективним об'єктом дослідження. У роботі також було проведено аналіз відібраних ягід, з подальшою оцінкою потенційних змін вітамінного складу, антиоксидантної активності, а також органолептичних властивостей напоїв після додавання ягід. Найбільш значне поліпшення у смаку, ароматі, кольорі та текстурі напоїв спостерігалося у чаю, збагаченого екстракт омхурми, та дошабу, чорницею, які отримали максимальні бали за всіма параметрами після збагачення. Антиоксидантна активність напоїв також значно підвищилася після додавання ягідних екстрактів. Розглянуті мікробіологічні та хімічні ризики, пов'язані з використанням свіжих ягід, і запропоновані заходи для забезпечення безпеки напоїв допомогли сформувати подальший вектор вивчення цієї сфери

Ключові слова: антиоксидантна активність; здорове харчування; функціональні продукти; мікробіологічний аналіз; рецептури

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
***Scientific Horizons*, 27(9), 110-120**



UDC 631.95.631.4:504.4
Doi: 10.48077/scihor9.2024.110

Improvement of methods of rational use in conditions of land degradation in the Almaty region, Karasai district

Assem Aidarova
Graduate Student
Kazakh National Agrarian Research University
050010, 8 Abay Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0009-0007-2411-5776

Ardak Omarbekova*
PhD, Associate Professor
Kazakh National Agrarian Research University
050010, 8 Abay Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-6607-7292

Galymzhan Ussipbayev
Graduate Student, Senior Lecturer
Kazakh National Research Technical University
050013, 22 Satbaev Str., Almaty, Republic of Kazakhstan
https://orcid.org/0009-0002-4099-011X

Dariga Onalbayeva
Graduate Student
Kazakh National Agrarian Research University
050010, 8 Abay Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0009-0005-5235-6601

Sandugash Mauyayeva
Graduate Student
Kazakh National Agrarian Research University
050010, 8 Abay Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-6413-349X

***Article's History*:**
Received: 20.02.2024
Revised: 15.07.2024
Accepted: 28.08.2024

Abstract. The study was aimed at identifying the potential of modern methods of rational land use in the Karasai district of the Almaty region of Kazakhstan, taking into account their intensive degradation. The research methodology was represented by the methods of statistical observation, comparison, analytical-structural grouping and forecasting. The priority goals of modernisation of agriculture of the Republic in the technological aspect have been analysed. It was established that innovative

***Suggested Citation*:**
Aidarova, A., Omarbekova, A., Ussipbayev, G., Onalbayeva, D., & Mauyayeva, S. (2024). Improvement of methods of rational use in conditions of land degradation in the Almaty region, Karasai district. *Scientific Horizons*, 27(9), 110-120. doi: 10.48077/scihor9.2024.110.

*Corresponding author

approaches to land use have the potential to increase the level of efficiency of the agrarian sector, improve the state of local and regional landscape. The concept of improving the state of degraded lands, including a system of management measures and practical activities, has been developed. It was proved that it should be based on the synergy of economic efficiency and environmental safety, with the mandatory introduction of modern innovative technological approaches. The effectiveness of methods of rational use of degraded lands as an effective tool for the transformation of the agrarian sector has been determined. It was proposed to intensify the development of organic agricultural production, which is positioned as the gentlest for degraded landscapes. It was proved that the implementation of sustainable management of landscape complexes in the innovative context implies the use of information monitoring technology, which anticipates the diagnosis, genesis and forecasting of the state of the studied ecosystems. Such measures will make it possible to develop programmes for the restoration of ecological functions of natural landscapes, which is an integral part of sustainable development programmes. Actualised the situation in the context of ecologisation of land use in Kazakhstan, predicted further destruction of ecosystems of agrarian landscapes in case of use of aggressive methods of soil cultivation. The necessity of introduction of improved methods of rational land use is substantiated, and the specificity of the introduction of organic and biological technologies of agricultural production is outlined, with an indication of tangential risks and challenges in the economic realities of Kazakhstan. The study substantiated that the application of integrated management and ecosystem approach have a synergistic potential to ensure the rational use of land in the Almaty region, the Karasai district in the conditions of their degradation

Keywords: farming; sustainable development; modernisation; intensification; organic production

INTRODUCTION

Pollution of soil cover, and depletion due to irrational use, lead to undesirable ecological consequences for the land resources of Kazakhstan. Intensification of land use for a long time contributed to large-scale chemicalisation of soils, development of processes of their salinity, erosion, and minimization of organic matter content. Natural processes of regeneration and self-purification do not provide renewal of degraded natural landscapes. The low threshold of natural resistance of land resources of the Republic to degradation is due to the narrow homeostatic range, peculiarities of natural resource potential, and insignificant adaptive capacity. Increasing requirements for the quality of agricultural products in the global market environment leads to the need to search for new opportunities for the formation of competitive advantages of agricultural producers in crisis conditions, which in synergy will allow the national agricultural sector to increase and maintain its own position in the market, while minimizing further land degradation.

Today, special attention is paid to improving the economic efficiency of the agricultural sector to form sustainable competitiveness in a dynamic market environment (Pasichnyk *et al.*, 2023). The development of agricultural production in Kazakhstan in the concept of prioritization of the foundations of sustainable development requires the introduction of gentle farming techniques. Such a strategy to ensure competitiveness of the greatest functionality focuses on internal and external investment in promising projects, the implementation of innovative solutions and practical developments of successful international experience, the establishment of mechanisms for financing projects of organic production.

In the Karasai district of the Almaty region, the qualitative change of land is clearly demonstrated. Destructive processes have a negative systemic impact on all tangential components of the ecosystem. Under such conditions, the necessity of formation and introduction of a new conceptual approach to the regional land use strategy is actualised. Many scientific works and researches of the present day are devoted to the improvement of methods of rational use in the conditions of land degradation (Skliar *et al.*, 2024). Strategies of technological modernization of farming, and gentle methods of soil cultivation, which raise the level of economic efficiency and environmental safety, are studied in the works of modern authors E.A. Guliyeva (2021) and G.K. Kurmanova *et al.* (2022). Researchers focus on the practical aspects of organic production through innovative technological solutions that are sparing to the soil, and complementary to the principles of a 'green' economy.

Scientists D. Glover *et al.* (2019) analysed the destructive changes of land resources that are difficult to regenerate. The authors are convinced that degradation is provoked by the long-term accumulation of toxic chemicals in soils from agricultural activities. The researchers are convinced of the feasibility of transforming the traditional land use system to an organic one. In continuation, F. Caffaro *et al.* (2020) investigate organic production as a regulator of ecosystem health. The scientists pay special attention to the potential of technological transfers as a promising vector of innovative transformation of the agricultural industry.

Researchers X. Yin *et al.* (2022) substantiate the functionality of monitoring systems, which they position as the basis of the ecosystem approach to agricultural activities, providing preventive protection against negative environmental impacts. At the same time, J. Clapp and S.-L. Ruder (2020) conclude in their research that to meet the existing global growth in demand for organic products with limited resource capacity can only be achieved through effective technological modernization of agricultural projects. Researchers M. Herrero *et al.* (2020) propose an integrated approach to optimize the state of degraded lands, within the framework of sustainable development programmes and green economic course. The approach provides measures to neutralise the negative impact of anthropogenic load, maximize the elimination of pollution and regeneration of natural resources, and restore natural landscape complexes.

Without levelling the significance of scientists' conclusions, still many issues in the field of improving methods of rational use in the conditions of land degradation require detailing and searching for optimal solutions. In particular, the processes of integration of organic and precision farming systems in the realities of Kazakhstan are studied fragmentarily. The aim of the study was to analyse the potential of innovative approaches to optimize the rational use of degraded land resources (in the context of the Karasai district of Almaty region of Kazakhstan).

MATERIALS AND METHODS

Statistical observation made it possible to form generalizing information that is representative as a characteristic of the whole set of attributes of the phenomenon under study. In order to determine the level of greening of land use, the main indicators of qualitative changes were compared. The specifics of precision farming development within the strategy of circularity of agricultural production processes have been determined, and measures to improve the management paradigm in the sphere of agrarian production have been proposed. The optimal conditions and solutions in the context of efficiency and expediency of the complex of methods of rational use in the conditions of land degradation on the basis of 'green' economic development and sustainable decarbonisation of technological processes have been specified. Prerequisites for active practical use of organic and precision farming technologies in Kazakhstan are formed.

Analytical and structural grouping allowed forming a step-by-step algorithm for the introduction of innovative gentle farming technologies, taking into account the socio-economic features of activity in the agrarian sector of Kazakhstan, in particular, the Karasai district of the Almaty region. To determine the disadvantages, risks, and advantages of certain solutions in the context of transforming the approach to land use on degraded lands, the forecasting method was used. The synergy of economic feasibility and ecological safety, which forms a system of circular sustainable economic activity, was chosen as the predominant orientation.

To assess the dynamics of organic agriculture development, official statistical information of the Ministry of Agriculture of the Republic of Kazakhstan (2022) and the Bureau of National Statistics (2024) was used. In addition, the research process used strategic programme documents and regulatory legal acts in the industry under study, in particular, Land Code of the Republic of Kazakhstan (2003), Law of the Republic of Kazakhstan No. 464-IV (2011), the Ecological Code of the Republic of Kazakhstan (2021), Strategic measures to combat desertification in the Republic of Kazakhstan until 2025 (United Nations Development Programme, 2015), Kazakhstan's Final Report on the LDN Target Setting Programme (United Nations Convention to Combat Desertification, 2018), and Law of the Republic of Kazakhstan No. 423-IV LRK (2015).

RESULTS

Prolonged extensive land use in the agricultural sector actualises the need to transform traditional production processes towards intensive methods and new technologies. Protection of degraded lands corresponds to the basic paradigm of agricultural sustainability, as the priority of rational use in the conditions of land degradation is determined precisely by the sustainable use of landscapes. The basis for modernisation and ecologisation of land use in Kazakhstan is the state innovation policy, the purpose of which should be renewable resource use, integration of technological achievements and scientific approaches, formation of mechanisms and methods to stimulate innovation activity.

Organic farming has a huge potential for development in Kazakhstan. As of 2024, the total area of fields allocated to organic farming is more than 200 thousand hectares, which is confirmed by European certification organizations Land Code of the Republic of Kazakhstan, 2003; Bureau of National Statistics, 2024). Implementation and adaptation of effective technologies of organic farming, stimulation of targeted investment, professional development form the basis for intensive development of the agricultural sector in the Republic. In 2022 and 2023, Kazakhstan exported organic products worth about 35 million USD (Fig. 1), which demonstrates positive dynamics.

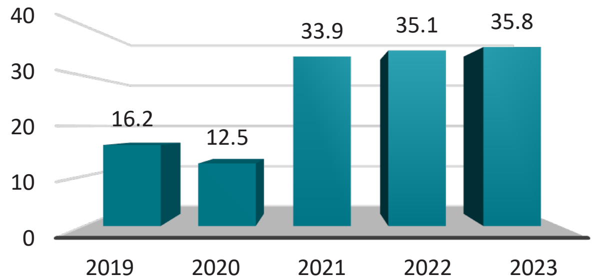


Figure 1*. Export of organic products from Kazakhstan to the EU, million USD*

Source: *developed by the authors, based on Ministry of Agriculture of the Republic of Kazakhstan (2022)*

Priority export positions of Kazakhstan are wheat, flax seeds, and soya beans. According to the Ministry of Agriculture of the Republic of Kazakhstan (2022) and Ecological Code of the Republic of Kazakhstan (2021), in Kazakhstan, today there are 38 farms certified for the production of organic products. Certification is a necessary step in the effective development of organic agriculture, significantly increasing the level of trust between producers and consumers. Law of the Republic of Kazakhstan No. 423-IV LRK (2015) and No. 464-IV (2011) defines the basic norms of organic production (social, legal, economic and organizational). They regulate the vector of ensuring the rational use of soils, including degraded soils, and promote environmental protection and food security. Intensification of implementation of precision farming systems is part of the strategy of practical functionality of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services BesNET. The platform was initiated in 2012, and today it unites about 140 countries of the world. Kazakhstan is supported by BesNET through the BES Solutions Fund to scale up and implement the key priorities identified during the Central Asia Regional Trialogue in Almaty in October 2019.

Organic farming has a number of defining parameters, the most significant of which is considered to be the prohibition of aggressive agrochemicals in the production process, which minimizes the negative impact on the environment by preventing chemical pollution and ensuring the preservation of natural soil microflora. In addition, organic farming involves strict adherence to crop rotations so that there is no risk of soil depletion by sowing the same crops. The obligatory use of legumes in the crop rotation allows the soil to be saturated with nitrogen in this natural way (Aldieri *et al.*, 2021). Almaty oblast is a region of Kazakhstan rich in natural resources and with the potential for intensive economic activity. The resource-raw material and monocultural system of nature management has caused the formation of many environmental problems. On the territory of intermountain valleys of Kegenya and Narynkola, foothill sloping plains of Zailiyskiy Alatau, water erosion processes are a potential danger. The territory has a significant slope and dissection. The mentioned problem concerns also farms of the Karasai district.

Also, gully erosion is actively and universally manifested. In particular, it causes significant damage to natural pastures and fodder lands of the Almaty region, located on slopes. Such phenomena provoke processes of turf destruction and loss of valuable components of pasture grasses. Due to long-term irrational use of territories for irrigated and rainfed farming, the predominant share of pastures in the foothills in the Karasai district is characterized by severe degradation. Soil salinization is observed in the floodplains of rivers and around lakes, which is caused by a violation of the hydrological regime of the landscape ecosystem. Modernisation of sustainable land use practices within degraded landscapes mainly implies the integration of innovative agrotechnologies, optimisation of fertilizer and chemigation systems with priority given to biological methods of plant protection and organic fertilizers (Rose *et al.*, 2021). Implementation of the latest scientific-research developments, contributes to the intensive growth of export potential.

The innovative technology of precision farming involves the preliminary study of agrophysical and agrochemical indicators of fields. On the basis of the collected information, it is reasonable to draw up special electronic maps of fields. GPS systems can be used effectively for this purpose. The new generation of functional field maps makes it possible to develop an optimal individualized system of tillage and fertilization, plant protection, and crop adjustments (Fleming *et al.*, 2021). Precision farming provides for continuous monitoring of soil conditions, which makes it possible to strategically plan a system for optimising the parameters of degraded land (Fig. 2).

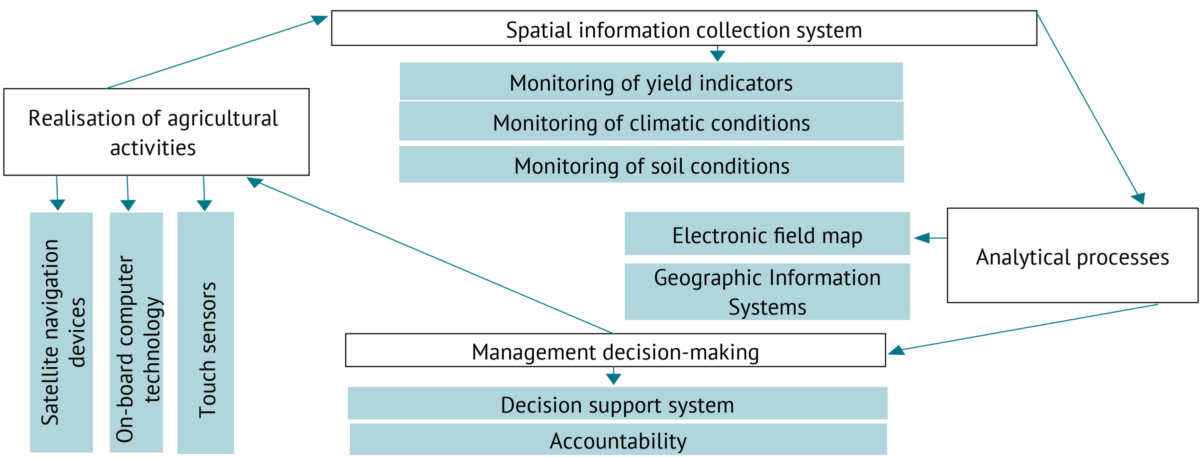


***Figure 2**. Method of precision farming technology on degraded sites*
***Source:** developed by the authors based on A. Raihan et al. (2022)*

Technological transformation of land use involves energy efficiency, optimization of irrigation equipment and systems, precision farming concept, and bioenergy strategies. Methods that are tolerant to the natural environment, keeping soil conditions within ecological norms (Kernecker *et al.*, 2021). Innovative technological techniques and algorithms that allow the implementation of a step-by-step transformation of the land use system give a possibility of guaranteeing compliance with European standards of sustainable development, the scientific validity of ecologization of agrarian processes, and implementation of gentle land cultivation technologies (Rolandi *et al.*, 2021). Strategic management of degraded land resources in Kazakhstan, and, in particular, in the Karasai district of the Almaty region has certain peculiarities. The main factors affecting the process are summarized in Table 1.

***Table 1**. Limiting factors of management of degraded land resources in Kazakhstan*

Limitation factor	Influence
Natural and climatic conditions	Direct dependence of production activities on environmental factors, propensity of the territory to water and wind erosion
Territorial dispersion of production	Difficulty in making timely operational decisions and adjusting strategic plans due to imperfections in the management system
Seasonality	Increased risk of unforecasted performance due to seasonal specificity of impact
Organizational and legal forms of management	Precision farming farms are under significant pressure from external determinants
Regulatory and legislative basis	The need for adaptation to innovative management practices in the context of land degradation

Source: *developed by the authors*

Thus, among the specific prerequisites for improving land use methods in Karasai district of Almaty region, are identified: specificity of living conditions of the population of rural areas – the basis of the farmer community; dependence on natural and weather-climatic peculiarities, which creates the need to provide a reliable material and technical base; seasonality of agrarian production, which creates unevenness in the use of material resources throughout the year; specificity of production on the basis of living organisms and natural systems, dependence of economic factors of activity on the efficiency of natural reproduction processes.

The main directions of innovation activities within the concept of rational use of land resources, in the future, should be targeted advisory centres, close to the agricultural producer (Clapp, 2021). The level of popularity of agricultural advisory services in Kazakhstan is currently insignificant. At the same time, advisory services can stimulate the improvement of the ecological condition of land, allowing to obtain significant economic benefits based on the integration of innovative technologies (Rocchi *et al.*, 2020). It is possible to highlight specific features of the proposed methodology of rational use in conditions of land degradation in the Almaty region, Karasai district, among which (Ruzzante *et al.*, 2021; Lacoste *et al.*, 2021): low level of accuracy and reliability of forecasting, which is associated with the specific nature of the region; the necessity of optimizing production processes due to seasonal shortage of basic resources; the need for comprehensive monitoring; systemic problems of agricultural production.

The system of precision organic farming can be considered as the foundation of innovative development in the context of the conservation of degraded lands. Its effective development provides for the gradual and effective achievement of objectives, which include: strengthening of the status in the market environment, diversification of production, development of new sales directions; increasing production volumes, efficient utilization of assets and saving resources; ensuring production stability by stabilizing resource reserves and insuring risks. The precision farming system provides a balance between environmental stability and economic efficiency of agricultural production (Bilushenko, 2023). Minimization of mechanical tillage of the soil cover, absence of chemicalization processes, individualization of agricultural technologies and processes stimulate an increase in demand for organic products, growth of its share in exports, encourage the spread of organic land use in other regions (Sadik-Zada, 2020; Farrokhi & Pellegrina, 2023).

In order to analyse the effectiveness of the introduction of precision farming technology, the rate of implementation of its elements in European countries was analysed, which allows us to predict the positive dynamics of the impact of technology, if implemented, on changes in soil productivity in Kazakhstan (Fig. 3).

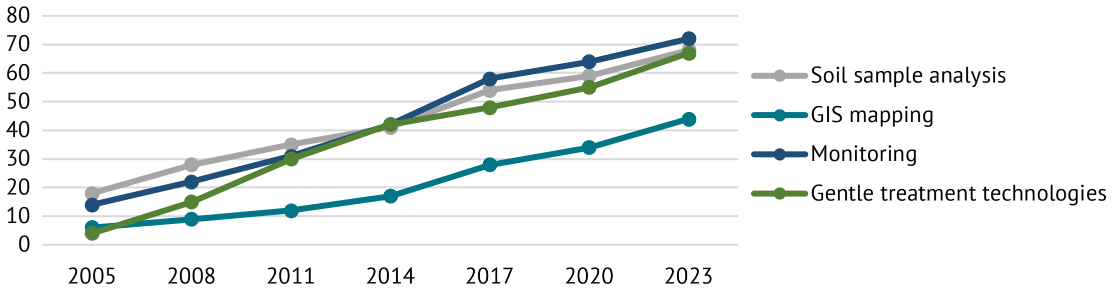


***Figure 3**. Rate of implementation of precision farming elements in developed European countries, %*
***Source:** developed by the authors based on European Commission (2023)*

As is evident from Figure 3, over the period 2005-2023, the process of implementation of precision farming technology and some of its conceptual approaches is characterized by positive dynamics, with a significant intensification of the process after 2014. This period is characterized by global awareness of the level of depletion of the natural potential of landscape resources and the realization of the need for an immediate transition to extensive tillage technology. At the same time, the level of integration of GIS-technologies remains much lower than other elements of precision farming technology, although progressive positive dynamics characterize it.

Introduction of organic production on a large scale in Kazakhstan is limited by the imperfect regulatory and legal framework, the predominant share of exports, underdevelopment of the domestic organic market, limited range of goods, low awareness of the population, lack of investment in organic production. At the same time, there is a significant potential in the industry, which can be unlocked with the help of targeted international support and attract investment opportunities. In the future, an important function is assigned to the integral ecological assessment of soils for comprehensive analysis of the situation and preventive protection of cause-and-effect relationships in the ecosystem. At the same time, a special role in the process should be given to engineering and ecological research, which takes into account that landscapes of this type are an active area of exogenous geological processes.

Mapping for fixing the existing anthropogenic load on degraded land resources should be singled out separately. Cartographic modelling using GIS-technologies is one of the priority methodological bases for research of degraded soils and assessment of their condition (United Nations Development Programme, 2015; United Nations Convention to Combat Desertification, 2018; European Commission, 2023). They demonstrate immediate effectiveness in the context of ecological and landscape monitoring data analysis, digital mapping, forecasting and modelling of the dynamics of natural-anthropogenic systems.

Geoinformation technologies are currently very actively used in the Republic of Kazakhstan. Most of the projects based on geoinformation systems, which use ESRI software, have already become a standard used in many state enterprises and departments. GIS-technologies are maximally adapted to work in a dynamic geographical environment, and therefore it is expedient to use them for solving problems of ensuring environmental safety and sustainable development of territories with the help of spatially distributed arrays of reliable data (Skydan *et al.*, 2021). On the basis of GIS-technologies, the direction of operative mapping in real-time dimension is created, which forms the possibility of operative influence on the process in case of necessity, as well as an inventory of objects, monitoring of their dynamics, and prognostic analytics.

GIS-technologies actualize the possibilities of preserving degraded lands through ecological and landscape management, in particular through buffering (Fedoniuk *et al.*, 2024). Modern GIS tools allow buffer zones to be formed automatically, and they can be built around objects of any type. Also, a popular aspect of land management is the implementation of network analysis, which is carried out in order to determine the three-dimensional modelling of spatial tasks. Precision farming has a significant resource potential and the prospect of large-scale integration on the territory of Kazakhstan. At the same time, farms, as a small form of entrepreneurship, have a number of advantages in comparison with large agrarian enterprises of agricultural production, in the context of the implementation of precision farming systems: economical logistics, ease of integration into the market environment, increased level of adaptability due to the small scale of production, quick reaction to the dynamics of market conditions. At the same time, in Kazakhstan, the segment of farms needs optimization of the legislative and regulatory-methodological basis for development, as well as stimulation of their competitiveness and profitability by the state.

The ecosystem approach ensures the balance of individual ecosystem components among themselves and with the anthropogenic component (de Janvry & Sadoulet, 2020). Integrated land use in the condition of land degradation will effectively address such strategic objectives as optimization of nature management, improvement of soil sustainability, prompt response to risks and threats, and quality informative monitoring. Thus, the modern methodology of rational use under conditions of land degradation in Kazakhstan should combine vectors of innovative optimization of agricultural activity, protection of land from destruction, its regeneration, as well as technological modernization of the agricultural sector, which in synergy can provide favourable conditions for the most effective development of sustainable agriculture in Kazakhstan.

DISCUSSION

Increasing the level of ecological sustainability of farming systems in conditions of land degradation is based on the need to integrate precision and organic agrarian production systems to minimize destructive processes. Most modern scientists working in the interdisciplinary field are convinced of this. Scientific research confirms the fact of destructive influence of long-term extensive use of land resources. Scientists I. Cisternas *et al.* (2020) are convinced that the modernization of land use is a gradual transition from traditional economic methods to innovative technological methods, while it should correspond to the priorities of the green economy. The position of scientists reflects the main scientific idea of the current study. In the context of the Almaty region, the level of modernization of economic processes of land use depends on the efficiency of practical implementation of innovative research and development and foreign experience.

Modernisation of degraded land use, according to the research of X. Yang *et al.* (2021), is represented by typical modes of development of intelligent agriculture: precision farming, objective farming and order farming. The authors then derive several underlying technologies and programmes from the above regimes, including blockchain-based solutions for data integrity, cryptography and key management, authentication and access control, physical countermeasures and intrusion detection systems, and privacy preservation. It is worth paying attention to the associated cybersecurity risks, because the strategy of digitalization of management processes proposed by the authors will potentially be accompanied by many threats to information security, on which the efficiency of alternative farming depends. Precision farming forms a direction for the development of alternative systems of gentle farming in degraded areas, which has a particularly promising potential for the Almaty region, given the level of destruction of local ecosystems (Bragina *et al.*, 2018).

C. Gras and D.M. Cáceres (2020) argue that the long-term results of precision agriculture are local regeneration of degraded soils, preventive protection from salinization and erosion processes. The authors analyse the algorithm of influence of modern technological innovations on the level of sustainability of farming. At the same time, it is possible to discuss with the authors about the expediency of the priority of economic benefit in the context of Almaty region as a representative region of Kazakhstan, because the proposed dialectic positions the mediating role of technological innovations to achieve high levels of crop yields and expanding the reach of capital over insufficient and non-capitalised nature.

The results of the review of the scholar R. Prăvălie (2021) showed that there are currently about twenty ways of land degradation. The most common and destructive among them, the author singles out aridity, erosion phenomena, salinization, and acidification of soil, soil compaction, land pollution and biological invasion, soil subsidence, landslides, and others. The research results of H. Xie *et al.* (2020) demonstrate the evolutionary ways of dynamic monitoring of land degradation, reveal the potential of ecological management. The article concludes that the directions of prospective degradation research should summarize the process, mechanisms, and consequences of destructive impact, the application of new technologies, new methods for monitoring land degradation, improving the reconstruction strategy of degraded land, multidisciplinary integrated system research, building a policy guarantee system for the reconstruction of degraded land and strengthening land resources engineering research. In the concept proposed by the authors, from the point of view of possibilities of its implementation in the region of Almaty oblast, it is worth adding the possibilities of levelling the negative effects on land resources by introducing protective buffer zones, introducing restrictions on the use of heavy agricultural machinery.

S. Mahata and V.N. Sharma (2021) draw attention to the need to implement closed-cycle technologies that minimize the negative impact on the environment. The authors point out the main factors of land degradation, emphasizing on the extent and severity of the process. They also propose innovative methods for assessing landscape and soil conditions. It is worth discussing with scientists about the expediency of using a unified assessment system. Priority should belong to a differentiated methodology that takes into account many regional and local factors of land condition. Precision agriculture contributes to food security. This is convinced in the studies by scientists L. Olsson *et al.* (2019). According to the authors, large-scale use of digital maps and GIS technologies allows for preventive protection of land from degradation, which will increase the efficiency of agricultural production. The creation of an interactive map of degraded lands in the Almaty region will allow for the most effective coordination of efforts to optimize the land use system.

A. Hossain *et al.* (2020) offer potential solutions to reduce soil degradation through understanding integrated land management practices. The study contains relevant information on the account of agricultural development, topography, economics and environmental management. It should be emphasized that the proposals of the scientists are foreseen to be feasible for practical use in the Almaty Oblast of Kazakhstan only if the appropriate policy framework is provided in the Republic to mitigate agricultural land degradation. In the studies of K. Hermans and R. McLeman (2021), the authors analyse the scheme of organic production, arguing the need for intensive investment in precision and organic farming systems. It is evident that it is renewability that is positioned as the main development of sustainable landscapes, ensuring soil regeneration.

R. Prăvălie *et al.* (2021) argue that precision organic farming ensures the balance of the socio-economic system, positively influencing the natural resource potential of land use. Analysing the findings of scientists, it is necessary to focus on the existing potential in Kazakhstan to attract international mechanisms of interaction and targeted investments in the field of agro-ecological projects. Potential long-term benefits of such a development strategy in the context of the Almaty Oblast include increased economic efficiency of the industry and improved environmental parameters, including agro-ecological landscapes. The realisation of such a goal anticipates the expansion of the functionality of the management paradigm in the agricultural sector, taking into account the digital transformation of economic processes. This is convinced by W. Shao *et al.* (2024), also drawing attention to the need to implement an effective monitoring system in the land use sector.

Summarising the research results and conclusions of modern scientists, it is necessary to indicate the main preconditions for improving the methods of rational use in the conditions of land degradation in the Almaty region, Karasai district. Among them: prevention of soil erosion due to ploughing or placement and cultivation of crops on slopes; avoiding soil compaction due to the use of heavy machinery; prevention of soil pollution and chemical poisoning, uncontrolled use of protection products and fertilisers that can change soil pH; maintenance of soil water and chemical regimes to prevent desertification, landslides, mudflows, secondary salinisation; prohibition of destruction of forests and shrub vegetation to preserve soil cover; ensuring bioenergetic regime of soils (devegetation and dehumification).

CONCLUSIONS

The analysis of existing approaches to rational land use in conditions of land degradation shows that the most effective strategy requires a synergy of efforts aimed at increasing the level of functionality of land resources and the ability to regenerate. It is advisable to realize these objectives by optimising management policies. The transformation of land use systems should take place in close interrelation with the technological and organisational-technical optimisation of the main production processes in the direction of the renewability of natural resources. Innovative approaches to land use have the potential to increase the level of efficiency of the agrarian sector, and improve the condition of the local and regional landscape. The concept of improving the state of degraded lands should be based on the synergy of economic efficiency and environmental safety, with the mandatory introduction of modern innovative technological approaches, and information technology for monitoring, diagnostics and forecasting.

Realisation of tasks of sustainable management of landscape complexes in an innovative context implies the use of information monitoring technology, which anticipates diagnosis, genesis and forecasting of the state of the studied ecosystems. Such measures imply programmes for the restoration of ecological functions of natural landscapes, which is an integral part of sustainable development programmes. The study is limited by the possibilities of experimental verification of the obtained results in real socio-economic conditions of development of the Almaty region of Kazakhstan. Unquestioning compliance with the requirements in terms of the maximum load on land resources, bringing the existing norms in organic production to the standards of developed countries, the application of a closed cycle of resource use contributes to the optimization of soil conditions in the Karasai district of the Almaty region. The possibilities of wide implementation of geoinformation technologies, satellite navigation devices and electronic mapping require further research.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Aldieri, L., Brahmi, M., Chen, X., & Vinci, C.P. (2021). Knowledge spillovers and technical efficiency for cleaner production: An economic analysis from agriculture innovation. *Journal of Cleaner Production*, 320, article number 128830. doi: 10.1016/j.jclepro.2021.128830.

[2] Bilushenko, A. (2023). Analisis of phitodiversity according to the state of vegetation PF the Petropavlovsk Estuary Lanscape Reserve and its surroundings. *Biological Systems: Theory and Innovation*, 14(3-4), 7-24. doi: 10.31548/biologiya14(3-4).2023.001.

[3] Bragina, E.V., *et al.* (2018). Wildlife population changes across Eastern Europe after the collapse of socialism. *Frontiers in Ecology and the Environment*, 16(2), 77-81. doi: 10.1002/fee.1770.

[4] Bureau of National Statistics. (2024). *The main indicators of the development of livestock (January-July 2024)*. Retrieved from http://surl.li/yqskxq.
[5] Caffaro, F., Cremasco, M.M., Roccato, M., & Cavallo, E. (2020). Drivers of farmers' intention to adopt technological innovations in Italy: The role of information sources, perceived usefulness, and perceived ease of use. *Journal of Rural Studies*, 76, 264-271. doi: 10.1016/j.jrurstud.2020.04.028.
[6] Cisternas, I., Velásquez, I., Caro, A., & Rodríguez, A. (2020). Systematic literature review of implementations of precision agriculture. *Computers and Electronics in Agriculture*, 176, article number 105626. doi: 10.1016/j.compag.2020.105626.
[7] Clapp, J. (2021). Explaining growing glyphosate use: The political economy of herbicide-dependent agriculture. *Global Environmental Change*, 67, article number 102239. doi: 10.1016/j.gloenvcha.2021.102239.
[8] Clapp, J., & Ruder, S.-L. (2020). Precision technologies for agriculture: Digital farming, gene-edited crops, and the politics of sustainability. *Global Environmental Politics*, 20(3), 49-69. doi: 10.1162/glep_a_00566.
[9] de Janvry, A., & Sadoulet, E. (2020). Using agriculture for development: Supply- and demand-side approaches. *World Development*, 133, article number 105003. doi: 10.1016/j.worlddev.2020.105003.
[10] Ecological Code of the Republic of Kazakhstan. (2021, January). Retrieved from https://adilet.zan.kz/eng/docs/K2100000400.
[11] European Commission. (2023). *EU Agricultural Outlook: 2023-2025*. Retrieved from https://agriculture.ec.europa.eu/system/files/2024-01/agricultural-outlook-2023-report_en_0.pdf.
[12] Farrokhi, F., & Pellegrina, H.S. (2023). Trade, technology, and agricultural productivity. *Journal of Political Economy*, 131(9), 2509-2555. doi: 10.1086/724319.
[13] Fedoniuk, T.P., Pyvovar, P.V., Skydan, O.V., Melnychuk, T.V., & Topolnytskyi, P.P. (2024). Spatial structure of natural landscapes within the Chornobyl Exclusion Zone. *Journal of Water and Land Development*, 60, 79-90. doi: 10.24425/jwld.2024.149110.
[14] Fleming, A., Jakku, E., Fielke, S., Taylor, B.M., Lacey, J., Terhorst, A., & Stitzlein, C. (2021). Foresighting Australian digital agricultural futures: Applying responsible innovation thinking to anticipate research and development impact under different scenarios. *Agricultural Systems*, 190, article number 103120. doi: 10.1016/j.agsy.2021.103120.
[15] Glover, D., Sumberg, J., Ton, G., Andersson, J., & Badstue, L. (2019). Rethinking technological change in smallholder agriculture. *Outlook on Agriculture*, 48(3), 169-180. doi: 10.1177/0030727019864978.
[16] Gras, C., & Cáceres, D.M. (2020). Technology, nature's appropriation and capital accumulation in modern agriculture. *Current Opinion in Environmental Sustainability*, 45, 1-9. doi: 10.1016/j.cosust.2020.04.001.
[17] Guliyeva, E.A. (2021). The role of the national innovation system in the process of ensuring sustainable economic development. In *Proceedings of the international conference on theoretical and applied economic practices "Economic growth in conditions of globalization"* (pp. 420-423). Chisinau: National Institute for Economic Research.
[18] Hermans, K., & McLeman, R. (2021). Climate change, drought, land degradation and migration: Exploring the linkages. *Current Opinion in Environmental Sustainability*, 50, 236-244. doi: 10.1016/j.cosust.2021.04.013.
[19] Herrero, M., *et al.* (2020). Innovation can accelerate the transition towards a sustainable food system. *Nature Food*, 1, 266-272. doi: 10.1038/s43016-020-0074-1.
[20] Hossain, A., Krupnik, T.J., Timsina, J., Mahboob, M.G., Chaki, A.K., Farooq, M., Bhatt, R., Fahad, S., & Hasanuzzaman, M. (2020). Agricultural land degradation: Processes and problems undermining future food security. In S. Fahad, M. Hasanuzzaman, M. Alam, H. Ullah, M. Saeed, I. Ali Khan & M. Adnan (Eds.), *Environment, climate, plant and vegetation growth* (pp. 17-61). Cham: Springer. doi: 10.1007/978-3-030-49732-3_2.
[21] Kernecker, M., Busse, M., & Knierim, A. (2021). Exploring actors, their constellations, and roles in digital agricultural innovations. *Agricultural Systems*, 186, article number 102952. doi: 10.1016/j.agsy.2020.102952.
[22] Kurmanova, G.K., Sukhanberdina, B.B., & Urazova, B.A. (2022). Factors of production of agriculture of the Republic of Kazakhstan. *Economy: Strategy and Practice*, 17(1), 93-109. doi: 10.51176/1997-9967-2022-1-93-109.
[23] Lacoste, M., *et al.* (2021). On-farm experimentation to transform global agriculture. *Nature Food*, 3, 11-18. doi: 10.1038/s43016-021-00424-4.
[24] Land Code of the Republic of Kazakhstan. (2003, June). Retrieved from https://adilet.zan.kz/eng/docs/K030000442_.
[25] Law of the Republic of Kazakhstan No. 423-IV LRK "On Production of Organic Products". (2015, November). Retrieved from https://adilet.zan.kz/eng/docs/Z1500000423.
[26] Law of the Republic of Kazakhstan No. 464-IV "On Introduction of Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan Regarding Regulation of Land Relations". (2011, July). Retrieved from https://adilet.zan.kz/rus/docs/Z1100000464.

[27] Mahata, S., & Sharma, V.N. (2021). The global problem of land degradation: A review. *National Geographical Journal of India*, 67(2), 216-231. doi: 10.48008/ngji.1773.
[28] Ministry of Agriculture of the Republic of Kazakhstan. (2022). *State register of breeding animals in all categories of farms*. Retrieved from https://data.egov.kz/datasets/view?index=gosregistr_plemjivotnyh_vovse4.
[29] Olsson, L., Barbosa, H., Bhadwal, S., Cowie, A., Delusca, K., Flores-Renteria, D., Hermans, K., Jobbagy, E., Kurz, W., Li, D., Sonwa, D.J., & Stringer, L. (2019). Land degradation. In *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (pp. 345-436). Cambridge: Cambridge University Press. doi: 10.1017/9781009157988.006.
[30] Pasichnyk, N., Dudnyk, A., Opryshko, O., Kiktev, M., & Petrenko, M. (2023). Use of neural networks for planning the correct selection of plant and soil samples in precision agriculture technologies. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 19(6), 1-12. doi: 10.31548/dopovidi6(106).2023.005.
[31] Prăvălie, R. (2021). Exploring the multiple land degradation pathways across the planet. *Earth-Science Reviews*, 220, article number 103689. doi: 10.1016/j.earscirev.2021.103689.
[32] Prăvălie, R., Patriche, C., Borrelli, P., Panagos, P., Roșca, B., Dumitraşcu, M., Nita, I.-A., Săvulescu, I., Birsan, M.-V., & Bandoc, G. (2021). Arable lands under the pressure of multiple land degradation processes. A global perspective. *Environmental Research*, 194, article number 110697. doi: 10.1016/j.envres.2020.110697.
[33] Raihan, A., Muhtasim, D.A., Farhana, S., Pavel, M.I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. *Energy and Climate Change*, 3, article number 100080. doi: 10.1016/j.egycc.2022.100080.
[34] Rocchi, L., Boggia, A., & Paolotti, L. (2020). Sustainable agricultural systems: A bibliometrics analysis of ecological modernization approach. *Sustainability*, 12(22), article number 9635. doi: 10.3390/su12229635.
[35] Rolandi, S., Brunori, G., Bacco, M., & Scotti, I. (2021). The digitalization of agriculture and rural Areas: Towards a taxonomy of the impacts. *Sustainability*, 13(9), article number 5172. doi: 10.3390/su13095172.
[36] Rose, D. C., Wheeler, R., Winter, M., Lobley, M., & Chivers, C.A. (2021). Agriculture 4.0: Making it work for people, production, and the planet. *Land Use Policy*, 100, article number 104933. doi: 10.1016/j.landusepol.2020.104933.
[37] Ruzzante, S., Labarta, R., & Bilton, A. (2021). Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development*, 146, article number 105599. doi: 10.1016/j.worlddev.2021.105599.
[38] Sadik-Zada, E.R. (2020). Natural resources, technological progress, and economic modernization. *Review of Development Economics*, 25(1), 381-404. doi: 10.1111/rode.12716.
[39] Shao, W., Zhang, Z., Guan, Q., Yan, Y., & Zhang, J. (2024). Comprehensive assessment of land degradation in the arid and semiarid area based on the optimal land degradation index model. *CATENA*, 234, article number 107563. doi: 10.1016/j.catena.2023.107563.
[40] Skliar, V., Smoliar, N., Kozak, M., Liubynskyi, O., & Skliar, Y. (2024). Ecological and cenotic features of natural regeneration of forests in the Left-Bank Polissya of Ukraine. *Ukrainian Journal of Forest and Wood Science*, 15(2), 118-134. doi: 10.31548/forest/2.2024.118
[41] Skydan, O.V., Fedoniuk, T.P., Pyvovar, P.V., Dankevych, V.Ye., & Dankevych, Y.M. (2021). Landscape fire safety management: The experience of Ukraine and the EU. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, 6(450), 125-132. doi: 10.32014/2021.2518-170X.128.
[42] United Nations Convention to Combat Desertification. (2018). *Kazakhstan's Final Report on the LDN Target Setting Programme*. Retrieved from https://www.unccd.int/sites/default/files/ldn_targets/2018-11/Kazakhstan%20LDN%20TSP%20Country%20Report.pdf.
[43] United Nations Development Programme. (2015). *Strategic measures to combat desertification in the Republic of Kazakhstan until 2025*. Retrieved from https://www.undp.org/ru/kazakhstan/publications/strategicheskie-mery-po-borbe-s-opustynivaniem-v-respublike-kazakhstan-do-2025-goda.
[44] Xie, H., Zhang, Y., Wu, Z., & Lv, T. (2020). A bibliometric analysis on land degradation: Current status, development, and future directions. *Land*, 9(1), article number 28. doi: 10.3390/land9010028.
[45] Yang, X., Shu, L., Chen, J., Ferrag, M. A., Wu, J., Nurellari, E., & Huang, K. (2021). A survey on smart agriculture: Development modes, technologies, and security and privacy challenges. *IEEE/CAA Journal of Automatica Sinica*, 8(2), 273-302. doi: 10.1109/jas.2020.1003536.
[46] Yin, X., Chen, J., & Li, J. (2022). Rural innovation system: Revitalize the countryside for a sustainable development. *Journal of Rural Studies*, 93, 471-478. doi: 10.1016/j.jrurstud.2019.10.014.

Удосконалення методів раціонального використання в умовах деградації земель в Карасайському районі Алматинської області

Асем Айдарова
Аспірант
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0009-0007-2411-5776

Ардак Омарбекова
Кандидат наук, доцент
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-6607-7292

Галимжан Усипбаєв
Аспірант, старший викладач
Казахський національний дослідницький технічний університет
050013, вул. Сатбаєва, 22, м. Алмати, Республіка Казахстан
https://orcid.org/0009-0002-4099-011X

Даріга Оналбаєва
Аспірант
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0009-0005-5235-6601

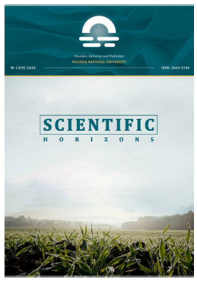
Сандугаш Мауяєва
Аспірант
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-6413-349X

Анотація. Дослідження було спрямоване на ідентифікацію потенціалу сучасних методів раціонального землекористування в Карасайському районі Алматинської області Казахстану з огляду на їх інтенсивну деградацію. Методологія дослідження представлена методами статистичного спостереження, порівняння, аналітично-структурного групування та прогнозування. Проаналізовано пріоритетні цілі модернізації сільського господарства Республіки в технологічному аспекті. Встановлено, що інноваційні підходи до землекористування володіють потенціалом підвищення рівня ефективності аграрної галузі, поліпшення стану локального та регіонального ландшафту. Розроблено концепцію поліпшення стану деградованих земель, що включає систему управлінських заходів і практичних заходів.Доведено,що вона має бути заснована на синергії економічної ефективності та екологічної безпеки, з обов'язковим впровадженням сучасних інноваційних технологічних підходів. Визначено ефективність методів раціонального використання деградованих земель як дієвого інструменту для трансформації аграрної галузі. Запропоновано інтенсифікувати розвиток галузі органічного сільськогосподарського виробництва, яке позиціонується як найбільш щадне для деградованих ландшафтів.Доведено,що реалізація завдань сталого управління ландшафтними комплексами в інноваційному контексті має на увазі використання інформаційної технології моніторингу, що передбачає діагностику, генезу та прогнозування стану екосистем, що вивчаються. Такі заходи дадуть можливість розробляти програми відновлення екологічних функцій природних ландшафтів, що є невід'ємною частиною програм сталого розвитку. Актуалізовано ситуацію в контексті екологізації землекористування в Казахстані, спрогнозовано подальшу деструкцію екосистем аграрних ландшафтів у разі використання агресивних методів обробітку ґрунту. Обґрунтовано необхідність упровадження вдосконалених методів раціонального використання земель, окреслено специфіку впровадження органічних і біологічних технологій сільськогосподарського виробництва, із зазначенням дотичних ризиків і викликів в економічних реаліях Казахстану. У дослідженні обґрунтовано, що застосування інтегрованого управління та екосистемного підходу мають синергетичний потенціал забезпечення раціонального використання земель Алматинської області, Карасайського району в умовах їхньої деградації

Ключові слова: землеробство; сталий розвиток; модернізація; інтенсифікація; органічне виробництво

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
***Scientific Horizons*, 27(9), 121-133**



UDC 338.43:339.564(85)
Doi: 10.48077/scihor9.2024.121

Competitiveness of the La Libertad region in agricultural exports, Peru, 2011-2023

Alberto-Marcos Soriano-Colchado
Master of Science in Agricultural Economics, Professor
Pedro Ruiz Gallo University
391 Juan XXIII Ave., Lambayeque, Peru
https://orcid.org/0000-0002-0425-429X

Ramón-Alberto Diez-Matallana
Master of Science in Agricultural Economics, Professor
Universidad Nacional Agraria La Molina
15076, 012 La Molina Ave., Lima, Peru
https://orcid.org/0000-0001-8247-1452

Raquel-Margot Gómez-Oscorima*
Master of Science in Agricultural Economics, Professor
Universidad Nacional Agraria La Molina
15076, 012 La Molina Ave., Lima, Peru
https://orcid.org/0000-0002-5823-9159

Luis-Alberto Jiménez
Doctor in Economics, Professor
Universidad Nacional Agraria La Molina
15076, 012 La Molina Ave., Lima, Peru
https://orcid.org/0000-0002-6082-1893

Carolay-Zully Vasquez-Quispe
Master of Science in Agricultural Economics, Assistant Professor
Peruvian University of Applied Sciences
15076, 2255 Salaverry Ave., Lima, Peru
https://orcid.org/0000-0003-4582-9106

Article's History:
Received: 18.03.2024
Revised: 30.07.2024
Accepted: 28.08.2024

Abstract. The increasing global demand for high-value agricultural products emphasises the need to understand regional export competitiveness. The study aimed to evaluate La Libertad's comparative advantages in agricultural exports from 2011 to 2023. By employing the Revealed Comparative Advantage (RCA), Export Comparative Advantage (ECA), and Import Comparative Advantage (ICA) indices, alongside Porter's Diamond,

Suggested Citation:
Soriano-Colchado, A.-M., Diez-Matallana, R.-A., Gómez-Oscorima, R.-M., Jiménez, L.-A., & Vasquez-Quispe, C.-Z. (2024).Competitiveness of the La Libertad region in agricultural exports, Peru, 2011-2023. *Scientific Horizons*, 27(9), 121-133. doi: 10.48077/scihor9.2024.121.

*Corresponding author

the region's performance and the determinants of competitiveness across 11 key export products were analysed. These products include fruits such as blueberries, avocados, and grapes, as well as vegetables such as asparagus and piquillo peppers. The analysis revealed strong ECAs for fruits and vegetables, with values ranging from 1.56 to 7.08, and a promising specialisation in cane sugar (RCA of 1.28). The findings indicate that most of these products possess strong to moderate comparative advantages in international markets, with products like blueberries and avocados leading in competitiveness. However, certain challenges remain, including the need for strategic business management and technological innovation to maintain and improve the sector's competitiveness. The study underscores the importance of continuous monitoring and adaptation to ensure the sustainability and growth of Peru's agro-export sector. These findings offer valuable insights for policymakers and regional planners seeking to enhance La Libertad's agricultural export potential

Keywords: Porter's Diamond; fruits and vegetables; revealed comparative advantages

INTRODUCTION

The competitiveness of agricultural exports is a key factor in a country's economic development. The agro-export sector, particularly in regions with fertile land and favourable climates, is essential in generating economic income and creating employment opportunities. At the regional level, understanding competitive advantages is crucial for ensuring the long-term sustainability of the agricultural industry, as agricultural exports are often seen as a catalyst for economic progress, particularly in developing countries, where they can contribute to poverty reduction, food security, and sustainable development. This research is highly relevant as it sheds light on the competitiveness of the agro-export sector in the La Libertad region of Peru, a significant hub for non-traditional exports. Evaluating regional performance can provide policymakers with insights to enhance competitiveness, address market challenges, and drive economic growth. Several researchers have studied the dynamics of agricultural exports. M. Babacan (2018) noted that international trade not only fosters economic growth but also enhances innovation and productivity within the business sector. Moreover, it strengthens competitiveness, a key driver for long-term development. J. Salas-Canales (2020) analysed the growth of Peru's agricultural exports, identifying a substantial increase in non-traditional exports. The author highlighted that exports of products such as blueberries, grapes, and avocados grew exponentially, with irrigation projects and trade agreements being significant contributors to this growth. A deeper look into Peruvian agriculture is provided by D.A. Escalante *et al.* (2023), who assert that between 2000 and 2019, exports of blueberries, grapes, avocados, and asparagus soared due to increased investments in agricultural technologies and infrastructure. This boost in productivity allowed Peru to surpass countries like Chile, the United States, and Mexico in the export of key products such as blueberries and avocados. The impressive performance of the agro-export sector has placed Peru among the world's leading exporters of high-value crops. These achievements are further enhanced by Peru's ability to meet international quality standards, which has allowed it to access competitive global markets and ensure the success of its agricultural exports.

Additionally, the determinants of competitiveness in agriculture have been widely explained through Porter's Diamond Model, which has been recognised as a critical framework. According to P.H. Tsai *et al.* (2023) and P. Grdeń and A. Jakubczyk (2023), this model examines the factors that contribute to a country's or region's ability to compete in agriculture, highlighting four key determinants: factor conditions (labour, capital, infrastructure, and natural resources), demand conditions (including consumer preferences for agricultural products and market size), related and supporting industries (such as agricultural suppliers, machinery, and logistics), and firm strategy, structure, and rivalry (encompassing farm management practices and competition among agricultural producers). Government policies, investments in rural infrastructure, and the adoption of technological innovations are identified as pivotal factors influencing the agricultural sector's competitiveness both regionally and globally. In the research of G. Harya *et al.* (2023), this model emphasised the notion of competitive advantage from dynamic capabilities and the expectation of improving industry performance at the regional level, demonstrating the importance of policy frameworks and technological innovations. Its findings underscore the role of effective government in influencing the factors that create an enabling environment for agricultural innovation and competitiveness.

Given the significant role that agriculture plays in Peru's economy and the rapidly evolving global market, it is imperative to assess the comparative advantages of the La Libertad region's agricultural exports. This research aimed to evaluate the international competitiveness of the agro-export sector in La Libertad, with a focus on fruits and vegetables. By calculating the Revealed Comparative Advantage (RCA), Export Comparative Advantage (ECA), and Import Comparative Advantage (ICA) indices, this study seeks to identify the region's strengths and key determinants of competitiveness using Porter's Diamond framework. Additionally, this analysis will offer valuable insights into how La

Libertad can continue to enhance its competitive position in global markets, ensuring the sustainability and growth of its agro-export sector.

MATERIALS AND METHODS

Calculation of the Revealed Comparative Advantage Index to measure the competitiveness of agricultural export goods. To calculate the comparative advantage index for agro-exportable goods, a modified version of T. Vollrath's (1991) approach was used. This version improves upon the original Balassa formula by avoiding double counting between country pairs, reducing the asymmetry between export and import values through the application of the natural logarithm (ln), and including imports in the original formula (Laursen, 1998). It is expressed through equations (1 to 3):

$$RCA_{ia} = ECA_{ia} - ICA_{ia}, \quad (1)$$

$$ECA_{ia} = ln\ (X_{id}/X_{in})/(X_{rd}/X_{rn}), \quad (2)$$

$$ICA_{ia} = ln\ (M_{id}/M_{in})/(M_{rd}/M_{rn}), \quad (3)$$

where *RCA* stands for Revealed Comparative Advantage, *ECA* represents Export Comparative Advantage, and *ICA* denotes Import Comparative Advantage. In these formulas, *X* and *M* refer to exports and imports, respectively. The subscript *i* refers to the country or region being analysed, *a* corresponds to the specific product under study, *r* indicates a group of countries or the rest of the world, and *n* represents the total goods, excluding product *a*. To evaluate the comparative advantages of the selected products within the fruit and vegetables category, equation (2) for ECA was used, focusing solely on export values, as Peru does not import these products. Conversely, for the analysis of sugar, which is both exported and imported, equation (1) for RCA was applied.

Interpretation of possible ECA and RCA index values. The interpretation of the value resulting from equation (2): a value greater than 1 indicates a comparative advantage, suggesting specialisation, while a value less than 1 indicates a comparative disadvantage, suggesting importation. Regarding the result of equation (1), the RCA can be positive or negative, depending on the ECA and ICA indices. If the value is positive, it indicates that the country has a comparative advantage in the given product, a strong export sector, and greater competitiveness; that is, the higher the value of the index, the greater the competitiveness and, consequently, the participation of that product in international trade (Vollrath, 1991). If the RCA index is less than 1, it indicates a comparative disadvantage in the product, with the country having a weak export sector and low competitiveness, making importation more favourable. A positive RCA indicates that the country or region has good competitive performance in the foreign market; if negative, it implies a comparative disadvantage in exports (the product should not be exported). If the ICA is positive, imports have a comparative advantage (it is advantageous to import), whereas if negative, it shows that imports cannot compete in the domestic market due to low demand or the existence of factors (such as trade barriers) that limit or prevent their internal marketing. A combination of these indices may be found in the results: ECA > 0 and ICA < 0 with RCA > 0; ECA > 0 and ICA > 0 with RCA ⩾ 0; ECA < 0 and ICA < 0 with RCA < 0 and finally ECA < 0 and ICA > 0 with RCA < 0 (the last two scenarios are undesirable for the country under consideration).

Interpretation of possible ECA values. M.E. Pérez-Romero *et al.* (2022), based on J. Hinloopen and C. Marrevijk (2004), classified the ECA values by ranges and interpreted them as follows: 0 ⩽ ECA < 1: no comparative advantages. 1 < ECA ⩽ 2: weak comparative advantage. 2 < ECA ⩽ 4: moderate comparative advantage, ECA > 4: strong comparative advantage. To measure the competitiveness of the region's agro-export sector using revealed comparative advantage indices, the following information was considered: export and import values of selected agricultural products from the total merchandise of La Libertad and the rest of the world, in nominal US$ FOB, sourced from the Central Reserve Bank of Peru (CRBP) (2022) and TradeMap (n.d.).

Products under evaluation in the study and assessment sequence. A sample of 11 export products from the region was selected, comprising vegetables (asparagus, artichokes, piquillo peppers, and paprika peppers), fruits (blueberries, avocados, grapes, mangoes, watermelons, and mandarins), and sugar cane derivatives (sugar for domestic consumption or industrial use). The ECA index was calculated separately for fruit and vegetables, as these products are only exported. The RCA index was then applied to sugar, followed by the respective index for each category that groups the products (fruit and vegetables). The analysis period spanned 12 years, from 2011 to 2023. To determine the export comparative advantage indices for each product for the period 2011-2023, the averages of the annual ECA values were used. The Import Comparative Advantage index for sugar was estimated using FOB import values over the same period. Measures of competitiveness based on trade flows assume the existence of free trade and do not account for distortions caused by trade barriers, exchange rate policies, tariffs, subsidies, or variations in demand due to changing consumption patterns. While the comparative advantage indices provide static results, competitiveness evolves over time, meaning it is dynamic.

RESULTS AND DISCUSSION

ECA index for fresh fruit. The ECA indices for the products during the period 2011-2023 show values classified, according to M. Pérez-Romero *et al.* (2022), within the ranges of weak comparative advantage (watermelon: 1.29), moderate comparative advantage (mandarin:

2.57, grape: 2.79, and mango: 3.54), and strong comparative advantage (avocado: 5.40 and blueberry: 6.18). These values reflect their competitive performance in exports and specialisation, which is advantageous due to their significant presence in the external market, except in one case (watermelon), which shows a weak comparative advantage and limited participation in the external market. However, its specialisation would still be justified by a value greater than 1. The results of the competitiveness measurements using the ECA indices are presented in Table 1. Blueberries, mandarins, grapes, avocados, and mangoes displayed an upward trend in competitiveness over the period. In the case of mandarins, the trend was downward until 2016, when it reached its lowest point, after which it increased steadily. Watermelon, however, showed a decline in its export competitiveness index and a reduction in its market share, with only one buyer: Chile.

***Table 1**. ECA of fresh fruits*

Fruits	ECA
Blueberry	6.18
Avocado	5.40
Mango	3.54
Grape	2.79
Mandarin	2.57
Watermelon	1.29

***Source:** compiled by the authors based on Trade Map (n.d.)*

The high competitive performance demonstrated by the ECA indices for blueberries and avocados, particularly the Hass and Fuerte varieties, reflects the dynamic and sustained growth of exports. This growth is attributed to their high profitability and increasing interest in the foreign market due to their nutraceutical properties, which are beneficial to human health, positioning them in important markets such as the United States and the Netherlands. Recently, exports have also been made to China, Belgium, Singapore, and Russia (Trade Map, n.d.). The growing global demand for blueberries and avocados, particularly from the US and Europe, has led national growers to dedicate more land to these crops, improve yields, and develop new varieties to meet consumer demand. According to the Fresh Fruit Report (2021), commercial intelligence analyses suggest there are large potential markets for these products, such as China and Japan. The area planted with grapes is relatively small, and the increase in acreage is moderate; however, yields in the r egion are very close to those of the main grape producers in the country (Ica and Piura). There is considerable potential for increasing grape production and productivity, as the region possesses the right soil and climate conditions for the successful development of the crop.

The provinces of Gran Chimú and Chepén concentrate most of the region's grape production, followed by Virú and Ascope. In terms of mandarins, the region's exports have gained momentum since 2016 (Fig. 1). The ECA index for this product increased significantly during the period 2016-2020, reaching +0.41 (Table 1), due to the rise in citrus exports, meeting the growing demand from the United States, the main importer, as well as from the United Kingdom, the Netherlands, Canada, and China. It is important to note that, according to V. Ballena (2019), the La Libertad region has increased citrus production and exports; however, its share of the national mandarin market remains low. This may be attributed to the climatic conditions of the northern Peruvian coast, characterised by high temperatures and humidity (Cáceres Candia *et al.*, 2021). Consequently, citrus fruits are susceptible to pests and diseases throughout their growth cycle, which adversely affects their productivity. Globally, Cyprus leads in yields per hectare with 50 tonnes, and China is the largest exporter.

Regarding vegetables (Table 2), asparagus (7.11), paprika peppers (5.71), and piquillo peppers (4.05) stand out, as they present ECA values greater than 4, indicating a strong comparative advantage. Artichokes (1.80) exhibit a weak comparative advantage.

***Table 2**. ECA of fresh vegetables*

Vegetables	ECA
Asparagus	7.11
Paprika peppers	5.71
Piquillo peppers	4.05
Artichoke	1.80

***Source:** compiled by the authors based on Trade Map (n.d.)*

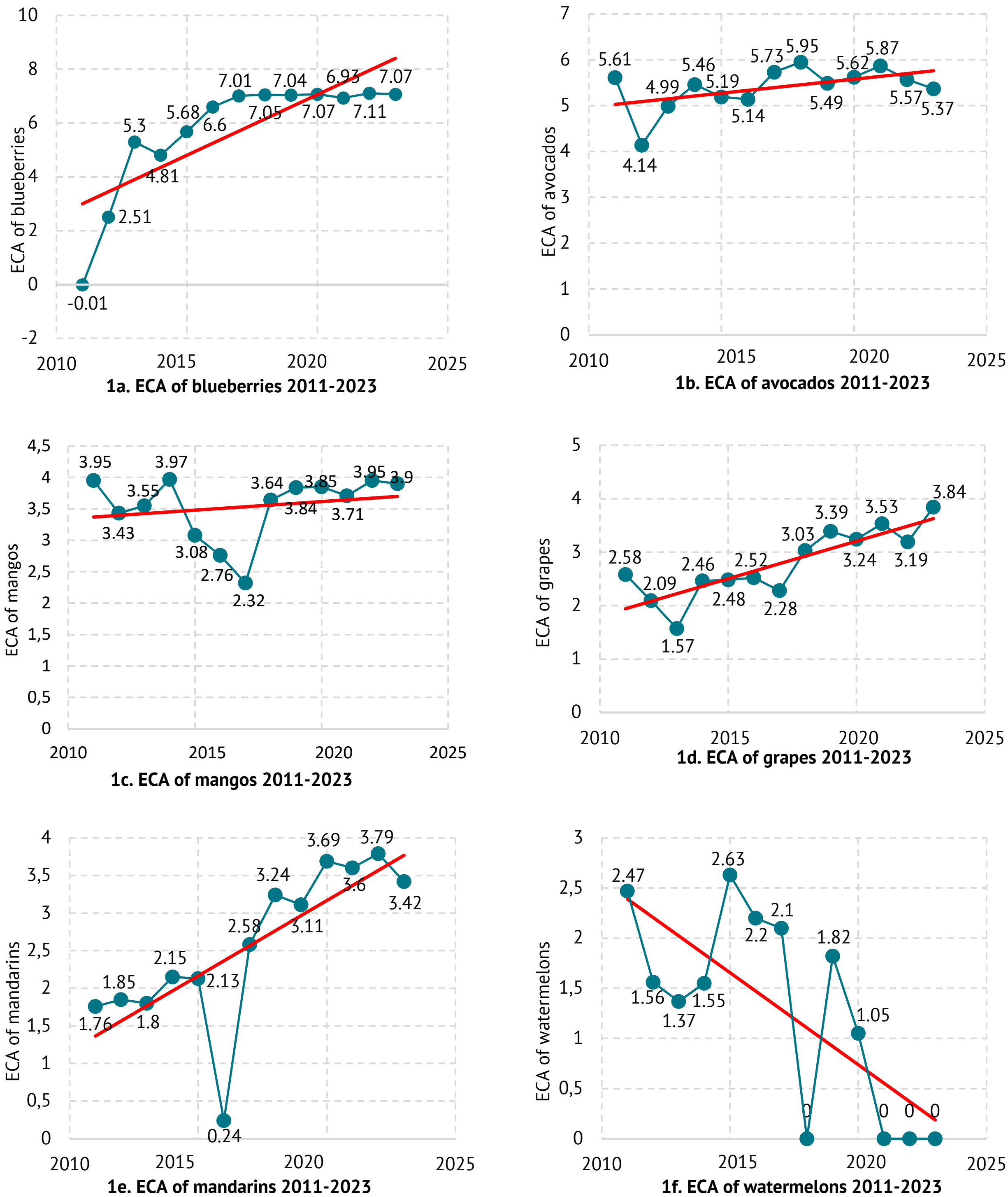


***Figure 1**. ECA indices of fruits*

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

For asparagus, a key product for the region and the country, competitiveness increased throughout the period 2011-2023. It is worth noting that if the evolution of asparagus competitiveness is divided into two periods, there was a decline from 2013 to 2017, which coincides with the boom in blueberry production and exports (2013-2014), which partially displaced asparagus cultivation. However, since 2018, Peru – and La Libertad in particular – has repositioned itself in the global asparagus market, resulting in increasing competitiveness indices (Fig. 2).

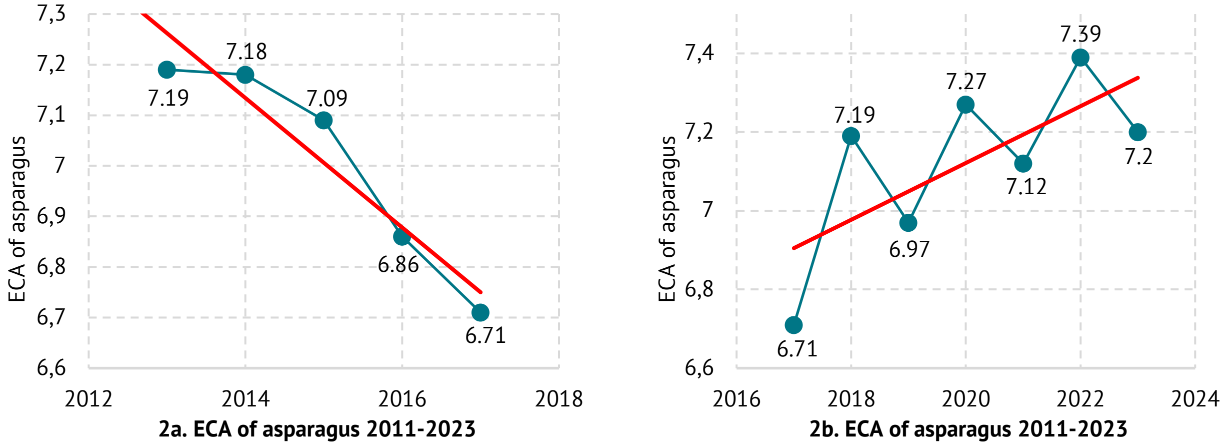


***Figure 2**. ECA of asparagus*

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

Asparagus was one of the first non-traditional foreign products to be adapted in the region, positioning itself in the United States (USA), followed by the United Kingdom, the Netherlands, Spain, Canada, and others. Its quality and good taste have enabled its exports to increase rapidly. High yields have consolidated Peru as one of the world's leading suppliers of asparagus, along with China and Mexico. The artichoke has a weak comparative advantage (ECA of 1.80), although it has an important presence in the international market, with a stagnant competitiveness trend in the last years of the period from 2018 to 2023 (Fig. 3). It is mainly exported in canned form or as whole pieces, with the main buyers being the United States, Spain, and France.

Of the Capsicum genus, the piquillo pepper has had a mixed performance, with a decline in exports and restrictions on access to markets due to post-harvest contamination. However, the ECA index indicates its high competitiveness and the trend shows an increase over time. It is exported preserved and dried as a powder. For paprika pepper, competitiveness gas decreased over the period from 2012 to 2023 (Fig. 4). The product is exported preserved and ground. The main destinations are the USA, Mexico, Spain, Germany, and France.

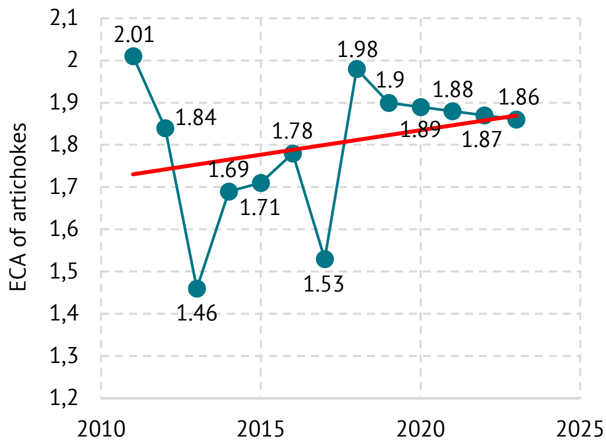


***Figure 3**. ECA of artichokes 2011-2023*

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

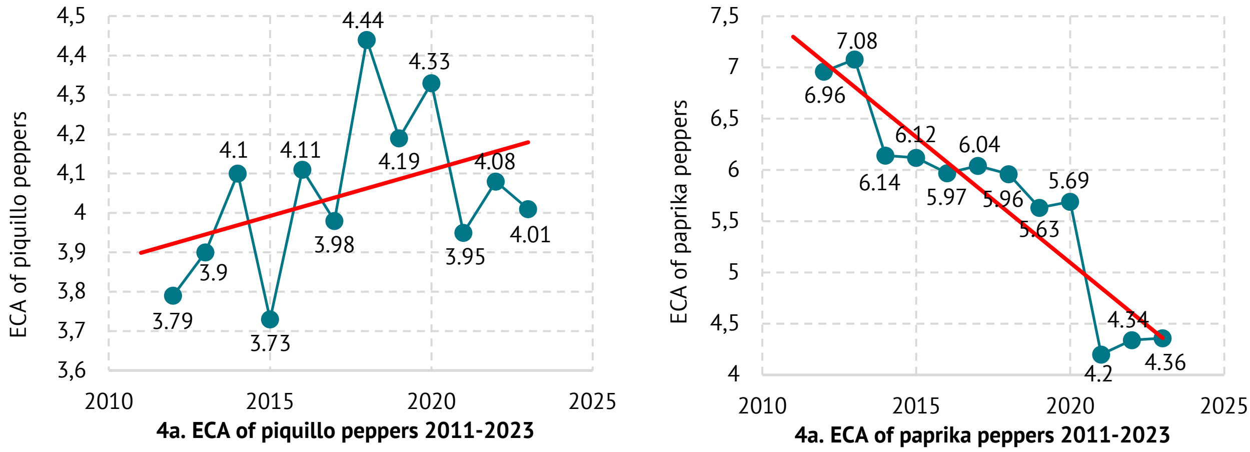


***Figure 4**. ECA of piquillo peppers and paprika peppers 2012 – 2023*

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

The RCA (Revealed Comparative Advantage) index for sugar was obtained by taking the difference between the ECA (Export Comparative Advantage) and ICA (Import Comparative Advantage) indices to determine whether the product has a revealed comparative advantage. Statistical information on sugar imports for the La Libertad region is not available, and the authors worked with data at the national level. This does not diminish the significance of the results, as a large part of Peru's sugar production comes from this region (Flores *et al.*, 2022). Sugar has a positive RCA of 1.27, with positive ECA > ICA values, indicating a moderate comparative advantage of its exports; both are positive, meaning that the country's imports are important in internal trade. The trend of the ECA is increasing while that of the ICA is decreasing, although both exhibit fluctuations (Table 3, Fig. 5).

***Table 3**. ECA and ICA of sugar*

Product	ECA	ICA	RCA
Sugar	2.44	1.17	1.27

***Source:** compiled by the authors based on Trade Map (n.d.)*

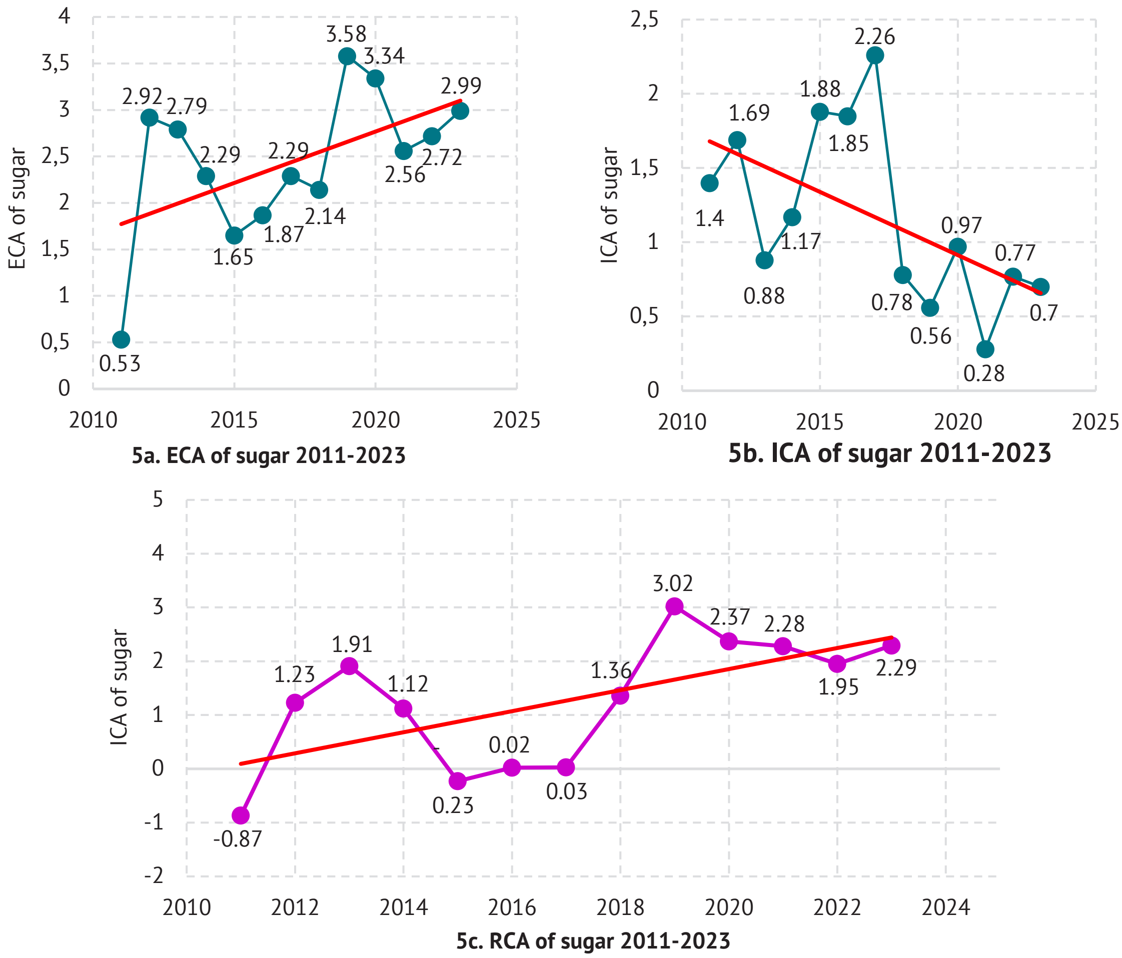


***Figure 5**. ECA, ICA, and RCA of sugar (2011-2023)*

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

Export Comparative Advantage (ECA) of products by category. Figure 6 analyses the products by category: fruits and vegetables. In the period 2011-023, La Libertad showed an increasing competitive performance in fruits but was more stable in vegetables. From 2012 to 2016, vegetable exports dominated fruit exports; however, since 2019, fruits have overtaken vegetables. This performance is explained by the expansion of blueberry production and exports led by La Libertad, alongside higher exports of avocados, grapes, and mangoes, which significantly increased overall fruit exports. International trade in fresh fruits and vegetables has become increasingly consolidated in recent decades in developed countries due to sustained growth in consumption, which is attributed to changes in dietary preferences for health and aesthetics. In fresh fruit, exports grew significantly, especially of avocados, grapes, mangoes, mandarins, and blueberries, to the United States, the Netherlands, Spain, Chile, the United Kingdom, Hong Kong, South Korea, China, Canada, Russia, and others (Duarte, 2019). For vegetables, the leading products were asparagus and paprika. As with fruits, the United States led the ranking in vegetables, followed by Spain, the Netherlands, France, and the United Kingdom, among others.

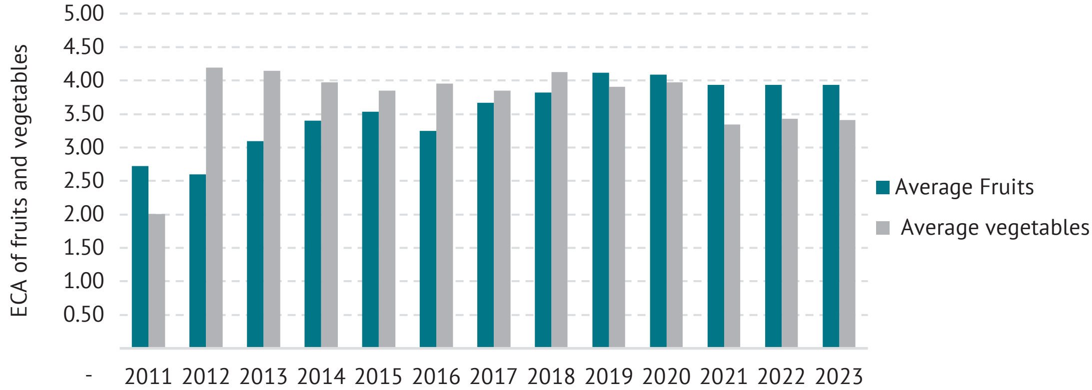


Figure 6*. Fruits and vegetables ECA evolution 2011-2023*

Source: *compiled by the authors*

Competitiveness is then addressed in terms of the specialisation and productivity of the region and the country.

International Competitiveness, Specialisation, and Productivity. In La Libertad, the products with a strong comparative advantage discussed in the previous section – fruits (blueberries, avocados), vegetables (asparagus), and sugar cane – exhibit higher productivity than both Peru and several leading countries in the world. This is reflected in the position of Peru and La Libertad in the export ranking (Table 4).

Table 4*. Export ranking of the main crops*

Crop	Peru/ world	La Libertad/Peru (%)	The three most important exporting countries
Canned asparagus	2°	43.2	China (50%); Peru (36%); Netherlands (6%)
Fresh asparagus	2°	n.d.	Mexico (34%); Peru (30%); USA (11%)
Avocados	3°	31.6	Mexico (50%); Netherlands (11%); Peru (10%)
Canned artichokes	2°	14.0	China (41%); Peru (7%); Netherlands (6%)
Fresh blueberries	2°	54.0	Chile (19%); Peru (15%); Spain (13%)
Fresh grapes	6°	4.11	Chile (14%); USA (12%); Italy (9%)
Fresh mangoes	6°	1.20	Mexico (15%); Vietnam (12%); Netherlands (11%)
Paprika pepper	6°	0,0	China (39%); India (18%); Spain (18%)
Fresh watermelon	38°	52.6	Spain (22%); Mexico (15%); Iran (9%)
Sugar cane derivatives	62°	48.4	Brazil (16%); Thailand (10%); France (9%)

Source: *compiled by the authors based on Trade Map (n.d.)*

A region with high productivity is likely to be highly competitive due to its lower unit costs. This is clearly the case in La Libertad; if factor specialisation is added to the production of these goods, international competitiveness will be guaranteed. The methodology employed to estimate the competitiveness indices (ECA, ICA, RCA) is similar to that used by M. Anderson *et al.* (2021), who determined the revealed competitiveness of Peru and South America in the production of rice and potatoes. J. Heredia and J. Huarachi (2009) evaluated the RCA for the Lambayeque region of Peru, using a larger sample of agro-industrial products and the index values for competitive products were of a higher magnitude than those obtained in this research for La Libertad.

Determinants of the competitiveness of the region's agro-exports. Once the competitiveness of La Libertad has been measured, it is also necessary to identify the factors that have enabled this success, as well as those that have constrained it. A descriptive analysis is conducted of the main components that have facilitated the export of products which have established themselves in the international market, using the qualitative model (Inga-Ávila, 2022) known as Porter's Diamond. This considers: 1) factor conditions, 2) demand conditions, 3) related industries, and 4) the structure and rivalry within the industries – attributes that constitute the system referred to by Porter (1991) as the "Diamond". Two additional variables complete the framework of the analysis: government influence and random or causal events. The competitiveness of the export sector depends significantly on the quality of logistics infrastructure and services (World Bank, 2016). In La Libertad, there are deficiencies in road infrastructure and in the cargo capacity of ports and airports, which do not meet the demands of exporters. Moreover, there is a shortage of skilled workers in the digital technologies necessary to compete successfully with foreign companies. The paralysis of the third phase of the Chavimochic irrigation project is hindering the incorporation of 20,000 new hectares of crops and the enhancement of irrigation for the 50,000 hectares already under cultivation (SPCH, 2023). If these factors were strengthened, the productivity potential of the La Libertad region would be greater, and its competitiveness would be sustainable over time.

In summary, the analysis of the ECA indices from 2011 to 2023 reveals that La Libertad's agricultural exports exhibit notable competitive advantages. Both blueberries and avocados stand out with high ECA values, reflecting strong international competitiveness. Vegetables such as asparagus and paprika also demonstrate robust advantages, while watermelon and artichokes have weaker comparative positions. The trend analysis indicates that blueberries, avocados, grapes, and mandarins have generally become more competitive over the period, whereas mangoes, watermelons, and certain vegetables have seen a decline. The RCA index for sugar indicates a moderate competitive stance, with challenges in balancing exports and imports. Despite these competitive strengths, La Libertad faces significant obstacles, including infrastructure inefficiencies and logistical issues, which impact its overall competitiveness. These findings underscore the region's potential and highlight areas where improvements are necessary to sustain and enhance its agro-export sector.

The efficiency and simplicity of calculating the competitiveness indices (ECA, ICA, and RCA) for La Libertad in its agro-exports reflect the findings of S. Gariballa *et al.* (2023), who obtained these indices for rice and potatoes from Peru and South America and found that they were not competitive in these products. Likewise, the competitiveness of Peruvian agricultural products was also evaluated by D.A. Escalante *et al.* (2023), who compared the competitiveness of blueberries, grapes, avocados, coffee, and asparagus with products from other Latin American countries during the period 2010-2019, analysing two categories: the degree of specialisation and the degree of competitiveness using the competitiveness matrix. They found a high degree of specialisation in Peruvian blueberries, grapes, and avocados; coffee and asparagus were the least competitive. Peru's competitive potential in blueberries was confirmed by C. Aggio *et al.* (2022) through a case study on blueberry producers in Argentina, which revealed that their strategy, based on achieving high prices out of season, was less efficient than that of Peruvian blueberry exporters. The study agrees with the findings of J.C. Montes Ninaquispe *et al.* (2024) regarding the high competitiveness of Peru in blueberries. Regarding the importance of institutional factors, the findings of the research on the competitiveness of La Libertad align with those of H.-P. Feng *et al.* (2023), which indicated that membership in the European Union (28 members) positively impacted the economic development and competitiveness of all Union members. In contrast, C.E. Ospina *et al.* (2023) found that the Hass avocado system in Cauca improves its competitiveness through technological support driven by institutions and international cooperation, which favours producers' access to export markets.

In the specific case of rare earth industries, A. Thibeault *et al.* (2023) point out that competitiveness is the fundamental framework for achieving the development of any industry and highlight the role of government in strengthening it, in line with Porter's thinking: information, incentives, competitive pressures, access to firms, institutions, infrastructure, knowledge resources, and management skills contribute to increasing competitiveness indicators. Each region has different comparative advantages due to climate, access to resources, technology, innovation, agricultural practices, and other factors. Competitiveness implies the efficiency of production, logistics management, and factors external to the firm, and it changes over time as it depends on the internal and external conditions in which firms operate (De & Singh, 2022).

C.E. Ospina *et al.* (2023) assess the avocado value chain in Valle del Cauca (Colombia), taking into account biophysical, social, economic, and technological factors. They found that the Hass avocado system in Cauca is heterogeneous and dispersed, with varying degrees of modernisation and articulation with markets. Moreover, technological progress is driven by institutions and international cooperation, which promotes access to export markets for small and medium-sized producers. To ensure the sustainability of an agro-export sector that is well positioned in the world market, it is necessary to understand its level of competitiveness, monitor its performance over time, and reduce the obstacles that hinder its improvement. J. Hancco (2022) found that strategic business management significantly impacts the competitiveness of 127 micro and small agro-export firms in Tacna, Peru. R. Ramos-Sandoval (2019) points out that the small size of Peruvian agribusinesses could hinder their internationalisation by preventing them from achieving economies of scale and adopting technological innovations. On the other hand, recent popular protests against agro-exporters, alleging wage and labour productivity inequality in the sector (Castillo, 2021), align with the issues identified 30 years ago by M. Carter and D. Mesbah (1993), who found a link between agricultural export growth, land concentration, and labour instability.

M. Mills-Novoa (2020) critically points out that agricultural and water policies since 2009 have reallocated water to agro-export companies. It should be noted that agro-export crops generate a growing water footprint. In this context, X. Esteve-Llorens *et al.* (2022) observe that Peru exploits abundant groundwater for avocados and asparagus, but high-tech irrigation systems minimise water use, and low pesticide mobility prevents the degradation of natural water bodies. To alleviate the water deficit, desalination of seawater is a strategy employed in Greece (Panagopoulos & Giannika, 2023; Harati *et al.,* 2023). This could provide more water for agricultural irrigation, which could alleviate the water shortage in many areas of Peru, such as La Libertad. However, this could be further addressed through irrigation projects, which, although expensive, can be implemented over many years, as demonstrated by the Chavimochic project (SPCH, 2023). The Chavimochic project began in 1988 to harness the waters of the Santa River to meet the irrigation needs of 144,000 hectares in the Chao, Virú, Moche, and Chicama valleys. After the completion of the first and second phases, the irrigation of 28,000 hectares has been improved, and 46,665 hectares will be included in the Chao, Virú, and Moche valleys.

E. Roszko-Wójtowicz and M. Grzelak (2020) used macroeconomic variables to rank European Union (EU) member states by competitiveness and found that membership in the EU (28 members) had a positive impact on economic development and competitiveness in both the EU-13 (more developed) and the EU-15 (less developed) countries. Measuring competitive performance using comparative advantage indices from international trade is a practical way of determining whether a country or region has comparative advantages. P. Crupi *et al.* (2021) point out that competitiveness is measured by taking into account prices, exchange rates, production, financial, fiscal, and transport costs using the Export Competitive Advantage (ECA), Import Competitive Advantage (ICA), and Revealed Competitive Advantage (RCA). Y. Bahta (2021) evaluated South Africa's agri-food competitiveness with the RCA, the Lafay Index (LI), the Export Diversification Index (EDI), the Main Export Category (MEC), the Hirschman Index (HI), and the influence of factors using regression analysis. C. Aggio *et al.* (2022) used a case study of the blueberry agrosystem to assess Argentina's competitiveness in this product and found that its strategy, based on achieving high prices out of season, was less efficient than that of blueberry exporters from Peru. Z. Tamar and A. López (2022) found that Mexico has RCA in 15 of the 37 major agricultural products of Mexico, the US, and Canada, from the period 1990-2017, with per capita income, total population, rural population, arable land, and agricultural capital as significant factors. D.A. Escalante *et al.* (2023) compared the competitiveness of the five main Peruvian products with similar products from other Latin American countries in the period 2010-2019, analysing two categories: the degree of specialisation and the degree of competitiveness using the competitiveness matrix. They found a high degree of specialisation in Peruvian blueberries, grapes, and avocados; coffee and asparagus were the least competitive. J.C. Montes Ninaquispe *et al.* (2024) applied a quantitative approach to evaluate the sustainability and competitiveness of Peru's blueberry exports. They calculated the Herfindahl-Hirschman Index (HHI) and the Balassa RCA index. They found very high growth in the United States (115% annually) and robust growth in the Netherlands and the United Kingdom. However, the HHI showed great dependence on the United States. The RCA indicated that Peru is competitive in blueberries compared to the United States (values ranging from 0.09 to 0.55 during the study period). In summary, the literature identifies competitive advantages for Peru in Peruvian agricultural products, and this is confirmed by the present work for the region of La Libertad, using a simple and research-friendly methodology such as that of revealed comparative advantages.

CONCLUSIONS

The competitiveness indicators show that La Libertad's agricultural exports have comparative advantages and that specialisation is advantageous. The most competitive fruits are blueberries and avocados, and in vegetables, the most competitive are asparagus, artichoke, and paprika, which have the highest ECA indices. The least competitive fruits are mango, tangerine, grape, and watermelon, while for vegetables, the least competitive is piquillo pepper. The evolution of the competitiveness indices shows that blueberries, avocados, grapes, and mandarins have become more competitive over the period, while mangoes, watermelons and all vegetables except piquillo peppers have become less competitive. The RCA for sugar shows that it is weakly competitive, with a positive net value very close to zero, indicating that exports are moderately competitive but imports are also competitive in the domestic market. The competitiveness indices for exports and imports increase over the period studied, although the competitiveness of imports tends to increase faster than that of exports. In general, La Libertad is competitive in the fruit and vegetable trade because it has developed competitive advantages based on regional comparative advantages. However, there are still factors that affect business logistics and increase the cost of products: the inefficiency and lack of capacity of the regional port and airport infrastructure, customs inefficiency, poor local road infrastructure, a lack of skilled workers in digital technologies, and the failure to complete the Chavimochic Special Project, which would integrate agricultural land and improve land irrigation.

Future research should delve into several important areas. First, it should explore how the increased competitiveness of La Libertad's agro-exports has influenced the regional economy. Additionally, investigating whether the growth in exports has had a positive impact on small-scale family farming is crucial. Understanding the potential for further expansion of La Libertad's agro-exports and assessing the prospects for broadening the sector will provide valuable insights. Addressing these questions will be essential for refining strategies to boost competitiveness and tackle ongoing challenges in the agro-export sector.

ACKNOWLEDGEMENTS

The authors would like to thank Ivanna Abigail Cubas Cubas, a student at the Faculty of Economics and Planning at the Universidad Nacional Agraria La Molina, for her help in designing and editing the figures.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Aggio, C., Milesi, D., Verre, V., Zanazzi, L., & Lengyel, M. (2022). Rise and fall (and recovery?) of the blueberry business in Argentina: An analysis of private and public-private strategies. *Journal of Agribusiness in Developing and Emerging Economies*, 12(4), 584-603. doi: 10.1108/JADEE-10-2021-0270.

[2] Anderson, M., Gómez, R., Diez, R., & Linares, A. (2021). Competitiveness of Peru and South America in the production of rice (*Oryza sativa*) and potato (*Solanum tuberosum*). *Scientific Annals*, 82(1), 11-21. doi: 10.21704/ac.v82i1.1737.

[3] Babacan, M. (2018). Beyond planning and liberalization: Foreign trade and industrial development in Turkey. In *Turkish economy* (pp. 355-384). Cham: Palgrave Macmillan. doi: 10.1007/978-3-319-70380-0_16.

[4] Bahta, Y.T. (2021). Competitiveness of South Africa's agri-food commodities. *AIMS Agriculture and Food*, 6(4), 945-968. doi: 10.3934/agrfood.2021057.

[5] Ballena, V. (2019). Evolution of foreign trade by customs according to primary production in Peru, 2005-2015. *Regional and Sectoral Economic Studies*, 19(1), 77-107.

[6] Cáceres Candia, D.P., Risco Mendoza, A., Quiroz-Delgado, P.E., & Apaza-Tapia, W.E. (2021). Control of Botrytis cinerea Pers. in 'Okitsu' Satsuma mandarin by biological and chemical fungicides in Huaura, Peru. *Peruvian Journal of Agronomy*, 5(1), 18-24. doi: 10.21704/pja.v5i1.1760.

[7] Carter, M.R., & Mesbah, D. (1993). Can land market reform mitigate the exclusionary aspects of rapid agro-export growth? *World Development*, 21(7), 1085-1100. doi: 10.1016/0305-750X(93)90001-P.

[8] Castillo, L.P. (2021). *Situation of the agro-export and agro-industrial sector and the new law on the agricultural labour regime*. Peru: Institute for Trade Union Studies.

[9] Central Reserve Bank of Peru (CRBP). (2022). Retrieved from https://www.bcrp.gob.pe/en.

[10] Crupi, P., Faienza, M.F., Naeem, M.Y., Corvo, F., Clodoveo, M.L., & Muraglia, M. (2023). Overview of the potential beneficial effects of carotenoids on consumer health and well being. *Antioxidants*, 12(5), article number 1069. doi: 10.3390/antiox12051069.

[11] De, A., & Singh, S.P. (2022). Analysis of competitiveness in agri-supply chain logistics outsourcing: A B2B contractual framework. *Sustainability,* 14(11), article number 6866. doi: 10.3390/su14116866.

[12] Duarte, O. (2019). Analysis of the various factors affecting productivity in fruit growing: The case of Peru. Chile: Cieplan.

[13] Escalante, D.A., Olivera, J.M., Miranda, M.R., & Venegas, P.B. (2023). Peruvian agro-export sector: A competitiveness study on their main products in the period 2010-2019. *Journal Globalization, Competitiveness and Governability*, 17(2), 34-50. doi: 10.58416/GCG.2023.V17.N2.01.

[14] Esteve-Llorens, X., Ita-Nagy, D., Parodi, E., Gonzales-García, S., Moreira, M.T., Feijoo, G., & Vázquez-Rowe, I. (2022). Environmental footprint of critical agro-export products in the Peruvian hyper-arid coast: A case study for green asparagus and avocado. *Science of the Total Environment*, 818, article number 151686. doi: 10.1016/j.scitotenv.2021.151686.

[15] Feng, H.-P., Yu, P.-C., Huang, S.-H., Huang, Y.-C., Chen, C.F., Sun, C.-A., Wang, B.L., Chien, W., & Chiang, C.-H. (2023). The benefit of vegetarian diets for reducing blood pressure in Taiwan: A historically prospective cohort study. *Journal of Health, Population and Nutrition*, 42, article number 41. doi: 10.1186/s41043-023-00377-3.

[16] Flores, S.R., Pérez-Delgado, O., Naveda-Renny, N., Benites, S.M., De La Cruz–Noriega, M., & Narciso, D.A.D. (2022). Generation of bioelectricity using molasses as fuel in microbial fuel cells. *Environmental Research, Engineering and Management*, 78(2), 19-27. doi: 10.5755/j01.erem.78.2.30668.

[17] Fresh Fruit Report. (2021). Retrieved from https://preciso.pe/proyecto/fresh-fruit-fresh-report/.

[18] Gariballa, S., Al-Bluwi, G.S.M., & Yasin, J. (2023). Increased fruit and vegetable consumption mitigates oxidative damage and associated inflammatory response in obese subjects independent of body weight change. *Nutrients*, 15(7), article number 1638. doi: 10.3390/nu15071638.
[19] Grdeń, P., & Jakubczyk, A. (2023). Health benefits of legume seeds. *Journal of the Science of Food and Agriculture*, 103(11), 5213-5220. doi: 10.1002/jsfa.12585.
[20] Hancco, J.F.A. (2022). Competitiveness: A strategic resource-based approach to business management. *TECHNO Review. International Technology, Science and Society Review*, 11(5), 1-15. doi: 10.37467/revtechno.v11.4449.
[21] Harati, M., Tayarani-Najaran, Z., & Javadi, B. (2023). Dietary flavonoids: Promising compounds for targeting α-synucleinopathy in Parkinson's disease. *PharmaNutrition,* 24, article number 100334. doi: 10.1016/j.phanu.2023.100334.
[22] Harya, G. I., Hanani, N., Asmara, R., & Muhaimin, W. (2023). Dynamic capabilities for leading industries: Proof of export commitment of chocolate products. *Bulgarian Journal of Agricultural Science,* 29(4), 579-589.
[23] Heredia, J., & Huarachi, J. (2009). The Revealed Comparative Advantage Index (RCA) between Peru and the World's Leading Exporters: The case of the Lambayeque Region. *Diffusion Notebooks*, 14(26), 27-56. doi: 10.46631/jefas.2009.v14n26.02.
[24] Hinloopen, J., & van Marrewijk, C. (2004). *Dynamics of Chinese comparative advantage*. Amsterdam and Rotterdam: Tinbergen Institute Discussion.
[25] Inga-Ávila, M.F. (2022). Dynamics of the behavior of competitiveness factors in the textile sector. *Uncertain Supply Chain Management*, 10(2022) 877-886. doi: 10.5267/j.uscm.2022.3.007.
[26] Laursen, K. (1998). *Revealed comparative advantage and the alternatives as measures of international specialization*. Copenhagen: Copenhagen Business School.
[27] Mills-Novoa, M. (2020). Making agro-export entrepreneurs out of Campesinos: The role of water policy reform, agricultural development initiatives, and the specter of climate change in reshaping agricultural systems in Piura, Peru. *Agriculture and Human Values*, 37(3), 667-682. doi: 10.1007/s10460-019-10008-5
[28] Montes Ninaquispe, J.C., Arbulú Ballesteros, M.A., Cruz Salinas, L.E., García Juárez, H.D., Farfán Chilicaus, G.C., Martel Acosta, R., Guzmán Valle, M.D.L.Á., & Coronel Estela, C.V. (2024). A strategy for the sustainability of Peru's blueberry exports: Diversification and competitiveness. *Sustainability*, 16(15), article number 6606. doi: 10.3390/su16156606.
[29] Ospina, C.E., Garavito, L.V., & Correa, D.L. (2023). Hass avocado value chain: inter-institutional processes towards export in Cauca, Colombia. *RIVAR*, 10(28), 235-252. doi: 10.35588/rivar.v10i28.5333.
[30] Panagopoulos, A., & Giannika, V. (2023). Study on the water resources and the opportunities for sustainable desalination & minimal/zero liquid discharge (MLD/ZLD) practices in Greece (Eastern Mediterranean). *Sustainable Water Resources Management*, 9, article number 106. doi: 10.1007/s40899-023-00884-5.
[31] Pérez-Romero, M.E., Azuara-Jiménez, J.A., Jiménez-Islas, D., Ventura-Cruz, I., & Flores-Romero, M.B. (2022). Analysis of comparative advantage in global biofuels production. *Business Unrest*, 22(2), 55-70. doi: 10.19053/01211048.13862.
[32] Ramos-Sandoval, R. (2019). Does associativity affect likelihood Peruvian small-scale farms internationalization? In *2019 IEEE sciences and humanities international research conference* (pp. 1-4). Peru: IEEE. doi: 10.1109/SHIRCON48091.2019.9024858.
[33] Roszko-Wójtowicz, E., & Grzelak, M.M. (2020). Macroeconomic stability and the level of competitiveness in EU member states: A comparative dynamic approach. *Oeconomia Copernicana*, 11(4), 657-688. doi: 10.24136/OC.2020.027.
[34] Salas-Canales, J. (2020). Non-traditional agro-exports and their contribution to Peruvian economic development. *Mastery of Science*, 6(1), 4-27. doi: 10.23857/dc.v6i1.1343.
[35] SPCH (Special Project Chavimochic). (2023). Retrieved from https://www.gob.pe/chavimochic.
[36] Tamar, Z., & López, A. (2022). The trinomial of comparative advantages revealed in Sader's North American basket of goods and services. *The Anáhuac Journal*, 19(2), 39-69. doi: 10.36105/theanahuacjour.2019v19n2.02.
[37] Thibeault, A., Ryder, M., Tomomewo, O., & Mann, M. (2023). A review of competitive advantage theory applied to the global rare earth industry transition. *Resources Policy*, 85, article number 103795. doi: 10.1016/j.resourpol.2023.103795.
[38] Trade map. (n.d.). Retrieved from https://www.trademap.org/Index.aspx.
[39] Tsai, P.H., Chen, C.J., & Yang, H.C. (2021). Using Porter's diamond model to assess the competitiveness of Taiwan's solar photovoltaic industry. *Sage Open,* 11(1). doi: 10.1177/2158244020988286.
[40] Vollrath, T. (1991). A theoretical evaluation of alternative trade intensity measures of revealed comparative advantage. *Review of World Economics*, 127, 265-280. doi: 10.1007/BF02707986.
[41] World Bank. (2016). Retrieved from https://documents1.worldbank.org/curated/en/555181547057977330/pdf/133561-WP-P145783-Analisis-dela-Logistica-Peru.pdf.

Конкурентоспроможність регіону Ла Лібертад в експорті сільськогосподарської продукції, Перу, 2011-2023

Альберто-Маркос Соріано-Кольчадо
Магістр наук з аграрної економіки, професор
Університет Педро Руїса Гальо
просп. Хуана XXIII, 391, м. Ламбаєке, Перу
https://orcid.org/0000-0002-0425-429X
Рамон-Альберто Дієс-Маталана
Магістр наук з аграрної економіки, професор
Національний аграрний університет Ла-Моліна
15076, просп. Ла Моліна, 012, м. Ліма, Перу
https://orcid.org/0000-0001-8247-1452
Ракель-Марго Гомес-Оскоріма
Магістр наук з аграрної економіки, професор
Національний аграрний університет Ла Моліна
15076, просп. Ла Моліна, 012, м. Ліма, Перу
https://orcid.org/0000-0002-5823-9159
Луїс-Альберто Хіменес
Доктор економічних наук, професор
Національний аграрний університет Ла Моліна
15076, просп. Ла Моліна, 012, м. Ліма, Перу
https://orcid.org/0000-0002-6082-1893
Каролай-Зуллі Васкес-Кіспе
Магістр наук з аграрної економіки, доцент
Перуанський університет прикладних наук
15076, просп. Салаверрі, 2255, м. Ліма, Перу
https://orcid.org/0000-0003-4582-9106

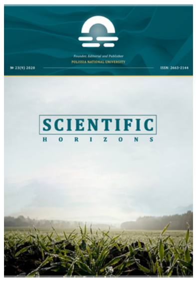
Анотація. Зростання світового попиту на високовартісні сільськогосподарські продукти підкреслює необхідність розуміння конкурентоспроможності регіонального експорту. Мета полягала в тому, щоб оцінити порівняльні переваги La Libertad в експорті сільськогосподарської продукції за період 2011-2023 років. Використовуючи індекси виявленої порівняльної переваги (RCA), порівняльної переваги експорту (ECA), порівняльної переваги імпорту (ICA) і діаманта Портера, було досліджено показники регіону та детермінанти конкурентоспроможності в 11 ключових експортних продуктах, включаючи такі фрукти, як чорниця, авокадо, виноград і овочі, такі як спаржа та перець пікільо. Аналіз показує сильні ECA для фруктів і овочів, зі значеннями в діапазоні від 1,56 до 7,08, і життєздатну спеціалізацію на тростинному цукрі (RCA 1,28). Отримані дані показали, що більшість із цих продуктів мають значні або помірні порівняльні переваги на міжнародних ринках, причому такі продукти, як чорниця та авокадо, є лідерами за конкурентоспроможністю. Однак певні проблеми залишаються, зокрема потреба в стратегічному управлінні бізнесом і технологічних інноваціях для підтримки та підвищення конкурентоспроможності сектора. Дослідження підкреслює важливість постійного моніторингу та адаптації для забезпечення стійкості та зростання агроекспортного сектору Перу, а результати пропонують цінну інформацію для політиків і регіональних планувальників для підвищення експортного потенціалу сільськогосподарської продукції Ла Лібертад

Ключові слова: діамант Портера; фрукти та овочі; виявлені порівняльні переваги

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua

Scientific Horizons, 27(9), 134-147



UDC 339.5:633:355.01

Doi: 10.48077/scihor9.2024.134

Logistics transformation on grain and oilseeds markets during the war in Ukraine: Marketing approaches and strategies

Olha Bodnar*

Doctor of Economics, Professor

National University of Kyiv-Mohyla Academy

04655, 2 H. Skovoroda Str., Kyiv, Ukraine

https://orcid.org/0000-0002-4188-2965

Yulia Halchynska

Doctor of Economics, Professor

National University of Life and Environmental Sciences of Ukraine

03041, 11 Heroiv Oborony Str., Kyiv, Ukraine

https://orcid.org/0000-0003-4260-3072

Yaroslava Larina

Doctor of Economics, Professor

Kyiv National Economic University named after Vadym Hetman

03057, 54/1 Peremohy Ave., Kyiv, Ukraine

https://orcid.org/0000-0002-2712-7824

Anna Filatova

Postgraduate Student

National University of Life and Environmental Sciences of Ukraine

03041, 11 Heroiv Oborony Str., Kyiv, Ukraine

https://orcid.org/0000-0003-1139-0481

Ihor Stepanets

Postgraduate Student

National University of Life and Environmental Sciences of Ukraine

03041, 11 Heroiv Oborony Str., Kyiv, Ukraine

https://orcid.org/0009-0002-2375-6612

Article's History:

Received: 19.04.2024

Revised: 24.07.2024

Accepted: 28.08.2024

Abstract. The Russian military invasion has caused a collapse in food supplies from Ukraine to world markets. The transformation of Ukrainian export logistics has been carried out under critical conditions and extremely limited deadlines. This article evaluated the transformations in logistics in the grain and oilseeds markets due to the war, discussed the impact of international agreements on export and logistics supply chains, and proposed marketing strategies for the trade of grain, oilseeds, and related

Suggested Citation:

Bodnar, O., Halchynska, Yu., Larina, Ya., Filatova, A., & Stepanets, I. (2024). Logistics transformation on grain and oilseeds markets during the war in Ukraine: Marketing approaches and strategies. *Scientific Horizons*, 27(9), 134-147. doi: 10.48077/scihor9.2024.134.

*Corresponding author

products during wartime. The authors employed various general scientific and special methods and approaches, including a systematic approach, abstract-logical and graphic methods, retrospective and comparative analysis, correlation-regression analysis, and forecasting methods. A periodisation of the export logistical transformation due to the war was used. It included the following stages: the collapse of logistics; the growth of exports due to the impact of international agreements; and the operation of an alternative Ukrainian maritime corridor with the support of international partners. The significant impact of production and sales transformations caused by the war on the growth of wheat export logistics costs for various supply bases was demonstrated. The authors concluded that the export logistics risks were primarily mitigated by low grain and oilseed prices for agricultural producers. An assessment of the grain, oil crops, and processing products export market in Ukraine was also provided. The development of effective marketing strategies was highlighted. The practical value of the study lies in the use of the research results for developing marketing strategies for enterprises and European cooperation development projects in the agrarian sector

Keywords: logistics; food supply chains; prices; costs; agricultural enterprises; food safety; export; international agreements

INTRODUCTION

The stability of production, trade, and logistics chains in Ukraine, which ensured the country's presence in global food markets, has proven to be one of the key prerequisites for maintaining food security in numerous countries worldwide. Several studies have revealed the critical importance of Ukraine's domestic logistics for global food supply chains and the stability of international markets for grain, oilseeds, and related products.

The research by I. Savenko *et al.* (2022) indicates that the production and export potential of the grain and oilseeds market in Ukraine increased significantly due to substantial investments in logistics, including the development of seaport infrastructure. This contributed to Ukraine›s growing share in the global trade of these products, reaching 8.7% for grain, 2.7% for oilseeds, and 39.8% for sunflower oil. The study by N. Galunets (2019) demonstrates that Ukraine plays a significant role in addressing food supply issues in import-dependent countries, as well as in ensuring the availability of food products and combatting hunger worldwide. The Russian military invasion of Ukraine and the occupation of parts of the southern regions severely impeded the operations of strategic seaports and disrupted logistics in the supply chain of agricultural products and raw materials for their production. O. Penkova and A. Kharenko (2023) explored the content and role of marketing logistics in exports and identified the challenges faced by crop production exporters due to the full-scale war with the russian federation. According to O. Kovalenko and A. Kyrychenko (2023), this led to a decline in the volume of grain, oilseeds, and related products exported from Ukraine and increased price volatility in the global food market. This issue was also highlighted in a publication of the Food and Agricultural Organization by the United Nations (FAO, 2023).

Therefore, it is important to understand how to mitigate such risks through the development of marketing strategies and logistics for agricultural enterprises during crises. O. Krasnorutskyy *et al.* (2023) have emphasised the role of effective marketing strategies and tools during wartime, which contribute to increasing the competitiveness of agricultural enterprises. Additionally, I. Zhofan *et al.* (2023) have justified the development of marketing strategies for agricultural sector enterprises in Ukraine's grain markets and estimated the economic potential of Ukrainian farmers. Moreover, the issue of global food security is widely discussed among scientists. T. Hassen and H. Bilali (2022) investigated the direct and indirect impact of the Russia-Ukraine war on global food security. They emphasise that the war may jeopardise the implementation of the Sustainable Development Goals. At the same time, W. Leal Filho *et al.* (2023) propose measures to mitigate the conflict's impacts on food security and promote sustainable agriculture.

Despite valuable scientific contributions to research on the impact of armed conflict on global and local food markets, there is a need for a comprehensive study of the new changes in the logistics of food supplies to global markets as a result of military aggression in Ukraine. The purpose of this study was to investigate the transformations in the grain and oilseeds market due to the war, assess the impact of international agreements on the supply of Ukrainian products, and identify strategies to improve marketing strategies and logistics.

MATERIALS AND METHODS

The study was based on official documents and reports from the Ministry of Agrarian Policy and Food of Ukraine (2023), the World Bank (2023), and the Food and Agricultural Organization of the United Nations (OECD, 2022; FAO, 2023). Datasets from the official websites of the United Nations Conference on Trade and Development (UNCTAD, 2022) and the Ukrainian Agrarian Council (2023) were also utilised. Amendments to Ukrainian legislation (Decree of the President of Ukraine. No. 654/2022, 2022) and European legislation regarding the regulation of agricultural trade were also analysed, including Regulation (EU) 2022/870 (2022), Regulation (EU) 2023/1077 (2023), Commission Implementing Regulation (EU) 2023/903 (2023), Commission Implementing Regulation (EU) 2023/1100 (2023), and other relevant regulations.

The method of logical generalisation was employed to assess the potential for developing production, trade, and logistics chains, which was strategically important under martial law and for ensuring Ukraine's food security. Price volatility in the agricultural markets was identified using statistical methods. Logistic transformations in the grain and oilseed markets during the war in Ukraine were illustrated through statistical tables and graphs. Abstract-logical and graphical methods were utilised to evaluate the impact of international initiatives and agreements on the functioning of export logistics in the grain, oilseeds, and processed products markets during the war in Ukraine. The systematic approach and retrospective analysis revealed the impact of the Black Sea Grain Initiative on the export of grain, oil crops, and processed products from Ukraine during the war. The comparative analysis method was applied to assess the effectiveness of wheat trade through the Grain Corridor within the framework of the humanitarian aid provided by the UN World Food Programme (2023).

The method of cause-and-effect analysis helped to identify the challenges in transport infrastructure in the European direction and assess the impact of the EU-Ukraine Solidarity Lanes Initiative on the export of grain and oil crops (European Commission, 2022). The method of correlation-regression analysis was applied to determine the potential of using Danube region ports as alternative routes for exporting grain, oilseeds, and their processed products during the war. Single-factor models were employed to identify changes in export logistics. The standard deviation indicator (STDEV) (as a built-in MS Excel function) was used to compare export volatility in the grain, oilseeds, and processed products markets across different transport routes. Marketing analysis enabled the assessment of the impact of the war on the cost of wheat export logistics in Ukraine, based on data from SE "Sangrant Plus" (2023) and Barva Invest (2023). The method of analysis was used to forecast the logistics capacities for exports in the grain, oilseeds, and processed products markets for the 2023/2024 marketing year (MY).

RESULTS

The initial period of the war (March-April 2022) critical challenges for the logistics of the grain and oilseeds markets, causing significant disruptions in supply chains. At the onset of the russian invasion, four deep-water seaports were occupied (Kherson, Skadovsk, Berdiansk, and Mariupol), and six others ceased operations due to military threats (Bilhorod-Dnistrovskyi, Odesa, Mykolaiv, Chornomorsk, including Olvia and Pivdennyi). The blockade of seaports resulted in a logistical collapse. In the pre-war period, 93-98% of the exports of grain, oilseeds, and related products were handled through these ports (Bielashov, 2022). Monthly exports had reached 7.8 million tonnes by November 2021. With the outbreak of war, these figures declined to 56-270 thousand tonnes. Only the river ports of the Danube region (Reni, Izmail, Kilia, and Ust-Dunaisk) remained operational, ensuring monthly exports of the aforementioned products, but up to 1 million tonnes until June 2022. Overall, the export of grains and sunflower oil decreased by 1.3 times in 2022 compared to 2021 (Trade Map data, 2023).

Disruptions in Ukraine's food supply chains increased price volatility in the global food market. In particular, the FAO food price index soared from 136 points in January 2022 to 158 points in May 2022. This represents the largest increase in the past decade (FAO, 2023). During this period, grain and oilseed prices on the European market rose by 1.4-1.5 times. Despite this, there was a sharp decrease in prices on Ukraine's domestic market for grain, oilseeds, and related products. For example, before the war (January 2022), prices for 3rd class wheat on an EXW basis were USD 314 per tonne, but during the first seven months of the war, these prices collapsed to USD 148 per tonne, representing a more than twofold decrease (Fig. 1).

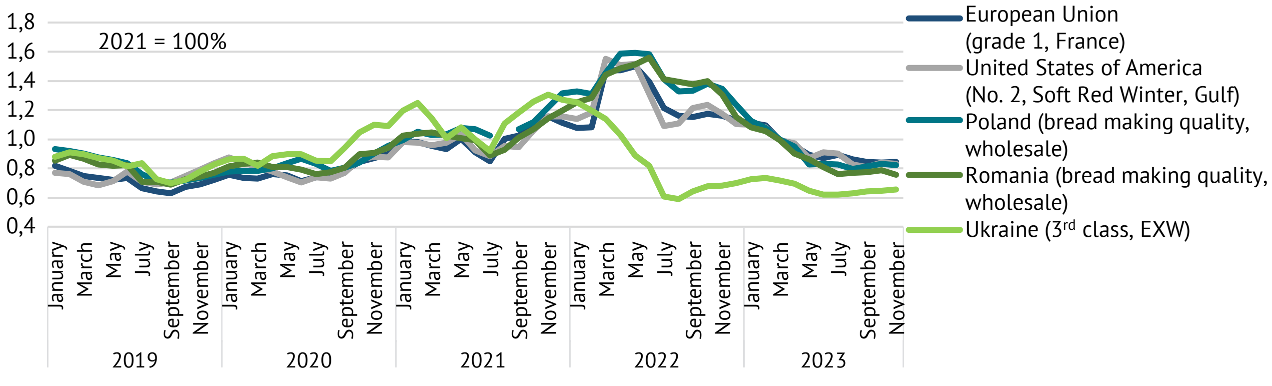


Figure 1*. Dynamics of food wheat price indices, %*
Source: *developed by the authors based on Food Price Monitoring and Analysis (2023)*

As a result, there was a forced and urgent transformation of export chains. In particular, export volumes were redistributed among different means of transportation. During the first year of the war, there was a significant increase in transportation by land. The share of road transport increased to 23%, and rail transport to 22%, depending on the type of cargo. Waterway transportation decreased significantly, accounting for only 59-72% of the export structure (Table 1).

***Table 1**. Changes in the transport logistics of grain, oilseeds, and related products exports during the war period in Ukraine, %*

Type of transport	Grain	Oilseeds	Sunflower oil
War period (March 2022-January 2023) Share in total transportation, %			
Road	6	23	18
Railway	22	17	15
Marine	72	59	64
Other	0	1	3
Changes in the share of transportation compared with the pre-war period (2021), pp			
Road	5.9	18.4	15.8
Railway	21.5	-1.0	13.7
Marine	-27.3	-19.4	-32.5
Other	0.0	1.0	3.0

***Source:** calculated by the authors based on Barva Invest data (2023)*

It must be acknowledged, that the process of restoring the destroyed logistics infrastructure was supported by international initiatives and agreements. These documents aimed to preserve Ukraine's presence in global supply chains and maintain the stability of the world food market. An analysis of the dynamics of export volumes for grain, oilseeds, and related products from Ukraine during the war reveals the significant impact of these agreements on the functioning of Ukraine's export logistics (Fig. 2).

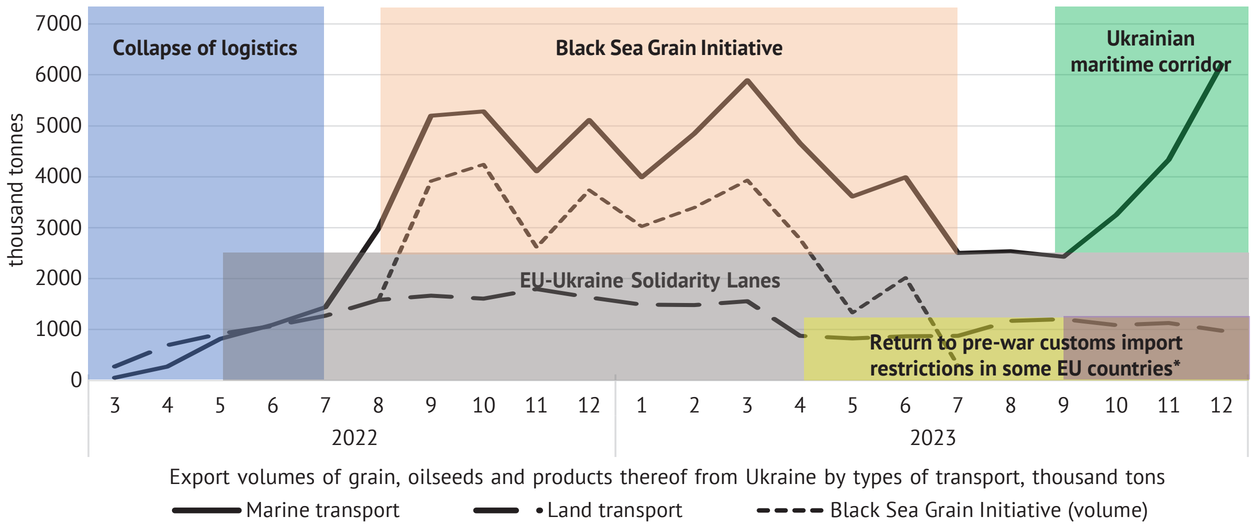


***Figure 2**. Impact of international initiatives and agreements on the export logistics of the market of grain, oilseeds, and related products of Ukraine during the war ***

***Note:** *April-September 2023 - Bulgaria, Poland, Romania, Slovakia, Hungary. September-December 2023 - Poland, Slovakia, Hungary. **Export includes the following goods: wheat, barley, corn, sunflower seeds, rapeseed, soybean, sunflower oil, soybean oil, and oil cakes*

***Source:** developed by the authors based on data from the Ministry of Agrarian Policy and Food of Ukraine (2023), European Commission (2022), and Barva Invest data (2023)*

Firstly, the partial restoration of maritime logistics occurred following the signing in July 2022 of the agreement titled "Initiative for the Safe Transportation of Grain and Foodstuffs from Ukrainian Ports", which aimed to unblock three Ukrainian ports: Odesa, Pivdennyi, and Chornomorsk. In various sources, this agreement is referred to as the "Black Sea Grain Initiative" (UNCTAD, 2022) or the "Grain Corridor" (Ministry of

Agrarian Policy and Food of Ukraine, 2023). This was a unique type of agreement that required the signing of two mirrored documents – one between Ukraine, the UN, and Turkey, and the other between the Russian Federation, the UN, and Turkey. The parties agreed to establish a safe logistics corridor for the export of grain and other food products from Ukrainian ports. Subsequently, specific routes were established, which were regularly monitored and controlled by the Joint Coordination Centre under the auspices of the UN in Istanbul to ensure compliance with the agreements. The validity period of the agreement lasted 120 days, with provisions for automatic renewal for subsequent periods.

In general, the validity of this agreement was extended twice: in November 2022 and March 2023. However, as of 19 August 2023, the Grain Agreement ceased to be in effect due to the withdrawal of the Russian Federation, which subsequently started the blockade of the Black Sea (Hirnyk, 2023). Consequently, the role of these international agreements in preventing the critical destruction of Ukraine's logistics chains is considered quite significant (UNCTAD, 2022). It should be noted that this agreement served as an effective mechanism for supplying grain, oilseeds, and related products to the global market. During its period of effectiveness, it ensured the operation of the largest export logistics route from Ukraine. Thanks to joint efforts, approximately 32.9 million tonnes of grain, oilseeds, and related products were exported through deep-water ports during the Grain Initiative's effective period. The majority of exports consisted of corn (17 million tonnes, 51%) and wheat (9 million tonnes, 27%). The export of oilseeds and related products was significantly smaller, totalling 5.6 million tonnes (17%), of which about 1.7 million tonnes (5%) was sunflower oil (Fig. 3).

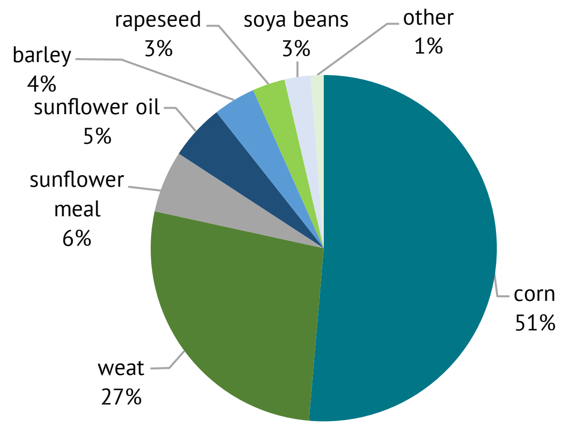


Figure 3*. Type structure of the export of grain, oilseeds and related products during the Grain Initiative period (August 2022-July 2023)*
Source: *developed by the authors based on data from the Black Sea Grain Initiative. Joint Coordination Centre (2023)*

Following the results of the export analysis, it was possible to account for more than a third of the total export of grain, up to 14% of oilseeds, and approximately 20% of related products through the deep-water seaports (Odesa, Pivdennyi, and Chornomorsk) during the war (February 2022-December 2023) due to the Black Sea Grain Initiative (2023) (Fig. 4).

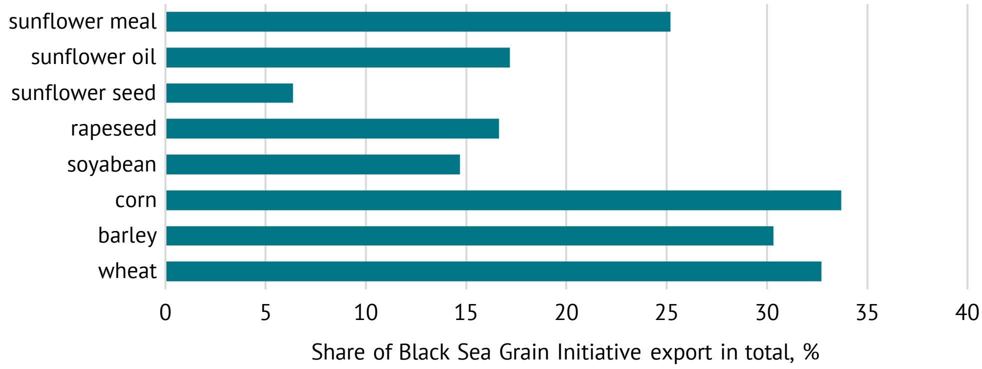


Figure 4*. Significance of the Black Sea Grain Initiative in the export of grain, oilseeds and related products from Ukraine during the war **
Note: ** February 2022-December 2023*
Source: *developed by the authors based on data from the Ministry of Agrarian Policy and Food of Ukraine (2023), Black Sea Grain Initiative. Joint Coordination Centre (2023)*

The Black Sea Grain Initiative enabled the elimination of the domestic market surpluses in Ukraine during the 2022/23 marketing year. Monthly export volumes through seaports reached 3.0-4.2 million tonnes (Fig. 2). Consequently, this led to a reduction in product stocks at the beginning of the 2023/24 marketing year by almost 2.5 times compared to the previous year. However, pre-war export volumes via this logistical route were not achieved, as sea routes accounted for only about 46% of the export of these products during the agreement's validity. Importantly, the signing of this agreement resulted in a rising price trend in Ukraine's domestic market, which lasted until February 2023. In particular, prices for 3rd class food wheat based on Ex Works (EXW) delivery increased by 25%, reaching USD 184 per tonne. Nonetheless, alignment with global trends was not achieved, as in the pre-war period, as logistics costs remained relatively high and exerted pressure on domestic prices (World Bank, 2023).

At the same time, is important to acknowledge the risks associated with exporting through the Grain Corridor due to the potential for blockage by the Russian side. During the period of the Grain Initiative from August 2022 to August 2023, the Russian Federation systematically threatened to terminate the agreements. The necessity of extending the agreement every 120 days created additional risks due to the unpredictability of reaching new agreements among the parties involved. However, one of the most critical risks during wartime was the high probability of shelling of the seaports engaged in the implementation of the Grain Initiative. Specifically, the ports of Chornomorsk and Odesa (July 2022, July 2023), as well as the infrastructure of the Danube region ports, sustained significant damage. According to experts' estimates, 167 port infrastructure facilities and 7 civilian ships were damaged, and around 300,000 tonnes of grain were destroyed (Muravskyi, 2023). In the early stages of the war, the indirect losses due to the blockade of Ukraine's Black Sea ports by the aggressor country's naval forces, including those caused by the decline in domestic prices and the increase in transport costs for export-oriented products, amounted to approximately USD 14.5 billion (World Bank, 2023).

The significant risks associated with this logistical route and the official withdrawal of shipping safety guarantees by the Russian side necessitated the search for alternative access to Black Sea routes. The ports in the Danube region were considered one of the key components of Ukrainian logistics for the supply of grain, oilseeds and their processed products to global markets. This became possible through the partial restoration of the ports of Izmail, Reni, Ust-Dunaisk, and Kilia. Logistical routes in this region were established through Romania and the Republic of Moldova. Notably, international agreements with the Republic of Moldova led to discounts being granted for the transit of products by rail to the port of Reni. Specifically, grain was discounted by 27% and sunflower oil by 39% (Ministry of Agrarian Policy and Food of Ukraine, 2023). The main objective of these efforts was to mitigate the effects of the blockade of deep-water ports.

However, the capacity of this logistical route is significantly lower. In the ports of the Danube region, the majority of vessels, carrying loads of up to 5,000 tonnes, were heading to Romania, where they were transshipped at the port of Constanta onto larger sea vessels, particularly Panamax vessels. According to expert estimates, the potential throughput capacity of the Danube region ports for transshipping grain, oilseeds, and related products is up to 3 million tons per month (Ukrainian Agrarian Council, 2023). In the pre-war period (2019-2021) the volume of cargo handling in the Danube seaports of Ukraine, particularly Izmail, Reni, and Ust-Dunaisk, was insignificant, accounting for only 2.5-4.2% of the total volume. During the war, actual maximum monthly export shipments through these ports reached 2.0 and 2.2 million tonnes in March and May 2023, respectively. At the beginning of the war, mainly grain was exported through the Danube region ports, primarily wheat. Since the beginning of 2023, the export of sunflower oil and oil cakes has increased (Fig. 5). Overall, this logistical route managed to facilitate the export of about 21 million tonnes of grain and oil products.

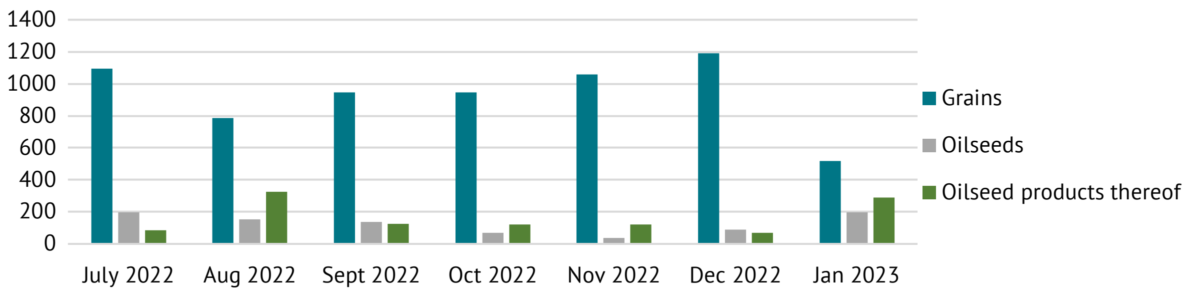


***Figure 5**. Dynamics of the export of grain, oilseeds, and related products through the Danube ports of Reni, Kilia, and Izmail between July 2022 and January 2023 (thousand tonnes)*
***Source:** developed by the authors based on Barva Invest data (2023)*

Therefore, despite the only partial utilisation of the Danube region ports, during the 2022-2023 marketing year (MY), they provided an alternative for the export of grain and oilseeds to some extent. This is also supported by the regression models constructed (Table 2). Based on the calculated correlation coefficients, it was found that during the studied period, there was an inverse relationship between export volumes through the Danube seaports and the use of highways, railways, or Black Sea ports. Specifically, for land transportation, the data shows a strong inverse relationship between export volumes (road transport: -0.74, rail transport: -0.67).

***Table 2**. Results of the correlation-regression analysis of the use of the Danube region ports as alternative routes for exporting grain, oilseeds and related products during the war (2022-2023 MY)*

Indicators	Factor signs		
	Road	**Railway**	**Deep-water seaports**
Correlation coefficient	-0.74	-0.67	-0.44
Determination coefficient	0.54	0.45	0.19
Elasticity coefficient	-5.252	-2.211	-0.094
X STDev	0.18	0.19	0.95
Regression equation	Y=2.23 – 1.612X	Y=2.80 – 1.394X	Y=2.05- 0.187X

***Source:** calculated by the authors based on data from the Ministry of Agrarian Policy and Food of Ukraine (2023)*

The calculated elasticity coefficient indicated that a 1% decrease in the volume of exports by road transport, on average, led to a 5.3% increase in exports through Danube region ports and a 2.2% increase in exports through rail transport. A comparative analysis of the STDEV indicator demonstrates that these routes were less risky compared to exports through deep-water ports from August 2022 to June 2023. The full realisation of the potential of this logistics route is possible with investments in the development of the infrastructure of the Danube region ports, which would increase the throughput capacity of the transport system. Furthermore, European investments are needed for the development of the ports of Galati and Constanta, as well as to enhance the throughput of the Sulina Canal. However, the shelling of the ports of Reni and Izmail, for instance in August 2023, and ongoing military threats undermine progress in this direction, creating conditions where investments carry a high degree of risk. An alternative to sea routes for the export of grain, oilseeds, and related products was land logistics, which has also undergone significant restructuring since the beginning of the war. Notable changes have occurred in internal railway and road transport routes, which were re-directed towards the river ports at the mouth of the Danube (Ust-Dunaisk, Izmail, Reni, Kilia) as well as land border crossings with neighbouring countries: Poland, Romania, Slovakia, Hungary, and Moldova.

To establish alternative logistics routes between Ukraine and EU countries, the European Commission launched the EU-Ukraine Solidarity Lanes Initiative. This initiative aimed to maintain Ukraine's integration into global supply chains and address global food security concerns (European Commission, 2022). It comprises a series of agreements in the areas of trade and logistics designed to expand Ukraine's opportunities for exporting grain, oilseeds, and related products. To this end, in May 2022, the European Parliament introduced temporary trade liberalisation in addition to the trade preferences already applicable to domestic goods under the Association Agreement between Ukraine and the EU. Other measures included the suspension of import duties, customs quotas, and trade protection measures on the import of grain, oilseeds and related products from Ukraine. These decisions were adopted by the European Parliament until May 2023 and were later extended to May 2024. This was a crucial step in supporting Ulraine's agricultural sector and opened up European markets to trade in domestic products. However, it also created certain contradictions both at the national and European levels.

The urgent transformation of Ukraine's logistics exacerbated several transport infrastructure challenges in the European direction, which increased obstacles to export to global food markets. In particular, regarding railway transportation, the issues include the non-compliance of railway track widths with European standards and the insufficient capacity of transhipment terminals. Road transport flows were limited by administrative obstacles associated with the cross-border movement of vehicles. To avoid these problems, within the framework of the Initiative, customs procedures and the processes for issuing export certificates, as well as veterinary and phytosanitary certificates of product quality, were streamlined and simplified, along with the increased capacities for storing grain and oilseeds near border points, stations along the "broad" track lines, and in EU seaports.

Furthermore, a Special Agreement on the liberalisation of freight transportation by road was concluded, which has been renewed until June 2024. This agreement provided for the abolition of the requirement for Ukrainian carriers to obtain permits for road transport (Decree of the President of Ukraine No. 654/2022, 2022). European transport corridors to Ukraine were also expanded. Through amendments to the Trans-European Transport Networks (TEN-T), the North Sea-Baltic Corridor and the Baltic-Black-Aegean Seas Corridor were extended (Regulation of the European Parliament No. 2022/870, 2022). This will create opportunities to eliminate logistical obstacles and attract future investments in modernising Ukraine's transport infrastructure (European Commission, 2022).

During the period of the Initiative, with the complete removal of tariff restrictions on the export of grain, oilseeds, and related products from Ukraine to European countries, export volumes increased significantly. In particular, between May 2022 and March 2023, grain exports to the EU increased by 2.4 times compared to the same period the previous year, oilseeds by 2 times, and sunflower oil by 1.2 times (Table 3). Simultaneously, the share of imports from Ukraine in total EU imports for the studied period reached 15% for grain, 9.6% for oilseeds, and 31.5% for sunflower oil. Most export flows were directed to EU countries that were the first link of the "Solidarity Lanes", including Poland, Hungary, Slovakia, Romania, and Bulgaria. For example, grain exports to Poland increased by 10 times compared to the previous period, oilseeds by 5.9 times, and sunflower oil by 3.2 times. Grain exports to Romania increased by 23.8 times, oilseeds by 217.7 times, and sunflower oil by 4.9 times.

***Table 3**. Export of certain types of agricultural products from Ukraine to EU countries within the framework of the EU-Ukraine Solidarity Lanes*

	Grain	Oilseeds	Sunflower oil
Relation to the similar period of the previous year (May 2021-March 2022) times			
Poland	10.0	5.9	3.2
Hungary	44.4	7.2	8.2
Slovakia	71.8	33.9	1.9
Bulgaria	18.3	58.6	9.8
Romania	23.8	217.7	4.9
EU countries, total	2.4	2.0	1.2
Export volume from Ukraine (May 2022-March 2023) USD million			
Poland	711	523	475
Hungary	539	279	87
Slovakia	154	90	23
Bulgaria	10	462	278
Romania	1645	813	79
Import share from Ukraine in total EU import, %	15.0	9.6	31.5
EU countries, total	5,385	3,362	2,462

***Note:** * excluding transit*
***Source:** calculated by the authors based on Trade Map data (2023)*

The influx of grain and oilseeds from Ukraine overwhelmed the domestic markets of neighbouring countries, exceeding the capacity of their transport and storage infrastructure. The excess of products was also due to increased logistics costs during the transit of these crops to EU countries. Moreover, the situation was complicated by a trend of price dumping in the global food market, which was replicated in EU markets (Fig. 1). In May 2023, the European Commission adopted a decision to limit the export of wheat, corn, sunflower seeds, and rapeseed from Ukraine to Poland, Hungary, Slovakia, Romania, and Bulgaria. This was done at the request of the national governments of these countries to protect domestic producers of grain and oilseeds from price reductions and to avoid unprofitable production (European Commission, 2022). These measures were extended in June 2023 and remained valid until September 2023, reducing the number of tariff items from 17 to 6 for certain types of products. It should be noted that there were no restrictions on the transit of products from Ukraine through these countries.

Starting in September 2023, the governments of Poland, Hungary, and Slovakia continued, at the national level, a de facto ban on the import of wheat and wheat flour, corn, rapeseed, sunflower seeds, oil cake, and oil meal from Ukraine to protect their domestic markets for these products (Laws of the Republic of Poland, 2023; Ministry of Economy of Ukraine, 2023). Following the restrictions placed on the export of grain, oilseeds, and related products, the monthly volume of deliveries from Ukraine through the Solidarity Lanes decreased by nearly half. In particular, in April 2023, these amounted to 874 thousand tonnes, compared to 1,560 thousand tonnes in March 2023 (Fig. 2). During the 2023 harvest period, a certain revival of export deliveries is evident, but the levels of the previous year (1.6-1.8 million tons per month) have not been reached.

Overall, due to the implementation of the EU-Ukraine Solidarity Lanes Initiative, Ukraine successfully established alternative opportunities for maintaining food supplies to global markets. During the period of its validity until December 2023, exports of grain, oilseeds, and related products from Ukraine by land routes amounted to 25 million tons. Along with the capabilities of the Black Sea Grain Initiative (Black Sea Grain Initiative…, 2023), it was possible to achieve maximum monthly export deliveries of products at 7.5 million tons (March 2023). However, a stable result was not consistently maintained.

The Ukrainian Alternative Sea Corridor demonstrated high effectiveness in exporting grain, oilseeds, and related products. This logistics route became operational thanks to the efforts of the Ukrainian Armed Forces and the support of international partners, particularly Romania, Bulgaria, and Turkey. The corridor was launched in September 2023 and ran through the territorial waters of Romania and Bulgaria. As a result, monthly exports by sea transport became stable. In particular, it was no less than 5.5 million tonnes from December 2023 to March 2024, and reaching 6.4 million tonnes in February 2024, the highest figure of the war period (Fig. 2). However, this logistics route remained highly risky due to military threats and the danger of mines. Thanks to these measures, it was possible to avoid a collapse in the domestic market of grain, oilseeds, and sunflower oil from Ukraine during the 2022/2023 MY. As a result, grain exports reached 49 million tonnes, oilseeds 9 million tons, and sunflower oil 5 million tons (Fig. 6). These figures include products from the 2022 harvest as well as significant stocks from the previous year. Consequently, the share of exports in production volumes was slightly higher than in the pre-war period reaching 91%, 50% and 113%, respectively.

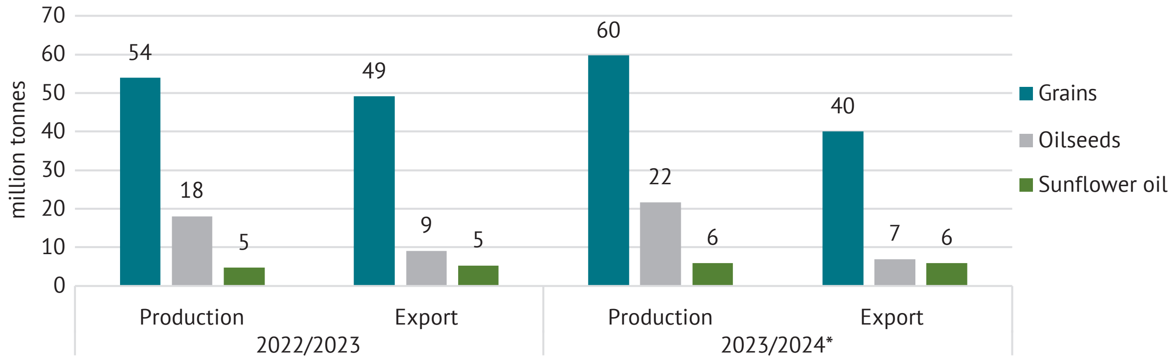


***Figure 6**. Assessment of the export volume needs for grain, oilseeds, and sunflower seeds from Ukraine in 2023/2024 MY (as of April 2024)*
Note: ** Forecast of production of grain and oilseeds according to the Ministry of Agrarian Policy of Ukraine, forecast of production of sunflower oil according to the data of the Association "Ukroliaprom"*
Source: *prepared by the authors based on data from the Ministry of Agrarian Policy and Food of Ukraine (2023), the Association "Ukroliaprom" (2023), and authors' forecasts*

The logistical transformations in the grain, oilseed, and related product markets amid the war, alongside the significant risks of export disruptions or delays due to military threats, resulted in a sharp increase in transport costs. According to this research, the average wheat logistics costs sea route (EXW-DAP Reni-FOB Constanta) were USD 140 in 2023. This represents a 1.9-fold increase compared to the pre-war period for deliveries to the Kherson Seaport (2021). The share of these costs in the export price rose to 44%, compared to only 22% in 2021 (Table 4).

***Table 4**. Impact of the war on the cost of wheat export logistics in Ukraine*

Indicators	2021 (pre-war period)		2023 (war period)	
Logistic chain	EXW-FOB Kherson	EXW-CPT Kherson	EXW-DAP Reni -FOB Constansa	EXW-DAP Gdansk
Type of transport	railway	road	railway& freight	road
Trade batch volume, tonnes				
Silo to port (destination)	500	500	500	300
Port to shipboard	1,000	x	1,000	x
Type of costs, USD per tonne *				
Warehousing costs (incl. delivery, acceptance, additional works and storing products in silo)	24.6	24.6	28.1	28.1
Domestic certification**	0.7	0.7	0.7	1.7
Delivery to the point of destination (incl. weighing, loading, costs):				
railway	19.8	x	44.1	x
road	x	31.7	x	87.0
Customs clearance and international certification***	1.2	1.2	2.8	4.0
Port costs	25.1	x	21.5	x

Table 4. Continued

Indicators	2021 (pre-war period)		2023 (war period)	
Insurance	0.4	x	4.8	1.5
Freight to destination port (Constanta)	x	x	37.7	x
Total costs, USD per tonne:				
railway	72	x	140	x
road	x	58	x	122
Costs increase, times	x	x	1.9	2.1
Share of costs in pricing export chain ****, %				
railway	22	x	44	x
road	x	17	x	33
Market price changes				
Food wheat price (EXW delivery), UAH per 1 ton, incl. VAT	318		189	
Price change, times	x		-1.7	

Note: ** The costs are calculated according to the NBU exchange rate as of February of the respective year and include VAT. ** Domestic certification includes a phytosanitary certificate and a protocol for testing product samples. *** International certification includes a certificate of origin and a certificate of quality and quantity of an independent surveyor. **** The indicator is determined with the deduction of VAT refunds*

Source: *calculated by the author based on data from SC "Sangrant Plus" (2023) and Barva Invest (2023)*

It should be noted that the growth in logistics costs placed significant pressure on the entire supply chain, which was primarily offset by price reductions for agricultural enterprises. For instance, the food wheat price reduction for agricultural enterprises during the studied period amounted to 1.7 times lower than previous levels. As a rule, the most vulnerable group consisted of small and medium-sized grain and oilseed producers, who had limited access to export logistics, especially during wartime. Compensation in most cases occurred due to a decrease in the profitability of these products. Furthermore, a marketing analysis was conducted to assess the possibilities of export logistics for these products in 2023/2024. It was assumed that all logistical routes in Ukraine were accessible as of January-March 2024. According to forecast calculations, the minimum export to global markets from Ukraine by all modes of transport until the end of the marketing period will be about 42 million tonnes of grain, 7 million tonnes of oilseeds, and 6 million tonnes of sunflower oil. In this case, it will be possible to retain international partners and avoid a deeper decline in production profitability. The distribution of supplies by land and sea transport will depend on Ukraine's military control over waterways.

According to our estimates, these volumes can be achieved if at least 95% of grain, 70% of oilseeds, and 70% of vegetable oil and vegetable oil are exported by sea transport. In addition, resolving the issues of land logistics will require financial assistance from the EU to compensate for transport costs to the deep-water ports of Lithuania, Latvia, Germany, Croatia, Slovenia, and Italy. In this case, transit to the countries of Africa and Asia would become profitable for exporters, thereby ensuring that products are accumulated in neighbouring European countries.

DISCUSSION

Efficient logistics is a crucial factor fora crucial factor for the uninterrupted functioning of food supply chains at both domestic and international levels. The challenges and risks posed by the war in Ukraine necessitate the development of innovative marketing approaches and strategies to promote grain, oil crops, and their derivatives in global markets. However, their sale requires a relevant legal framework based on international agreements. This study examines the positive impact of the Grain Initiative on the recovery of export supplies through Black Sea deep ports and emphasises the need for further development of logistics chains through Danube ports and neighbouring countries in the Black Sea region. A similar conclusion is drawn in the research by B. Kormych and T. Averochkina (2023), which also considers the economic benefits of these logistics routes.

R. Goyal and S. Steinbach (2023), using a method involving the analysis of high-frequency futures-trading price data, concluded that the Grain Initiative had a negligible effect on the level of uncertainty in the futures market amidst the war in Ukraine. In comparison with this research, which is based on a comprehensive assessment of the effectiveness of the Grain Agreement as illustrated by the markets of grain, oil crops, and their derivatives, a positive impact of the same agreement on the competitiveness of domestic agricultural producers has been recognised. The present research is more focused on a detailed analysis of its benefits and economic risks arising from obstacles and violations of agreements on Russia's side. Moreover, the analysis of the logistics routes through the Danube region ports revealed their significant potential, which requires investment.

R. Vos and J. Glauber (2023) also emphasise the importance of the Solidarity Lanes for both the European community and Ukraine. They expand upon the problem of Eastern European markets being oversaturated with Ukrainian grain and its consequences for European farmers. They suggest that comprehensive support for comprehensive support from the European Commission is necessary for the affected EU member states (Poland, Hungary, Romania, Bulgaria, and Slovakia). Therefore, the need to maintain Ukraine's presence in global grain markets is underscored. This research reaches a similar conclusion, despite the congestion in the markets of EU countries neighbouring Ukraine. The Solidarity Lanes remain one of the crucial logistics routes for the export of grain, oil crops, and their derivatives from Ukraine.

D. Poursina *et al.* (2024) employ the econometric analysis to determine the impact of the Black Sea Grain Initiative on price fluctuations in global wheat and corn markets. Both studies conclude on the economic value of the agreement in addressing global food security concerns. However, the present research also outlines an assessment of economic losses resulting from the Russian invasion. Nevertheless, more attention is paid to calculating the losses of the first link in the logistics export chain on the wheat market, i.e. agricultural producers. The research highlights the significant vulnerability of this link due to the transformation of logistics in the market for grain, oil crops and their derivatives. A similar perspective is found in the article by Y. Bielashov (2022). Both studies demonstrate that risk reduction is achievable through the gradual diversification of grain exports from Ukraine.

S. Devadoss and W. Ridley (2024) also estimate the losses incurred by Ukrainian wheat producers based on the Global Spatial Equilibrium Model (SEM) on the production-consumption, and trade of wheat in Ukraine. The study outlines the significant impact of the Russian invasion on the reduction of wheat consumption in importing countries. This conclusion is supported by the present research, which demonstrates that delays in export deliveries have increased threats to food security in import-dependent countries. S. Steinbach and Y. Yildirim (2024) examine the consequences of Russia's withdrawal from the Black Sea Grain Initiative, analyse the indirect volatility of agricultural markets, and demonstrate specific differences in the volatility of futures for various agricultural commodities. Y. Fang and Z. Fang (2022) also examine commodity market prices during the war in Ukraine. Similar to the present research, the authors conclude that the exacerbation of the Russian-Ukrainian conflict significantly affects the risk of market volatility and highlight similar results regarding the relationship between the escalation of the conflict and the level of volatility in commodity markets.

O. Shpychak *et al.* (2021) assess price food chains in crisis conditions, including those involved in the trade of grain, oil crops, and their derivatives. They emphasise the need to create parity relationships between participants in price chains to increase the effectiveness of food supply chains. The present research also reveals a significant increase in logistics costs amidst the uncertainty and transformation of wheat supply chains to global markets. Both studies conclude that in crisis conditions, compensation for losses is at the expense of agricultural commodity producers. N. Yaloveha (2023) demonstrates the need to shift market segment priorities and proposes measures in the area of marketing communications to promote goods during wartime. Both studies underline the importance of ensuring effective changes in marketing strategies for agricultural enterprises, particularly in logistic supply chains. Furthermore, according to this research, following strategic marketing principles in agribusiness, the export of raw materials should be gradually phased out. Instead, there should be a focus on developing trade in products with higher added value, which can be promoted in global and European markets. In particular, during the war and energy supply crisis, demand for bioenergy resources has increased. This creates opportunities for Ukraine to develop biofuel production and export it to EU countries.

The results of this research align with the conclusions drawn by other Ukrainian and foreign scientists, confirming their importance for the development of supply chains in the grain, oil crops, and derivatives markets.

CONCLUSIONS

The integration of Ukraine into global food chains has been preserved thanks to the introduction of several initiatives and agreements at the international level. As a result, pressure on the domestic market for grain, oilseeds, and related products in Ukraine was significantly reduced, as well as the threats to global food security. The recovery of exports through the Black Sea ports within the framework of the UN-led Grain Initiative facilitated up to 30% of total exports of grain, oilseeds, and their processing products during the war. Nevertheless, this was significantly lower compared to the pre-war period. This reduction occurred against the backdrop of constant uncertainty and the blocking of the Grain Initiative by the aggressor state. The ports of the Danube region provided alternative water transport export routes. However, critically short timeframes for resuming operations, constant military threats, and shelling prevented the realisation of this route's potential. The implementation of the EU-Ukraine Solidarity Lanes Initiative created opportunities to increase land-based exports of Ukrainian products to European and global markets. Railway and road routes were redirected to border crossings with neighbouring countries: Poland, Romania, Slovakia, Hungary, and Moldova. Renewed customs restrictions on exports to neighbouring countries led to a reduction in supplies. A significant contribution to the restoration of export logistics for grain, oil crops, and their processing products was also made by the Ukrainian Alternate Sea Corridor, which was supported by international partners.

The aforementioned transformations in logistics resulted in a doubling of its cost. This limited access to logistics for small and medium-sized producers. Moreover, it contributed to a decrease in domestic prices for grain, oilseeds, and related products, consequently reducing income from their production. There is an urgent need to rebuild the export model for agricultural products in Ukraine, focusing on products with higher added value. Additionally, developing exports in the European direction requires addressing technical and infrastructural differences in the transport systems of Ukraine and EU countries. In particular, this can be achieved through the development of multimodal transportation. It is also essential to establish an energy-efficient logistics infrastructure and continue harmonising domestic legislation with European standards. Another direction involves the construction of a network of domestic container terminals in Ukraine, which would improve access to global logistics for small and medium-sized producers and exporters of grain, oil products, and their derivatives.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Association "Ukroliaprom". (2023). Retrieved from https://ukroilprom.org.ua/.
[2] Barva Invest. (2023). Retrieved from https://www.barvainvest.com.
[3] Bielashov, Y. (2022). *Prospects of using sea corridors for safe export of grain to stimulate economic growth*. Retrieved from https://niss.gov.ua/doslidzhennya/ekonomika/perspektyvy-vykorystannya-morskykh-korydoriv-bezpechnoho-eksportu-zerna.
[4] Black Sea Grain Initiative. Joint Coordination Centre. (2023). Retrieved from https://www.un.org/en/black-sea-grain-initiative.
[5] Commission Implementing Regulation No. 2023/1100 "On Introducing Preventive Measures Concerning Certain Products Originating in Ukraine ". (2023, June). Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32023R1100.
[6] Commission Implementing Regulation No. 2023/903 "On Introducing Preventive Measures Concerning Certain Products Originating in Ukraine ". (2023, May). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0903&qid=1688460529893.
[7] Decree of the President of Ukraine No 654/2022 "On the Approval of the Agreement between Ukraine and the European Union on Freight Transportation by Road". (2022, September). Retrieved from https://zakon.rada.gov.ua/laws/show/654/2022#Text.
[8] Devadoss, S., & Ridley, W. (2024). Impacts of the Russian invasion of Ukraine on the global wheat market. *World Development*, 173, article number 106396. doi: 10.1016/j.worlddev.2023.106396.
[9] European Commission. (2022). *Commission to establish Solidarity Lanes to help Ukraine export agricultural goods*. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3002.
[10] Fang, Y., & Fang, Z. (2022). The Russia-Ukraine conflict and volatility risk of commodity markets. *Finance Research Letters*, 50, article number 103264. doi: 10.1016/j.frl.2022.103264.
[11] FAO. (2023). Retrieved from https://www.fao.org/home/en.
[12] Food Price Monitoring and Analysis. (2023). Retrieved from https://fpma.fao.org/giews/fpmat4/#/dashboard/home.
[13] Galunets, N. (2019). Place of the Ukrainian agricultural exports on the world food market. *Agricultural and Resource Economics: International Scientific E-Journal*, 5(4), 79-94. doi: 10.51599/are.2019.05.04.05.
[14] Goyal, R., & Steinbach, S. (2023). Agricultural commodity markets in the wake of the Black Sea Grain Initiative. *Economics Letters*, 231, article number 111297. doi: 10.1016/j.econlet.2023.111297.
[15] Hassen, T., & Bilali, H. (2022). Impacts of the Russia-Ukraine war on global food security: Towards more sustainable and resilient food systems? *Foods*, 11(15), article number 2301. doi: 10.3390/foods11152301.
[16] Hirnyk, K. (2023). *Russia has officially abandoned the "grain agreement"*. Retrieved from https://www.unian.ua/economics/agro/zernova-ugoda-rosiya-oficiyno-zayavila-pro-pripinennya-domovlenostey-12331053.html.
[17] Kormych, B., & Averochkina, T. (2023). Black Sea Grain Initiative is dead, long live the new trade corridor. *Lex Portus*, 9(4), 7-15. doi: 10.26886/2524-101X.9.4.2023.1.
[18] Kovalenko, O., & Kyrychenko, A. (2023). Transformations of global logistics food chains in the conditions of war in Ukraine. *Food Resources*, 11(20), 211-220. doi: 10.31073/foodresources2023-20-20.

[19] Krasnorutskyy, O., Marenych, T., Marchenko, V., & Pomohalova, N. (2023). Transformation of marketing of agricultural enterprises in wartime conditions. *Ukrainian Journal of Applied Economics and Technology,* 8(3), 10-17. doi: 10.36887/2415-8453-2023-3-1.
[20] Leal Filho, W., Fedoruk, M., Paulino Pires Eustachio, J.H., Barbir, J., Lisovska, T., Lingos, A., & Baars, C. (2023). How the war in Ukraine affects food security. *Foods*, 12(21), article number 3996. doi: 10.3390/ foods12213996.
[21] Ministry of Agrarian Policy and Food of Ukraine. (2023). Retrieved from https://minagro.gov.ua/.
[22] Ministry of Economy of Ukraine. (2023). Retrieved from https://www.me.gov.ua.
[23] Muravskyi, A. (2023). *The Ukrainian maritime corridor is a key breakthrough in 2023*. Retrieved from https://cfts.org.ua/articles/ukranskiy_morskiy_koridor__klyuchoviy_uspikh_2023_roku_2010/139518.
[24] OECD. (2022). Retrieved from https://www.oecd.org/en/publications/the-implications-for-oecd-regions-of-the-war-in-ukraine_8e0fcb83-en.html.
[25] Penkova, O., & Kharenko, A. (2023). Transformation of marketing logistics for the export of ukrainian crop production in the context of a full-scale war with the russian federation. *Scientific Bulletin of Mukachevo State University. Series "Economics"*, 10(1), 37-48. doi: 10.52566/msu-econ1.2023.037.
[26] Poursina, D., Schaefer, K.A., Hilburn, S., & Johnson, T. (2024). Economic impacts of the Black Sea Grain Initiative. *Journal of Agricultural Economics*, 75(1), 457-464. doi: 10.1111/1477-9552.12549.
[27] Regulation of the European Parliament and of the Council No. 2022/870 "On Temporary Trade-Liberalisation Measures Supplementing Trade Concessions Applicable to Ukrainian Products Under the Association Agreement Between the European Union and the European Atomic Energy Community and Their Member States, of the One Part, and Ukraine, of the Other Part". (2022, May). Retrieved from https://eur-lex.europa.eu/eli/reg/2022/870.
[28] Regulation of the European Parliament and of the Council No. 2023/1077 "On Temporary Trade-Liberalisation Measures Supplementing Trade Concessions Applicable to Ukrainian Products Under the Association Agreement Between the European Union and the European Atomic Energy Community and Their Member States, of the One Part, and Ukraine, of the Other Part". (2023, May). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1077&qid=1705128092137.
[29] Savenko, I., Sedikova, I., & Sedikov, D. (2022). Russian-Ukrainian conflict: Challenges for the grain market. *Food Industry Economics*, 14(2), 23-28. doi: 10.15673/fie.v14i2.2320.
[30] SC "Sangrant Plus". (2023). Retrieved from https://sun.kiev.ua/en/main.
[31] Shpychak, O.M., Lupenko, Y.O., & Pashko, S.O. (2021). *Methodological recommendations for the evaluation of price food chains*. Kyiv: National Scientific Centre "Institute of Agrarian Economics".
[32] Steinbach, S., & Yildirim, Y. (2024). Agricultural commodity market response to Russia's withdrawal from the grain deal. *Journal of Agricultural Economics*, 75(3), 1004-1016. doi: 10.1111/1477-9552.12611.
[33] Trade Map data. (2023). Retrieved from https://www.trademap.org/.
[34] Ukrainian Agrarian Council. (2023). *Danube ports are becoming an illiquid sales channel for Ukrainian wheat*. Retrieved from https://uacouncil.org/uk/post/dunajski-porti-staut-nelikvidnim-kanalom-zbutu-dla-ukrainskoi-psenici#.
[35] UNCTAD. (2022). *The role of the Black Sea Grain Initiative in bringing Ukrainian grain to the world*. Retrieved from https://unctad.org/system/files/official-document/osginf2022d6_en.pdf.
[36] Vos, R., & Glauber, J. (2023). *Eastern European farmers protest gluts of Ukraine food exports: The struggle to keep solidarity lanes open. Markets, Trade, and Institutions*. Retrieved from https://www.ifpri.org/blog/eastern-european-farmers-protest-gluts-ukraine-food-exports-struggle-keep-s)olidarity-lanes.
[37] World Bank. (2023). Retrieved from http://documents.worldbank.org/curated/en/099184503212328877/P1801740d1177f03c0ab180057556615497.
[38] World Food Programme. (2023). Retrieved from https://www.wfp.org.
[39] Yaloveha, N. (2023). Marketing communications in the conditions of war: Challenges and ways of promoting goods. *Scientific Notes of Lviv University of Business and Law*, 37, 373-379.
[40] Zhofan, I., Pashchenko, O., & Zharikova, O. (2023). Development of the marketing strategy of agricultural sector enterprises on the grain markets of Ukraine and the people's republic of China. *Bioeconomics and Agrarian Business*, 14(1). doi: 10.31548/economics14(1).2023.004.

Логістичні трансформації на ринках зернових та олійних культур під час війни в Україні: Маркетингові підходи та стратегії

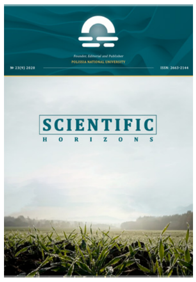
Ольга Боднар
Доктор економічних наук, професор
Національний університет «Києво-Могилянська академія»
04655, вул. Г. Сковороди, 2, м. Київ, Україна
https://orcid.org/0000-0002-4188-2965
Юлія Гальчинська
Доктор економічних наук, професор
Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 11, м. Київ, Україна
https://orcid.org/0000-0003-4260-3072
Ярослава Ларіна
Доктор економічних наук, професор
Київський національний економічний університет імені Вадима Гетьмана
03057, просп. Перемоги 54/1, м. Київ, Україна
https://orcid.org/0000-0002-2712-7824
Анна Філатова
Аспірант
Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 11, м. Київ, Україна
https://orcid.org/0000-0003-1139-0481
Ігор Степанець
Аспірант
Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 11, м. Київ, Україна
https://orcid.org/0009-0002-2375-6612

Анотація. Російське військове вторгнення спричинило колапс у постачанні продовольства з України на світові ринки. Трансформація вітчизняної експортної логістики здійснювалася в критичних умовах і вкрай обмежених термінах. Метою статті було оцінити трансформації логістики на ринках зернових та олійних культур внаслідок війни, обговорити вплив міжнародних угод на експортно-логістичні ланцюги поставок, розробити пропозиції щодо маркетингових стратегій торгівлі зерновими, олійними культурами та продуктами їх переробки у воєнний час. Авторами використано низку загальнонаукових і спеціальних методів і підходів: системний підхід, абстрактно-логічний і графічний методи, методи ретроспективного, порівняльного аналізу, кореляційно-регресійного аналізу та метод прогнозування. Запропоновано періодизацію трансформації експортної логістики внаслідок війни, що включає наступні етапи: колапс логістики; зростання експорту під впливом міжнародних угод; функціонування альтернативного українського морського коридору за підтримки міжнародних партнерів. Доведено значний вплив трансформацій виробництва та збуту через війну на зростання вартості логістики експорту пшениці для різних баз постачання. Автори стверджують, що експортні логістичні ризики компенсувалися переважно низькими цінами на зернові та олійні культури для сільгоспвиробників. Запропоновано оцінку експорту на ринку зернових, олійних культур та продуктів їх переробки України. Окреслено формування ефективних маркетингових стратегій. Практична цінність роботи полягає у використанні результатів дослідження при розробці маркетингових стратегій підприємств та проектів розвитку європейського співробітництва в аграрному секторі

Ключові слова: логістика; ланцюги постачання продовольства; ціни; витрати; сільськогосподарські підприємства; безпечність харчових продуктів; експорт; міжнародні угоди

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 148-161



UDC 338.43:339.9
Doi: 10.48077/scihor9.2024.148

Circular economy of the agricultural sector: Strategies and challenges in the context of globalisation

Vyacheslav Shebanin*
Doctor of Technical Sciences, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-0391-396X

Olena Shebanina
Doctor of Economics, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-7663-5991

Iurii Kormyshkin
Doctor of Economics, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-1005-1229

Antonina Drobitko
Doctor of Agricultural Sciences, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-6492-4558

Natalia Potryvaieva
Doctor of Economics, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-9781-6529

Article's History:
Received: 01.04.2024
Revised: 20.07.2024
Accepted: 28.08.2024

Abstract. The study aimed to validate the necessity of formulating and executing plans for incorporating the concepts of the circular economy into Ukraine's agriculture sector, while considering the impacts of globalisation and problems arising from the war. This study examined the fundamental principles and intellectual underpinnings that differentiate the circular economy from the conventional economic model. The

Suggested Citation:
Shebanin, V., Shebanina, O.,Kormyshkin, Iu., Drobitko, A., & Potryvaieva, N. (2024). Circular economy of the agricultural sector: Strategies and challenges in the context of globalisation. *Scientific Horizons*, 27(9), 148-161. doi: 10.48077/scihor9.2024.148.

**Corresponding author*

fundamental concept of the circular economy in the agricultural sector was justified, and the primary benefits of implementing this economic model in the field of agriculture were established. The European Commission has approved the strategy for the Common Agricultural Policy for the period 2023-2027. This strategy emphasises the primary responsibilities that EU member states must undertake to implement the principles of the circular economy in agriculture. The primary patterns in the operation of agriculture in Ukraine are recognised, and the significance of the agricultural sector in the framework of gross domestic product (GDP) formation and foreign exchange profits is established. The destruction of infrastructure, mining activities, and occupation of regions resulted in a decline in the cultivated land and animals, leading to a loss in physical productivity. Due to the war, there has been a decline in production and logistics capabilities, resulting in a large fall in the export of agricultural products. Consequently, the profitability of firms in this sector of the Ukrainian economy has also decreased. Ukrainian agricultural firms lack the financial resources to independently support creative development, which includes the implementation of new technology solutions that form the foundation of the circular economy. Considering the effects of globalisation and military conflict, it is justified that prioritising innovation and investment support, particularly by the State, should be a strategic direction for implementing the principles of the circular economy of agriculture in Ukraine. This approach will enhance economic efficiency and create new opportunities

Keywords: agriculture; closed-loop model; sustainable development; waste recycling; regenerative agriculture; biotechnology

INTRODUCTION

The linear economy, characterized by 'production-consumption-disposal,' is declining due to its role in depleting natural resources, polluting ecosystems, and driving climate change. This has increased the need for alternative models that promote sustainable development and resource conservation. The circular economy offers a solution, combining economic benefits with environmental protection by conserving resources, reducing waste, and utilizing renewables (Kirchherr *et al.,* 2023). Unlike the linear model, it creates closed cycles where materials and products are reused, and waste is converted into resources for future production. Implementing a circular economy in agriculture can mitigate environmental impacts, boost economic productivity, and achieve social balance. This is particularly relevant for Ukraine, where agriculture is crucial to the economy, contributing significantly to GDP, job creation, export earnings, and financial stability, especially after the damage to the metallurgical industry from Russian aggression. Despite global challenges, the circular economy's potential in Ukraine's agricultural sector is immense and could be vital for the country's sustainable economic development.

The circular or closed-loop economy is one such model that is increasingly attracting the attention of scientists in the modern world of the global economy. O. Dovgal *et al.* (2024) studied this topic in the context of Ukrainian realities. The authors' conclusion states that, despite the challenging circumstances, Ukraine is making progress in implementing the principles of circular economy and sustainable development, albeit it is not fully implemented. State-level entities are currently establishing distinct structures and implementing corresponding regulations, which has garnered a favourable response from businesses. The authors highlight that Ukraine has the potential to emerge as a frontrunner in adopting the concepts of the circular economy, especially following its recovery from the devastating aftermath of the conflict. In essence, everything will be completely recreated, giving us a competitive edge over other countries that have to reconstruct their current manufacturing, logistics, and infrastructure capacities in order to follow circular economy ideas.

Problematic aspects of the functioning of the Ukrainian agro-industrial complex have been studied by O. Shebanina *et al.* (2023). The papers note the need to develop mechanisms to stimulate partnerships based on private investment in waste management, encourage the use of recycled materials and support the introduction of innovative technological solutions. Some researchers conclude that the strategic directions for further progress of Ukraine's economy in the coming years, in the face of global challenges, are the rational use of available resources and the modernization of existing production facilities, which will enable economic recovery (Shubalyi *et al.*, 2023). In the context of the agricultural sector, researchers note that most agricultural enterprises use outdated equipment, which negatively affects productivity and product quality. Often, agricultural enterprises have a low level of management culture and organizational structure, which leads to inefficient use of resources and low labour productivity. The military invasion of Ukraine has significantly exacerbated existing challenges and created new problems for the agricultural sector of the national economy.

Although there have been scientific advancements, the implementation of circular economy principles and methodologies in the Ukrainian agricultural sector remains inadequately researched. This is particularly pertinent in the present circumstances marked by global concerns and issues linked to the military war in Ukraine. The purpose of the study is to provide evidence for the necessity of developing and implementing strategies to use circular economy principles in the agricultural sector of Ukraine. To achieve this objective, it is imperative to examine the fundamental principles of the circular economy, its benefits and drawbacks for the agricultural industry, and the viability of introducing this model in the present circumstances of Ukrainian agriculture through innovative approaches. The reason for this is that innovation and technology play a vital role in the shift towards a circular management model. This model necessitates a comprehensive approach to creating suitable policies and assuring their support and implementation by government, academia, and business.

MATERIALS AND METHODS

The study applies the method of extrapolation to extend the findings on the circular economy to the agricultural sector, identify its main principles and highlight its economic benefits, in particular in agriculture. The analysis of the European Commission's Common Agricultural Policy (CAP) for 2023-2027, which is part of the EU's Green Deal (Delivering the European…, 2021), provides a framework that Ukraine can follow to implement circular economy principles in agriculture. The essay uses data from the State Statistics Service of Ukraine to highlight the importance of agriculture to the Ukrainian economy and the need for circular economy practices. In particular, it looks at the GDP and monetary value of agriculture, forestry and fisheries (State Statistics Service, n.d.). Using dynamic analysis and the calculation of averages, the average growth rates of GDP and the agricultural sector from 2013 to 2023 were determined and estimated. The article also calculates the share of agriculture in GDP from 2013 to 2023, distinguishing between the pre-war (2013-2021) and the war (2022-2023) periods to identify relevant trends.

To evaluate the effects of the conflict and determine the current patterns in Ukraine's agricultural industry, we analysed the growth rates of cultivated land for specific crops and the animal population using official information from 2021 to 2023 (State Statistics Service, n.d.). To assess the impact of changes in the volume of sown areas and the number of livestock on the performance of the country's agriculture, the agricultural production index was used, which is one of the key economic indicators used to study changes in agricultural production over a certain period. This index reflects not only the total volume of production, but also allows analysing the structure and dynamics of changes in different segments of the agricultural sector.

Using structural analysis, the share of agricultural products in the total structure of exports was calculated based on statistics on export operations in foreign economic activity and the dynamics of this indicator was presented (State Statistics Service, n.d.). The analysis was carried out for the period from 2018 to 2023 in the context of individual export items of crop and livestock products. Based on an analysis of the shares of loss-making and profitable enterprises in agriculture for the period 2021-2023, and using statistics on expenditures on basic, applied research and scientific and technical (experimental) development in agriculture, forestry, and fisheries (official data available for the period 2021-2022), the main challenges and problems that hinder the implementation of the principles of the circular economy in the country's agricultural sector were identified and substantiated (State Statistics Service, n.d.).

RESULTS

The circular economy aims to optimize resource efficiency and minimize waste, contrasting with the linear economy's "extract, manufacture, consume, and dispose" model. It promotes closed-loop systems where resources are recycled and reused (Corvellec *et al.,* 2022). Key principles include designing durable products that are easy to repair and upgrade, reducing the need for replacements and conserving resources. The product-as-a-service model, where items are leased or rented, encourages manufacturers to produce high-quality, long-lasting goods since they retain ownership and responsibility for maintenance and disposal (Marsh *et al.,* 2022). Another principle is utilizing production waste as a resource, integrating materials traditionally discarded back into production through recycling, composting, or repurposing (Kennedy & Linnenluecke, 2022). The circular economy also emphasizes the regenerative use of resources, such as using renewable energy, restoring ecosystems, and ensuring sustainable resource extraction. Applied to agriculture, these principles support sustainable development, food security, resource efficiency, and waste reduction (Fassio & Chirilli, 2023).

Several crucial issues should be encompassed while implementing the core concepts of the circular economy in the agricultural sector. These include utilising agricultural waste in production processes, such as converting crop residues into biogas or compost. Additionally, it involves using natural and biodegradable materials for packaging and storing products, adopting drip irrigation systems and reusing water for irrigation purposes. Furthermore, it entails promoting organic farming practices, minimising the use of pesticides and chemical fertilisers, supporting biodiversity, and implementing recycling and reuse strategies for waste, whether it be for creating new products, animal feed, or fertiliser (Yang *et al.,* 2023). The application of circular economy principles in the agricultural sector has several advantages, such as a decreased environmental impact. This is achieved by minimising waste and reducing the utilisation of chemicals, which in turn helps to protect ecosystems and enhance the quality of soil and water resources (Selvan *et al.,* 2023). The aforementioned factors contribute to the preservation of crop productivity and the mitigation of risks related to severe weather conditions. This leads to improved economic efficiency by promoting the judicious utilisation of resources and the recycling of waste, resulting in reduced production expenses and enhanced profitability for agricultural enterprises (Kucher *et al.,* 2021).

The European Green Deal advocates for the implementation of a circular economy framework, which seeks to minimise waste and optimise the utilisation of resources (Arru *et al.,* 2022). This entails the reconfiguration of products, processes, and business models with the aim of diminishing resource use and enhancing recycling and reuse. The Circular Economy Action Plan delineates strategies to accomplish this objective, encompassing more stringent rules on single-use plastics and incentives for sustainable product design (Chioatto & Sospiro, 2023). In accordance with the aforementioned path, the European Union introduced the Common Agricultural Policy for the period of 2023-2027 in the year 2023. This policy initiative is crucial for the advancement of agriculture and rural areas in the EU. Its objective is to address pressing issues such as climate change, biodiversity decline, rural population decline, and unstable agricultural markets (Table 1).

Table 1*. Main goals and objectives of CAP 2023-2027 in terms of applying the principles of the circular economy*

CAP 2023-2027 objectives	CAP 2023-2027 objectives in the context of ensuring the functioning of the circular economy of the EU agricultural sector
1. Increasing environmental sustainability and addressing climate change	1.Reducing greenhouse gas emissions: encouraging the use of emission-reducing practices in agriculture, such as precision agriculture and sustainable livestock management.
	2.Promoting biodiversity: support for measures that enhance biodiversity, including the conservation of natural habitats and the development of agroforestry.
	3.Sustainable resource management: efficient use of natural resources with a focus on soil health, water management and reduction of chemicals such as pesticides and fertilizers.
	4. Measures to promote circular practices, such as organic farming, agroecology and the use of biogas from agricultural waste.
2.Strengthening the socio-economic structure of rural areas	To promote economic growth, job creation, women's involvement in agriculture, social integration and regional development of rural areas, as well as the development of a circular bioeconomy and sustainable forest management.
3. Promoting knowledge and innovation	Knowledge sharing and training: facilitating access to knowledge and best practices through training programmes, advisory services and farmer networks.
	Research and development: supporting agricultural research to develop innovative solutions for sustainable agriculture.

Source: *compiled by the authors based on The common agricultural policy: 2023-27 (2023)*

The Common Agricultural Policy for the period 2023-2027 is a component of the Farm to Fork strategy. The strategic initiative, initiated in 2020, delineates multiple objectives that align with the concepts of the circular economy. The primary objective is to minimise food waste. The objective of the strategy is to minimise food waste per person by 50% at the retail and consumer stages by 2030, while also decreasing food losses across the entire manufacturing and consumption process. Furthermore, it promotes the use of farming techniques such as precision agriculture, agroecology, organic farming, and agroforestry. These methods enhance soil health and biodiversity while minimising the reliance on pesticides (Dey *et a*l., 2022). Furthermore, the plan entails enhancing resource utilisation efficiency, specifically with regards to water and soil, by implementing techniques such as crop rotation, cover crops, and conservation agriculture (Moreira *et al.*, 2023). Lastly, it aims to minimise the use of chemicals, specifically by decreasing reliance on chemical pesticides and fertilisers through the promotion of integrated pest management and organic farming methods that safeguard ecosystems and human well-being. Hence, the incorporation of circular economy principles into agriculture holds significance for EU nations, as seen by the Farm to Fork strategy (n.d.) and the European Green Deal. The agriculture industry in Europe may make a substantial contribution to a sustainable and resilient food system by minimising waste, preserving resources, and advocating for circular economy principles. Agriculture plays a crucial role in Ukraine's food security and overall economy. The significance of this sector has notably grown in recent years, particularly during the war (Table 2).

Table 2*. Comparison of Ukraine's GDP and the share of the agricultural sector in the GDP structure in 2013-2023*

Years	GDP, nominal, UAH million	Agriculture, forestry and fisheries, UAH million
2013	1,465,198	128,738
2014	1,586,915	161,145
2015	1,988,544	239,806

Table 2. Continued

Years	GDP, nominal, UAH million	Agriculture, forestry and fisheries, UAH million
2016	2,385,367	279,701
2017	2,981,227	303,419
2018	3,560,302	360,998
2019	3,977,198	356,563
2020	4,222,026	393,077
2021	5,450,849	593,367
2022	5,191,028	444,024
2023	6,537,825	484,150

Source: *compiled by the authors based on the State Statistics Service of Ukraine (n.d.)*

During the study period, the agriculture sector's contribution to the GDP structure grew about ten times. At the same time, if we compare the data before the military year of 2021 with 2013, the growth was almost 4.61 times, which outpaced the growth of GDP itself, which in 2021 grew by only 3.7 times compared to 2013. This is evidence that agriculture grew faster than any other sector of the country's economy. The share of agriculture in the GDP structure of Ukraine in the period 2013-2023 was constantly fluctuating, and averaged about 10% in the pre-war period (until 2022) (Fig. 1).

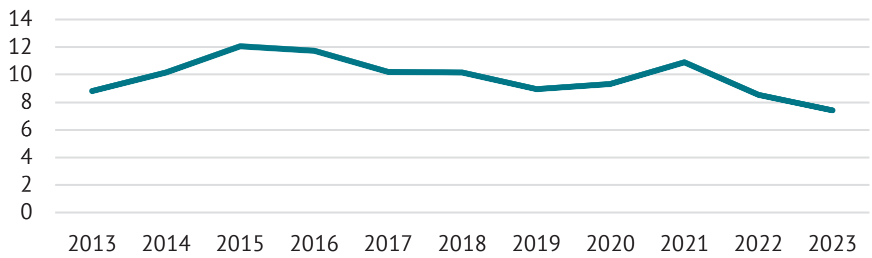


Figure 1*. The percentage contribution of the agricultural industry to the structure of GDP from 2013 to 2023*
Source: *compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

However, as a result of the war, the share of agriculture in the country's total GDP decreased by 2.33% in 2022 and by another 1.15% in 2023. The war has intensified numerous destructive processes that have had a negative impact on Ukraine's agricultural sector. The hostilities resulted in the destruction, contamination, or seizure of large areas of agricultural land (Table 3).

Table 3*. Percentage change in the area under crops in Ukraine*

Years	Cereals and pulses	Beetroot	Sunflower	Potatoes	Vegetable crops
2021/2022	-23.91	-18.94	-20.07	-5.85	-17.83
2022/2023	-9.74	35.87	-1.38	0.17	5.03

Source: *compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

In general, over the two years of war, the area under grain decreased by 33.65%, sunflower by 21.45%, potatoes by 5.68%, vegetables by 12.8%, with only beetroot showing positive dynamics and increasing by 16.93%. In the frontline regions and regions where hostilities are ongoing, in particular in Zaporizhzhia, Kharkiv, Donetsk and Kherson, a significant part of the land used for growing grain crops became unsuitable for cultivation due to hostilities and mining. Restoring and expanding cultivated areas in safer regions, such as Poltava and Vinnytsia, has become a priority to maintain food security. Zaporizhzhia and Kherson regions, which have traditionally been leaders in sunflower cultivation, also experienced a significant reduction in acreage. Dnipro and Kropyvnytskyi oblasts remain important regions for sunflower cultivation, although they also face certain difficulties due to logistical and economic issues. In addition, landmines, infrastructure destruction, and the destruction of machinery and storage facilities have reduced the ability to cultivate fields and store products. Some regions that used to be key to agricultural production have become inaccessible or unsafe for farming. The same negative trends exist in livestock production, as evidenced by the number of farm animals (Table 4).

Table 4. Volumes of farm animals in Ukraine for the period 2021-2024 (data as of 1 January of the respective year)

Years	Number of farm animals (thousand heads)			Poultry, million heads
	Cattle	Pigs	Sheep and goats	
2021	2,874	5,876.2	1,140.4	200.7
2022	2,644	5,608.8	1,094.3	202.2
2023	2,307.1	4,948.3	941.4	180.5
2024	2,156.2	5094	906.3	184.7

Source: *compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

Some farms were caught up in the hostilities, which led to the loss of livestock, destruction of infrastructure and reduced production. It also made logistics and exports more difficult. The rising cost of feed, energy, and other production costs has put many farmers under pressure. Additional pressure on the industry was exerted by currency fluctuations, which affected production costs and competitiveness on foreign markets. As can be seen from the table, during the study period, there was a negative trend in the number of almost all types of livestock in Ukraine (Fig. 2).

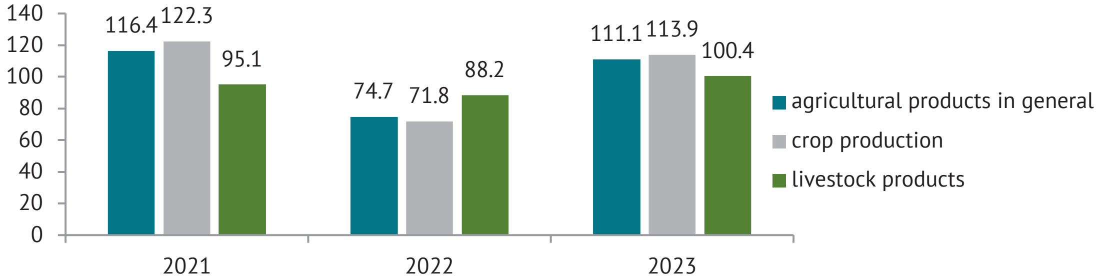


Figure 2. *Indices of agricultural products in Ukraine for 2021-2023*
Source: *compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

Despite a slight increase in agricultural production indices in 2023, against the backdrop of a drop in 2022 due to military operations in Ukraine, agricultural production volumes have not yet reached the levels of 2021. Thus, the average value of production volumes in various agricultural sectors (crop and livestock) in 2023 was 14.2% lower than in pre-war 2021. It should also be noted that the decline in physical output in 2022 was more pronounced in the crop sector, with specialized enterprises showing a more rapid decline. For example, the output of agricultural enterprises decreased by almost 30%, while the decline in production by households was about 20% (State Statistics Service, n.d.). The war has also led not only to a reduction in production capacity, but also to more complicated logistics and the loss of markets. Blocked ports, destroyed roads and railways, and the imposition of export restrictions due to the hostilities have made it much more difficult or even impossible to deliver products to end consumers. This has led to a decline in farmers' incomes, affected GDP, and consequently affected exports and foreign exchange earnings, which are essential for stabilizing the hryvnia in the foreign exchange market. In recent years, the agricultural sector has become the flagship export sector of the Ukrainian economy (Table 5).

Table 5. Share of exports of selected agricultural products in 2018-2023

Export items, %	2018	2019	2020	2021	2022	2023
Live animals, products of animal origin	2.6	2.6	2.4	2	3.3	3.8
Products of plant origin	20.9	25.8	24.2	22.8	30.5	32.4
Including cereals	15.3	19.2	19.1	18.1	20.6	23
Fats and oils of animal or vegetable origin	9.5	9.5	11.7	10.3	13.5	15.6

Source: *compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

The most significant export item in the agricultural sector is the sale of grain crops, with its share increasing by almost 8 percentage points in 2023 compared to 2018. In general, the agricultural sector has become the dominant sector in the structure of exports of foreign economic activity of business entities during the period under review. While in 2018 the share of agriculture was 33%, in 2023 it was 52%. However, the volume of export earnings for all agricultural products has significantly decreased over the 2 years of war, and for some items still does not reach the level of 2019 (Fig. 3).

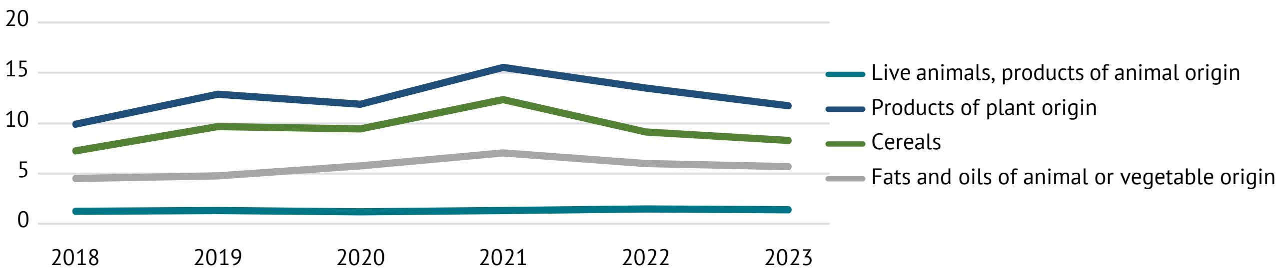


Figure 3. *Dynamics of export revenue from agricultural products, billion USD (for the period 2018-2023)*
Source: *compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

As can be seen from the figure, the most rapid decline in export earnings is observed for plant products, of which cereals are a component. The total decrease in foreign exchange earnings from grain exports in 2022-2023, compared to the pre-war year 2021, was almost 33%. All of the above necessitates the formation of a strategy for the implementation of an intensive type of agricultural sector development based on the circular economy as a promising area that combines economic efficiency and environmental sustainability (Silvius *et al.*, 2023). The introduction of innovative technologies and the transition to closed production and consumption cycles not only increase productivity without expanding production capacity or increasing sown areas, which is especially significant for Ukraine, but also create a more sustainable agricultural system capable of coping with the challenges of the modern world (Vinayagam *et al.*, 2023).

In order to make progress in sustainable production and consumption, innovation plays a vital role (Gonçalves *et al.,* 2022). In the field of agriculture, where the availability of natural resources is crucial, the adoption of innovative practices is necessary in order to shift towards a circular economy (Rusch *et al.*, 2023). Technological advancements, such as the utilisation of drones and sensors in precision farming, improve resource management by optimising the allocation of water, fertiliser, and pesticides (Yrjälä *et al.,* 2022). This method decreases expenses and minimises the ecological footprint. Furthermore, contemporary biotechnologies facilitate the transformation of agricultural waste into useful commodities such as biochar, biogas, and organic fertilisers, hence diminishing waste and dependence on non-renewable energy sources (Sant'Ana *et al.*, 2024). The 2023 strategy for the development of Ukraine's agro-industrial complex emphasises the importance of recycling and biomethane production as major components of the circular economy (Ministry of Agrarian Policy and Food of Ukraine, 2023).

Novel agricultural solutions are progressing the utilisation of alternative raw resources, such as insect proteins and algae, for the production of biofuels (Rauw *et al.*, 2023). These alternatives alleviate the burden on conventional systems and promote sustainable development, which is a fundamental principle of the circular economy. In addition, the implementation of innovative packaging technologies such as biodegradable materials and smart packaging has shown effective in prolonging the shelf life of food products and minimising food waste (Kusumowardani *et al.,* 2022). This, in turn, contributes to the resolution of global hunger and food security concerns (Muscio & Sisto, 2020). Utilising digitalisation and information sharing platforms is essential for implementing circular economy concepts, as they facilitate effective and sustainable farm management (Kleisiari *et al.,* 2021; Ye *et al.,* 2023). Shared agricultural machinery platforms help small farms avoid resource overproduction and lower capital costs. This results in a reduction in the release of greenhouse gases and the consumption of resources, as evidenced by research undertaken by C. Lehmann *et al.* (2022). Investments are essential for fostering innovation and economic growth as they offer financial backing for research and development. This, in turn, leads to the development of innovative solutions and enhances the competitiveness of industries (Bjerke & Johansson, 2022).

Companies and private investors also play a major part in funding research (Zou & Li, 2022). This can be beneficial for businesses, as innovation and new technologies can lead to competitive advantages. Famous examples include investments by large corporations in research in IT, pharmaceuticals, and biotechnology. Investments also contribute to the creation and development of the necessary infrastructure for innovation in all areas, including the agricultural sector. This includes both physical infrastructure (e.g. laboratories, production facilities) and digital infrastructure (e.g. high-speed internet, cloud technologies). A well-developed infrastructure can accelerate the process of developing and adopting new technologies in business (Baah *et al.*, 2024). In addition, investments in education, training, and skills development contribute to the creation of a strong human capital base ready to perform innovative tasks (Castillo-Valero & García-Cortijo, 2021). Investment in innovation can also be stimulated through government support and policies. Public investment in research, tax incentives for companies engaged in innovation, grants, and subsidies create favourable conditions for the development of innovation (Alston & Pardey, 2021).

Public policies aimed at supporting innovation help to attract private investment in this area (Wang *et al.*, 2021). This is relevant for Ukrainian agricultural companies, as it is quite difficult to finance innovative developments in the current environment, as enterprises have significantly reduced production and sales volumes, which significantly affects their profitability (Fig. 4).

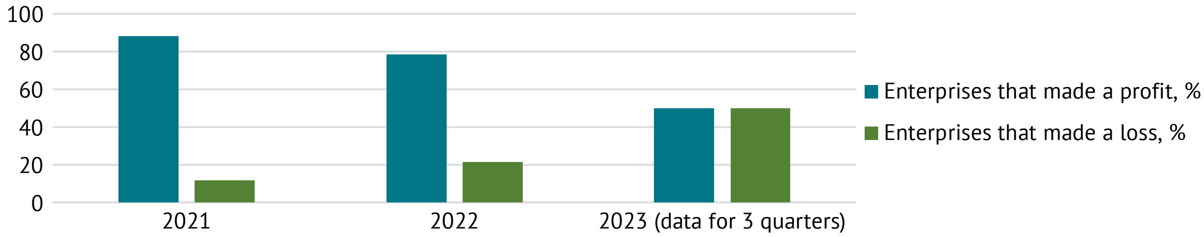


***Figure 4**. Structure of profitable and unprofitable enterprises in agriculture in 2021-2023*
***Source:** compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

As the figure shows, the situation with regard to profitability for Ukrainian agricultural enterprises has deteriorated significantly: while in 2022 only a fifth of enterprises was unprofitable, in 2023 (data for the first 9 months of the year are available) this figure increased by almost 30 percentage points, meaning that half of all agricultural enterprises made losses. This state of affairs leads to their inability to finance innovations at their own expense, which is also evidenced by the statistics of low innovation and investment activity in the activities of agricultural enterprises (Fig. 5).

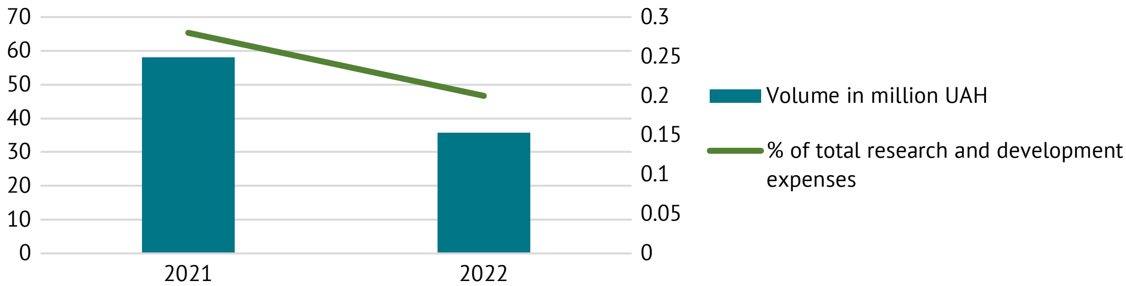


***Figure 5**. Expenditures on basic and applied research and scientific and technical research (developments in agriculture, forestry, and fisheries)*
***Source:** compiled by the author based on the State Statistics Service of Ukraine (n.d.)*

The data shows a decline in agricultural research and development (R&D) spending and its share of the total R&D budget in Ukraine. The restricted allocation of finances for agricultural innovation is primarily driven by economic volatility, including fluctuations in currency, high inflation rates, and economic downturns. These factors discourage the long-term commitment of resources. Small and medium-sized agricultural firms encounter substantial obstacles in accessing cost-effective financing as a result of elevated expenses and limitations. Although there have been some improvements through state concessional lending, these efforts have been further hindered by the ongoing war. In addition, the war has exacerbated the movement of young people from rural areas, which in turn diminishes the number of specialists available to drive innovation. The industry is confronted with difficulties stemming from a dearth of specialised education, obsolete technologies, and insufficient infrastructure. The lack of access to technology, information, and platforms for exchanging knowledge significantly impedes innovation in agriculture.

In addition, an unstable legal framework and frequent regulatory changes create uncertainty for investors. An imperfect system of property rights protection and bureaucratic obstacles also reduce the attractiveness of investment in the sector. High levels of corruption in government agencies involved in agricultural regulation discourage investment. Investors often face non-transparent procedures and demands for bribes. In general, support from government and international institutions is needed to successfully implement innovations in the agricultural sector and ensure the principles of a circular economy. This could include subsidies for research and development, creating favourable conditions for investment in environmentally friendly technologies, and promoting cooperation between science and business. However, this should be done on the basis of a specific strategy with goals, objectives, and indicators.

DISCUSSION

The study's findings highlight the circular economy as a groundbreaking approach to addressing urgent environmental and economic challenges. The circular economy promotes a closed-loop system that prioritises the reuse, repair, refurbishing, and recycling of resources, in contrast to the traditional linear economy's "take, make, dispose" strategy. E. Arruda *et al.* (2021) similarly identify the circular economy as a shift towards sustainable development amid global challenges. While A. Velenturf and P. Purnell (2021) emphasize circular economy concepts, this research stresses the importance of implementing these principles to address resource depletion and scarcity. The circular economy fosters innovation, economic growth, and environmental benefits, aligning with V. Shebanin *et al.* (2022) on sustainable development through closed-loop technologies. J. Velasco-Muñoz *et al.* (2021) note that agriculture faces resource depletion, climate change, and pollution, requiring new technical solutions, with Q. Ren and J. Albrecht (2023) advocating for circular economy strategies in agriculture to address these issues.

Primarily, these are ecological advantages. The agricultural industry is a substantial contributor to the release of greenhouse gases, the contamination of water, and the deterioration of soil quality. The adoption of a circular model effectively minimises the environmental impact by optimising resource utilisation. For instance, instead of incinerating or depositing crop residues in landfills, they can be utilised as organic fertiliser. This practice reduces the reliance on chemical fertilisers and enhances soil structure, as highlighted by M. Martínez-Moreno *et al.* (2024) in their examination of current circular economy practices, obstacles, and motivators in the agricultural sector.

The method, as advocated by A. Khajuria *et al.* (2022), is crucial for establishing a sustainable food system and enhancing environmental resilience. Strategies encompass regenerative agriculture, utilisation of renewable energy, recycling of trash, and implementation of closed production cycles. Regenerative approaches, such as low tillage and crop rotation, help restore ecosystems. Innovations like vertical farming improve resource efficiency, especially in locations with limited water availability (Shah *et al.,* 2024). Renewable energy sources such as solar and biogas diminish dependence on fossil fuels and enhance waste management efficiency (Shahini *et al.,* 2023). Ukraine is confronted with a notable obstacle due to the lack of a comprehensive state strategy for agricultural development based on circular economy concepts. Ukraine should utilise its abundant natural resources and important economic position to promote a circular agricultural sector. This is essential for achieving economic growth, ensuring food security, and maintaining sustainability.

In general, agriculture, excluding the processing component, accounted for more than 10 percent of GDP between 2013 and 2021, while during the war years this figure fell to about eight percent. However, despite this, agriculture remains the main export item of the national economy, accounting for more than 50 per cent of all export transactions. However, according to the study, the amount of foreign exchange earnings has significantly decreased compared to 2021. All this happened as a result of the war, which, along with existing problems for the agricultural sector, such as the lack of state support and regulatory mechanisms, high costs of introducing new technologies and innovations, which is a significant obstacle for many farms that cannot afford the transition to a circular model of management, limited information and relevant education, has caused new challenges for Ukrainian agriculture. First and foremost, it is the destruction of infrastructure, as the hostilities have led to the destruction of farms, transport, and logistics facilities (Dunayev *et al.*, 2024). The absence of adequate infrastructure poses challenges to the implementation of circular economy ideas. Infrastructure has a crucial role in aiding the transition to a circular economy, especially in the agricultural sector (Nunes & Sytnychenko, 2024). The circular system necessitates the presence of physical assets and services for the collection, transportation, processing, storage, and distribution of resources. This requirement is supported by the findings of the conducted study, as well as the results of the study done by A. Nogueira *et al.* (2020).

Another significant problem today is landmines and the "contamination" of agricultural land with unexploded ordnance, which makes it impossible to use it safely. The armed conflict has also led to the migration of people, particularly agricultural workers in the south-east of Ukraine, which has led to labour shortages in many sectors of the agricultural sector. This makes harvesting, animal care and other important agricultural tasks difficult. In addition, it leads to the loss of knowledge and experience that has been accumulated over generations and makes it difficult to introduce new technologies and practices, as well as to lower productivity and product quality, as also pointed out by N. Musayeva *et al.* (2024), who study the role of innovation in mitigating the effects of war on Ukrainian agriculture. All of the above has had a significant negative impact on the Ukrainian agricultural sector, which is confirmed by the data obtained in this study. In particular, there was a significant decrease in the area under crops, almost all major crops, and a decrease in livestock. As a result, the physical volume of production decreased significantly, which, combined with the logistical difficulties of selling it both domestically and abroad, led to the loss of national agricultural enterprises. In particular, in 3 quarters of 2023, half of all agricultural enterprises made losses. Accordingly, this makes it impossible to carry out innovative activities, which cannot be fully implemented without investment support.

The utilisation of new technology in contemporary agricultural practices is being propelled by globalisation processes. This is primarily aimed at enhancing crop yields, optimising resource utilisation, and mitigating environmental consequences. These efforts align with the core principles of the circular economy (Reshetilov, 2022). Investing in research and using cutting-edge technologies are crucial for the advancement of circular models in the agricultural industry. This encompasses the advancement of novel processing techniques, biotechnology, and management information systems. The circular economy promotes the advancement of novel technologies and strategies that can enhance the sustainability and productivity of the agricultural sector, as supported by the research conducted by D. Pemsl *et al.* (2022). For instance, precision farming technologies have the ability to optimise the use of water and fertilisers, resulting in a reduction in their consumption and an increase in crop yields. Biotechnology enables the development of novel crop varieties that possess resistance against pests and diseases, hence diminishing the reliance on pesticides.

Globalisation and wartime challenges necessitate that the agricultural sector adopts modern technologies and innovations to meet increasing demands, adapt to climate change, and stay competitive globally. These changes enhance productivity, sustainability, and food security. Strategic international cooperation, infrastructure development, technological advancements, and skilled workforce training are crucial for integrating agriculture into the global economy. Securing investments and support from government and international organizations will help Ukraine's agricultural sector grow, particularly through adopting a circular economy approach. This involves funding R&D for new technologies, supporting small businesses in circular economy practices, and providing education for farmers on these new methods.

CONCLUSIONS

The proportion of agriculture in the composition of the Gross Domestic Product (GDP) varies approximately at a level of 10%. From 2013 to 2021, this industry experienced a higher growth rate compared to Ukraine's GDP. Additionally, when considering other industries like food processing and related processing, this figure might be substantially higher. Furthermore, Ukraine holds a prominent position as a major global exporter of agricultural products. Agricultural product exports contribute to over 50% of the nation's overall export revenue. However, the war has exacerbated the existing problems of the national agricultural sector and significantly reduced the production capacity of business entities due to the destruction of fixed assets, transport and logistics infrastructure, and a reduction in sown areas due to mining and seizure of territories. As a result, the volume of physical production in the sector has significantly decreased. This had a corresponding impact on sales opportunities, so foreign exchange earnings from agricultural exports decreased by 33% in 2022-2023. Farmers suffered significant losses, which also affected tax revenues to the state budget. The financial situation of agricultural enterprises does not allow them to invest in innovative development using their own resources, which is the basis for the introduction of modern technological solutions that ensure the formation of a circular economy in this area. Expenditures on research and development in agriculture in the period under review did not exceed 0.3% of the total expenditures for this purpose in all sectors of the economy. However, it should be noted that such conclusions are based on the available general statistics and do not take into account the innovation and investment activity of individual enterprises in the agricultural sector.

The conflict and economic volatility have diminished investor enthusiasm for Ukraine's agriculture industry. This has hindered the process of attracting investment in the development of the sector and the modernisation of manufacturing. The study highlights that investments in innovation and technology play a crucial role in implementing the principles of the circular economy, particularly in the era of globalisation. These investments enhance economic efficiency and generate new growth opportunities through precision farming, biotechnology, closed-loop systems, while also reducing the environmental impact. Ukrainian agricultural firms lack the financial capacity to independently provide the necessary investment support for the successful application of these technologies. Hence, this component should serve as the foundation for the state's strategic growth of the agricultural sector.

Additional research should focus on formulating a plan to provide financial assistance for the implementation of new technologies and innovations. This plan should involve the establishment of specific financial tools, partnerships between the public and private sectors, educational and advisory initiatives, infrastructure improvement, and the engagement of international investors. This strategy will facilitate the incorporation of circular economy ideas into the operations of Ukrainian agricultural firms and bolster the sustainable growth of the country.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Alston, J.M., & Pardey, P.G. (2021). The economics of agricultural innovation. *Handbook of Agricultural Economics*, 5, 3895-3980. doi: 10.1016/bs.hesagr.2021.10.001.

[2] Arru, B., Furesi, R., Pulina, P., Sau, P., & Madau, F.A. (2022). The circular economy in the agri-food system: A performance measurement of European countries. *Economia Agro-Alimentare*, 24(2). doi: 10.3280/ecag2022oa13245.

[3] Arruda, E., Melatto, R., Levy, W., & de Melo Conti, D. (2021). Circular economy: A brief literature review (2015-2020). *Sustainable Operations and Computers*, 2, 79-86. doi: 10.1016/j.susoc.2021.05.001.

[4] Baah, C., Rijal, A., Agyabeng-Mensah, Y., Afum, E., & Acquah, I.S. (2024). Does circular economy entrepreneurship drive technical capabilities for circular economy performance? The moderating role of environmental dynamism. *Management of Environmental Quality: An International Journal*, 35(3), 567-586. doi: 10.1108/MEQ-07-2023-0233.

[5] Bjerke, L., & Johansson, S. (2022). Innovation in agriculture: An analysis of Swedish agricultural and non-agricultural firms. *Food Policy*, 109, article number 102269. doi: 10.1016/j.foodpol.2022.102269.

[6] Castillo-Valero, J.S., & García-Cortijo, M.C. (2021). Factors that determine innovation in agrifood firms. *Agronomy*, 11(5), article number 989. doi: 10.3390/agronomy11050989.

[7] Chioatto, E., & Sospiro, P. (2023). Transition from waste management to circular economy: The European Union roadmap. *Environment, Development and Sustainability*, 25, 249-276. doi: 10.1007/s10668-021-02050-3.

[8] Corvellec, H., Stowell, A.F., & Johansson, N. (2022). Critiques of the circular economy. *Journal of Industrial Ecology*, 26(2), 421-432. doi: 10.1111/jiec.13187.

[9] Delivering the European Green Deal. (2021). Retrieved from https://commission.europa.eu/publications/delivering-european-green-deal_en.

[10] Dey, P.K., Malesios, C., Chowdhury, S., Saha, K., Budhwar, P., & De, D. (2022). Adoption of circular economy practices in small and medium-sized enterprises: Evidence from Europe. *International Journal of Production Economics*, 248, article number 108496. doi: 10.1016/j.ijpe.2022.108496.

[11] Dovgal, O., Borko, T., Miroshkina, N., Surina, H., & Konoplianyk, D. (2024). Circular economy as an imperative for sustainable development. *Scientific Bulletin of Mukachevo State University. Series "Economics"*, 11(1), 19-28. doi: 10.52566/msu-econ1.2024.19.

[12] Dunayev, I., Kuchma, M., Byelova, L., Jatkiewicz, P., Bilichenko, O., & Poberezhets, H. (2024). Wartime destruction: Regional assessment of damage to Ukraine's infrastructure. *International Journal of Environmental Studies*, 81(1), 8-17. doi: 10.1080/00207233.2024.2314862.

[13] Farm to Fork strategy. (n.d.). Retrieved from https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en.

[14] Fassio, F., & Chirilli, C. (2023). The circular economy and the food system: A review of principal measuring tools. *Sustainability*, 15(13), article number 10179. doi: 10.3390/su151310179.

[15] Gonçalves, A., Galliano, D., & Triboulet, P. (2022). Eco-innovations towards a circular economy: Evidence from case studies of collective methanisation in France. *European Planning Studies*, 30(7), 1230-1250. doi: 10.1080/09654313.2021.1902947.

[16] Kennedy, S., & Linnenluecke, M.K. (2022). Circular economy and resilience: A research agenda. *Business Strategy and the Environment*, 31(6), 2754-2765. doi: 10.1002/bse.3004.

[17] Khajuria, A., Atienza, V.A., Chavanich, S., Henning, W., Islam, I., Kral, U., & Li, J. (2022). Accelerating circular economy solutions to achieve the 2030 agenda for sustainable development goals. *Circular Economy*, 1(1), article number 100001. doi: 10.1016/j.cec.2022.100001.

[18] Kirchherr, J., Yang, N., Schulze-Spüntrup, F., Heerink, M.J., & Hartley, K. (2023). Conceptualising the circular economy (revisited): An analysis of 221 definitions. *Resources, Conservation and Recycling*, 194, article number 107001. doi: 10.1016/j.resconrec.2023.107001.

[19] Kleisiari, C., Kyrgiakos, L.S., Pardalos, P., & Vlontzos, G. (2021). New technologies contribution on the agrifood sector for achieving circular economy goals. In *Modelling for sustainable management in agriculture, food and the environment* (pp. 1-27). London: CRC Press. doi: 10.1201/9780429197529-1.

[20] Kucher, A., Kucher, L., & Pashchenko, Y. (2021). Circular economy in the system of sustainable development of agrarian sector in the conditions of European integration. *Economy and Society*, 32. doi: 10.32782/2524-0072/2021-32-24.

[21] Kusumowardani, N., Tjahjono, B., Lazell, J., Bek, D., Theodorakopoulos, N., Andrikopoulos, P., & Priadi, C.R. (2022). A circular capability framework to address food waste and losses in the agri-food supply chain: The antecedents, principles and outcomes of circular economy. *Journal of Business Research*, 142, 17-31. doi: 10.1016/j.jbusres.2021.12.020.

[22] Lehmann, C., Cruz-Jesus, F., Oliveira, T., & Damásio, B. (2022). Leveraging the circular economy: Investment and innovation as drivers. *Journal of Cleaner Production*, 360, article number 132146. doi: 10.1016/j.jclepro.2022.132146.

[23] Marsh, A.T., Velenturf, A.P., & Bernal, S.A. (2022). Circular Economy strategies for concrete: Implementation and integration. *Journal of Cleaner Production*, 362, article number 132486. doi: 10.1016/j.jclepro.2022.132486.
[24] Martínez-Moreno, M.M., Buitrago, E.M., Yniguez, R., & Puig-Cabrera, M. (2024). Circular economy and agriculture: Mapping circular practices, drivers, and barriers for traditional table-olive groves. *Sustainable Production and Consumption*, 46, 430-441. doi: 10.1016/j.spc.2024.02.036.
[25] Ministry of Agrarian Policy and Food of Ukraine. (2023). *Strategy for the development of the agricultural sector.* Retrieved from https://minagro.gov.ua/investoram/prezentatsiia-stratehiia-rozvytku-ahropromyslovoho-kompleksu.
[26] Moreira, S.G., Hoogenboom, G., Nunes, M.R., Martin-Ryals, A.D., & Sanchez, P.A. (2023). Circular agriculture increases food production and can reduce N fertiliser use of commercial farms for tropical environments. *Science of the Total Environment*, 879, article number 163031. doi: 10.1016/j.scitotenv.2023.163031.
[27] Musayeva, N., Tanriverdiyeva, G., Faradjova, D., & Mammadova, U. (2024). Assessment of the competitiveness of food products of Ukraine in the domestic and foreign markets. *Business Strategy and Development*, 7(1), article number e336. doi: 10.1002/bsd2.336.
[28] Muscio, A., & Sisto, R. (2020). Are agri-food systems really switching to a circular economy model? Implications for European research and innovation policy. *Sustainability*, 12(14), article number 5554. doi: 10.3390/su12145554.
[29] Nogueira, A., Ashton, W., Teixeira, C., Lyon, E., & Pereira, J. (2020). Infrastructuring the circular economy. *Energies*, 13(7), article number 1805. doi: 10.3390/en13071805.
[30] Nunes, P., & Sytnychenko, K. (2024). Strategic forecasts for circular economy transition: Evaluation of the role of technology in economic development. *Economics, Entrepreneurship, Management*, 11(1), 25-36. doi: 10.56318/eem2024.01.025.
[31] Pemsl, D.E., Staver, C., Hareau, G., Alene, A.D., Abdoulaye, T., Kleinwechter, U., & Thiele, G. (2022). Prioritising international agricultural research investments: Lessons from a global multi-crop assessment. *Research Policy*, 51(4), article number 104473. doi: 10.1016/j.respol.2022.104473.
[32] Rauw, W.M., Gomez-Raya, L., Star, L., Øverland, M., Delezie, E., Grivins, M., & Formato, G. (2023). Sustainable development in circular agriculture: An illustrative bee legume poultry example. *Sustainable Development*, 31(2), 639-648. doi: 10.1002/sd.2435.
[33] Ren, Q., & Albrecht, J. (2023). Towards a circular economy: The impact of policy instruments on circular economy innovation for European small medium-sized enterprises. *Ecological Economics*, 207, article number 107761. doi: 10.1016/j.ecolecon.2023.107761.
[34] Reshetilov, G. (2022). Implementation of environmental policy of Ukraine in the context of circular economy. *Ukrainian Black Sea Region Agrarian Science*, 26(3), 87-96. doi: 10.56407/2313-092X/2022-26(3)-8.
[35] Rusch, M., Schöggl, J.P., & Baumgartner, R.J. (2023). Application of digital technologies for sustainable product management in a circular economy: A review. *Business Strategy and the Environment*, 32(3), 1159-1174. doi: 10.1002/bse.3099.
[36] Sant'Ana, L.H., Oliveira, J.R., Gonçalves, G., Tusset, A.M., & Lenzi, G.G. (2024). Circular economics in agricultural waste biomass management. *Biomass*, 4(2), 543-554. doi: 10.3390/biomass4020029.
[37] Selvan, T., Panmei, L., Murasing, K.K., Guleria, V., Ramesh, K.R., Bhardwaj, D.R., & Deshmukh, H.K. (2023). Circular economy in agriculture: Unleashing the potential of integrated organic farming for food security and sustainable development. *Frontiers in Sustainable Food Systems*, 7, article number 1170380. doi: 10.3389/fsufs.2023.1170380.
[38] Shah, W., Hao, G., Yasmeen, R., Yan, H., & Qi, Y. (2024). Impact of agricultural technological innovation on total-factor agricultural water use efficiency: Evidence from 31 Chinese provinces. *Agricultural Water Management*, 299, article number 108905. doi: 10.1016/j.agwat.2024.108905.
[39] Shahini, E., Luhovyi, S., Kalynychenko, H., Starodubets, O., & Trybrat, R. (2023). Rational use of oilseed waste to increase dairy productivity. *International Journal of Environmental Studies*, 80(2), 442-450. doi: 10.1080/00207233.2022.2147727.
[40] Shebanin, V., Kormyshkin, I., Reshetilov, G., Allakhverdiyeva, I., & Umanska, V. (2022). Sustainable development of the socio-economic security system of the region based on closed cycle technologies. *Rivista di Studi sulla Sostenibilita*, 12(2), 271-288.
[41] Shebanina, O., Burkovska, A., Petrenko, V., & Burkovska, A. (2023). Economic planning at agricultural enterprises: Ukrainian experience of increasing the availability of data in the context of food security. *Agricultural and Resource Economics*, 9(4), 168-191 doi: 10.51599/are.2023.09.04.08.
[42] Shubalyi, O., Khomytskyi, V., & Moshchych, S. (2023). Methodological provision of the analysis and assessment of the development of the circular economy in the EU. *Economic Forum*, 13(1), 18-26. doi: 10.36910/6775-2308-8559-2023-1-3.

[43] Silvius, J., Hoogstra, A.G., Candel, J.J., de Olde, E.M., de Boer, I.J., & Termeer, C.J. (2023). Determining the transformative potential of circular agriculture initiatives. *Ambio*, 52(12), 1968-1980. doi: 10.1007/s13280-023-01894-5.

[44] State Statistics Service of Ukraine. (n.d.). Retrieved from https://www.ukrstat.gov.ua.

[45] The common agricultural policy: 2023-27. (2023). Retrieved from https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en#documents.

[46] Velasco-Muñoz, J.F., Mendoza, J.M., Aznar-Sánchez, J., & Gallego-Schmid, A.A. (2021). Circular economy implementation in the agricultural sector: Definition, strategies and indicators. *Resources, Conservation and Recycling*, 17, article number 105618. doi: 10.1016/j.resconrec.2021.105618.

[47] Velenturf, A.P., & Purnell, P. (2021). Principles for a sustainable circular economy. *Sustainable Production and Consumption*, 27, 1437-1457. doi: 10.1016/j.spc.2021.02.018.

[48] Vinayagam, V., Sikarwar, D., Das, S., & Pugazhendhi, A. (2023). Envisioning the innovative approaches to achieve circular economy in the water and wastewater sector. *Environmental Research*, article number 117663. doi: 10.1016/j.envres.2023.117663.

[49] Wang, Q., Zhang, M., & Wang, W. (2021). Analysis of the impact of foreign direct investment on urbanisation in China from the perspective of "circular economy". *Environmental Science and Pollution Research*, 28(18), 22380-22391. doi: 10.1007/s11356-020-12321-7.

[50] Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A.I., Fawzy, S., & Yap, P. (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters*, 21(1), 55-80. doi: 10.1007/s10311-022-01499-6.

[51] Ye, F., Ouyang, Y., & Li, Y. (2023). Digital investment and environmental performance: The mediating roles of production efficiency and green innovation. *International Journal of Production Economics*, 259, article number 108822. doi: 10.1016/j.ijpe.2023.108822.

[52] Yrjälä, K., Ramakrishnan, M., & Salo, E. (2022). Agricultural waste streams as a resource in circular economy for biochar production towards carbon neutrality. *Current Opinion in Environmental Science & Health*, 26, article number 100339. doi: 10.1016/j.coesh.2022.100339.

[53] Zou, F., & Li, T. (2022). The impact of agricultural ecological capital investment on the development of green circular economy. *Agriculture*, 12(4), article number 461. doi: 10.3390/agriculture12040461.

Циркулярна економіка аграрного сектора: стратегії та виклики в умовах глобалізації

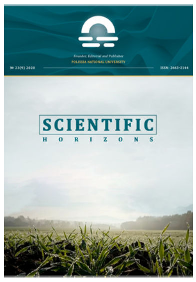
В'ячеслав Шебанін
Доктор технічних наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-0391-396X
Олена Шебаніна
Доктор економічних наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-7663-5991
Юрій Кормишкін
Доктор економічних наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-1005-1229
Антоніна Дробітько
Доктор сільськогосподарських наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-6492-4558
Наталя Потриваєва
Доктор економічних наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-9781-6529

Анотація. Дослідження мало на меті підтвердити необхідність розробки та реалізації планів впровадження концепції циркулярної економіки в аграрному секторі України, враховуючи вплив глобалізації та проблеми, що виникли внаслідок війни. У цьому дослідженні розглядалися фундаментальні принципи та інтелектуальні підвалини, які відрізняють циркулярну економіку від традиційної економічної моделі. Обґрунтовано фундаментальну концепцію циркулярної економіки в аграрному секторі та встановлено основні переваги впровадження цієї економічної моделі в сільському господарстві. Європейська Комісія затвердила стратегію Спільної аграрної політики на період 2023-2027 років. Ця стратегія наголошує на першочергових обов'язках, які країни-члени ЄС повинні взяти на себе для впровадження принципів циркулярної економіки в сільському господарстві. Визнано основні закономірності функціонування сільського господарства в Україні та встановлено значення аграрного сектору у формуванні валового внутрішнього продукту (ВВП) та валютних надходжень. Руйнування інфраструктури, видобуток корисних копалин та окупація регіонів призвели до скорочення посівних площ та поголів'я тварин, що спричинило втрату фізичної продуктивності. Через війну відбулося зниження виробничих і логістичних можливостей, що призвело до значного падіння експорту сільськогосподарської продукції. Як наслідок, прибутковість фірм у цьому секторі української економіки також знизилася. Українським аграрним компаніям бракує фінансових ресурсів, щоб самостійно підтримувати творчий розвиток, який включає впровадження нових технологічних рішень, що формують основу циркулярної економіки. Враховуючи наслідки глобалізації та військового конфлікту, обґрунтовано, що стратегічним напрямом впровадження принципів циркулярної економіки в сільському господарстві України має стати пріоритетність інноваційної та інвестиційної підтримки, зокрема з боку держави. Такий підхід сприятиме підвищенню економічної ефективності та створенню нових можливостей

Ключові слова: сільське господарство; модель замкнутого циклу; сталий розвиток; переробка відходів; регенеративне землеробство; біотехнології

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(9), 162-176



UDC 338.242.4:338.45
Doi: 10.48077/scihor9.2024.162

Kyrgyz Republic production-resource and export potential state regulation mechanism

Saltanat Derkenbaeva*
Senior Lecturer
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0002-4580-9730

Chinara Adiyaeva
Senior Lecturer
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0002-2022-1439

Nurila Ibraeva
PhD in Economics, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0002-0301-6070

Tinatin Sydykova
Senior Lecturer
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0001-9844-0570

Gulnara Oganova
Senior Lecturer
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0003-1581-726X

Article's History:
Received: 07.03.2024
Revised: 25.07.2024
Accepted: 28.08.2024

Abstract. The study addressed the mechanism of state regulation of the production, resource and export potential of the Kyrgyz Republic. The study aimed to improve the system of state regulation of the agricultural sector to increase national food security. The analysis revealed a steady increase in production of the main types of agricultural products over the period 2014-2024: cereals by 11.6%, potatoes by 12.5%, vegetables by 18.2%, meat by 24.5% and milk by 17.1%. However, the study also showed

Suggested Citation:
Derkenbaeva, S., Adiyaeva, Ch., Ibraeva, N., Sydykova, T., & Oganova, G. (2024). Kyrgyz Republic production-resource and export potential state regulation mechanism. *Scientific Horizons*, 27(9), 162-176. doi: 10.48077/scihor9.2024.162.

**Corresponding author*

uneven levels of self-sufficiency across different types of products: the high levels of self-sufficiency in potatoes (167.4%), vegetables (164.5%) and milk (116.5%) contrast with the low levels of self-sufficiency in fruit and berries (18.2%), vegetable oil (44%) and sugar (69%). An analysis of the existing state regulatory mechanisms revealed a comprehensive legal framework, including the Law of the Kyrgyz Republic No. 320 "On Food Security" and the "Food Security and Nutrition Programme for 2019-2023", but their implementation is limited by insufficient funding and administrative barriers. Based on the analysis, recommendations were developed to optimise the state regulatory mechanism, including the introduction of a differentiated subsidy system, optimisation of the structure of exports and imports of agricultural products, increasing the efficiency of agricultural production, development of agricultural processing and improving the food quality control system. Proposed measures include the creation of the brand "Ecologically clean products of Kyrgyzstan", the introduction of the Global G.A.P. certification system, the creation of a network of regional agricultural-consulting centres, the development of agro-industrial parks and the modernisation of quality control laboratories. The implementation of these measures aims to overcome the identified problems create more favourable conditions for the development of agriculture and ensure food security in the Kyrgyz Republic

Keywords: agricultural sector; agricultural production; food security; self-sufficiency; subsidies; concessional lending; export potential

INTRODUCTION

In the context of global climate change and the growing instability of global food markets, the problem of effective state regulation of the agricultural sector is becoming critical to ensuring national food security. For the Kyrgyz Republic, which has significant agricultural potential, optimisation of agricultural production and resource management mechanisms is becoming a key factor in ensuring sustainable development of rural areas, increasing food self-sufficiency and strengthening its position in regional agri-food markets. Effective state regulation in this area is intended not only to stimulate the growth of agricultural production but also to ensure national food independence in the long term.

The problem of the study is the insufficient efficiency of the existing mechanisms of state regulation of the agricultural sector of the Kyrgyz Republic, which prevents the full realisation of the national agricultural potential and limits its ability to ensure food security. Despite favourable natural and climatic conditions and significant land resources, Kyrgyzstan has several challenges in the agricultural sector, including low labour productivity in agriculture, insufficient mechanisation and technological equipment, dependence on food imports for several key items, poorly developed processing industry and limited access of local producers to international agricultural markets (Sakkaraeva & Kumashev, 2024). These factors together pose risks to the national food security and the sustainable development of its agricultural sector.

The study of the impact of state regulation on the innovation activity of enterprises attracts the attention of many scientists. As such, F. Wang and X. Dai (2020) revealed the relationship between regulatory policy and innovation activities of companies, emphasising the key role of resource reallocation in this process. Their findings confirm the need for a careful approach to the development of regulatory mechanisms to stimulate innovation. At the same time, the efficient use of natural resources remains a key issue for many developing economies. An interesting perspective on this issue is provided by Z. Gao *et al.* (2024), who rethink the concept of the "resource curse" in the context of the Chinese model of economic development. Their research shows that, with the right approach, dependence on the resource industry can become a driver of high-quality economic growth.

An equally important aspect of government regulation is the support of key sectors of the economy (Kryvenko, 2022). In this context, a study by A.A. Naizabekova and Z.D. Iskakova (2024) on the role of investment in agriculture in ensuring sustainable economic development is noteworthy. Their study emphasises the need for a balanced approach to the allocation of investment resources between different sectors of the economy. Analysing the impact of natural resources on economic development in a broader context, a study by S. Erdoğan *et al.* (2020) is noteworthy. The authors analysed the relationship between natural resource abundance, financial development and economic growth in the example of the Next-11 countries. Their findings can be particularly useful for developing economic development strategies in resource-dependent countries.

An important aspect of government regulation of export potential is support for small and medium-sized businesses (Dolynska, 2023). In this context, the study by O. Malca *et al.* (2020) is noteworthy, as they address export support programmes as catalysts for the export activities of small and medium-sized enterprises. Their study underlines the importance of government initiatives in stimulating the export activity of small and medium-sized enterprises. Continuing the discussion on the development of export potential, the study by N. Mozhaikina and I. Ostrovskyi (2024), devoted to the peculiarities of the development and management of export potential of small and medium-sized enterprises, is also worth consideration. The authors proposed several valuable recommendations for improving the mechanisms of state support for export-oriented small and medium-sized enterprises.

G. Gertz and M.M. Evers (2020) contributed to the understanding of global economic competition by a study on the prospects of state capitalism in geo-economic competition. Their study raised important questions about the role of the state in shaping the competitive advantages of national economies on the world stage. The study by V. De Marchi and M. Alford (2022), which provides a systematic analysis of public policy and modernisation in global value chains, is also notable. Their study offers valuable insights for developing effective strategies for integrating national producers into international production networks.

Despite the significant amount of research in this area, many aspects of the mechanism of state regulation of production, resource and export potential, especially in the context of the specifics of the Kyrgyz Republic's economy, remain insufficiently studied. In particular, the issues of adapting successful international practices to the conditions of the transforming economy of Kyrgyzstan, as well as developing a comprehensive approach to stimulating innovation activity and export potential, considering the existing resource constraints, require additional analysis. The study aimed to improve the mechanism of state regulation of the agricultural sector of the Kyrgyz Republic to ensure the food security of the country.

MATERIALS AND METHODS

The methodological basis of the study was formed by the principles of systematicity and objectivity, which provided a comprehensive approach to the study of the mechanism of state regulation of the agricultural sector and food security of the Kyrgyz Republic in their dynamics and interrelation with the broader socio-economic context. The study was based on an analysis of a wide range of sources. The regulatory framework is composed of key legislative acts of the Kyrgyz Republic, including Law of the Kyrgyz Republic No. 183 (2008), Law of the Kyrgyz Republic No. 161 (2012), Law of the Kyrgyz Republic No. 52 (2019), Law of the Kyrgyz Republic No. 67 (2004). The study of these documents identified the legal framework and mechanisms of state regulation in the field of food security and the agricultural sector.

An important source of information was the national strategic development documents, in particular Resolution of the Government of the Kyrgyz Republic No. 320 (2019). Analysis of this document identified the main directions and priorities of State policy in the area of food security. The programme contains a comprehensive approach to solving food security problems, including measures to increase the availability and quality of food, develop agricultural production, improve the nutrition of the population and strengthen the food safety control system. The document addresses the improvement of the efficiency of land and water resources use, development of seed and livestock breeding, and improving mechanisms of state support for agricultural producers. The study of this programme identified key metrics used by the Government to assess the level of food security and to define target metrics for the development of the agricultural sector in the medium term.

To assess the current state and dynamics of development of the agricultural sector and food security of the Kyrgyz Republic, statistical data provided by the National Statistical Committee of the Kyrgyz Republic (2015-2024). Metrics of production of the main types of agricultural products, the level of self-sufficiency of the country in food, exports and imports of agricultural products for the period 2014-2024 were analysed. The study addressed and analysed scientific publications on state regulation of the agricultural sector, food security and agricultural development in transition countries. Particular attention was devoted to studies that analyse successful international experiences in these areas.

Based on the analysis, the main trends in the development of the agricultural sector and food security in the Kyrgyz Republic were identified. In particular, the report noted a steady increase in the production of major agricultural products, and an increase in export potential in some sectors, while maintaining dependence on imports for several key food products. To assess the effectiveness of the existing state regulatory mechanisms, the current regulatory framework and institutional structure were analysed. This identified both positive aspects and problem areas in the existing regulatory system. Based on the analysis, recommendations were developed to optimise the mechanism of state regulation in the field of food security and the development of the agricultural sector of the Kyrgyz Republic. These recommendations include proposals to improve the subsidy system, optimise the structure of exports and imports of agricultural products, increase the efficiency of agricultural production, develop agricultural processing and improve the system of quality control and food safety.

RESULTS

Analysis of the current state and dynamics of development of the agrarian sector and food security of the Kyrgyz Republic (2014-2024). Agriculture is primary in the economy of the Kyrgyz Republic, being the basis for ensuring national food security. Over the period 2014-2024, the agricultural sector of Kyrgyzstan demonstrated mixed dynamics of development, facing several challenges and demonstrating certain achievements. The share of agriculture in the national gross domestic product (GDP) was 14.7% in 2014, and by 2023 it had decreased to 11.3%. Despite the relative decline in the share of GDP, the absolute volume of agricultural production has increased over this period. According to the National Statistical Committee of the Kyrgyz Republic (2015; 2023), the production of major agricultural products in the Kyrgyz Republic in 2014-2024 showed steady growth in all key areas, indicating the gradual development of the country's agricultural sector. Table 1 illustrates the dynamics of production of the main types of agricultural products for the period 2014-2023. This table reflects changes in the production of key crops in the Kyrgyz Republic over a ten-year period, which traces long-term trends and identifies noticeable fluctuations in the national agricultural sector.

***Table 1**. Dynamics of production of main types of agricultural products in the Kyrgyz Republic, 2014-2023 (thousand tonnes)*

Crop	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Cereals	1,445.9	1,723.1	1,728.1	1,681.8	1,741.5	1,781.4	1,856	1,329.1	1,867.3	1,623.8
Wheat	572.7	704.6	661.5	601	615.9	601.2	629.1	362.7	592.5	440.4
Barley	317	370.2	415.3	424.4	429.3	465.9	510.2	274.1	539.6	382.1
Grain corn	556.1	641.9	648.7	653.4	692.9	711.8	714.1	691.1	732.6	799.9
Rice	27.2	30.2	34.8	38.2	40.8	41.2	44.5	46.3	44.2	46.8
Pulses	90.1	96.7	97.7	102.6	106.6	108.6	107.2	85.5	80.6	72.3
Oilseeds	35.7	49	41.3	39.7	35.4	31.1	23.9	17.8	19.7	15.3
Cotton	69	44.1	52.1	65.3	74.7	80.2	72.8	66.9	76.5	63.4
Tobacco	1.9	1.3	0.5	1.5	1.8	0.9	1	1.1	1.2	1.4
Sugar beet	173.6	183.2	705.2	712.3	773	741.1	448.8	365.6	468.1	621
Potatoes	1,320.7	1,416.4	1,388.4	1,416	1,446.6	1,373.8	1,327.2	1,289.1	1,275	1,286.8
Vegetables	919.7	1,052.1	1,069.3	1,086.7	1,094.9	1,133.6	1,131.2	1,114.2	1,163.6	1,216.6
Gourds	193.3	248.6	237.3	259.1	249.1	245.8	261.5	224.9	226.1	235.6
Fruits and berries	237	209.2	239.3	240.6	251.4	269.5	278	266.4	275.5	278.9
Grapes	8.5	5.7	8.6	8.6	8.8	8.9	9.3	7.4	7.3	5.1

***Note:** values are in thousands of tonnes*
***Source:** compiled by the authors based on National Statistical Committee of the Kyrgyz Republic data (2016-2023)*

Based on the analysis of data on the production of major crops in Kyrgyzstan for the period 2014-2023, several key trends and their interrelationships can be identified. Grain production in general shows an upward trend, increasing from 1445.9 thousand tonnes in 2014 to 1623.8 thousand tonnes in 2023, reaching a peak of 1867.3 thousand tonnes in 2022. However, this growth was not uniform, reflecting the influence of various factors, including climatic conditions and changes in agricultural policy. Notably, there are mixed trends within the cereals category. Wheat production, traditionally an important crop for the country's food security, is showing a downward trend after peaking at 704.6 thousand tonnes in 2015, reaching 440.4 thousand tonnes in 2023. This decline may be due to farmers switching to other, more profitable crops, as well as the impact of climatic factors. In contrast, corn production is showing steady growth, increasing from 556.1 thousand tonnes in 2014 to 799.9 thousand tonnes in 2023. This growth may be due to increased demand for corn as a fodder crop, as well as its greater resistance to climate change compared to wheat.

Potato and vegetable production also shows positive dynamics. Potato production grew from 1320.7 thousand tonnes in 2014 to 1286.8 thousand tonnes in 2023, reaching a peak of 1446.6 thousand tonnes in 2018. Vegetable production increased from 919.7 thousand tonnes to 1216.6 thousand tonnes over the same period. This trend can be attributed to growing domestic demand and developing export opportunities for these crops. Sugar beet production is subject to significant fluctuations, which may be a result of changes in government policy to support the industry and fluctuations in sugar market prices. The sharp increase in production from 183.2 thousand tonnes in 2015 to 773.0 thousand tonnes in 2018 was likely caused by favourable market conditions and government incentives. The subsequent decline and new growth to 621.0 kt in 2023 may reflect the industrial adaptation to changing market conditions.

Production of cotton and oilseeds is showing a downward trend. This may be caused by competition for land resources with more profitable crops, as well as difficulties in ensuring the competitiveness of these crops on the international market. At the same time, the production of fruits and berries shows a steady increase from 237.0 thousand tonnes in 2014 to 278.9 thousand tonnes in 2023, which may be the result of government programmes to develop horticulture and the growing demand for fruits and berries. These trends point to ongoing structural changes in Kyrgyz agriculture. Farmers are shifting towards more profitable and climate-resilient crops such as maize, vegetables and fruits. At the same time, there is a decline in the production of traditional industrial crops such as cotton and oilseeds.

Large fluctuations in the production of some crops, especially cereals and sugar beet, point to the need for a more stable and long-term agricultural policy. This policy should account for not only market factors but also food security, environmental sustainability and climate change adaptation. Despite the overall growth in agricultural production, Kyrgyzstan continues to face serious challenges in ensuring food security. The analysis of the national self-sufficiency in basic foodstuffs as of January-August 2023 reveals a complex overview, showing both achievements and problem areas in the country's agricultural sector (Providing Kyrgyzstan with..., 2023).

Kyrgyzstan has made significant progress in cereal production, meeting 77.6% of its domestic needs for bread products through domestic production. However, the country is still dependent on imports, which account for 62.6% of the domestic bakery market. This points to the need for further development of the grain sector to strengthen food independence. Potato vegetable and melon production is particularly successful. Self-sufficiency in potatoes reached 167.4% and in vegetables and melons 164.5%. Addressing export and import operations, these figures are even higher: 167.9% and 182.4% respectively. This high level of production not only fully meets domestic needs, but also creates significant export potential, helping to strengthen the country's economy. At the same time, fruit and berry production remains a problematic area. Self-sufficiency in these products is only 18.2% and 35.3% when imports are addressed. Imported products account for more than half of the domestic fruit and berry market (50.4%). This points to the need to develop horticulture and berry growing in the country to reduce dependence on imports.

The situation in the livestock sector is more favourable. Self-sufficiency in meat reaches 80.5%, and 97.1% when imports are considered. Imports account for 20.1% of the domestic meat market. This indicates a positive development in the livestock sector but also points to the potential for further production growth. The dairy industry demonstrates strong performance: self-sufficiency in milk is 116.5%, and including export and import operations, it is 118.8%. This not only fully meets domestic needs, but also creates opportunities for dairy exports. Egg production covers 63.9% of domestic demand, and with imports, the supply reaches 79.2%. This points to the need for further development of poultry farming to achieve full self-sufficiency. The situation with sugar and vegetable oil production remains challenging. Self-sufficiency in sugar is 69% and in vegetable oil 44%. Imports affect supply in the domestic market with 34.2% for sugar and 57.5% for vegetable oil. This underscores the need to develop the respective agricultural and food industries.

Thus, despite achieving self-sufficiency in several key food products such as potatoes, vegetables and milk, Kyrgyzstan is still dependent on imports for many important food categories. This poses risks to national food security and points to the need for further development of the agricultural sector, especially in the production of cereals, fruit, sugar and vegetable oil. The implementation of a targeted policy to increase agricultural productivity and sustainable food production is crucial for strengthening Kyrgyz food security and achieving the Sustainable Development Goals. The analysis of Kyrgyz foreign trade in agricultural products in 2023 demonstrates a significant increase in national export potential while maintaining dependence on imports for several key food commodities. Exports of agri-food products from Kyrgyzstan in 2023 reached an impressive volume of 818.9 thousand tonnes, which is 231.8 thousand tonnes or 39.5% more compared to the same period of 2022. This significant growth indicates the strengthening of Kyrgyz position in international agricultural markets.

The structure of exports demonstrates the diversity of Kyrgyz agricultural products. The main export commodities were vegetables with a volume of 186.8 thousand tonnes, fruits – 139.1 thousand tonnes, nuts – 88.5 thousand tonnes and pulses – 70.5 thousand tonnes. Potatoes (43.5 thousand tonnes) and dried fruits (34.9 thousand tonnes) also accounted for a significant volume. This structure of exports reflects the strengths of Kyrgyzstan's agriculture, in particular, favourable conditions for growing vegetables, fruits and nuts (Exports of agricultural..., 2023). Despite success in exports, Kyrgyzstan continues to be dependent on imports for several important food products. Imports include significant volumes of poultry meat (65.1 thousand tonnes), dairy products (14.7 thousand tonnes), and large quantities of eggs (192.6 million eggs). In addition, the country imports cattle (26.3 thousand heads) and horses (7.3 thousand heads), which indicates an insufficient development of domestic livestock production in some segments (What agricultural products..., 2024).

The significant volume of imports of feed for animals, poultry and fish (about 63,000 tonnes in total) indicates the dependence of the livestock sector on foreign supplies, which may negatively affect the competitiveness of Kyrgyz livestock products. The current situation in Kyrgyz foreign trade in agricultural products points to the need for further development of the national agricultural sector. Despite successes in exports of vegetables, fruits and nuts, which demonstrate national potential in these areas, Kyrgyzstan still faces serious challenges in ensuring food security. Dependence on imports for several key foodstuffs, rising food prices and insufficient development of agricultural infrastructure pose risks to the sustainable provision of quality and affordable food to the population.

Several key factors influence the development of the agricultural sector and food security in Kyrgyzstan. Climate conditions and natural risks, such as droughts and frosts, create instability in agricultural production. Limited land and water resources constrain the potential for expanding agricultural production. The low level of mechanisation and technological equipment in agriculture leads to a decrease in labour productivity and production efficiency. Insufficient development of storage and processing systems for agricultural products limits opportunities for value-addition and extending the shelf life of products. Limited access of farmers to financial resources hampers investments in modernisation and expansion of production. The volatility of world food prices creates additional risks for the stability of the domestic market. The following table provides a visual representation of the current state of food security in Kyrgyzstan and the key factors affecting it (Table 2).

***Table 2**. Key Metrics of Food Security in Kyrgyzstan and Factors Influencing its Provision*

Metric	Value	Influencing factors
Level of self-sufficiency in bread products	77.6%	Climate conditions, limited land resources
Level of self-sufficiency in meat products	80.5%	Insufficient development of the feed base, low mechanisation
Level of self-sufficiency in dairy	116.5%	Traditionally developed livestock farming
Level of self-sufficiency in vegetables and melons	164.5%	Favourable climatic conditions
Level of self-sufficiency in fruits and berries	18.2%	Insufficient development of horticulture
Food price growth (2014-2023)	78.5%	Volatility of global prices, dependence on imports
Share of agriculture in GDP	11.7%	Low labour productivity, limited investment
Share of agricultural exports in total exports	15.3%	Insufficient development of storage and processing systems

***Note:** self-sufficiency level is calculated as the ratio of domestic production to total consumption; food price growth is presented as cumulative growth for the period 2014-2023*
***Source:** compiled by the authors*

These factors together form a complex environment for the development of agriculture and food security in Kyrgyzstan. They require a comprehensive approach to solving problems and improving mechanisms of state regulation in this area. Measures are needed to stimulate Kyrgyz production, improve the efficiency of agriculture, develop the agro-industrial complex and optimise the structure of food exports and imports. This situation highlights the need to improve the mechanisms of state regulation in the field of food security, including stimulation of Kyrgyz production, improvement of agricultural efficiency, development of the agro-industrial complex and optimisation of the structure of food exports and imports.

State mechanisms for regulating the agricultural sector and ensuring food security in the Kyrgyz Republic. The system of state regulation of the agricultural sector and food security in the Kyrgyz Republic is a complex and multi-level structure based on interrelated legislation, targeted programmes and specialised support measures. The central element of this system is Law of the Kyrgyz Republic No. 183 (2008). This law is central to establishing the legal framework to ensure national food independence, economic and physical accessibility of food and its safety for the Kyrgyz population. The Law of the Kyrgyz Republic No. 183 (2008) contains several key definitions that form the conceptual basis of the state policy in the field of food security. It defines such relevant concepts as “food security”, “food independence”, “economic accessibility of food” and “physical accessibility of food”. These definitions outline the goals and objectives of state policy in this area.

An important aspect of the law is the establishment of the principles of state policy in the field of food security. These include ensuring physical and economic availability of safe food products for all segments of the population, guaranteeing food quality and safety, supporting Kyrgyz agricultural producers, and developing competitive agricultural production. The law delineates the powers of different levels of government in food security. It defines the competencies of the Government of the Kyrgyz Republic, authorised state bodies and local self-government bodies. This delineation allows for the creation of an effective system of management and control in food security at all levels of government. The law addresses the regulation of the formation and use of state food reserves. This aspect is critical to ensuring the stability of the food supply in the event of emergencies or sharp fluctuations in the market. The law establishes the procedure for the formation, storage and use of food reserves, providing quick state response to crises in the food supply sector.

In addition, the law provides mechanisms for monitoring and evaluating the state of food security in the country. This includes the regular collection and analysis of data on food production, imports and consumption, as well as an assessment of the country’s self-sufficiency in basic foodstuffs. This approach identifies potential threats to food security, which can be used to take the necessary measures promptly. The Government of the Kyrgyz Republic developed and approved Resolution of the Government of the Kyrgyz Republic No. 320 (2019). This program addresses a set of objectives, including increasing the availability and quality of food, developing agricultural production, improving the population's nutrition and strengthening the food safety control system. The programme provides several specific support measures for agricultural producers. These include subsidies for the purchase of plant protection products, which are regulated by the draft Regulations on the Procedure... (2017). According to this draft regulation, subsidies are granted by the Ministry of Agriculture, Food Industry and Land Reclamation of the Kyrgyz Republic to reimburse part of the costs of purchasing pesticides permitted for use in the Kyrgyz Republic.

The subsidy rate is set at 20% of the cost of plant protection products. Subsidies are granted if there are crop areas treated with plant protection products. The recipients of subsidies may be agricultural producers and organisations of the agro-industrial complex, regardless of their legal form and form of ownership, engaged in the production of agricultural products. However, the effectiveness of these subsidies remains a matter of debate. There are concerns that the number of subsidies allocated may not be sufficient to ensure significant productivity growth in the sector. This may be due to limited budgetary resources and potential difficulties in administering the subsidies, especially for small farms. In addition, the process of obtaining subsidies requires farmers to prepare and submit a significant amount of documentation, which may pose additional difficulties, especially for small farms.

Another important mechanism for supporting agricultural producers is the system of preferential lending. It is implemented through state-owned banks and specialised funds such as Aiyl Bank and the Kyrgyz-Russian Development Fund. The legal basis for this mechanism is Law of the Kyrgyz Republic No. 161 (2012), which defines the principles and procedures for the functioning of state financial development institutions. Despite the existence of this system, access to financial resources for many agricultural producers remains limited. This is related to high collateral requirements, complicated loan processing procedures and insufficient financial literacy of small farmers. As a result, a significant part of agricultural enterprises, especially small farms, do not have access to the necessary financial resources to modernise production and increase productivity. As a member of the Eurasian Economic Union (EAEU), Kyrgyzstan adheres to a common customs and tariff policy in regulating foreign trade in agricultural products. The main regulatory act in this area is the Customs Code of the Eurasian Economic Union. According to this code, the Single Customs Tariff of the EAEU applies to imports of agricultural products from third countries (Mukhametov *et al.*, 2023).

To protect the domestic market and support Kyrgyz producers, Kyrgyzstan uses several methods within the framework of EAEU membership. These include tariff and non-tariff measures to regulate foreign trade, which are applied following the EAEU Treaty and decisions of the Eurasian Economic Commission. In respect of imports of agricultural products, Kyrgyzstan, as a member of the EAEU, applies the EAEU Common Customs Tariff, which may include seasonal duties on certain types of products. These measures aim to protect the interests of Kyrgyz producers in certain periods of the year. As for agricultural exports, Kyrgyzstan may impose temporary restrictions on the export of certain types of goods following national legislation and obligations under the EAEU. The basis for such measures is Law of the Kyrgyz Republic No. 52 (2019), which provides for the possibility of imposing export bans and restrictions to ensure national security, protect the domestic market and fulfil the international obligations of the Kyrgyz Republic. These measures can be used to ensure the country's food security in cases of crop failure, emergencies or significant price fluctuations in the world food market.

The food quality and safety control system in Kyrgyzstan is based on the Law of the Kyrgyz Republic No. 67 (2004) and the relevant technical regulations. This law establishes the legal basis for the development, adoption, application and enforcement of mandatory requirements for products, including food products. The Centre for Standardisation and Metrology under the Ministry of Economy of the Kyrgyz Republic is central to the quality control system (Regulations on the..., 2021). This body is responsible for the development and implementation of national quality standards that are harmonised with international standards, in particular Codex Alimentarius. The activities of the Centre are regulated by Law of the Kyrgyz Republic No. 67 (2004), which defines the principles and procedures for the development and application of technical regulations and standards.

The State Inspectorate for Veterinary and Phytosanitary Safety under the Government of the Kyrgyz Republic controls the safety of products of animal and plant origin. This body is regulated by Law of the Kyrgyz Republic No. 175 (2014) and Law of the Kyrgyz Republic No. 2 (2015). The Inspectorate conducts regular inspections of agricultural enterprises, storage and sale of products, as well as border control of import and export of agricultural products. Despite the existence of a comprehensive regulatory system, its effectiveness remains a matter of concern. The main problems are related to insufficient funding from regulatory authorities, lack of modern laboratory equipment for analyses, and insufficient coordination between the various agencies involved in ensuring food security. In general, state regulation mechanisms for the agricultural sector and food security in the Kyrgyz Republic cover a wide range of measures from legislative regulation to specific programmes to support producers and control the quality of products. However, the effectiveness of these mechanisms is limited by several factors, including insufficient financial resources, administrative barriers and difficulties in coordinating the actions of various government agencies. This indicates the need to further improve the system of state regulation to better address the challenges of agricultural development and food security in the country.

Recommendations for optimising the state regulation mechanism. Improvement of the system of subsidising agricultural producers is a key factor in increasing the efficiency of the agricultural sector in Kyrgyzstan. The existing system, which provides for 20% reimbursement of costs for plant protection products, does not take into account regional specifics and is difficult for small farmers. The experience of Turkey shows that a differentiated approach to subsidies can significantly increase their efficiency. In Turkey, subsidies for seeds and seedlings range from 30% to 75% depending on region and crop, which resulted in a 20-25% increase in yields over five years (Cevher & Cevher, 2021). Considering this, it is recommended to introduce a comprehensive system of differentiated subsidies in Kyrgyzstan. For mountainous areas with limited cultivated areas, subsidies for the purchase of high-yielding seeds and seedlings should be increased to 40% of the cost. In arid regions, such as the Batken region, a 50% subsidy for the introduction of drip irrigation should be introduced. This is particularly relevant given the successful experience in Israel, where the use of drip irrigation reduced water consumption by 30-40% while increasing yields (Ayars *et al.*, 2024).

For organic farmers, whose number in Kyrgyzstan is growing, but still small, it is advisable to provide 60% subsidies for certification of products according to international standards. Such a measure is successfully applied in Tunisia, where the area of organic farmland tripled in five years (Benabdelkader *et al.*, 2021). Implementation of these measures will require amendments to the Regulations on the Procedure for Granting Subsidies to Agricultural Commodity Producers for the Purchase of Plant Protection Products (2017) and the creation of a "single window" based on district departments of agriculture to receive applications and counselling of farmers. Optimisation of the structure of exports and imports of agricultural products is the next important step in ensuring the food security of the country. Currently, Kyrgyzstan exports raw materials with low added value, importing significant amounts of food (Omurgazieva *et al.*, 2024). To change this situation, it is necessary to develop a programme to support exports of high-value-added products. A successful example of such an approach is the experience of Chile, which in recent years has significantly increased exports of wine and fruit through the creation of a national brand and active promotion in international markets (Panez *et al.*, 2020).

Similarly, to the Chilean experience, it is recommended that Kyrgyzstan create a brand "Ecologically clean products of Kyrgyzstan" to promote organic fruits, honey, and dried fruits in the EAEU and Chinese markets. At the same time, it is necessary to introduce a Global G.A.P. certification system for the 500 largest fruit and vegetable producers. This will facilitate access for Kyrgyz products to foreign markets, especially in the EU, where this standard is widely recognised. To optimise imports, the Kyrgyz poultry industry should be encouraged to reduce chicken meat imports by 50% within 5 years. A similar strategy was successfully implemented in Morocco, which not only fully supplied the domestic market but also became an exporter of poultry meat within a decade (Fagrach *et al.*, 2023). The implementation of these measures will require the development and adoption of a state programme for the development of agricultural exports for 2025-2030, as well as the establishment of the Agency for the Promotion of Agricultural Exports under the Ministry of Agriculture.

Improving the efficiency of agricultural production is critical to ensuring food security in Kyrgyzstan. Currently, the country faces problems of low agricultural productivity, insufficient use of modern technologies and fragmentation of land plots. To address these problems, it is recommended to create a comprehensive system of support for farmers, including advisory services, promotion of cooperation and the renewal of machinery. A successful example of the implementation of such a strategy is the experience of India, where an extensive network of agricultural advisory centres Krishi Vigyan Kendra was established, which led to a significant increase in labour productivity in the agricultural sector (Varshney *et al.*, 2019). Similar to the Indian experience, it is recommended to create a network of 7 regional agricultural-consulting centres in Kyrgyzstan based on existing agricultural universities and research institutes. These centres will provide farmers with information on modern farming and livestock production technologies, as well as advice on farm management and product marketing.

The development of agricultural cooperation is another important area for improving the efficiency of the agricultural sector. A successful example in this area is the experience of dairy co-operatives in Kenya, which helped small-scale producers improve the quality of their products and find stable markets (Onyango *et al.*, 2023). Building on this experience, it is recommended to develop an agricultural cooperative development programme that includes tax incentives and grants for newly established cooperatives. To upgrade the agricultural machinery fleet, it is proposed to introduce a preferential leasing programme with a 50% subsidy of the down payment for small and medium-sized farms. A similar programme has been successfully implemented in Brazil (Baccarin *et al.*, 2020). The implementation of these measures will require the adoption of the Law on Agricultural Consulting, amendments to the Tax Code of the Kyrgyz Republic, and the establishment of a state leasing company.

The development of agricultural processing and the creation of added value is a key factor in increasing the competitiveness of the Kyrgyz agricultural sector. Currently, the country has an underdeveloped processing industry and a low level of domestic processing of agricultural products. To solve this problem, it is recommended to create an infrastructure for processing agricultural products and stimulate the development of processing enterprises. A successful example of implementing such a strategy is the experience of Thailand, where the creation of agro-industrial clusters has led to a significant increase in the production of high-value-added products. Similarly, to the Thai experience, it is recommended to create 4 agro-industrial parks in Kyrgyzstan in the main agricultural regions of the country (Chui, Issyk-Kul, Osh and Talas oblasts). For instance, a complex to produce canned beans and other legume products could be created in the Talas region, which is known for its beans.

To stimulate the development of small processing enterprises in rural areas, it is proposed to develop a programme of concessional lending with an interest rate not exceeding 5% per annum. It is also recommended to introduce a system of tax preferences for vertically integrated agro-industrial complexes. A successful example of such integration in other countries is Olam International in Singapore, which has created vertically integrated chains of production and processing of various crops in developing countries. Implementation of these measures will require the adoption of the Law "On Agricultural Parks in the Kyrgyz Republic", amendments to the Tax Code of the Kyrgyz Republic and the establishment of a special fund for preferential lending to processing enterprises under the Russian-Kyrgyz Development Fund. Improving the system of quality control and food safety is critical to ensure food security and increase the competitiveness of Kyrgyz products in international markets. Currently, the country faces the problems of insufficiently equipped laboratories, lack of product traceability and food smuggling. To address these problems, it is recommended to modernise the system of quality control and food safety following international standards.

A successful example of modernising a quality control system is the experience of Chile, which managed to bring its system in line with EU and US requirements in a short time, which opened access to these important markets for Chilean products (Lu *et al.*, 2021). In Kyrgyzstan, it is recommended to equip 5 key laboratories of the Centre for Standardisation and Metrology and the State Inspectorate for Veterinary and Phytosanitary Safety with modern equipment to conduct analyses following EU standards. The introduction of a digital system for traceability of products "from field to counter" based on blockchain technology is another important step in improving food safety. Such a system has been successfully implemented in Australia, where it has significantly reduced cases of product falsification and increased consumer confidence (Ellahi *et al.*, 2023). Implementation of these measures will require the development and adoption of a state programme for modernisation of food quality control laboratories for 2025-2030, amendments to Law of the Kyrgyz Republic No. 67 (2004) and Criminal Code of the Kyrgyz Republic (2021).

Based on the recommendations presented to optimise the mechanism of state regulation in food security in Kyrgyzstan, it is possible to identify key areas and appropriate measures that can potentially bring significant benefits to the development of the national agricultural sector. For a clear presentation of this information, a summary table reflecting the main recommendations, their expected results and examples of successful international experience is presented below (Table 3).

***Table 3**. Key recommendations for optimising the mechanism of state regulation of the agricultural sector in Kyrgyzstan*

Direction	Recommended actions	Expected results	International experience
Subsidisation	Differentiated subsidies (up to 40% for seeds, 50% for drip irrigation, 60% for organic certification)	Yield growth by 20-25%, water consumption reduction by 30-40%	Turkey, Israel, Tunisia
Exports and imports	Creation of the brand "Ecologically clean products of Kyrgyzstan", introduction of Global G.A.P., development of poultry farming	Exports up 30%, imports down 50%	Chile, Morocco
Production efficiency	Establishment of 7 agricultural consulting centres, development of cooperation, and a preferential leasing programme for machinery	Increased labour productivity, 40% increase in the number of cooperatives	India, Kenya, Brazil
Product processing	Establishment of 4 agro-industrial parks, preferential lending of up to 5% per annum	Growth in the production of high-value-added products	Thailand, Singapore
Quality control	Modernisation of 5 key laboratories, implementation of a traceability system	Compliance with international standards, reduction of counterfeit products	Chile, Australia

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

Thus, the proposed recommendations, based on the successful experience of other countries and accounting for the specifics of Kyrgyzstan, will significantly optimise the mechanisms of state regulation in the field of food security in the country. Their implementation will increase the efficiency of agricultural production, increase exports of high-value-added products, develop the processing industry and improve the quality and safety of food, which will ensure the sustainable development of the agricultural sector of the Kyrgyz Republic.

DISCUSSION

The study of the mechanism of state regulation of the agricultural sector and food security in the Kyrgyz Republic revealed several key aspects and trends. The analysis showed that over the period 2014-2024, there has been a steady increase in the production of major agricultural products, including cereals, potatoes, vegetables, meat and milk. There is also an increase in the export potential of agricultural products, as evidenced by a 39.5% increase in exports of agri-food products in 2023 compared to the previous year. However, the study also identified several challenges, including insufficient self-sufficiency in certain types of food, dependence on imports for several key food products, and insufficient development of agricultural storage and processing systems. The analysis of government regulatory mechanisms showed the existence of a comprehensive regulatory framework but also identified problems in the implementation and effectiveness of existing support measures for agricultural producers.

The results of the study revealed insufficient development of innovation in the agricultural sector of Kyrgyzstan, which indicates the need to revise the existing mechanisms of state regulation in this area. In this context, the concept of "regulatory abstinence" proposed by M. Dewey and D. Di Carlo (2022), represents an alternative approach to stimulating innovation in agriculture. The authors consider the selective non-application or relaxation of regulations as an agricultural policy tool that can stimulate innovation and economic growth in certain agricultural sectors. However, an analysis of the situation in Kyrgyzstan shows that the approach described by M. Dewey and D. Di Carlo is practically not applied in the country. While the researchers note the potential effectiveness of this approach to stimulate innovation, the situation in Kyrgyzstan is characterised by the lack of effective mechanisms to support innovation in the agricultural sector.

This points to the need not only to revise existing regulations but also to develop a comprehensive strategy for innovative agricultural development that could include elements of "regulatory abstinence" combined with active measures to support innovation. Such an approach could be used to stimulate innovation in agricultural sectors that have the potential to diversify Kyrgyzstan's agricultural production and increase its productivity. For example, it could promote the development of innovative technologies in organic farming, precision agriculture or the development of new crop varieties adapted to local conditions.

The results of this study revealed a significant growth in agri-food exports from Kyrgyzstan, which increased by 39.5% in 2023 compared to the previous year. However, the analysis also revealed the national dependence on imports for several key food commodities. This finding takes on particular significance considering the study by M.A. Bashir *et al.* (2020), who investigated the relationship between export diversification and energy efficiency using OECD countries as an example. Although this study did not focus directly on energy efficiency, the situation in Kyrgyzstan is consistent with the findings of M.A. Bashir *et al.* on the importance of export diversification for sustainable economic development. However, the situation in Kyrgyzstan has its peculiarities. Unlike the OECD countries considered in their study, Kyrgyzstan faces more fundamental problems of structural transformation of the agricultural sector.

The analysis shows that for Kyrgyzstan, the issue of agricultural export diversification is closely linked not only to energy efficiency, but also to a wider range of issues, including the development of the processing industry, improving product quality to meet international standards, and integration into global food supply chains. This underscores the need to develop a comprehensive agricultural export diversification strategy that considers the specific conditions and constraints of Kyrgyzstan's agricultural sector, including its geographical location, agricultural production structure and available natural resources. In the context of analysing regulatory governance in the agricultural sector through the prism of political economy, the study by M. Guidi *et al.* (2020) provides an important theoretical framework. The authors propose to consider regulatory governance not only as a technical but also as a political process, influenced by various interest groups and institutional factors. This approach is particularly relevant for analysing the situation in the agricultural sector of Kyrgyzstan, where, as this study has shown, there are significant problems in the implementation of legislation and coordination between various government agencies responsible for agricultural development and food security. The conclusions of M. Guidi *et al.* on the importance of taking political factors into account when developing regulatory policy are confirmed by the identified institutional problems in Kyrgyzstan.

In particular, the results of the study point to the need for a deeper analysis of the political economy factors influencing the formulation and implementation of agricultural policy in the country. This includes not only formal institutions and procedures, but also informal practices, the distribution of power among different interest groups in the agricultural sector, and the historical patterns of interaction between the state and agricultural producers. Addressing these factors can help develop more effective and enforceable regulatory mechanisms that contribute to the development of the agricultural sector's productive and resource potential and improve Kyrgyz food security.

Considering the issues of modern economic regulation in the agricultural sector and its adaptation to changing conditions, C. Decker (2023) provides important theoretical and practical conclusions. The author emphasises the need to adapt regulatory mechanisms to rapidly changing technological and economic conditions, which is especially relevant in the era of digitalisation and globalisation of agricultural production. The findings of this study, which indicate insufficient development of innovation in Kyrgyz agriculture and the national weak integration into global food supply chains, suggest that the regulatory system of the agricultural sector does not fully meet the current challenges. In contrast to the developed economies considered by C. Decker, Kyrgyzstan faces more fundamental problems in creating an effective regulatory environment in agriculture. This includes not only technical aspects of regulation but also basic issues of institutional development, increasing transparency and accountability of regulatory bodies in the agricultural sector, as well as creating a culture of compliance among agricultural producers. In this context, C. Decker's proposals for introducing more flexible and adaptive forms of regulation may be particularly valuable for the Kyrgyz agricultural sector. However, their implementation will require significant efforts to strengthen the institutional capacity of agricultural regulators, develop feedback mechanisms for farmers and agricultural enterprises, and increase the overall level of digitalisation of the agricultural sector and its management.

Addressing the issue of taking national characteristics into account in the formulation of agricultural policy, the study by B. Clift (2021) provides a relevant perspective within the comparative analysis of political economy. The author emphasises the importance of historical, cultural and institutional characteristics of countries in the formulation of economic policies. This observation finds confirmation in the results of the present study, which indicate the need to adapt the international experience to the specific conditions of the agricultural sector in Kyrgyzstan. In particular, the identified problems in the implementation of agricultural legislation and coordination between government agencies responsible for agricultural policy indicate the importance of addressing the institutional characteristics of the country when developing regulatory mechanisms. However, the situation in Kyrgyzstan demonstrates that simply recognising national peculiarities is not enough. The results of the study show that the country faces serious challenges in adapting international practices of agricultural sector regulation to its conditions. This is particularly noticeable in the areas of innovative agricultural development and integration into global food supply chains, where Kyrgyzstan lags far behind many countries (Tsapova *et al.*, 2024). In this context, B. Clift's approach to comparative political economy analysis can be particularly useful for identifying successful practices of agricultural sector regulation in countries with similar characteristics and adapting them to Kyrgyz conditions.

Analysing aspects of sustainable agricultural development and the role of the state in this process, G. D'Alisa and G. Kallis (2020) offer an alternative view of economic development through the concept of "degrowth". Although the authors focus on developed economies, their ideas can be partially applied to the agricultural sector of Kyrgyzstan. The authors consider the role of the state in the context of the transition to more sustainable models of economic development, which are not based solely on the constant growth of production. Although Kyrgyzstan does not face the challenges of the developed economies discussed by the authors, their observations on the need to rethink the role of economic growth in public policy may be relevant for the Kyrgyz agricultural sector in the long term. The findings of this study, which point to the uneven development of different agricultural sub-sectors and problems with food security, emphasise the importance of finding more sustainable models for agricultural development.

In the context of Kyrgyzstan, this may not denote abandoning agricultural production growth, but rather reorienting towards higher quality and more inclusive growth that considers environmental and social aspects. This is particularly relevant considering the identified problems with agricultural diversification and the uneven distribution of benefits from agricultural sector development. For example, this could include support for organic farming, the development of agroecological practices, and the promotion of high-value-added products rather than simply increasing the production of raw materials (Trusova *et al.*, 2021). However, the implementation of such ideas in the Kyrgyz agricultural sector will require significant institutional changes and a rethinking of the role of the state in agricultural development, including a review of the subsidy system, support for small farmers and rural development.

In general, a comparison of the results of the study with the works of other authors can be used to conclude that Kyrgyzstan faces several unique challenges in the field of state regulation of economic potential. While many of the theoretical concepts developed for developed economies remain relevant, their application requires significant adaptation to the country's specific conditions. Particular attention should be paid to the diversification of the economy, the development of innovation and the improvement of the institutional environment for more efficient use of national production, resource and export potential. It is important to consider not only economic but also social, environmental and political aspects of development, which requires a comprehensive and interdisciplinary approach to the development and implementation of regulatory policy.

CONCLUSIONS

An analysis of the current state and dynamics of the agricultural sector over the period 2014-2024 revealed an upward trend in the production of major agricultural products. An increase in the production of grain crops by 11.6%, potatoes by 12.5%, vegetables by 18.2%, meat by 24.5% and milk by 17.1% was noted. These figures indicate a gradual development of agricultural production in the country. An analysis of Kyrgyz self-sufficiency in staple foods has revealed a mixed picture, reflecting both achievements and challenges in the country's agricultural sector. Despite the overall growth in agricultural production, there is a significant shortage of several key food items.

Particularly low self-sufficiency is observed in the production of fruits and berries, where the level is only 18.2%. This indicates a significant dependence on imports of fruits and berries, which may be due to the underdevelopment of horticulture and berries growing in the country. The production of vegetable oil also remains a problematic area with a self-sufficiency level of 44%, which indicates the need to develop oilseeds and processing capacities. The situation with sugar is somewhat better, but still insufficient, with a self-sufficiency level of 69%, indicating the need to expand sugar beet production and modernise sugar factories. On the other hand, Kyrgyzstan has reached a high level of self-sufficiency in some agricultural products, which creates potential for exports. For example, the level of self-sufficiency in potatoes reaches 167.4%, which not only fully meets domestic needs, but also creates significant export potential. A similar situation is observed in the production of vegetables, where the level of self-sufficiency is 164.5%, which indicates a well-developed vegetable production in the country. The dairy industry also shows positive metrics, with a self-sufficiency level of 116.5%, which allows it not only to supply the domestic market but also to export dairy products. This unevenness in the levels of self-sufficiency for different types of products indicates the need for a more balanced approach to the development of various sectors of the Kyrgyz agriculture and food industry.

A study of existing mechanisms of state regulation revealed the existence of a comprehensive legislative framework, including the Law "On Food Security" and the "Food Security and Nutrition Programme for 2019-2023". Based on the analysis, recommendations for optimising the mechanism of state regulation have been developed. The key areas of improvement are the introduction of a differentiated subsidy system, optimisation of the structure of export and import of agricultural products, increasing the efficiency of agricultural production, development of agricultural processing and improvement of the system of food quality control. The developed recommendations are aimed at overcoming the identified problems creating more favourable conditions for the development of agriculture and ensuring the food security of the country. The limitations of this study are related to the use of secondary data and the lack of field research. Prospects for further research include a more detailed analysis of the effectiveness of the proposed measures in practice, exploring the possibilities of adapting the successful international experience to the specific conditions of Kyrgyzstan and studying the impact of climate change on the country's food security. Particular attention should be devoted to the analysis of the potential for the development of organic agriculture and its role in ensuring food security in Kyrgyzstan.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Ayars, J.E., Zaccaria, D., & Bali, K.M. (2024). *Microirrigation for crop production: Design, operation and management*. Amsterdam: Elsevier Science. doi: 10.1016/C2021-0-02073-3.
[2] Baccarin, J.G., de Oliveira, J.A., & Mardegan, G.E. (2020). The environmental, social and economic effects of recent technological changes in sugarcane on the State of São Paulo, Brazil. *Journal of Agrarian Change*, 20(4), 598-617. doi: 10.1111/joac.12384.
[3] Bashir, M.A., Sheng, B., Doğan, B., Sarwar, S., & Shahzad, U. (2020). Export product diversification and energy efficiency: Empirical evidence from OECD countries. *Structural Change and Economic Dynamics*, 55, 232-243. doi: 10.1016/j.strueco.2020.09.002.
[4] Benabdelkader, M., Saifi, R., & Saifi, H. (2021). Sustainable agriculture in some Arab Maghreb countries (Morocco, Algeria, Tunisia). In M. Abu-hashim, F.K. Allouche & A. Negm (Eds.), *Agro-environmental sustainability in MENA regions* (pp. 233-261). Cham: Springer. doi: 10.1007/978-3-030-78574-1_10.
[5] Cevher, C., & Cevher, Ş.C. (2021). Effect of state subsidies granted to farmers for certified seeds on wheat yield in Turkey. *AGROFOR*, 6(2), 35-42. doi: 10.7251/AGRENG2102035C.
[6] Clift, B. (2021). *Comparative political economy: States, markets and global capitalism*. London: Bloomsbury Publishing.
[7] Criminal Code of the Kyrgyz Republic. (2021). Retrieved from https://mvd.gov.kg/rus/ministry/normative-bases/22.
[8] Customs Code of the Eurasian Economic Union. (2018). Retrieved from https://www.irtek.am/views/act.aspx?aid=150345.

[9] D'Alisa, G., & Kallis, G. (2020). Degrowth and the state. *Ecological Economics*, 169, article number 106486. doi: 10.1016/j.ecolecon.2019.106486.
[10] De Marchi, V., & Alford, M. (2022). State policies and upgrading in global value chains: A systematic literature review. *Journal of International Business Policy*, 5(1), 88-111. doi: 10.1057/s42214-021-00107-8.
[11] Decker, C. (2023). *Modern economic regulation: An introduction to theory and practice*. Cambridge: Cambridge University Press. doi: 10.1017/9781009083621.
[12] Dewey, M., & Di Carlo, D. (2022). Governing through non-enforcement: Regulatory forbearance as industrial policy in advanced economies. *Regulation & Governance*, 16(3), 930-950. doi: 10.1111/rego.12382.
[13] Dolynska, M. (2023). Superficies as one of the legal forms of land use in farming activities. *Social and Legal Studios*, 6(3), 16-23. doi: 10.32518/sals3.2023.16.
[14] Ellahi, R.M., Wood, L.C., & Bekhit, A.E. (2023). Blockchain-based frameworks for food traceability: A systematic review. *Foods*, 12(16), article number 3026. doi: 10.3390/foods12163026.
[15] Erdoğan, S., Yıldırım, D.Ç., & Gedikli, A. (2020). Natural resource abundance, financial development and economic growth: An investigation on Next-11 countries. *Resources Policy*, 65, article number 101559. doi: 10.1016/j.resourpol.2019.101559.
[16] Exports of agricultural products from Kyrgyzstan in 2023 totalled 820 thousand tonnes. (2023). Retrieved from https://interpost.kg/blog/news/export-of-agricultural-products-from-kr-in-2023-amounted-820-thousand-tons.html.
[17] Fagrach, A., Fellahi, S., Challioui, M.K., Arbani, O., El Zirani, I., Kichou, F., & Bouslikhane, M. (2023). Backyard poultry flocks in Morocco: Demographic characteristics, husbandry practices, and disease and biosecurity management. *Animals*, 13(2), article number 202. doi: 10.3390/ani13020202.
[18] Gao, Z., Li, L., & Hao, Y. (2024). Resource industry dependence and high-quality economic development of Chinese style: Reexamining the effect of the "Resource Curse". *Structural Change and Economic Dynamics*, 68, 1-16. doi: 10.1016/j.strueco.2023.09.013.
[19] Gertz, G., & Evers, M.M. (2020). Geoeconomic competition: Will state capitalism win? *Washington Quarterly*, 43(2), 117-136. doi: 10.1080/0163660X.2020.1770962.
[20] Guidi, M., Guardiancich, I., & Levi-Faur, D. (2020). Modes of regulatory governance: A political economy perspective. *Governance*, 33(1), 5-19. doi: 10.1111/gove.12479.
[21] Kryvenko, N. (2022). Development of trade and economic relations of the BSEC countries. *Scientific Bulletin of Mukachevo State University. Series "Economics"*, 9(1), 9-23. doi: 10.52566/msu-econ.9(1).2022.9-23.
[22] Law of the Kyrgyz Republic No. 161 "On the State Development Bank of the Kyrgyz Republic". (2012, August). Retrieved from https://online.zakon.kz/Document/?doc_id=31240523.
[23] Law of the Kyrgyz Republic No. 175 "On Veterinary Medicine". (2014, December). Retrieved from https://cbd.minjust.gov.kg/205396/edition/1278754/ru.
[24] Law of the Kyrgyz Republic No. 183 "On Food Security of the Kyrgyz Republic". (2008, August). Retrieved from https://faolex.fao.org/docs/pdf/kyr96019.pdf.
[25] Law of the Kyrgyz Republic No. 2 "On Plant Quarantine". (2015, January). Retrieved from https://cbd.minjust.gov.kg/205424/edition/1278732/ru.
[26] Law of the Kyrgyz Republic No. 52 "On Customs Regulation". (2019, April). Retrieved from https://cbd.minjust.gov.kg/111908/edition/1289610/ru.
[27] Law of the Kyrgyz Republic No. 67. "On Technical Regulation in the Kyrgyz Republic". (2004, May). Retrieved from https://cbd.minjust.gov.kg/1453/edition/1185288/ru.
[28] Lu, H., Mangla, S.K., Hernandez, J.E., Elgueta, S., Zhao, G., Liu, S., & Hunter, L. (2021). Key operational and institutional factors for improving food safety: A case study from Chile. *Production Planning & Control*, 32(14), 1248-1264. doi: 10.1080/09537287.2020.1796137.
[29] Malca, O., Peña-Vinces, J., & Acedo, F.J. (2020). Export promotion programmes as export performance catalysts for SMEs: Insights from an emerging economy. *Small Business Economics*, 55(3), 831-851. doi: 10.1007/s11187-019-00185-2.
[30] Mozhaikina, N., & Ostrovskyi, I. (2024). Features development and management of the export potential in small and medium-sized enterprises. In *Traditional and innovative approaches in economics: Theory, methodology, practice* (pp. 206-222). Riga: Baltija Publishing. doi: 10.30525/978-9934-26-407-8-10.
[31] Mukhametov, A., Aliyeva, N., Musayeva, N., & Mammadova, U. (2023). Antioxidant activity and phenolic content of cereal food concentrates: Import control issues. *Agriculturae Conspectus Scientificus*, 88(4), 317-324.
[32] Naizabekova, A.A., & Iskakova, Z.D. (2024) The role of investing in agriculture for sustainable economic development. *Bulletin of "Turan" University*, 1, 241-255. doi: 10.46914/1562-2959-2024-1-1-241-255.

[33] National Statistical Committee of the Kyrgyz Republic. (2015-2024). Agriculture of the Kyrgyz Republic 2010-2014. Retrieved from https://stat.gov.kg/media/publicationarchive/f033ee5d-fb21-42cb-862f-ef9c7e44ab52.pdf.
[34] Omurgazieva, N., Tilekeeva, B., Bekkozhaeva, A., Chanachev, N., & Cholponkulov, T. (2024). Impact of tax policy on the development of agrarian enterprises and organisations. *Ekonomika APK*, 31(3), 34-44. doi: 10.32317/2221-1055.2024030.34.
[35] Onyango, V.A., Owuor, G., Rao, E.J., & Otieno, D.J. (2023). Impact of cooperatives on smallholder dairy farmers' income in Kenya. *Cogent Food & Agriculture*, 9(2), article number 2291225. doi: 10.1080/23311932.2023.2291225.
[36] Panez, A., Roose, I., & Faúndez, R. (2020). Agribusiness facing its limits: The re-design of neoliberalization strategies in the exporting agriculture sector in Chile. *Land*, 9(3), article number 66. doi: 10.3390/land9030066.
[37] Providing Kyrgyzstan with food products. (2023). Retrieved from https://agro.gov.kg/ru/11322/.
[38] Regulations on the Centre for Standardisation and Metrology under the Ministry of Economy and Finance of the Kyrgyz Republic. (2021). Retrieved from https://cbd.minjust.gov.kg/158201/edition/1088056/ru.
[39] Regulations on the Procedure for Granting Subsidies to Agricultural Commodity Producers for the Purchase of Plant Protection Products. (2017). Retrieved from https://www.gov.kg/wp-content/uploads/2017/10/poryadok-PREDOSTAVLENIYA-GOSUDARSTVENNOY-PODDERZHKI.docx.
[40] Resolution of the Government of the Kyrgyz Republic No. 320 "On Approval of the Programme of Food Security and Nutrition in the Kyrgyz Republic for 2019-2023". (2019, June). Retrieved from https://faolex.fao.org/docs/pdf/kyr195970.pdf.
[41] Sakkaraeva, D., & Kumashev, M. (2024). Analysis of the agro-industrial sector of the Kyrgyz Republic. *Ekonomika APK*, 31(2), 41-50. doi: 10.32317/2221-1055.202402041.
[42] Trusova, N.V., Prystemskyi, O.S., Hryvkivska, O.V., Sakun, A.Zh., & Kyrylov, Y.Y. (2021). Modeling of system factors of financial security of agricultural enterprises of Ukraine. *Regional Science Inquiry*, 13(1), 169-182.
[43] Tsapova, O., Zhailaubayeva, S., Kendyukh, Y., Smolyaninova, S., & Abdulova, O. (2024). Industry specifics and problems of digitalization in the agro-industrial complex of the Republic of Kazakhstan. *Journal of the Knowledge Economy*. doi: 10.1007/s13132-024-02283-3.
[44] Varshney, D., Joshi, P.K., & Dubey, S.K. (2019). Direct and spillover effects of agricultural advisory services: Evidence from the farm science centre in Uttar Pradesh, India. *IFPRI Discussion Paper 01850*. doi: 10.2499/p15738coll2.133316.
[45] Wang, F., & Dai, X. (2020). Regulation and product innovation: The intermediate role of resource reallocation. *Journal of Evolutionary Economics*, 30(4), 1035-1061. doi: 10.1007/s00191-020-00676-6.
[46] What agricultural products Kyrgyzstan imported and exported in 2023. (2024). Retrieved from https://24.kg/ekonomika/284609_kakuyu_selhozproduktsiyu_kyirgyizstan_importiroval_ieksportiroval_v2023_godu/.

Механізм державного регулювання виробничо-ресурсного та експортного потенціалу Киргизької Республіки

Салтанат Деркенбаєва
Старший викладач
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0002-4580-9730
Чинара Адіяєва
Старший викладач
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0002-2022-1439
Нуріла Ібраєва
Кандидат економічних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0002-0301-6070
Тінатін Сидикова
Старший викладач
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0001-9844-0570
Гульнара Оганова
Старший викладач
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0003-1581-726X

Анотація. Дослідження присвячено аналізу механізму державного регулювання виробничо-ресурсного та експортного потенціалу Киргизької Республіки. Метою роботи було вдосконалення системи державного регулювання аграрного сектора для підвищення продовольчої безпеки країни. Проведений аналіз виявив стійке зростання виробництва основних видів сільськогосподарської продукції за період 2014-2024 рр.: зернових культур на 11,6 %, картоплі на 12,5 %, овочів на 18,2 %, м'яса на 24,5 % і молока на 17,1 %. Однак дослідження також засвідчило нерівномірність у рівнях самозабезпеченості за різними видами продукції: високі показники щодо картоплі (167,4 %), овочів (164,5 %) та молока (116,5 %) контрастують із низьким рівнем самозабезпеченості фруктами та ягодами (18,2 %), рослинною олією (44 %) та цукром (69 %). Аналіз наявних механізмів державного регулювання виявив наявність комплексної законодавчої бази, що включає Закон Киргизької Республіки № 320 "Про продовольчу безпеку" та "Програму продовольчої безпеки та харчування на 2019-2023 роки", проте ефективність їхньої реалізації обмежується недостатнім фінансуванням та адміністративними бар'єрами. На основі проведеного аналізу було розроблено рекомендації щодо оптимізації механізму державного регулювання, що включають впровадження диференційованої системи субсидування, оптимізацію структури експорту та імпорту агропродукції, підвищення ефективності сільськогосподарського виробництва, розвиток переробки сільгосппродукції та вдосконалення системи контролю якості продуктів харчування. Запропоновані заходи включають створення бренду "Екологічно чисті продукти Киргизстану", впровадження системи сертифікації Global G.A.P., створення мережі регіональних центрів агроконсалтингу, розвиток агропромислових парків і модернізацію лабораторій контролю якості. Реалізація цих заходів спрямована на подолання виявлених проблем і створення більш сприятливих умов для розвитку сільського господарства та забезпечення продовольчої безпеки Киргизької Республіки

Ключові слова: аграрний сектор; сільськогосподарське виробництво; продовольча безпека; самозабезпеченість; субсидіювання; пільгове кредитування; експортний потенціал

Журнал
«НАУКОВІ ГОРИЗОНТИ»

Том 27, № 9
2024

Редагування англомовних текстів:
С. Воровський

Відповідальний редактор:
Д. Кокра

Редагування бібліографічних списків:
Д. Кокра

Комп'ютерна верстка:
О. Глінченко

Підписано до друку з оригінал-макета 28.08.2024
Ум. друк. арк. 20,7
Тираж 100 прим.

Видавництво: Поліський національний університет
10008, б-р Старий, 7, м. Житомир, Україна
Тел. (0412) 22-04-17
E-mail: info@sciencehorizon.com.ua
https://sciencehorizon.com.ua

Journal
"SCIENTIFIC HORIZONS"

Volume 27, No. 9
2024

Editing English-Language Texts:
S. Vorovsky

Managing Editor:
D. Kokra

Editing Bibliographic Lists:
D. Kokra

Desktop Publishing:
O. Glinchenko

Signed to the print with the original layout 28.08.2024
Conventional Printed Sheet 20.7
Circulation 100 copies

Publisher: Polissia National University
10008, 7 Staryi Bvld., Zhytomyr, Ukraine
Tel. (0412) 22-04-17;
E-mail: info@sciencehorizon.com.ua
https://sciencehorizon.com.ua/en