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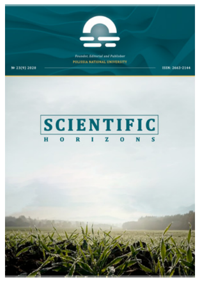

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Effect of probiotic biopreparation on fatness, organoleptic, and chemical parameters of broiler chicken meat

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Abstract. The relevance of this study was to use the probiotic biopreparation Subtiform in the production of broiler chickens to increase productivity and improve the organoleptic and chemical characteristics of poultry slaughter products. The purpose of this study was to determine the effect of a probiotic biopreparation on the fatness of broiler chickens, the chemical composition of meat and chemical parameters using the developed patented express and optimised methods. The following methods

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were used: physical, organoleptic, chemical. It was found that the use of *Bacillus subtilis* and *Bacillus licheniformis* ($2.5×10^9$ CFU/g) with whey powder filler increased productivity, specifically, the live weight of broiler chickens increased by 4.02% (P<0.001) when fed at a dose of 2.0 g/10 dm^3 of water and by 4.75% (P<0.001) in experiment 3 compared to the control group. An increase in indicators in the experimental group 3 was found, namely, the average daily weight gain of carcasses – by 8.33% (P<0.001); total weight of the bird carcass and neck giblets – by 26.48% (P<0.001); weight of internal fat – by 1.89 times (P<0.001) compared to the control. Statistical significance (P<0.001) was also found in the increase in the weight of internal organs (stomach, liver, heart, adrenal gland) in experimental groups 2 and 3 compared to the control. The improvement in organoleptic and tasting characteristics of poultry meat and meat broth after feeding the probiotic preparation, specifically in experimental group 3, was summarised. The obtained quantitative and qualitative chemical parameters using express and optimised methods indicated the freshness of broiler chickens meat at (0-4)°C cooling, at which it is allowed to sell poultry carcasses up to 5 days, of control and experimental groups 1, 2, 3. The practical value of this study lies in the use of a probiotic biopreparation by veterinary specialists at broiler chick production facilities to increase the productivity of broiler chickens and improve the quality and safety of their slaughter products

Keywords: probiotic; poultry fatness; chemical composition of meat; qualitative and quantitative indicators; express and advanced methods

INTRODUCTION

The relevance of this study lies in determining the effect of the probiotic biopreparation on the fattening of broiler chickens, as well as on organoleptic, tasting, and chemical parameters. S.L. Weimer *et al.* (2018) noted that in European countries, in the production of broiler chicken meat, the search for probiotic preparations is carried out to satisfy food market operators with intensive poultry rearing technology and obtain high quality and safety indicators of meat and slaughter products. P. Chaturvedi *et al.* (2021) noted that probiotics are an alternative to preventing the use of antibiotics in animal feeding, as antibiotic resistance is emerging, which should be assessed for their toxicity levels when investigating them in the environment and in animals, and to identify potential hazardous risks to human health and the environment.

When broiler chickens were fed the probiotic preparation of *Bacillus subtilis* (10^6 CFU/g) for 6 weeks, an increase in the average weight of the poultry group was determined by 17.19% as early as in the 5th week compared to the control group (P<0.05). According to Y. Dong *et al.* (2020), research findings indicated that the probiotic preparation of *Bacillus subtilis* can be used instead of antibiotics to stimulate the growth of poultry, improve immunity, and increase resistance to infectious diseases of poultry. The positive effect of probiotic preparations containing *Clostridium butyricum* ($6×10^9$ CFU/g) and *Enterococcus faecalis* ($2×10^{10}$ CFU/g) on animal productivity, increase in final weight, increase in average daily gain and feed conversion was established (Wang *et al.*, 2019). EU legislation prohibits the use of various antibiotics in poultry feeding. Thus, when a probiotic containing *C. butyricum* was used in the feeding of broiler chickens, poultry productivity increased due to improved morphological characteristics of blood and internal organs and stimulation of immune development.

M.E. Abd El-Hack *et al.* (2020) point out that strict regulatory parameters for the use of antibiotics in poultry feed have been introduced. Therefore, the use of *Bacillus subtilis*, the most popular bacterium, is an alternative to the use of industrial feed for poultry, specifically, it increases immunity, improves productivity, organoleptic characteristics, and the chemical composition of broiler chickens. In the context of the development of intensive technologies for raising broiler chickens, it is necessary to feed them with high-quality probiotic preparations that have inhibitory properties against opportunistic and pathogenic strains of microorganisms and viruses. For fifteen years, H.H. Xiong (2023) has been searching for an alternative use of probiotic preparations that affect the increase in the productivity of animals and poultry due to the effect on antioxidant activity and immunological status. All this indicated an increased resistance of poultry and animals to the effects of opportunistic and pathogenic microorganisms, which is supported by the findings of J. Choi *et al.* (2023).

K. Queenan *et al.* (2022) noted that the use of developed and implemented probiotics in the field of broiler chickens is caused by the growing problem of antibiotic-resistant microorganisms. Therefore, in broiler production, it is necessary to implement food safety and quality control systems for broiler chickens, including traceability systems and hazard analysis systems at critical control points, and to consider the health of the bird, quality feeding, and environmental sustainability. According to C.J. Savelli *et al.* (2021), the Food Safety, Health and Welfare Management System for Poultry regulates risk-based controls related to the safe feeding of animals and poultry during the rearing and production of slaughter products, as well as the establishment of critical control points in the food and feed chains. Food market operators in the production of broiler chickens ensure a new formation of international legislation on the production of safe poultry products under the supervision of a veterinary specialist, including the use of probiotic preparations in the poultry feeding ration.

Thus, the use of the new probiotic Subtiform preparation is highly relevant for the development of poultry production in Ukraine and the provision of safe food products to ordinary consumers. The purpose of this study was to determine the effect of the probiotic biopreparation on the fatness of broiler chickens, the chemical composition of meat, and chemical parameters using the developed patented express and optimised methods.

THEORETICAL OVERVIEW

C. Chen *et al.* (2020) found that the development of modern poultry farming in foreign countries is based on the use of optimised technological processes for the production, processing, and circulation of broiler meat. Pasture and free-range systems have become the most popular for the production of broiler chickens. However, according to R.E. Jeni *et al.* (2021), there are still problems associated with exposure to microorganisms and their foodborne pathogens in these environments, and therefore, probiotics should be allowed in the poultry diet as feed additives to improve food safety and poultry health by reducing pathogens and improving the production of quality meat.

T.M. Mohamed *et al.* (2022) indicated that when poultry were fed the main diet containing the *Bacillus subtilis* probiotic (5×10^8 CFU/g), the average daily weight gain of broiler chickens and the weight of internal organs increased. The organoleptic and chemical characteristics of the meat were also improved. The use of the probiotic preparation *Bacillus amyloliquefaciens* LFB112 in broiler poultry production resulted in higher live weight and average daily gain, lower feed conversion rate compared to the control group (without the addition of the probiotic), and a decrease in fat content. As reported by M. Ahmat *et al.* (2021), the immune status of poultry also increased during poultry rearing. L. Zhang *et al.* (2021) noted that the addition of 1% probiotics (*L. casei*, *L. acidophilus* and *Bifidobacterium*) to broiler chickens' water had a positive effect on growth performance, carcass characteristics, including the determination of the first category of poultry, immune function and antioxidant capacity in poultry, a decrease in the total number of E. coli and Salmonella, and an increase in the number of lactobacilli ($P<0.05$).

L. Jacobs *et al.* (2020) state that the safety of water for broiler chickens should be considered when feeding probiotics to poultry. It is necessary to follow sanitary and hygienic requirements for watering them, as well as to test the microbiological parameters of the water, as these criteria affect the health and welfare of poultry, as well as their productivity. According to F.V. Baba and Z. Esfandiari (2023), the use of probiotics in broiler production is an urgent issue in that it prevents the occurrence of diseases of infectious aetiology, normalises the composition of the microflora in the intestine, increases poultry fatness, quality, and safety of meat and offal, and prevents the biological risk of diseases in broiler chickens. F.U. Memon *et al.* (2022) found that the safety and quality of broiler chicken meat depends on the health of the poultry, on the safety and quality of feed, and therefore feed should be monitored for toxins produced by harmful microorganisms, specifically *Aspergillus fumigates, Stachybotrys alternans*, *Aspergillus flavus*, etc. Therefore, stabilising the balance of the poultry intestines with the use of probiotics is crucial in terms of poultry disease resistance and the production of high-quality and safe products.

The feeding of broiler chickens with probiotic preparations can reduce the incidence of infectious gastrointestinal diseases, leading to increased poultry productivity and improved quality and safety of poultry meat (Abdulkhaliq & Sabow, 2023). Additionally, it can increase the weight of muscle tissue, improve the taste of meat broth and cooked meat, and enhance the chemical composition of meat, particularly its energy value (caloric content).

N.R. Wani *et al.* (2023) noted that feeding probiotics to broiler chickens for up to 42 days of rearing not only increases their productivity, i.e., an increase in carcass weight, an increase in absolute and average daily gain, a decrease in feed inversion, but also improves the chemical composition of poultry meat, which satisfies ordinary consumers with useful nutrients that are easily absorbed by the body. According to P. Chaturvedi *et al.* (2021), the key issue nowadays is the use of probiotics in poultry farming to prevent and treat gastrointestinal infections of bacterial and viral aetiology, increase poultry fatness, normalise intestinal microflora in dysbiosis of various origins. G. Delgado-Pando *et al.* (2019) found high efficiency in the use of probiotics from the *Bacillus* genus for the prevention and treatment of staphylococcal and salmonellosis infections.

To more effectively determine the quality of poultry meat and fat, including its freshness, scientists are developing rapid and optimised methods. Thus, W. Yao *et al.* (2021) developed and implemented a method for the identification of volatile substances (aldehydes, esters, volatile fatty acids) in broiler chicken meat processing by determining the aroma via ion mobility spectrometry with gas chromatography in free space over steam (HS-GC-IMS). Y. Wang *et al.* (2019) found that the use of probiotic preparations in broiler poultry farming increases their productivity, namely carcass weight gain, safety, and quality of meat and offal, which provides the average consumer with nutrients that are quickly absorbed.

MATERIALS AND METHODS

In 2021-2023, at the Skybynetska Poultry Farm LLC in the village of Skybyntsi, Tetiiv district, Kyiv region, a study was conducted on the 42nd day of slaughter of broiler chickens of the COBB-500 cross at the end of rearing of the control group, which was not fed with probiotic, and experimental groups 1, 2, 3, which were fed from 28 days to 42 days with the probiotic biopreparation Subtiform in doses, respectively: 0.5, 2.0, and 4.0 g/10 dm^3 of water per 20 birds in a cage. The probiotic biopreparation is a symbiotic preparation manufactured at the Biotechnology Centre of Ukraine, Vinnytsia region, Ukraine, containing bacteria of the genus *Bacillus subtilis* and *Bacillus licheniformis* (2.5×10^9 CFU/g) and whey powder.

The study was conducted in the accredited research laboratory of the Department of Veterinary and Sanitary Expertise and Laboratory Diagnostics of Bila Tserkva National Agrarian University, as well as in the research chemical and toxicological department of the State Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise.

Investigation of carcass fatness indicators of broiler chickens. In the experimental groups of poultry, when fed in different doses, the effect of the probiotic biopreparation on the fattening of broiler chickens carcasses was investigated, namely their live weight at the beginning and end of the experiment; absolute weight gain; average daily weight gain; total weight of the bird carcass, including the neck; weight of the carcass without internal organs; weight of internal fat of the bird carcass; weight of internal organs (stomach, liver, heart, adrenal gland) according to generally accepted methods (Bogatko, 2019).

Investigation of organoleptic and tasting characteristics of broiler chicken meat. After slaughtering broiler chickens, carcass samples in the amount of 6 pieces from each control and experimental groups were subjected to tests for organoleptic parameters, specifically the appearance of carcasses, degree of plumage removal, skin condition, condition of the bone system, muscle consistency, colour of muscle tissue, skin colour, colour of subcutaneous and internal adipose tissue, odour on the surface of the carcass and near the bones, cooking test for assessing the quality of meat broth (DSTU 3143:2013, 2014), and the tasting characteristics of meat broth and cooked meat were determined according to a 5-point scale for evaluating each of the indicators (DSTU 4823.2:2007, 2009).

Study of the chemical composition of broiler chicken meat. Chemical composition of broiler chickens: the mass fraction of moisture was determined by mixing a homogenised meat sample at 25°C with sand and drying it at (103±2)°C, and then calculating it using the formula (DSTU ISO 1442:2005, 2008); mass fraction of solids by calculating the difference from 100% and the mass fraction of water; mass fraction of fat by boiling the meat sample with dilute hydrochloric acid until the bound and unbound lipid fractions are released, filtering the resulting mass, drying, and extracting the fat remaining on the filter with n-hexane or petroleum ether, and then calculating it according to the formula (DSTU ISO 1443:2005, 2008); the mass fraction of protein by the Kjeldahl method, considering the conversion factor for the mass fraction of nitrogen to the mass fraction of protein (DSTU ISO 937:2005, 2007); the mass fraction of ash by determining the mass of the residue after burning the meat sample and then piercing it, and subtracting the mass fraction of crude ash in percentage according to the formula (DSTU ISO 936:2008, 2008); carbohydrate content by subtracting the sum of the mass fractions of protein, fat, and ash from the mass fraction of dry matter, and energy value by determining the energy value by calculating the formula of already known nutritional data (mass fractions of protein, carbohydrates and fat) using energy value coefficients (4.0, 9.0).

Study of chemical parameters of fat and meat of broiler chickens. The chemical parameters of fat and meat of broiler chickens were also determined, namely: the acid number of fat by extracting a sample of meat with an alcohol-benzene mixture and subsequent titration of free fatty acids in the presence of phenolphthalein indicator and subtraction in mg of potassium hydroxide (Utility model patent No. 147314, 2021); fat peroxide number by extracting the fat sample with solutions of a mixture of ice-cold acetic acid and chloroform, potassium iodide solution and subsequent titration of free iodine and subsequent titration with sodium hyposulphite and calculation using the formula in % iodine (Utility model patent No. 147145, 2021); the reaction of the fat sample with neutral red to detect colour change and determine freshness (Utility model patent No. 147144, 2021); Nesler's number using the Nesler reagent and colour change from greenish yellow to intense orange depending on the degree of freshness of the meat (Utility model patent No. 147313, 2021); copper sulphate reaction by precipitation of enzymatic hydrolysis products of proteins accumulated during autolytic decomposition of meat and transferred to the broth during cooking (DSTU 8253:2015, 2017); content of volatile fatty acids by their isolation by water vapour distillation and determination of their mass fraction by titration with sodium hydroxide and calculation according to the formula in mg *KOH*/g(Utility model patent No. 152944, 2023); ammonia content and ammonium salts formed as a result of autolysis of meat, to form yellow-brown mercuric iodide with Nesler's reagent (DSTU 8253:2015, 2017); the optical density of the meat and water extract by the photometric method for the extraction of the meat and water extract with Nessler's reagent using the FEC-3 photoelectrocolourimeter (Utility model patent No. 147315, 2021); *pH* value according to the ionometric method by extracting the meat sample with distilled water, and measuring the ion concentration using an AI ionometer (DSTU ISO 2917-2001, 2003); ammonia nitrogen content by treatment with sodium hydroxide solution in the presence of phenolphthalein indicator and subsequent calculation in mg according to the formula (Utility model patent No. 153118, 2023); hydrogen sulphide presence by its interaction with lead acetic acid (BM 12.3-2).

Statistical analysis. The reliability of the study was confirmed by the use of certified equipment, modern test methods, and statistical processing of the results. Statistical processing of the research results was conducted using the computer program "Microsoft Excel" (Maplesoft, 2008). The probability was determined according to the Student's t-test, considering the statistical significance criteria: $P<0.05$, $P<0.01$, $P<0.001$.

Biological ethics. Experimental studies were conducted following modern methodological approaches and the requirements and national standards, namely DSTU ISO/IEC 17025:2019 (2021) and Directive 2010/63/EU (2010), which were approved by the conclusion of the Ethics and Bioethics Commission of the Faculty of Veterinary Medicine of Bila Tserkva National Agrarian University dated 12 April 2023. Animal husbandry and all manipulations were performed following the provisions of the Procedure for conducting tests and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), and of the European Convention for the protection of vertebrates used for experimental and other scientific purposes (1986).

RESULTS

The results of the study of carcass fatness of broiler chickens in the control and experimental groups 1, 2, and 3 when fed the probiotic biopreparation Subtiform at doses of 0.5 g/10 l, 2.0 g/10 l, and 4.0 g/10 l, including the live weight of broilers at the beginning and end of the experiment are presented in Figure 1.

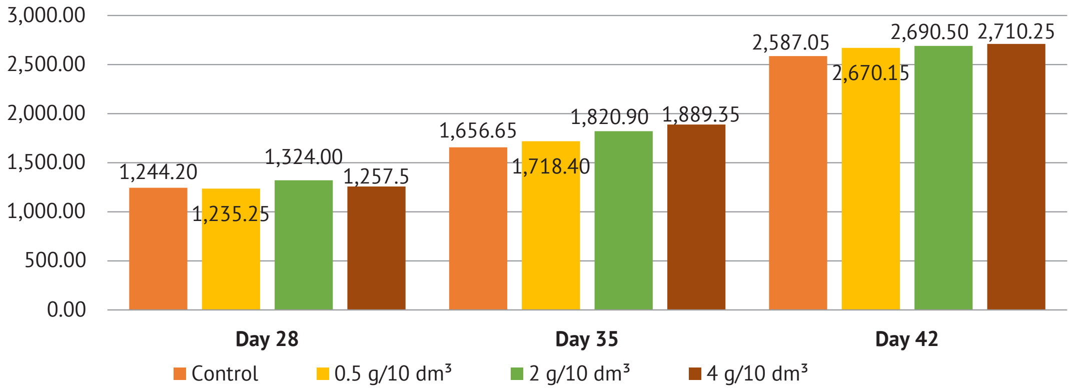

Figure 1. *Weight of broiler chickens at the beginning and end of the experiment with probiotic feeding, g (M±m, n=20)*
Source*: developed by the authors of this study based on the data obtained*

The obtained results suggest that at the beginning of the study, the live weight of broiler chickens with the use of probiotic at a dose of 0.5 g/10 dm^3 of water increased by 1.69% ($P<0.001$), in experimental groups 2 and 3, these indicators also increased, respectively, by 6.19% ($P<0.001$) and 1.13% ($P<0.001$) compared to the control. At the end of the experiment, the live weight of broiler chickens increased: in experiment group 1 – by 0.27% ($P<0.001$), in experiment group 2 – by 4.02% ($P<0.001$), and in experiment group 3 – by 4.75% ($P<0.001$) compared to the control, which indicated high feed digestibility when feeding the probiotic biopreparation at 4.0 g/10 dm^3 of water per 20 birds in a cage. The results of broiler chickens fattening, namely: absolute weight gain, average daily weight gain, total weight of the bird carcass, neck weight, carcass weight without internal organs, internal fat weight of the bird carcass, weight of internal organs (stomach, liver, heart, adrenal gland) are presented in Table 1.

Table 1. *Results of fattening of broiler chickens and carcass weight, internal organs for the use of probiotic biopreparation on Day 35 of poultry rearing, M±m, n=6*

Indicators	Control	Group 1 (0.5 g/10 l of water)	Group 2 (2.0 g/10 l of water)	Group 3 (4.0 g/10 l of water)
Absolute growth, g	1,343±2.22	1,329±2.44***	1,370±2.89***	1,453±2.38***
Average daily carcass weight gain, g	96±0.21	97±0.20***	98±0.23***	104±0.29***
Feed consumption per 1 kg of weight gain, kg	16.86±0.17	16.68±0.18	16.35±0.19*	15.42±0.16***
Total weight of the poultry carcass, with neck, g	1,945±2.44	1,972±2.21***	2,425±2.44***	2,460±2.21***
Carcass weight without internal organs, g	1,645±2.54	1,704±1.83***	2,075±2.89***	2,080±2.43***

Table 1. Continued

Indicators	Control	Group 1 (0.5 g/10 l of water)	Group 2 (2.0 g/10 l of water)	Group 3 (4.0 g/10 l of water)
Weight of internal fat of poultry carcass, g	13.09±0.02	13.58±0.01***	17.00±0.02***	24.70±0.02***
Stomach weight without contents, g	31.06±0.01	31.19±0.01***	32.24±0.01***	40.75±0.01***
Liver weight, g	46.28±0.03	46.62±0.04***	57.67±0.03***	62.24±0.04***
Heart weight, g	10.51±0.02	10.62±0.01***	12.70±0.02***	14.10±0.02***
Weight of the adrenal gland, g	1.53±0.01	1.67±0.01***	3.33±0.01***	3.81±0.01***

***Note**: ***P<0.05; **P<0.01; ***P<0.001 compared to the control*
***Source**: developed by the authors of this study*

It was found that the absolute weight gain of broiler chickens increased: in the experimental group 2 – by 2.01% (P<0.001), in the experimental group 3 – by 8.19% (P<0.001), and in the experimental group 1 this indicator slightly decreased by 1.04% (P<0.001) compared to the control. The average daily carcass weight gain in the experimental groups of poultry increased and was significant in terms of indicators (P<0.001), namely: in the experimental group 1 – by 1.04%, in the experimental group 2 – by 2.08%, in the experimental group 3 – by 8.33% compared to the control. Feed costs per 1 kg of poultry weight gain in the experimental group 1 were almost at the same level, but in the experimental group 2 this figure decreased by 3.02% (P<0.05), in the experimental group 3 – by 8.54% (P<0.001) compared to the control. Significant results were found in determining the total weight of the bird carcass and neck weight, which increased in the experimental group 1 – by 1.39% (P<0.001), experimental group 2 – by 24.68% (P<0.001), experimental group 3 – by 26.48% (P<0.001) compared to the control. An increase in carcass weight without internal organs was found in the experimental group 1 – by 3.59% (P<0.001), in the experimental group 2 – by 26.14% (P<0.001), in the experimental group 3 – by 26.44% (P<0.001) compared to the control.

The weight of internal fat from poultry carcasses was increased: in the experimental group 1 – by 1.04 times (P<0.001), in the experimental group 2 – by 1.30 times (P<0.001), in the experimental group 3 – by 1.89 times (P<0.001); indicators of internal organs of broiler chickens were increased, namely: weight of the stomach without contents: in the experimental group 1 – 1.01 times (P<0.001), in the experimental group 2 – 1.04 times (P<0.001), in the experimental group 3 – 1.31 times (P < 0.001); liver weight: in in the experimental group 1 – 1.01 times (P<0.001), in the experimental group 2 – 1.25 times (P<0.001), in the experimental group 3 – 1.34 times (P<0.001); heart weight: in in the experimental group 1 – 1.01 times (P<0.001), in the experimental group 2 – 1.24 times (P<0.001), in the experimental group 3 – 1.34 times (P<0.001); adrenal weight: in in the experimental group 1 – 1.09 times (P<0.001), in the experimental group 2 – 2.18 times (P<0.001), in the experimental group 3 – 2.49 times (P<0.001) compared to the control.

The study found the category of broiler chickens carcasses by fatness, namely, carcasses of birds obtained from control and experimental group 1 were assigned to the second category according to the following indicators: muscles are satisfactorily developed; pectoral muscles with the keel form an angle without a depression; fat deposits in the lower abdomen are insignificant; the keel of the thorax is not ossified, stands out. However, the carcasses of poultry from experimental groups 2 and 3 were classified in the first category: muscles were well developed, the shape of the sternum was rounded, fat deposits in the lower abdomen were greater than in the control (group 2) and significant (group 3), the keel of the thorax was not ossified and did not stand out.

The study established the organoleptic characteristics of broiler chickens in the control and experimental groups: appearance of the carcasses – well exsanguinated with a clean surface, without blood clots; degree of plumage removal: plumage was completely removed; skin condition: clean, dry, unweathered, without scratches, tears, spots and bruises; bone system condition: bone system without fractures, slight curvature of the keel of the sternum (control and group 1); bone system without fractures and deformities (groups 2 and 3); consistency of chilled meat (at 0-4°C): muscles are dense, elastic, the dimple is quickly levelled when pressed with a spatula; colour of muscle tissue: pale pink (control and group 1) and from pale pink to pink (groups 2 and 3); skin colour: pale yellow (control and group 1) and yellow (groups 2 and 3); colour of subcutaneous and internal adipose tissue: pale yellow, and internal adipose tissue: white (control and group 1) and yellow (groups 2 and 3); smell: smell on the surface of the carcass and near the bones – typical of good quality poultry meat, without foreign odours; cooking sample: broth of pleasant smell, transparent, with a small amount of fat balls on the surface of the broth (control and group 1) and a significant amount of fat balls (groups 2 and 3), without foreign odours. These indicators suggested the good quality of broiler chicken carcasses, namely their freshness. The tasting characteristics of meat broth and cooked broiler meat were carried out (Figs. 2 and 3).

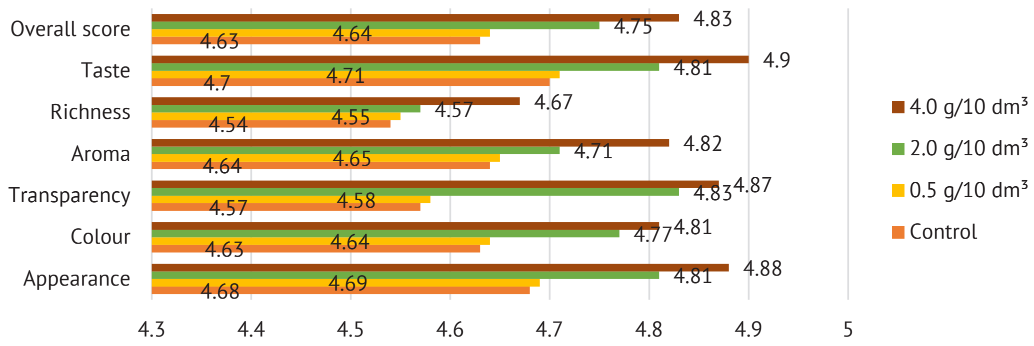

Figure 2. *Tasting characteristics of meat broth from broiler chicken meat (breast), in points*
Source*: developed by the authors of this study based on the data obtained*

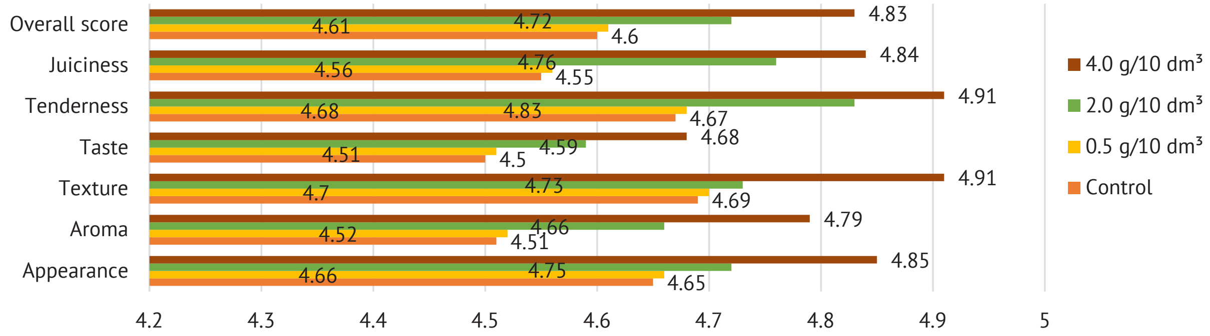

Figure 3. *Tasting characteristics of boiled broiler chicken meat (breast), in points*
Source*: developed by the authors of this study based on the data obtained*

Figure 2 shows that the best tasting characteristics of meat broth in terms of taste, richness, aroma, transparency, colour, and appearance were observed in the experimental group 3, with a total score of 4.85±0.062 points (P<0.05), which is 4.75% higher than in the control. The study also found that the best tasting characteristics of cooked meat in terms of juiciness, tenderness, taste, texture, aroma, and appearance were observed in the experimental group 3 with a total score of 4.83±0.060 points (P<0.05), which is 4.32% higher than in the control. Therefore, when poultry are fed a probiotic biopreparation at 4.0 g/10 dm^3 of water per group of 20 birds, the organoleptic and tasting characteristics of broiler meat are improved. Studies were carried out to determine the chemical composition of broiler chickens when they were fed a probiotic biopreparation at different doses – 0.5 g/10 dm^3, 2.0 g/10 dm^3, 4.0 g/10 dm^3 of water (Table 2).

Table 2. *Chemical composition of broiler chicken meat with the use of probiotic biopreparation, M±m, n=6*

Indicators	Control	Group 1 (0.5 g/10 dm³ of water)	Group 2 (2.0 g/10 dm³ of water)	Group 3 (4.0 g/10 dm³ of water)
Mass fraction of moisture, %	74.30±0.05	73.65±0.04***	73.50±0.04***	73.30±0.07***
Mass fraction of dry matter, %	25.70±0.02	26.35±0.02***	26.50±0.03***	26.70±0.06***
Mass fraction of fat, %	3.20±0.02	3.12±0.02***	2.90±0.01***	2.79±0.01***
Mass fraction of protein, %	22.36±0.020	22.41±0.02	22.49±0.04*	22.49±0.02***
Mass fraction of ash, %	0.96±0.01	0.97±0.01	0.98±0.01	0.99±0.01*
Carbohydrate content, g/100 g	0.03±0.001	0.05±0.001***	0.08±0.001***	0.15±0.01***
Caloric value, kcal/100 g	109.80±0.06	109.80±0.06	116.50±0.06***	118.90±0.07***

Notes*: * – P<0.05; *** – P<0.001 compared to the control*
Source*: developed by the authors of this study based on the data obtained*

Analysing the chemical composition of broiler chickens' meat after feeding the probiotic biopreparation Subtiform, it should be noted that the moisture content decreased in all experimental groups 1, 2, and 3 compared to the control group, respectively, by 0.84% (P<0.001), 1.08% (P<0.001), and 1.35% (P<0.001). Accordingly, the content of dry matter in meat increased in the experimental groups, namely, in the experimental group 1 – by 2.53% (P<0.001), in the experimental group 2 – by 3.11% (P<0.001), in the experimental group 3 – by 3.89% (P<0.001) compared to the control. A decrease in fat content was observed in the meat of broiler chickens in all experimental groups, namely: in group 1 – by 2.50% (P<0.001), in group 2 – 9.38% (P<0.001), in group 3 – 12.81% (P<0.001) compared to the control; however, the protein content slightly increased, respectively, in group 1 – by 0.22%, where statistical significance was not established, in group 2 – by 0.53% (P<0.05), and in group 3 – by 0.76% (P<0.001).

The mass fraction of ash in the meat of groups 1 and 2 increased slightly, without statistical significance, by 1.4% and 2.08%, respectively, while in group 3 – by 3.13% (P<0.05) compared to the control. The carbohydrate content in broiler chicken meat increased in group 1 by 1.67 times (P<0.001), in group 2 – by 2.67 times (P<0.001), and in group 3 – by 5.0 times (P<0.001) compared to the control. The highest energy value of broiler chicken meat was observed in group 3 – 118.90±0.07 kcal/100 g, which is 8.29% (P<0.001). However, in groups 2 and 3, this indicator increased by 2.67% (P<0.001) and 6.10% (P<0.001), respectively, compared to the control. Studies were also carried out to determine the chemical quality indicators of fat and meat of broiler chickens to determine the freshness of the poultry (Table 3).

Table 3. *Chemical parameters of poultry fat and meat with the use of probiotics, M±m, n=6*

Indicators	Control	Group 1 (0.5 g/dm³ of water)	Group 2 (2.0 g/dm³ of water)	Group 3 (4.0 g/dm³ of water)
Acid number of fat using an alcohol-benzene mixture (Patent No. 147314, 2021), mg *NaOH*	0.75±0.029	0.60±0.02***	0.57±0.03***	0.59±0.05***
Fat peroxide number (Patent No. 147145, 2021), % J (% iodine)	0.0058±0.0004	0.0047±0.0004	0.0045±0.0005*	0.0054±0.0005***
Reaction with neutral red (Patent No. 147144, 2021)	presence of a yellow-brown colour			
Nessler number (Patent No. 47313, 2021)	1.55±0.03	1.51±0.03	1.50±0.04	1.45±0.03*
Copper sulphate reaction	broth is clear, blue in colour			
FFA content, mg *KOH/g* (Patent No. 152944, 2023)	3.81±0.11	3.45±0.06***	2.95±0.06***	3.04±0.13***
Ammonia and ammonium salts (qualitative reaction)	extract is greenish-yellow in colour, slightly cloudy	extract is greenish-yellow in colour, transparent		
Optical density of meat and water extract by photometric method, Bel (Patent No. 147315, 2021)	0.824±0.005	0.809±0.003*	0.818±0.003	0.792±0.004***
pH value of the meat and water extract	6.21±0.02	6.19±0.01	6.18±0.01	6.15±0.01**
Ammonium nitrogen content, mg (Patent No. 153118, 2023)	0.61±0.01	0.57±0.01**	0.55±0.02**	0.43±0.02***
Presence of hydrogen sulphide in meat	drop of acetic acid lead turns pale brown			

Notes*: * – P<0.05; ** – P<0.01; *** – P<0.001 compared to the control*
Source*: developed by the authors of this study based on the data obtained*

Table 3 shows that the acid number of fat in experimental groups 1, 2, and 3 was statistically significant when their amount was reduced, respectively, by 1.25 times (P<0.001), 1.32 times (P<0.001), and 1.27 times (P<0.001), as well as a decrease in the peroxide number in the experimental group 2 – by 1.29 times (P<0.05) and in the experimental group 3 – by 1.07 times (P<0.001) compared to the control. In meat, the Nessler count in the experimental groups was within the range of the control group. However, the content of volatile fatty acids in the meat of broiler chickens in experimental groups 1, 2, and 3 was slightly reduced, respectively, by 1.10 times (P<0.001), 1.29 times (P<0.001), and 1.25 times (P<0.001) compared to the control.

The optical density of the meat and water extract in group 3 was statistically significant – 0.792±0.004 (P<0.001) compared to the control. The pH values of the meat and water extract in the experimental groups did not differ from those of the control group. The content of amino-ammonia nitrogen in poultry meat of experimental groups 1, 2, and 3 was statistically significant and, accordingly, decreased by 1.07 times (P<0.001), 1.11 times (P<0.001), and 1.42 times (P<0.001) compared to the control. The obtained quantitative chemical parameters indicated the freshness of broiler chicken meat in the control and experimental groups at a cooling temperature of (0-4)°C, at which it is allowed to sell poultry carcasses for up to 5 days. Based on the qualitative reaction with copper sulphate and the reaction of fat with neutral red, the absence of ammonia and ammonium and hydrogen sulphide salts, it was found that chicken fat and meat met the standards of freshness.

DISCUSSION

Studies established an increase in the live weight of broiler chickens at the end of rearing (42 days) when they were fed a probiotic biopreparation at 0.5 g, 2.0 g, and 4.0 g per 10 dm^3 of water for 20 birds in a cage, especially in experimental groups 2 and 3, respectively – by 4.02% (P<0.001) and 4.75% (P<0.001) compared to the control, and an increase in the weight of broiler chickens carcasses was observed – in group 2 – by 4.02% (P<0.001) and in group 3 – by 4.75% (P<0.001) compared to the control (Fig. 1). These indicators are consistent with the findings of T. Gunawardana *et al.* (2022). The results of the study indicated a healthy immune status of poultry and high feed digestibility when feeding probiotic biopreparation, and an increase in absolute growth in experimental group 3 was noted – by 8.19% (P<0.001), average daily carcass weight gain – by 8.33% (P<0.001), carcass weight without internal organs – by 26.44% (P<0.001) compared to the control group, and the weight of internal organs and internal fat also increased.

However, feed consumption per 1 kg of bird weight gain in group 3 was reduced by 8.54% (P<0.001) compared to the control (Table 1). P. Maharjan *et al.* (2021) proved a positive effect on the health of broiler chickens, feed digestibility and increased productivity and live weight gain in poultry, as well as improved fatness. This mechanism is explained by stimulating the activity of microorganisms in the poultry intestine and the stability of the balance of this microflora, stimulating feeding processes and activating the immune status of the poultry body. A.A. Masud *et al.* (2020) proved the positive effect of probiotic feed additives on improving the immune status and poultry productivity, specifically, an increase in the weight of carcasses, internal organs, and fat by 1.5-2.5 times.

The study also found that the best organoleptic characteristics of meat and tasting characteristics of meat broth and boiled meat were observed in the experimental group 3 with a total score of 4.85±0.062 points (P<0.05) and 4.83±0.060 points (P<0.05), which is 4.75% and 4.32% more than in the control, respectively. A. Rehman *et al.* (2020) argue that organoleptic and tasting characteristics are influenced by the digestibility of feed when probiotics are fed. The best indicators of the chemical composition of broiler chicken meat were found in experimental group 3 (4.0 g/10 dm^3 of water). These data are consistent with the findings of G.M. Suliman *et al.* (2023), namely, the protein content increased by 0.81% (P<0.001), the fat content decreased by 8.13% (P<0.001). According to X. Liu *et al.* (2023), the mass fraction of water slightly decreased by 1.29% (P<0.001), the mass fraction of dry matter increased by 3.95% (P<0.001). And according to A. Rehman *et al.* (2020), the caloric value increased to 118 kcal/100 g, the carbohydrate content increased by 5.4 times, and the mass fraction of ash slightly increased by 3.5%.

T. He *et al.* (2019) proved an increase in the natural resistance of broiler chickens using probiotics, which influenced the increase in carcass weight, the quality of the chemical composition of meat and offal. M.H. Haque *et al.* (2020) confirmed the positive effect of probiotics of the bacteria genus *Bacillus subtilis* and *Bacillus licheniformis* on increasing the productivity of broiler chickens, which led to an increase in meat quality, specifically, the chemical composition in terms of moisture, fat, protein, dry matter, etc., and affected the freshness of poultry meat, which extends the shelf life of poultry products.

Thus, L.W. Chen *et al.* (2020) argue that the use of probiotics from microbial species has antibacterial properties and immunomodulatory effects on the body of broiler chickens, they have a positive effect on the productivity and immunity of poultry. Notably, feeding the probiotic biopreparation Subtiform for 14 days, i.e., from day 28 to day 42 of broiler chickens rearing, provided an increase in body weight of broiler chickens by 2.0-8.2%, an increase in the average daily weight gain from 96 g to 104 g, and a decrease in feed consumption per 1 kg of weight gain by 1.97-7.55%. Thus, studies have confirmed that feeding broiler chickens with a probiotic biopreparation (*Bacillus subtilis* and *Bacillus licheniformis*) increases poultry productivity and improves the chemical composition of poultry meat. R. Jha *et al.* (2020) proved that probiotics with *Bacillus subtilis* have a positive effect on maintaining gut homeostasis and modelling the intestinal microbiota, preventing poultry intestinal infections, and as a result, increasing productivity and improving the chemical composition and chemical quality and safety of broiler chickens.

The findings are confirmed by N.H. Aziz *et al.* (2020), who found that broiler chicken carcasses were fresh in terms of organoleptic and chemical characteristics for 2, 4, and 5 days at (0-4)°C. According to C. Bortoluzzi *et al.* (2019), poultry are fed probiotics to potentially increase feed intake and nutrient retention and absorption, gut barrier function, antioxidant capacity, apoptosis and immune responses, which ultimately contribute to improved poultry metabolism and gastrointestinal health and performance of broiler chickens. According to J. Ding *et al.* (2017), the use of probiotics in broiler chickens improves health, reduces morbidity and mortality at certain critical stages of production, such as dietary stress (dietary changes, diets rich in concentrates) and health stress. S. Sharma *et al.* (2019) noted that in the functioning of the traceability system and Hazard Analysis and Critical Control Point (HACCP), veterinary practitioners should use express and optimised methods for monitoring the freshness of broiler chicken meat, which will be effective, inexpensive, and accessible in tests directly at the production and circulation of poultry slaughter products, which will meet the needs of consumers for quality and safe food.

Thus, the findings of the cited studies are in line with the research conducted to establish the effectiveness of using a probiotic biopreparation to increase the productivity of broiler chickens and improve the organoleptic, tasting, and chemical characteristics of poultry meat.

CONCLUSIONS

The present study found that when the probiotic biopreparation was fed to broiler chickens during days 28 to 42 of rearing at doses of 0.5 g/10 dm^3, 2.0 g/10 dm^3, 4.0 g/10 dm^3 of water, the increase in live weight of poultry in experimental groups 1, 2, and 3, respectively, was 0.27% ($P<0.001$), 4.02% ($P<0.001$), and 4.75% ($P<0.001$) compared to the control. It was found that the absolute weight gain of carcasses increased in experimental groups 2 and 3, respectively, by 2.01% ($P<0.001$) and 8.19% ($P<0.001$); the average daily weight gain of carcasses in experimental groups 1, 2, and 3 increased, respectively, by 1.04% ($P<0.001$), 2.08% ($P<0.001$) and 8.33% ($P<0.001$); total weight of the bird carcass and neck, respectively – by 1.39% ($P<0.001$), 24.68% ($P<0.001$) and 26.48% ($P<0.001$); weight of internal fat, respectively – by 1.04 times ($P<0.001$), 1.30 times ($P<0.001$) and 1.89 times ($P<0.001$) compared to the control. It was found that feed consumption per 1 kg of poultry weight gain in group 1 was almost at the same level, but in group 2 this indicator decreased by 3.02% ($P<0.05$), in group 3 – by 8.54% ($P<0.001$) compared to the control. The studies determined the category of broiler chicken carcasses by fatness: the second category – in the control and experimental group 1 (0.5 g/10 dm^3 of water); the first category – in experimental groups 2 (2.0 g/10 dm^3 of water) and 3 (4.0 g/dm^3 of water).

The studies established statistical significance ($P<0.001$) in increasing the weight of internal organs of broiler chickens (stomach, liver, heart, adrenal gland) in experimental groups 2 and 3, respectively, within 1.04-1.31 times ($P<0.001$); 1.25-1.34 times ($P<0.001$); 1.24-1.34 times ($P<0.001$); 2.18-2.49 times ($P<0.001$) compared to the control. The best organoleptic and tasting indices of broiler chicken meat were found in experimental group 3: meat broth – 4.85±0.062 points ($P<0.05$), which is 4.75% more than in the control; boiled meat – 4.83±0.060 points ($P<0.05$), which is 4.32% more than in the control.

The obtained quantitative and qualitative chemical parameters using express and optimised methods indicated the freshness of broiler chickens meat at (0-4)°C cooling, at which it is allowed to sell poultry carcasses up to 5 days, of control and experimental groups 1, 2, 3. It was established that according to the findings of the study, the probiotic biopreparation Subtiform at 4.0 g/10 dm^3 of water for 20 heads of poultry can be recommended to increase the fatness of broiler chickens and improve the chemical composition of meat, as well as to recommend patented express and optimised methods for determining the freshness of meat by express and optimised methods. Prospects for further research include determining the amino and fatty acid composition of broiler chicken meat and determining the biological value of meat using a probiotic biopreparation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Abd El-Hack, M.E., El-Saadony, M.T., Shafi, M.E., Shaza, Y.A., Qattan, S.Y.A., Batiha, G.E., Khafaga, A.F., Abdel-Moneim, A.E., & Alagawany, M. (2020). Probiotics in poultry feed: A comprehensive review. *Journal of Animal Physiological and Animal Nutrition*, 104(6), 1835-1850. doi: 10.1111/jpn.13454.

[2] Abdulkhaliq, F., & Sabow, A.D. (2023). Carcass characteristics and meat quality assessments in broiler chickens subject to different pre-slaughter restraining methods. *Tikrit Journal for Agricultural Sciences*, 23(2), 42-61. doi: 10.25130/tjas.23.2.4.

[3] Ahmat, M., Cheng, J., Abbas, Z., Cheng, Q., Fan, Z., Ahmad, B., Hou, M., Osman, G., Guo, H., Wang, J., & Zhang, R. (2021). Effects of *Bacillus amyloliquefaciens* LFB112 on growth performance, carcass traits, immune, and serum biochemical response in broiler chickens. *Antibiotics*, 10(11), article number 1427. doi: 10.3390/antibiotics10111427.

[4] Aziz, N.H., Khidhir, Z., Hama, Z.O., & Mustafa, N. (2020). Influence of probiotic (Miaclost) supplementation on carcass yield, chemical composition and meat quality of broiler chick. *Journal of Animal and Poultry Production*, 11(1), 9-12. doi: 10.21608/jappmu.2020.77767.

[5] Baba, F.V., & Esfandiari, Z. (2023). Theoretical and practical aspects of risk communication in food safety: A review study. *Heliyon*, 9(7), article number 18141. doi: 10.1016/j.heliyon.2023.e18141.

[6] Bogatko, N.M. (2019). *Methods of determining the fatness of poultry and slaughter animals: Methodical recommendations for improving the qualifications of veterinary medicine doctors*. Bila Tserkva.

[7] Bortoluzzi, C., Serpa Vieira, B., de Paula Dorigam, J.C., Menconi, A., Sokale, A., Doranalli, K., & Applegate, T.J. (2019). *Bacillus subtilis* DSM 32315 supplementation attenuates the effects of *Clostridium perfringens* challenge on the growth performance and intestinal microbiota of broiler chickens. *Microorganisms*, 7(3), article number 71. doi: 10.3390/microorganisms7030071.
[8] Chaturvedi, P., Shukla, P., Giri, B.S., Chowdhary, P., Chandra, R., Gupta, P., & Pandey, A. (2021). Prevalence and hazardous impact of pharmaceutical and personal care products and antibiotics in environment: A review on emerging contaminants. *Environmental Research*, 194, article number 110664. doi: 10.1016/j.envres.2020.110664.
[9] Chen, C., Li, J., Zhang, H., Xie, Y., Xiong, L., Liu, H., & Wang, F. (2020). Effects of a probiotic on the growth performance, intestinal flora, and immune function of chicks infected with *Salmonella pullorum*. *Poultry Science*, 99(11), 5316-5323. doi: 10.1016/j.psj.2020.07.017.
[10] Choi, J., Kong, B., Bowker, B.C., Zhuang, H., & Kim, W.K. (2023). Nutritional strategies to improve meat quality and composition in the challenging conditions of broiler production: A Review. *Animals (Basel)*, 13(8), article number 1386. doi: 10.3390/ani13081386.
[11] Delgado-Pando, G., Alvarez, C., & Moran, L. (2019). From farm to fork: New strategies for quality evaluation of fresh meat and processed meat products. *Journal of Food Quality*, 2019, article number 4656842. doi: 10.1155/2019/4656842.
[12] Ding, J., Dai, R., Yang, L., He, C., Xu, K., Liu, S., Zhao, W., Xiao, L., Luo, L., Zhang, Y., & Meng, H. (2017). Inheritance and establishment of gut microbiota in chickens. *Frontiers in Microbiology*, 8, article number 1967. doi: 10.3389/fmicb.2017.01967.
[13] Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific. (2010). Retrieved from https://www.fao.org/faolex/results/details/ru/c/LEX-FAOC098296/.
[14] Dong, Y., Li, R., Liu, Y., Ma, L., Zha, J., Qiao, X., Chai, T., & Wu, B. (2020). Benefit of dietary supplementation with *Bacillus subtilis* BYS2 on growth performance, immune response, and disease resistance of broilers. *Probiotics Antimicrob Proteins*, 12(4), 1385-1397. doi: 10.1007/s12602-020-09643-w.
[15] DSTU 3143:2013. (2014). *Poultry meat. General technical conditions*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=81578.
[16] DSTU 4823.2:2007. (2009). *Meat products. Organoleptic assessment of quality indicators. Part 2. General requirements*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=83084.
[17] DSTU 8253:2015. (2017). *Poultry meat. Methods of chemical analysis of freshness*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=71556.
[18] DSTU EN ISO/IEC 17025:2019. (2021). *General requirements for the competence of testing and calibration laboratories*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=88724.
[19] DSTU ISO 1442:2005. (2008). *Meat and meat products. Method for determination of moisture content (control method)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=82535.
[20] DSTU ISO 1443:2005. (2008). *Meat and meat products. Method for determining the total fat content*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=82655.
[21] DSTU ISO 2917-2001. (2003). *Meat and meat products. Determination of pH (control method)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=89528.
[22] DSTU ISO 936:2008. (2008). *Meat and meat products. The method of determining the mass fraction of total ash*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=89525.
[23] DSTU ISO 937:2005. (2007). *Meat and meat products. Determination of nitrogen content (control method)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=82211.
[24] European convention for the protection of vertebrate animals used for experimental and other scientific purposes. (1986). Retrieved from https://rm.coe.int/168007a67b.
[25] Gunawardana, T., Ahmed, K.A., Popowich, S., Kurukulasuriya, S., Lockerbie, B., Karunarathana, R., Ayalew, L.E., Liu, M., Tikoo, S.K., & Gomis, S. (2022). Comparison of therapeutic antibiotics, probiotics, and synthetic CpG-ODNs for protective efficacy against *Escherichia coli* lethal infection and impact on the immune system in neonatal broiler chickens. *Avian Diseasea*, 66(2), 165-175. doi: 10.1637/aviandiseases-D-22-00011.
[26] Haque, M.H., Sarker, S., Islam, M.S., Islam, M.A., Karim, M.R., Kayesh, M.E.H., Shiddiky. M.J.A., & Anwer, M.S. (2020). Sustainable antibiotic-free broiler meat production: Current trends, challenges, and possibilities in a developing country perspective. *Biology*, 9(11), article number 411. doi: 10.3390/biology9110411.
[27] He, T., Long, S., Mahfuz, S., Wu, D., Wang, X., Wei, X., & Piao, X. (2019). Effects of probiotics as antibiotics substitutes on growth performance, serum biochemical parameters, intestinal morphology, and barrier function of broilers. *Animals,* 9(11), article number 985. doi: 10.3390/ani9110985.
[28] Jacobs, L., Persia, M.E., Siman-Tov, N., McCoy, J., Ahmad, M., Lyman, J., & Good, L. (2020). Impact of water sanitation on broiler chicken production and welfare parameters. *Journal of Applied Poultry Research*, 29(1), 258-268. doi: 10.1016/j.japr.2019.10.013.

[29] Jeni, R.E, Dittoe, D.K., Olson, E.G., Lourenco, J., Corcionivoschi, N., Ricke, S.C., & Callaway, T.R. (2021). Probiotics and potential applications for alternative poultry production systems. *Poultry Science*, 100(7), article number 101156. doi: 10.1016/j.psj.2021.101156.

[30] Jha, R., Das, R., Oak, S., & Mishra, P. (2020). Probiotics (direct-fed microbials) in poultry nutrition and their effects on nutrient utilization, growth and laying performance, and gut health: A systematic review. *Animals*, 10(10), article number 1863. doi: 10.3390/ani10101863.

[31] 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.

[32] Liu, X., Ma, A., Zhi, T., Hong, D., Chen, Z., Li, S., & Jia, Y. (2023). Dietary effect of *Brevibacillus laterosporus* S62-9 on chicken meat quality, amino acid profile, and volatile compounds. *Foods,* 12(2), article number 288. doi: 0.3390/foods12020288.

[33] Maharjan, P., Martinez, D.A., Weil, J., Suesuttajit, N., Umberson, C., Mullenix, G., Hilton, K.M., Beitia, A., & Coon, C.N. (2021). Physiological growth trend of current meat broilers and dietary protein and energy management approaches for sustainable broiler production. *Animal*, 15(1), article number 100284. doi: 10.1016/j.animal.2021.100284.

[34] Masud, A.A., Rousham, E.K., Islam, M.A., Alam, M.U., Rahman, M., Mamun, A.A., Sarker, S., Asaduzzaman, M., & Unicomb, L. (2020). Drivers of antibiotic use in poultry production in Bangladesh: Dependencies and dynamics of a patron-client relationship. *Frontiers in Veterinary Science*, 7, article number 78. doi: 10.3389/fvets.2020.00078.

[35] Memon, F.U., Yang, Y., Zhang, G., Leghari, I.H., Lv, F., Wang, Y., Laghari, F., Khushk, F.A., & Si H. (2022). Chicken gut microbiota responses to dietary *Bacillus subtilis* probiotic in the presence and absence of *Eimeria infection*. *Microorganisms*, 10(8), article number 1548. doi: 10.3390/microorganisms10081548.

[36] Mohamed, T.M., Sun, W., Bumbie, G.Z., Dosoky, W.M., Rao, Z., Hu, P., Wu, L., & Tang, Z. (2022). Effect of dietary supplementation of *Bacillus subtilis* on growth performance, organ weight, digestive enzyme activities, and serum biochemical indices in broiler. *Animals*, 12(12), article number 1558. doi: 10.3390/ani12121558.

[37] Queenan, K., Cuevas, S., Mabhaudhi, T., Chimonyo, M., Shankar. B., Slotow, R., & Häsler, B. (2022). A food systems approach and qualitative system dynamics model to reveal policy issues within the commercial broiler chicken system in South Africa. *PLOS ONE*, 17(6), article number 0270756. doi: 10.1371/journal.pone.0270756.

[38] Rehman, A., Arif, M., Sajjad, N., Al-Ghadi, M.Q., Alagawany, M., Abd El-Hack, M.E., Alhimaidi, A.R., Elnesr, S.S., Almutairi, B.O., Amran, R.A., Hussein, E.O.S., & Swelum, A.A. (2020). Dietary effect of probiotics and prebiotics on broiler performance, carcass, and immunity. *Poultry Science*, 99(12), 6946-6953. doi: 10.1016/j.psj.2020.09.043.

[39] Savelli, C.J., Simpson, J., & Mateus, C. (2021). Exploring the experiences of members of the international food safety authorities network: An interpretative phenomenological analysis. *Journal of Food Protection*, 84(10), 1683-1697. doi: 10.4315/JFP-21-171.

[40] Suliman, G.M., Hussein, E.O.S., Alsagan, A., Al-Owaimer, A.N., Alhotan, R., Al-Baadani, H.H., Ba-Awadh, H.A., Qaid, M.M., & Swelum, A.A. (2023). Effects of adding nano-emulsified plant oil and probiotics to drinking water during different periods besides sex on processing characteristics, physicochemical properties, and meat quality traits of broiler chickens. *Frontiers in Veterinary Science*, 10, article number 1133605. doi: 10.3389/fvets.2023.1133605.

[41] Utility model patent No. 147144. (2021). *A method for determining the degree of freshness of poultry fat using neutral red*. Retrieved from https://iprop-ua.com/inv/e8u0r6wm/.

[42] Utility model patent No. 147145. (2021). *A method for improving the determination of the peroxide number of poultry fat*. Retrieved from https://iprop-ua.com/inv/etex6ntv/.

[43] Utility model patent No. 147313. (2021). *Method for determining the degree of freshness of poultry meat by Nesler's number*. Retrieved from https://iprop-ua.com/inv/qrv4n61o/.

[44] Utility model patent No. 147314. (2021). *A method for determining the acid number of poultry fat includes the use of an alcohol-benzene mixture*. Retrieved from https://iprop-ua.com/inv/f1disbck/.

[45] Utility model patent No. 147315. (2021). *Method for determining the degree of freshness of poultry meat by photometric method*. Retrieved from https://iprop-ua.com/inv/h2k0rdj4/.

[46] Utility model patent No. 152944. (2023). *Method for improving the determination of the mass fraction of volatile fatty acids in poultry meat*. Retrieved from https://iprop-ua.com/inv/fdsetnd0/.

[47] Utility model patent No. 153118. (2023). *Method for determining the content of amino-ammonia nitrogen in poultry meat*. Retrieved from https://iprop-ua.com/inv/blmv7379/.

[48] Wang, K., Cao, G., Zhang, H., Li, Q., & Yang, C. (2019). Effects of *Clostridium butyricum* and *Enterococcus faecalis* on growth performance, immune function, intestinal morphology, volatile fatty acids, and intestinal flora in a piglet model. *Food & Function*, 10(12), 7844-7854. doi: 10.1039/c9fo01650c.

[49] Wani, N.R., Rather, R.A., Farooq, A., Padder, S.A., Baba, T.R., Sharma, S., Mubarak, N.M., Khan, A.H., Singh, P., & Ara, S. (2023). New insights in food security and environmental sustainability through waste food management. *Environmental Science and Pollution Research*. doi: 10.1007/s11356-023-26462-y.

[50] Weimer, S.L., Wideman, R.F., Scanes, C.G., Mauromoustakos, A., Christensen, K.D., & Vizzier-Thaxton, Y. (2018). An evaluation of methods for measuring tress in broiler chickens. *Poultry Science*, 97(10), 3381-3389. doi: 10.3382/ps/pey204.
[51] Xiong, H.H., Lin, S.Y., Chen, L.L., Ouyang, K.H., & Wang, W.J. (2023). The interaction between flavonoids and intestinal microbes: A review. *Foods*, 12(2), article number 320. doi: 10.3390/foods12020320.
[52] Yao, W., Cai, Y., Liu, D., Chen, Yu., Jianrong, Li, J., Zhang, M., Chen, N., & Zhang, H. (2021). Analysis of flavor formation during production of Dezhou braised chicken using headspace-gas chromatography-ion mobility spectrometry (HS-GC-IMS). *Food Chemistry*, 370, article number 130989. doi: 10.1016/j.foodchem.2021.130989.
[53] Zhang, L., Zhang, R., Jia, H., Zhu, Z., Li, H., & Ma, Y. (2021). Supplementation of probiotics in water beneficial growth performance, carcass traits, immune function, and antioxidant capacity in broiler chickens. *Open Life Sciences*, 16(1), 311-322. doi: 10.1515/biol-2021-0031.

Вплив пробіотичного біопрепарату на вгодованість, органолептичні та хімічні показники м'яса курчат-бройлерів

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Анотація. Актуальність роботи полягала у використанні пробіотичного біопрепарату Субтіформ за виробництва курчат-бройлерів для підвищення продуктивності та покращення органолептичних та хімічних показників продуктів забою птиці. Метою роботи було визначити вплив пробіотичного біопрепарату на вгодованість курчат-бройлерів, хімічний склад м'яса і хімічні показники за розробленими запатентованими експресними і оптимізованими методиками. Використані наступні методи: фізичні, органолептичні, хімічні. Було встановлено, що застосування *Bacillus subtilis* і *Bacillus licheniformis* ($2{,}5\times10^9$ колонієутворюючі одиниці/г) з наповнювачем – сухої молочної сироватки, сприяло збільшенню продуктивності, зокрема жива вага курчат-бройлерів підвищувалася за випоювання у дозі 2,0 г/10 дм^3 води – на 4,02 % (P<0.001) та у досліді 3 – на 4,75 % (P<0,001) порівняно до контрольної групи. Встановлено підвищення показників у досліджуваній групі 3, зокрема, середньодобового приросту маси тушок – на 8,33 % (P<0,001); загальної маси тушки птиці та потроху з шиєю – на 26,48 % (P<0,001); ваги внутрішнього жиру – у 1,89 рази (P<0,001) порівняно до контрольної групи. Також спостерігалося статистична значущість (P<0,001) щодо збільшення маси внутрішніх органів (шлунку, печінки, серця, наднирника) у дослідних групах 2 і 3, порівняно до контрольної групи. Було узагальнено покращення органолептичних та дегустаційних показників мяса та м'ясного бульйону птиці за випоювання пробіотичного препарату, зокрема у дослідній групі 3. Отримані кількісні та якісні хімічні показники за використання експресних та оптимізованих методик вказували на свіжу ступінь м'яса курчат-бройлерів за охолодження (0-4) °C, за якої дозволено реалізації тушок птиці до 5 діб, контрольної і дослідних груп 1, 2, 3. Практичне цінність роботи полягала у використанні фахівцями ветеринарної медицини на потужностях з виробництва курчат-бройлерів пробіотичного біопрепарату для підвищення продуктивності курчат-бройлерів та покращення якості та безпечності продуктів їх забою

Ключові слова: пробіотик; вгодованість птиці; хімічний склад м'яса; якісні та кількісні показники; експресні та удосконалені методики

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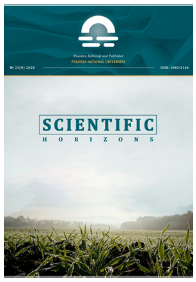

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Monitoring of the phytosanitary condition of *Larix decidua* Mill. plants in the Modryna tract of the Zviahel Forestry branch of the State Enterprise Forests of Ukraine

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Abstract. Phytosanitary monitoring of forest stands is currently a relevant and important area of scientific research that ensures observation, assessment, and forecasting of the dynamics (changes) of the quantitative and qualitative (including sanitary) state of forests and underlies the development of an effective system of tree protection. The purpose of this study was to identify the species composition and distribution of dominant phytopathogen species in the Modryna tract of the Zvyagelske Forestry branch and to identify the primary factors of *Larix decidua* Mill. decline. This study employed

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phytopathological, entomological, forest inventory, and comparative methods. The study identified and registered typical symptoms of damage and the consequences of the harmful effects of pests of *L. decidua* trees in the Modryna tract, leading to a general weakening of their sanitary condition. Symptoms of larch needle cast (meria needle blight) and browning were recorded on the needles; on the trunks – typical manifestations of cankers and fruiting bodies of a unique basidiomycete – *Lariciphomes officinalis*. Apart from infectious pathologies, sporadic wind and storm damaged larch trees, as well as other negative effects of wind exposure, were recorded in the study areas. The species composition of the pests of the surveyed larch trees included the following insect species: *Cephalcia lariciphila, Sacchiphantes viridis* Ratz., *Coleophora laricella*, *Zeiraphera diniana* Gn., *Lasiomma laricicola* Karl. It was generalised that the main threat to the centuries-old larch trees is the complex effect of anthropogenic, abiotic, and biotic (including parasitic) environmental factors that constantly and to varying degrees affect the sanitary and physiological state of ancient larch trees. The findings of this study provide information for predicting the risks of spreading pathogens and pests, which allows managing these risks and preventing their further spread

Keywords: centuries-old plants; species composition; pathoentomological surveys; symptoms; resistance

INTRODUCTION

The principal purpose of phytosanitary monitoring is to obtain information necessary for forecasting and signalling outbreaks of dangerous pathogens and pests, as well as for making decisions on protective measures. Considering the gradual change in climatic conditions, prolonged dry periods without adequate natural moisture and cyclical dieback of native tree species, European larch confidently occupies its ecological niche in the forest stands of different regions of Ukraine (Debryniuk & Fuchylo, 2020), and the investigation of the phytosanitary condition of larch stands in the Zhytomyr Polissia region is particularly relevant. Thus, most of larch stands grow in the Right Bank of Ukraine (Zeidler *et al.*, 2022). By now, the promising forestry species *Larix decidua* Mill. has been successfully cultivated in Zhytomyr Polissia for decades, as it is well acclimatised, fast-growing, productive, slender, durable, and hard. The valuable qualities of larch timber are associated with its high density and specific gravity, the presence of tannins, and resistance to decay. In their studies, Y. Fuchylo *et al.* (2017) often refer to the European larch as a "coniferous oak". E. Kügler (2020) noted that European larch is planted mainly on rich and relatively rich soils in pure culture or with admixtures of other species in the stands.

The Modryna tract is a botanical monument of national significance, and according to its administrative location, it belongs to the Horodnytsia settlement community of the Zvyagel district of Zhytomyr region. It is managed by the Zvyagel Forestry branch of the State Enterprise Forests of Ukraine, on the territory of the 28th quarter of the Nadsluchanske forestry. This tract is a "living monument" to the beginning of artificial forest creation in Polissia (The project of the organisation..., 2019). This unique nature reserve area covers 36 ha, where old-growth European larch trees grown in the climatic conditions of Zhytomyr Polissia are protected. In this area, almost every third tree can be classified as a reference tree in terms of its quality indicators (Pasternak & Nazarenko, 2019; Tashev & Dzyba, 2023). Y. Fuchylo *et al.* (2017) notes that the oldest stands were created more than 190 years ago in the form of a larch alley by the great-grandson of the famous philanthropist Prince Józef Klemens Czartoryski, and a monument was erected at the planting site, which has been preserved to this day.

European larch is not sensitive to low temperature conditions, grows successfully with common oak, and under appropriate mixing schemes does not cause significant loss of deciduous species from the composition of stands. Yu. Debryniuk (2020) notes that due to differentiation processes, high vital status is observed in larch stands of older age groups. About 90% of the plants are healthy and relatively healthy, and the most productive larch plantations in Western Polissia are those with narrowly crested bark, trunks well-cleaned from knots, and medium-density crowns.

European larch has an exotic status among conifers. In winter, the plants shed their needles, and in spring they are covered with new needles. It is worth noting the rather rapid accumulation of trunk stock by larch stands in the forest conditions of the Horodnytsia region – an average of 2 t/ha (The project of the organisation..., 2019). O. Krynytska *et al.* (2021) and V. Pisarenko *et al.* (2020) pointed out that in young larches, the main cause of plant dieback is a lack of moisture and turf process, and therefore all efforts are aimed at preventing these causes in forest areas. The phytosanitary condition of larch cultures varies with age. According to V. Buzun *et al.* (2018), in Vinnytsia and Sumy regions, an intensive growth of larch is observed, while in Kharkiv region, larch has the best indicator in fresh class I rich areas (9 points) and in fresh poor areas and class II fairly poor areas (7 points).

In Europe, *L. decidua* and *L. kaempferi*, together with a hybrid between them (*L.×eurolepis*), are important forest trees. According to modern data from P. Kunttu *et al.* (2021), larch canker is a fungal disease that causes ulcers that disfigure branches and trunks. It is considered the most damaging pathology of larch in Europe, especially at low altitudes and poorly drained areas (Bidolakh *et al.*, 2021). Studies on European larch canker conducted in England, Wales, and Scotland suggest that larch canker is not caused by frost but is probably caused by a primary infection by *Trichoscyphella willkommii* (Hart.) Nannf (Zeidler *et al.*, 2022).

According to R. Hartig, in France, European larch cancer has been confirmed to be caused by the pathogen *Lachnellula willkommii* (R. Hartig) Dennis, and with age, this tree species loses its uniform habit, and therefore it is planted less often (Kunttu *et al.*, 2018). Japanese larch and hybrid larch are ahead of it in terms of value and resistance to canker. Hybrid larch would be planted more frequently if sufficient seeds were available. V. Hayova *et al*. (2020), M. Shevchenko *et al*. (2021) recorded that several decades ago, also in Italy, various lesions of the European larch crown by pathogenic fungi were observed. Other fungal diseases include the needle disease *Meria laricis*, which causes significant defoliation, the root rot *Heterobasidion annosum*, and the fungus *Phaeolus schweinitzi*. In July, the crowns of larch forests turned yellow due to *Meria laricis*. Low temperatures and heavy precipitation were probably favourable factors in this case. After the 2000s, severe damage was caused by *Mycosphaerella laricina*, a rarely studied pathogen whose effects are exacerbated by hot temperatures and humidity in summer. In addition, insect outbreaks, especially of *Zeiraphera diniana*, have led to slower tree development with economic losses of tree stands (Büntgen *et al.*, 2020). Larch plants were resistant to windbreaks, but at the same time vulnerable to *Ips typographus* and other species of the Ips genus, such as *Ips cembrae*. K. Godvod *et al*. (2018) also associate the above bark beetles as carriers of pathogenic fungi. *Coleophora laricella* and *Zeiraphera diniana* can lead to significant defoliation.

The purpose of this study was to conduct ecological and pathological (pathoentomological) monitoring to establish the species composition and distribution of pathogens in larch stands and to identify factors of their weakening.

MATERIALS AND METHODS

The study was conducted during 2021-2023, carrying out forest pathological monitoring of stands in the Modryna tract of the Zvyagelske Forestry branch of the State Enterprise Forests of Ukraine (Fig. 1). Particular attention was paid to the tree stands in the autumn and spring, when pathogens and pests were actively developing. Desk review and identification of the material was carried out at the Department of Forestry, Forest Culrures, and Forest Inventory of Polissia National University and the Department of Forestry of the National University of Life and Environmental Sciences of Ukraine according to specialised methods (phytocoenology, forestry, mycology, ecology, forest inventory) (Lavrov *et al.*, 2018; Methodology of forestry research (biogeocenological) research, 2023; The world of mushrooms, 2023).

Figure 1. *General view of the Modryna tract (block 28 of Nadsluchanske forestry)*
Source*: compiled by the authors of this study*

This study employed phytopathological, entomological, forest inventory, and comparative methods. The results were presented using tabular and graphical research methods and methods of comparison. During detailed pathoentomological surveys of the tree stands, species diversity was described, and infectious disease pathogens were registered and identified. The sanitary condition of the tree stands, and individual large specimens was determined according to the generally accepted scale of categories (Sanitary rules..., 2020) (Table 1).

The types of identified pests on old-growth plants and the consequences of their activities were investigated (Sanitary rules..., 2020). The degree of defoliation of crowns of forest woody plants by category is presented in Table 2.

Table 1. *Determination of the phytosanitary status of forest woody plants by category*

Class index, score	Condition of the woody plant
I	healthy
II	weakened
III	very weakened
IV	drying
V	fresh deadwood
VI	old deadwood

Source*: Sanitary rules in the forests of Ukraine (2020)*

Table 2. *Determination of the degree of defoliation of crowns of forest woody plants by categories*

Category, score	Condition of the crown of a woody plant
0	no signs
1	up to 10% needle shedding
2	11-50% needle shedding
3	51-75% needle shedding
4	over 75% needle shedding

Source: *Sanitary rules in the forests of Ukraine (2020)*

The study selected 20 centuries-old larch trees with typical signs of damage, namely, affected needles, pest flight holes, fruiting bodies of macromycetes on trunks, symptoms of exudate leakage, and webbed nests. The first category included 9 specimens, the second – 7 specimens, and the third – 4 specimens.

The condition of the crowns was determined using a DJI Phantom 4 unmanned aerial vehicle (made in the People's Republic of China), dividing them into dense, medium-density, and loose. Mycological samples were collected on centuries-old specimens of European larch according to the ontogenetic features of the found species. In specialised laboratories, samples were identified by microscopy using MBI-3 and MBS-9 instruments (PTP ASMA-Prybor LLC, Ukraine) (magnification from ×8 to ×100), temporary micropreparations, mycological identifiers, and electronic photo identifiers Mushroom Identify (Index Fungorum, 2023; The world of mushrooms of Ukraine, 2023). The current Latin names of fungal pathogens (macro- and microbiota) were presented following the nomenclature database (Index Fungorum, 2023). The prevalence of pathogens was determined by the proportion of trees with typical fruiting bodies in the total number of woody plants in the study areas.

RESULTS AND DISCUSSION

Forest pathological monitoring and forest pathological examination in the Modryna tract are carried out on an ongoing basis. The phytosanitary condition is maintained properly. However, during the study, the effects of storms and windfalls were recorded. The forest, as a natural landscape, consists mainly of tall woody plants, which can cause roughness (unevenness) of the Earth's surface and become an obstacle to the movement of air flows. Even though the European larch forms a deeply developed root system with a taproot and strong side roots, which ensures its high wind resistance, a negative impact of wind was noted on the research site. The most visually noticeable manifestations of the direct effect of wind on larch trees were the formation of lopsided crowns, trunk tilt (sometimes deformation), and uneven growth of trunks, which is most often observed in glades and forest edges, i.e., in open areas where strong winds of one direction act. Strong and dry winds can also lead to the drying out of the assimilation apparatus of woody plants, as the moisture coming from the root system does not compensate for the losses that occur through the crown.

Furthermore, windblow (trees falling out together with the root system) and wind slash (tree trunk breaking at a certain height) of European larch were recorded in the Modryna tract (Fig. 2). The danger of these phenomena depends heavily on the characteristics of the wind, season, age of the tree plant, its sanitary and physiological condition, type and factual condition of the soil surface, etc. Under the direct influence of air masses, woody plants can be severely swayed, which often leads to the rupture of individual roots and, as a result, the entire tree dries up. This is especially dangerous when the wind gusts match the amplitude of the woody plant's oscillation. Low-power winds can break individual branches and shoots, damage the assimilation apparatus and vegetative organs. Mechanical damage to a tree by wind can be significantly aggravated if it carries particles of sand or snow. The indirect impact of wind on woody plants can also be manifested through the blowing of soil from under the root system, covering the tree with sand, and through the interaction of mechanical factors (and, as a result, damage to plants) of their shoots with the shoots of other plants. Notably, wind has a substantial impact on the formation of snow cover, which determines the structure of vegetation (mosaic vegetation) in the long term.

Figure 2. *Phenomena of windblow and wind slashes in the area under study*
Source: *compiled by the authors of this study*

During the detailed pathoentomological surveys of tree stands within the Modryna tract, pathologies of infectious origin were registered and identified, as well as the results of pest activity (Fig. 3), which exacerbate the overall phytosanitary condition at the studied sites.

Figure 3. *Results of pest complex activity on model woody plants of European larch*
Source: *compiled by the authors of this study*

They are dangerous for twenty-year-old trees (Fuchylo *et al*., 2017). Overcrowding reaches no more than 2%. The prevalence of pathogens (Fig. 4, left) was determined by the proportion of trees with typical fruiting bodies in the total number of woody plants and is presented in the diagram. The distribution of pests on larch plants in the study area is presented in Figure 4 (right).

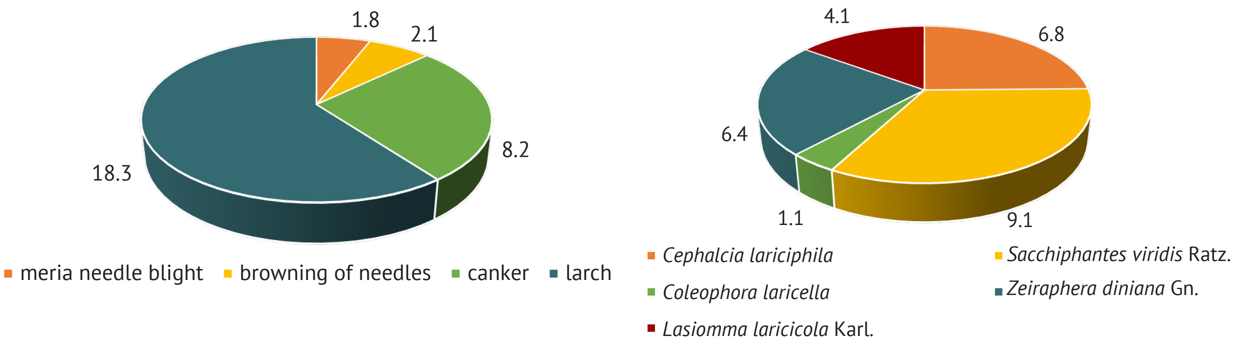

Figure 4. *The spread of infectious diseases (left) and pests (right) in the Modryna tract*
Source: *compiled by the authors of this study*

Larch needles clearly showed symptoms of larch needle cast (Fig. 5, left) and browning (Fig. 5, right), which lead to a change in the normal colour of the needles and rapid needle shedding.

Figure 5. *Symptomatic signs of infection of larch needles by pathogens Meria laricis (left) and Rhizosphaera kalkhoffii (right)*
Source: *compiled by the authors of this study*

Deformation of larch trunks was recorded, which is associated with the tree being affected at an early young age (3-20 years) by the pathogen of canker. At the site of the infection, a typical canker growth was observed, which was covered with oleoresin, which blackened during the oxidation process (Fig. 6 left). On some fallen shoots, directly under the crown of trees infected with canker, *Lachnellula willkommii* apothecia in the form of a white saucer were observed on a trunk, 4-6 mm in diameter. It was noted that the growth of the affected tree is significantly reduced. The prevalence is rare (less than 10.0%). It is worth noting the discovery of *Larchophomes officinalis* on a growing plant in the form of a basidioma (Fig. 6, right).

Figure 6. *Symptoms of damage by Lachnellula willkommii (left) and the fruiting body of Fomitopsis officinalis (right)*
Source: *compiled by the authors of this study*

Even though *F. officinalis* causes brown rot of wood on the trunk, it is listed in the Red Book of Ukraine with a rare status (Fuchylo *et al.*, 2017). The species diversity of infectious agents on the studied plants of European larch in the Modryna tract is presented in Table 3.

Table 3. *Species diversity of L. decidua pathogens in the Modryna tract*

English name of the pathology	Latin name of the pathogen (Index Fungorum)	Affected organ	Typical symptoms
Larch needle cast or meria needle blight	*Meria laricis*	Pine needles	The infected needles had sporadic dark brown spots that covered the entire surface. The infected needles were brown, curled, weakened, and shed prematurely
Browning of needles	*Rhizosphaera kalkhoffii*	Pine needles	Premature needle shedding caused by a change in the typical normal colour of the needles at the base of the shoots to a yellow-brown colour
Canker	*Lachnellula willkommii*	Shoots, trunk	The formation of brown depressed wounds, near which subsequently formed plaques, which, when destroyed, opened a cankerous wound. The infection site was covered with oleoresin, which later blackened
Agarikon (Laricifomes officinalis)	*Fomitopsis officinalis*	Trunk	The fruit bodies had a form of perennial caps with a whitish-yellow furrowed surface, which was gradually covered with cracks. The hymenophore of the basidioma is tubular

Source: *compiled by the authors of this study*

The pathologies recorded on the larch trees under study included larch needle cast, needle browning, canker, and agarikon. Pathogens affected needles, shoots, and trunks of trees with varying intensity. *M. laricis* and *L. willkommii* were the most damaging, causing visible signs of larch plants dieback. The effects of activities inherent in larch pests were also recorded (Table 4).

Table 4. *Types of identified pests on Larix decidua Mill. plants in the Modryna tract*

English name of the pest	Latin name of the pest	Damaged organ of a woody plant	Impact of activities
Web-spinning larch sawfly	*Cephalcia lariciphila* (Wachtl, 1898)	Pine needles	Eaten pine needles on shortened shoots
Fir and larch green adelgids	*Sacchiphantes viridis* Ratz.	Pine needles	Formation of a multi-chambered hive, which can contain up to 120 larvae at once
Western larch case-bearer	*Coleophora laricella* (Hübner)	Needles and shoots	Drying out of the ends of the needles, with pest forming a protective cover for its larvae
Larch tortrix	*Zeiraphera diniana* (Gn.)	Pine needles	Formation of webbed nests and pine needle eating
Larch fly	*Lasiomma laricicola* Karl.	Seeds and cones	The larvae developed in the cones, making winding passages and damaging the soft parts of the scales and seeds, often damaging the cone stem. The affected scales and seeds were brown, while cones completely dried out

Source: *compiled by the authors of this study*

The species of identified pests on *L. decidua* trees in the study area were represented by web-spinning larch sawfly, fir and larch green adelgid, western larch case-bearer, larch tortrix, and larch fly. The pests affected needles, shoots, seeds, and cones of trees with varying intensity. Thus, the larch needles within the study area are damaged by the following pests: web-spinning larch sawfly, fir and larch green adelgid, western larch case-bearer (Fig. 7, left) and tortrix (Fig. 7, right). However, significant damage and potential danger in forest pathology monitoring should be expected from the effects of the larch fly.

Figure 7. *The results of activity of Coleophora laricella (left) and webbed nest of Zeiraphera diniana (right)*
Source: *compiled by the authors of this study*

Specifically, all trees of the first category had a dense, healthy crown, no defoliation, and only a few pathogens. Of all the larch models, 9 were found to be such woody plants. Trees of the second category of phytosanitary condition (7 specimens) had a medium-density crown, defoliation degree of 1 point, and typical signs of damage by macromycetes and pests (Table 5).

Table 5. *Characteristics of the phytosanitary state of European larch trees*

Woody plant No.	Inventory characteristics		Phytosanitary category	Degree of defoliation, points	Crown density	Species composition of pathogens and pests
	Diameter, cm	Height, m				
1	64	33	I	0	dense	sporadic browning of needles
2	70	37	III	2	loose	larch tortrix, web-spinning larch sawfly
3	70	37	III	2	loose	needle browning, canker, web-spinning larch sawfly

Table 5. Continued

Woody plant No.	Inventory characteristics		Phytosanitary category	Degree of defoliation, points	Crown density	Species composition of pathogens and pests
	Diameter, cm	Height, m				
4	77	49	II	1	medium density	agarikon, larch adelgid
5	71	37	I	0	dense	sporadic browning of the needles
6	76	45	II	1	medium density	*Lasiomma laricicola* Karl.
7	68	35	II	1	medium density	agarikon, larch case-bearer
8	66	34	I	0	dense	–
9	63	32	I	0	dense	–
10	69	35	II	1	average density	
11	64	33	II	1	average density	canker, larch adelgid
12	78	49	II	1	average density	larch tortrix
13	64	34	II	1	average density	
14	68	35	I	0	dense	–
15	78	49	III	2	loose	canker, agarikon, larch tortrix
16	75	40	I	0	dense	sporadic browning of the needles
17	57	28	I	0	dense	sporadic signs of larch needle cast
18	59	29	I	0	dense	–
19	64	34	I	0	dense	sporadic browning of the needles
20	72	38	III	2	loose	agarikon, canker, larch case-bearer

Source: *compiled by the authors of this study*

A significant species composition of infectious agents was found on larch trees of the third phytosanitary category (4 specimens). All trees in this category have a loose crown, needles, pest holes, fungal fruiting bodies, webbed nests. Thus, it was found that the main threat to larch trees is the complex effect of anthropogenic, abiotic, and biotic (including parasitic) environmental factors that constantly and to varying degrees affect the sanitary and physiological state of larch trees.

Phytosanitary monitoring of the current state of forests is a key source of information on their condition and potential predictors of impact. The monitoring results allow forecasting the sanitary situation in the future in the studied forest stands and developing the best and effective measures to limit the spread of dominant pest and pathogen species. Based on the findings of the study on the actual phytosanitary status of *L. decidua* woody plants, it is possible to develop the best forest management strategies and identify the necessary measures to support ecosystem stability.

S. Ward and B. Aukema (2019) investigated the biology of the invasive defoliator *Coleophora laricella*, data on the degree of defoliation, as well as the impact of meteorological conditions on pests of the *Larix* genus, namely *Larix laricina* (Du Roi) K. Koch. and *Larix occidentalis* Nutt. This species is also registered by the authors of the study on *L. decidua*. U. Büntgen *et al.* (2020) noted climate change as a possible driving factor in disrupting 8-9 outbreak cycles of *Zeiraphera diniana*. The study conducted do not allow refuting or confirming these conclusions, as it was aimed solely at identifying the factors of weakening of the European larch in the Modryna tract. J. Holuša & K. Drapela (2023) and J. Embacher *et al.* (2023) propose to predict defoliation of *Larix decidua* trees caused by sawflies (Hymenoptera: Symphyta), namely *Cephalcia lariciphila* and *Tomostethus nigritus*, based on the relationship between population density using logistic regression. The authors of the current study did not conduct such research.

Authors from different continents, A. Harris *et al.* (2021), H. Dun *et al.* (2022; 2023), found that the main cause of the phenomenon of "rapid larch death" is the invasive oomycete *Phytophthora ramorum*. This phytopathogenic species has not been registered by the authors within the study area. E. Kügler (2020) conducted screening assays to assess the resistance of *L. decidua* to *Lachnellula willkommii*. However, in contrast to the studies conducted, Kügler does not provide a detailed description of the typical symptoms of this disease, which would be advisable when selecting experimental trees in the field. C. Robin *et al*. (2023) established the influence of *Larix decidua* genetic origin on susceptibility to the pathogen of canker and found that specimens of trees of Central European origin are the most resistant. Further research of the state of the unique trees growing in the Modryna tract by the authors of the present study also involves the formation of a "map of resistant trees" that are immune to pathogens and pests.

CONCLUSIONS

The Modryna tract is a unique nature reserve area where European larch trees grown in the climatic conditions of Zhytomyr Polissia are protected. The phytosanitary condition of the tree stands is maintained properly, however, during the study, the effects of wind slashes and windblows and the pathogenic complex of infectious agents were recorded.

Based on the authors' long-term research on woody plants of *L. decidua* in the Modryna tract, typical symptomatic signs of infection, as well as the consequences of pest activity that weaken the overall sanitary condition of the studied objects, were identified and described. Larch needles clearly show the typical symptoms of larch needle cast (meria needle blight) (causative agent – *Meria laricis* Vuill 1896) and browning (causative agent – *Rhizosphaera kalkhoffii* Bubák 1914); on the trunks – the consequences of the pathogenesis of canker (pathogen – *Lachnellula willkommii* (Hartig) Dennis, 1962) and fruiting bodies of *Fomitopsis officinalis* (Batsch Bondartsev & Singer, 1941). Apart from pathologies of infectious aetiology, negative effects of wind exposure were recorded in the study areas. The most visually noticeable manifestations of the direct effect of wind on *Larix decidua* woody plants are the formation of flag-shaped crowns, trunk tilt and deformation, and trunk eccentricity. There are sporadic larch trees affected by wind slash and windblow. The species composition of pests of European larch trees is limited to the following: web-spinning larch sawfly (*Cephalcia lariciphila* (Wachtl, 1898), fir and larch green aldegids (Sacchiphantes viridis Ratz.), western larch case-bearer (*Coleophora laricella* (Hübner)), larch tortrix (*Zeiraphera diniana* (Gn.)), larch fly (*Lasiomma laricicola* Karl.).

A detailed examination of 20 model European larch trees was carried out and the phytosanitary category of each plant was established. Specifically, all trees of the first category had a dense, healthy crown, no defoliation, and only a few pathogens. Of all the larch models, 9 were found to be such woody plants. Trees of the second category of phytosanitary condition (7 specimens) had a medium-density crown, defoliation degree of 1 point, and typical signs of damage by macromycetes and pests. A significant species composition of infectious agents was found on larch trees of the third phytosanitary category (4 specimens). All trees in this category have a loose crown, needles, pest holes, fungal fruiting bodies, webbed nests.

Thus, the visual inspection of larch trees growing within the Modryna tract makes it possible to register general violations of morphological characteristics and physiological state of the surveyed trees under the influence of the combined action of the above-mentioned factors, which is confirmed by the average indicators of the phytosanitary category and the degree of defoliation. Undoubtedly promising is a future systematic approach regarding the development of an algorithm for assessing and monitoring the condition of the unique *Larix decidua* trees growing in the Modryna tract with the establishment (identification) of the root causes of weakening and the main "aggressors of deterioration", which will create an exceptional "map of resistant larch trees" and use the obtained seed material for the formation of new immune larch stands.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Bidolakh, D., Kuziovych, V., Hrynyuk, Yu., Pidkhovna, S., & Tymanska, O. (2021). Assessment of the state of green spaces of the park-monument of landscape art of national importance "Skala-Podilsky Park". *Ukrainian Journal of Forest and Wood Science,* 12(3), 35-44. doi: 10.31548/forest2021.03.003.

[2] Büntgen, U., Liebhold, A., Nievergelt, D., Wermelinger, B., Roques, A., Reinig, F., Krusic, P.J., Piermattei, A., Egli, S., Cherubini, P., & Esper, J. (2020). Return of the moth: Rethinking the effect of climate on insect outbreaks. *Oecologia,* 192, 543-552. doi: 10.1007/s00442-019-04585-9.

[3] Buzun, V.O., Turko, V.M., & Siruk, Yu.V. (2018). *Book of forests of Zhytomyr region: Historical and economic essay.* Zhytomyr: O.O. Yevenok.

[4] Debryniuk, Yu.M. (2020). *Larix kaempferi* as a promising tree species for plantation afforestation in the forests of the Western Forest Steppe of Ukraine. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 20, 93-106. doi: 10.15421/412009.

[5] Debryniuk, Yu.M., & Fuchylo, Ya.D. (2020). *Plantation forests in Ukraine: Conceptual foundations, resource potential and energy use.* Lviv: Galician Publishing Union.

[6] Dun, H., Mackay, J., & Green, S. (2022). Phytophthora ramorum in larch: From epidemiology to host resistance. In *Proceedings of the sixth international workshop on the genetics of host-parasite interactions in forestry* (pp. 128-131). Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station.
[7] Dun, H.F., MacKay, J.J., & Green, S. (2023). Expansion of natural infection of Japanese larch by *Phytophthora ramorum* shows trends associated with seasonality and climate. *Plant Pathology,* 73(2), 419-430. doi: 10.1111/ppa.13821.
[8] Embacher, J., Zeilinger, S., Kirchmair, M., Rodriguez-R, L., & Neuhauser, S. (2023). Wood decay fungi and their bacterial interaction partners in the built environment – A systematic review on fungal bacteria interactions in dead wood and timber. *Fungal Biology Reviews,* 45, article number 100305. doi: 10.1016/j.fbr.2022.100305.
[9] Fuchylo, Y.D., Sbytna, M.V., Debrynyuk, Yu.M., Hayda, Yu.I., & Belelya, S.O. (2017). Prospects for the use of larch for the creation of timber plantations in the conditions of Ukraine. *Scientific bulletin of NLTU of Ukraine*, 27(10), 26-32. doi: 10.15421/40271003.
[10] Godvod, K., Brazaitis, G., Bačkaitis, J., & Kulbokas, G. (2018). The development and growth of larch stands in Lithuania. *Journal of Forest Science,* 64(5), 199-206. doi: 10.17221/6/2018-JFS.
[11] Harris, A.R., Brasier, C.M., Scanu, B., & Webber, J.F. (2021). Fitness characteristics of the European lineages of *Phytophthora ramorum*. *Plant Pathology*, 70(2), 275-286. doi: 10.1111/ppa.13292.
[12] Hayova, V.P., Heluta, V.P., & Shevchenko, M.V. (2020). Fomitopsis officinalis (Polyporales): Are there any records of the fungus known from Ukraine? *Ukrainian Botanical Journal,* 77(1), 40-43. doi: 10.15407/ukrbotj77.01.040.
[13] Holuša, J., & Drapela, K. (2023). Logistic regression approach to the prediction of tree defoliation caused by sawflies (Hymenoptera: Symphyta). *Journal of Forest Science*, 50(6), 284-291. doi: 10.17221/4625-JFS.
[14] Index Fungorum. (2023). Retrieved from http://www.indexfungorum.org.
[15] Krynytska, O.G., Yakhnytskyi, V.Yo., & Kramarets, V.O. (2021). Xylorophic macromycetes of mixed conifer-deciduous stands of Lviv Roztocze. *Scientific Bulletin of UNFU*, 31(4), 76-81. doi: 10.36930/40310412.
[16] Kügler, E. (2020). *Screening assays for assessing resistance of European larch to larch canker disease.* Alnarp: Swedish University of Agricultural Sciences.
[17] Kunttu, P., Helo, T., Kulju, M., Veteli, P., Julkunen, J., Miettinen, O., Pennanen, J., Moilanen, A., & Kotiranta, H. (2021). Diversity and distribution of Finnish aphyllophoroid and heterobasidioid fungi (Basidiomycota): An update. *Plant and Fungal Systematics*, 66(1), 79-105. doi: 10.35535/pfsyst-2021-0007.
[18] Kunttu, P., Juutilainen, K., Helo, T., Kulju, M., Kekki, T., & Kotiranta, H. (2018). Updates to Finnish aphyllophoroid funga (Basidiomycota): New species and range extensions. *Mycosphere*, 9(3), 519-564. doi: 10.5943/mycosphere/9/3/7.
[19] Lavrov, V.V., Blinkova, O.I., Ivanenko, O.M., & Polishchuk, Z.V. (2018). *Methodology for assessing anthropogenic disturbance of forest ecosystems based on the structure, distribution and activation of aphyllorophoroid fungi.* Bila Tserkva: BNAU.
[20] Methodology of forestry research (biogeocenological) research. (2023). Retrieved from http://subject.com.ua/agriculture/forest/151.html.
[21] Pasternak, V.P., & Nazarenko, V.V. (2019). *Forest inventory.* Kharkiv: KHNAU.
[22] Pisarenko, V.M., Kovalenko, N.P., Pospelova, G.D., Pishchalenko, M.A., Nechyporenko, N.I., & Sherstyuk, O.L. (2020). Modern strategy of integrated plant protection. *Bulletin of the Poltava State Agrarian Academy*, 4, 104-111. doi: 10.31210/visnyk2020.04.12.
[23] Robin, C., Wagner, S., Baubet, O., Ehrenmann, F., Castagneyrol, B., Capdevielle, X., Fabreguettes, O., Petit, R.J., & Piou, D. (2023). Effects of the cascading translocations of larch (*Larix decidua* Mill.) on canker disease due to *Lachnellula willkommii* (R. Hartig) Dennis. *Annals of Forest Science*, 80, article number 29. doi: 10.1186/s13595-023-01200-z.
[24] Sanitary rules in the forests of Ukraine. (2020). Retrieved from https://zakon.rada.gov.ua/laws/show/756-2016-%D0%BF#Text.
[25] Shevchenko, M.V., Heluta, V.P., Zykova, M.O., & Hayova, V.P. (2021). Current distribution data for the red-listed species of aphyllophoroid fungi in Ukraine. *Ukrainian Botanical Journal,* 78(1), 47-61. doi: 10.15407/ukrbotj78.01.047.
[26] Tashev, A., & Dzyba, A. (2023). Representation of the genus *Larix Mill*. in the protected areas of Ukrainian Polissia. *Ukrainian Journal of Forest and Wood Science*, 14(4), 8-25. doi: 10.31548/forest/4.2023.08.
[27] The project of the organization and development of forestry of the State Enterprise "Horodnitske forestry". (2019). Retrieved from https://lisproekt.gov.ua/.
[28] The world of mushrooms of Ukraine. (2023). Retrieved from http://gribi.net.ua.
[29] Ward, S.F., & Aukema, B.H. (2019). Climatic synchrony and increased outbreaks in allopatric populations of an invasive defoliator. *Biological Invasions*, 21, 685-691. doi: 10.1007/s10530-018-1879-9.
[30] Zeidler, A., Vacek, Z., Cukor, J., Borůvka, V., Vacek, S., Prokůpková, A., Linda, R., & Vacek, O. (2022). Is European larch (*Larix decidua* Mill.) a suitable substitute for Norway spruce (*Picea abies* (L.) Karst.) for agricultural land afforestation? *Forest Ecology and Management*, 517, article number 120257. doi: 10.1016/j.foreco.2022.120257.

Моніторинг фітосанітарного стану рослин *Larix decidua* Mill. в урочищі «Модрина» філії «Звягельське лісове господарство» Державного підприємства «Ліси України»

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Анотація. Фітосанітарний моніторинг лісових насаджень наразі є актуальним і важливим напрямком наукових досліджень, який забезпечує спостереження, оцінювання і прогнозування динаміки (змін) кількісного і якісного (у т.ч. санітарного) стану лісів, а також виступає основою для розробки ефективної системи захисту деревостанів. Метою дослідження була ідентифікація видового складу і поширення домінантних видів фітопатогенів на території Урочища «Модрина» філії «Звягельське лісове господарство» та виокремлення первинних чинників ослаблення *Larix decidua* Mill. Під час проведення досліджень застосовано фітопатологічні, ентомологічні, лісівничо-таксаційні, порівняльні методи. Було зафіксовано та ідентифіковано типові симптоми ураження, а також наслідки шкодочинного впливу шкідників дерев *L. decidua* в урочищі «Модрина», що ведуть до загального ослаблення їхнього санітарного стану. На хвої зафіксовано симптоми інфікування шютте (меріозу) і побуріння; на стовбурах – типові прояви ступінчастого раку та плодові тіла унікального базидіоміцети – модринофомесу лікарського. Окрім інфекційних патологій, на досліджуваних ділянках зафіксовано поодикові вітровальні та буреломні дерева модрини, а також інші негативні прояви впливу вітру. Видовий склад шкідників обстежуваних дерев модрини включає наступні види комах: павутинний модриновий пильщик, ялицево-модриновий зелений хермес, модринова міль чохликова, модринова листовійка, муха модринова. Узагальнено, що головною загрозою для великовікових дерев модрини є комплексна дія антропічних, абіотичних та біотичних (у т.ч. паразитарних) чинників навколишнього середовища, що постійно та в різній ступені впливають на санітарний та фізіологічний стан великовікових модринових дерев. Результати досліджень надають інформацію для прогнозування ризиків поширення збудників хвороб та шкідників, що дозволяє управляти цими ризиками та запобігати їхньому подальшому розповсюдженню

Ключові слова: великовікові рослини; видовий склад; патоентомологічні обстеження; симптоматика; резистентність

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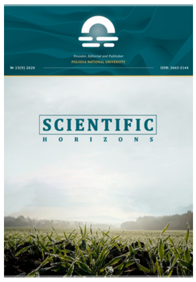

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Taraxacum officinale in meadow fodder production

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Abstract. The relevance of this study lies in the fact that the value of *Taraxacum officinale* for fodder production is extremely limited, although it is one of the most common species on natural and sown fodder lands. The purpose of this study was to experimentally establish the biological value and possibilities of introducing

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Taraxacum officinale into the culture, its technological suitability for cultivation in pure sowings and mixtures with cereal-legumes. The study employed the following methods: field, laboratory, analytical, and statistical. The study found possibilities of sowing *Taraxacum officinale* in the grass stand and ways of using it with green and roughage, best sowing methods and productivity, content of biologically active substances, etc. It was proved that sowing of *Taraxacum officinale* in the grass stand ensures its content in green and roughage at 2-4%, which is an insufficient amount of active ingredient for use as fodder additives. It is more promising to sow *Taraxacum officinale* in pure crops. The yield of dry mass and roots of *Taraxacum officinale* without irrigation was 1.5-2.4 t/ha. Under irrigation, the yield of dry weight of its leaves increased. The best method of sowing is wide-row sowing with row spacing of 25-35 cm. The main biologically active substances are flavonoids, polysaccharides, bitters, vitamins, pectin substances, and hemicellulose. *Taraxacum officinale* contains nutrients that are typical for fodder and are fully analysed for zootechnical purposes. Specifically, it has a high crude protein content (22.3% in leaves and 18.4% in leaves and roots). According to other indicators of the full zootechnical analysis, the feed from *Taraxacum officinale* meets the zootechnical requirements. The inclusion of *Taraxacum officinale* in the feeding ration can ensure the production of organic livestock products that meet the current requirements of the European Green Deal strategy

Keywords: yield; chemical composition; irrigation; sowing methods; phytomixtures; biologically active substances; feed nutrition

INTRODUCTION

When producing organic livestock products, it is important to exclude fodder additives (premixes) containing artificial antibiotics, probiotics, hormones, etc. from the feed rations. When used in fodder, even in small quantities, they have a positive physiological effect. However, it soon became clear that these premixes also have negative effects on the animal and human body. Thus, a need occurred to replace artificial growth stimulants with natural ones. One of these types of medicinal and fodder herbs is *Taraxacum officinale*. Therefore, there was a need for an in-depth investigation of its biological value, productivity on different types of soil and moisture conditions, and the need to introduce it into culture in pure sowings or as part of sown grass stands. For fodder production, this is important when used as a biological growth stimulant for animals.

In recent publications on the value of *Taraxacum officinale* for fodder production, some authors have noted its presence in sown and natural grasses. Specifically, I. Slusar *et al*. (2017) indicate that its presence in grass stands in an amount not exceeding 5%, without reducing productivity, increases the consumption of green mass. V. Kurhak *et al*. (2023) note that under conditions of surface improvement of meadows, *Taraxacum officinale* appears in the grass stand by self-seeding and plays a positive role as an exporter in the formation of grass stands and contains biologically active substances. Professors A. Bogovin and M. Ptashnik (2020) have repeatedly noted that the presence of *Taraxacum officinale* in sown and natural meadows as a forage increases the appetite of cattle and sheep on pasture and has a high feed value score.

Taraxacum officinale is one of the most common plant species in natural and sown meadows and pastures, in gardens, forest edges, and green park areas of Polissia and Forest-Steppe settlements. In agriculture, this species is considered by A. Bogovin and M. Ptashnik (2020), while P. Zaiats *et al*. (2023) consider it a weed in crops, especially in gardens and perennial fodder crops. In hayfields and pastures, it is regarded as an unseeded forb in mountain meadows (Karbivska *et al*., 2021), and in drained peatlands (Shtakal & Shtakal, 2020). *Taraxacum officinale* plays the role of a grass stand stabiliser in succession changes during its long-term use, when some sown grass species fall out of the stand. According to I. Komarova (2018) and T. Antosyak *et al*. (2023), official and folk medicine consider *Taraxacum officinale* as a means to stimulate kidney and liver function, a sedative, in diseases of the gastrointestinal tract, in the diet of patients with diabetes mellitus and other diseases. V.V. Moisiienko (2020) recommends using *Taraxacum officinale* for the treatment of farm animals. Specifically, in the treatment of animals, *Taraxacum officinale* extracts, infusions, and decoctions are made from leaves and roots to increase the secretory function of the glands of the stomach and intestines of farm animals.

As for the possibility and effectiveness of using *Taraxacum officinale* as an organic additive for fodder, there have been almost no such studies. Therefore, there is a need for a more in-depth investigation of the technological suitability, yield, chemical composition, and biologically active substances of this species to explain its value in fodder production and the need for its introduction into the culture. Therefore, the purpose of this study was to investigate the biological value of *Taraxacum officinale* for organic fodder production, its technological suitability, and the possibility of introducing it into culture.

MATERIALS AND METHODS

Field research on the effectiveness of including *Taraxacum officinale* in grass stands on typical chernozem and drained peatlands, productivity and quality of fodder on chernozem under irrigation and without it, and the best methods of sowing under irrigation were conducted in a stationary experiment on typical chernozem at the Panfilska Research Station of the National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences" in 1992-1995 and 2020-2023. The agrophysical and agrochemical indicators of soil fertility are presented in Table 1. The analysis methods were chosen considering that they are suitable for chernozem soils with an acid solution reaction close to neutral.

Table 1. *Agrophysical and agrochemical indicators of black soil fertility of a typical experimental plot in the layer 0-30 cm*

Indicators	**Parameters and units of measurement**	
	Panfilska Research Station "IA NAAS"	**Experimental station of medicinal plants of the IAEM NAAS**
Humus content, %	3.08-3.15	2.43
Lightly hydrolysed nitrogen content, mg/kg	125.8	103.6
Mobile phosphorus content, mg/kg	237-270	384.4
Exchangeable potassium content, mg/kg	80-100	103.6
Degree of saturation of the dressing complex with bases, %	85-99	75-87
Hydrolytic acidity, mg-EQ per 100 g soil	2.1	2.9
pH_{salt}	5.7	5.0
Folding density	1.18	1.25

Source: *compiled by the authors of this study*

Typical chernozems on light loams have the following physical and agrochemical properties in the arable layer:

- humus content (according to Tyurin) was determined following DSTU 4289:2004 (2005);
- the content of easily hydrolysable nitrogen (according to Cornfield) was determined titrimetrically in Conway cups following DSTU 7863:2015 (2016) using a ST-150C thermostat (Ukraine);
- The content of mobile phosphorus was determined according to DSTU 4115:2002 (2002) using a photocolourimetric KFC-3 photoelectrophotometer;
- The content of mobile potassium (Chirikov) was determined using a FLAFO-4 half-beam photometer (Germany);
- The pH_{salt} was determined potentiometrically using an ionometer I-160 MI following DSTU ISO 10390:2007 (2009);
- The degree of saturation of the dressing complex with bases was determined by calculation;
- hydrolytic acidity was determined potentiometrically using the ionometer I-160MI according to DSTU 7537:2014;
- The density of the compaction was determined using a Wile Soil penetrometer.

The productivity of the aboveground mass of *Taraxacum officinale* depending on the sowing methods (row spacing 25 cm, 35 cm, 45 cm, 55 cm, and 65 cm) under drip irrigation was studied on typical black soils of the Experimental Station of Medicinal Plants of the Institute of Agroecology and Environmental Management of the National Academy of Agrarian Sciences of Ukraine, Lubny district, Poltava region in 2020-2022. During the experiments, a drip irrigation system was installed to maintain the moisture content of the root layer of the soil during the growing season at 80% of the lowest moisture (LM) to increase seed germination.

Taraxacum officinale officinalis is officially authorised in the EU under Regulation 1831/2003 on fodder additives for use in animal feeding (European Union, 2003). The plot area in the experiments of the Panfilska Research Station was 10-20 m^2, fourfold replication. Seeding rates for wide-row sowing with 45 cm row spacing of *Taraxacum officinale* were 7 kg/ha of germinating seeds. Sowing was carried out with a hand seeder in the first decade of April. For the inclusion of *Taraxacum officinale* in the composition of grass mixtures, cereal-legume mixtures with a sowing rate of 25 kg/ha were used on typical black soil and cereal mixtures with a sowing rate of 28 kg/ha on drained peat soils.

No mineral fertilisers were applied to the pure grass crops, as this would contradict organic farming. Crop care consisted of manual weeding and 2-3 inter-row treatments to control weeds. The weather conditions of the vegetation periods over the years of research were characterised by air temperature 0.9-1.3°C higher than the long-term average and precipitation 35-70 mm higher than normal, which was observed mainly in the second half of the growing season.

Leaves were harvested during the flowering phase and roots in autumn. All records and observations of the growth and development of medicinal and fodder herbs were carried out following the methods of the Institute of Forage and Podillia of the National Academy of Agrarian Sciences of Ukraine (Babych, 1994; Babych, 1998). The dry matter content in the green mass was determined by the thermostat-weight method with drying of samples at 105°C, while the complete zootechnical analysis of *Taraxacum officinale* and in vitro digestibility and mineral element content were determined following DSTU 4117:2007(2007) by infrared spectrometry with computer software. The content of biologically active substances in air-dried raw materials was determined according to the methods given in the State Pharmacopoeia of Ukraine and the European Pharmacopoeia (European pharmacopeia: 7.0., 2010; State Pharmacopoeia of Ukraine, 2015). According to the regulatory documents of Ukraine and the EU, which are presented in the above pharmacopoeias, the content of biologically active substances in *Taraxacum officinale* plants in the flowering phase should be 20% for extractives. The statistical processing of the obtained results of field experiments was carried out by the method of analysis of variance using modern Microsoft Excel application packages according to B.A. Dospekhov. Experimental studies of *Taraxacum officinale* plants, including the collection of plant material, complied with national and international guidelines. The authors of the study followed the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

There are two ways to solve the problem of producing fodder containing biologically active substances: to include medicinal and fodder herbs in cereal-legume mixtures, or to sow them in pure crops and then add them to animal diets. Subject to the inclusion of *Taraxacum officinale* in the composition of grass mixtures, the study was conducted in 1993-1995 and 2021-2023 on the drained deep peat bogs of the Supii River floodplain in plot No. 3, and on typical chernozems of field No. 10 of the first field crop rotation of the Panfilska Research Station of the IA NAAS. Grassland yield data show that on peat soils it was 7.1-7.5 t/ha of dry weight in 1992-1995 and 8.4-8.5 t/ha of dry weight in 2021-2023, respectively (Table 2). In both cases, yield increases from the inclusion of *Taraxacum officinale* in the grass mixture were not significant, although there was a tendency for yields to increase. Analogous results were obtained on typical chernozems, with the difference that the yields were slightly lower at 5.1-6.3 t/ha and the *Taraxacum officinale* content in the grass stand was slightly lower (2%).

Table 2. *Dry weight yield of grasses, t/ha, and content of Taraxacum officinale in it on peat soils and typical chernozems, %*

Types of herbs	Years of research			
	Average for 1992-1995	***Taraxacum officinale* content in the grass stand, %**	**Average for 2021-2023**	***Taraxacum officinale* content in the grass stand, %**
	On peat soils			
Bromus L., *Phalaris* plants, *Phleum* L. – control	7.1		8.4	
Control + 7% *Taraxacum officinale*	7.5	4	8.5	3
LSD_{05}	0.89		0.59	
	On typical chernozems			
Bromus L., *Phleum* L., *Trifolium* plants – control	5.7		5.1	
Control + 7% *Taraxacum officinale*	6.3	2	5.3	2
LSD_{05}	0.74		0.68	

Notes*: LSD – least significant difference at the 5% level of significance*
Source*: compiled by the authors of this study*

As a result of long-term studies, it was found that if *Taraxacum officinale* is included in the composition of old-growth grass stands in the amount of 7% of the sowing rate, the factual composition in the grass stand is 3-4% on dried peat soils and 2% on typical chernozems, respectively, which is significantly lower than the calculated sowing rate. However, simple calculations confirm that in quantitative terms, this can amount to 0.25-0.3 t/ha of dry mass on peat soils and 0.11-0.13 t/ha of dry mass on typical chernozems over the years. At a feeding rate of 4-5 kg of roughage in cattle diets, no more than 80-150 g of *Taraxacum officinale* can actually be ingested with roughage, which is significantly lower than the doses of feeding medicinal and fodder herbs to obtain a substantial effect. However, these figures may be somewhat overstated, as the bulk of the leaves of *Taraxacum officinale* are located near the root rosette on the soil surface and are not mowed. Furthermore, the content of *Taraxacum officinale* fluctuates over the years and mowing, which makes it impossible to set feeding rates. Therefore, in this case, to meet the need for biologically active substances, it is necessary to additionally add this species or other medicinal and feed grasses to the fodder. A considerable disadvantage of including *Taraxacum officinale* in the grass stand is that in this case it is not possible to harvest the roots as the bulk of the *Taraxacum officinale*.

Therefore, a much more promising way to use *Taraxacum officinale* in fodder production is to sow it in clean crops with subsequent harvesting of both the aboveground and root mass. Studies have suggested the possibility of growing *Taraxacum officinale* in pure crops. However, on rainfed lands, getting friendly germination is problematic due to low seed germination and frequent moisture deficits. Therefore, on the typical chernozems of the Panfilska Research Station of the IA NAAS in 2020-2022, sparse seedlings of this crop were obtained and, as a result, its yield was not high (Table 3). Thus, the total yield of green mass and roots was 7.3-10.7 t/ha and 1.5-2.4 t/ha of dry mass. Therewith, the share of leaves was 0.5-0.8 t/ha or 33-35% and roots 1.0-1.6 t/ha or 65-67%. That is, the bulk of the *Taraxacum officinale* is the roots.

Table 3. *Yield of Taraxacum officinale by years, t/ha and quality indicators of its fodder, %*

Types of herbs	Yields by year								
	Green leaf mass			Dry mass of leaves			Dry mass of roots		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
Taraxacum officinale	10.7	8	7.3	0.8	0.6	0.5	1.6	1.1	1.0
Fodder quality indicators	Protein	Fat	Fibre	REM	Ash	Digestibility	K_2O	P_2O_5	CaO
Taraxacum officinale Leaves/leaves and root	22.3/18.4	4.9/2.03	22.2/23.1	42.1/48.0	8.5/8.5	67/69	2.33/251	0.86/0.88	1.39/1.34

Source: *compiled by the authors of this study*

As for the data of a complete zootechnical analysis of medicinal and fodder herbs, they are not sufficiently covered in the modern literature. There are separate publications on the quality of *Echinacea pallida*, *Matricaria chamomilla*, *Calendula officinalis*, etc. (Poberezhec *et al.*, 2018; Novakovska *et al.*, 2022). However, there is a lack of data on a complete zootechnical analysis of *Taraxacum officinale*. Studies have shown that *Taraxacum officinale* is a valuable crop for fodder production because it has a high crude protein content (22.3% in leaves and 18.4% in root leaves). In this respect, it even exceeds the protein content of legumes. In terms of the content of other components of the full zootechnical analysis, it has a sufficient amount of crude fat (2.0-4.9%), crude fibre (22-23%) and REM (42-48%) and is well supplied with potassium (2.3-2.5%), phosphorus (0.86-0.88%), and calcium (1.3-1.4%) and has good fodder digestibility (55.5-63%). The nutritional value of the leaves is slightly higher than that of the roots due to the higher content of digestible protein.

Considering that *Taraxacum officinale* has low seed germination and the best methods of sowing have not been established, research aimed at solving these issues was conducted at the Research Station of Medicinal Plants of the IAEM NAAS. Irrigation was used to increase the field germination of seeds. Under drip irrigation, five sowing methods were studied with row spacing of 23 cm, 35 cm, 45 cm, 55 cm, and 65 cm (Fig. 1). As a result, it was found that the best methods of sowing are wide-row with row spacing of 25-35 cm, which provided a yield of dry leaf mass under the condition of threefold mowing during the growing season of 3.45-3.54 t/ha. With a row spacing of 45 cm, the *Taraxacum officinale* yield slightly decreased, and with a row spacing of 55-65 cm, it decreased significantly to 2.14-1.53 t/ha. That is, under irrigation, the yield of leaves of this crop increases significantly. However, irrigation is an additional cost that deteriorates the economic performance of fodder additives.

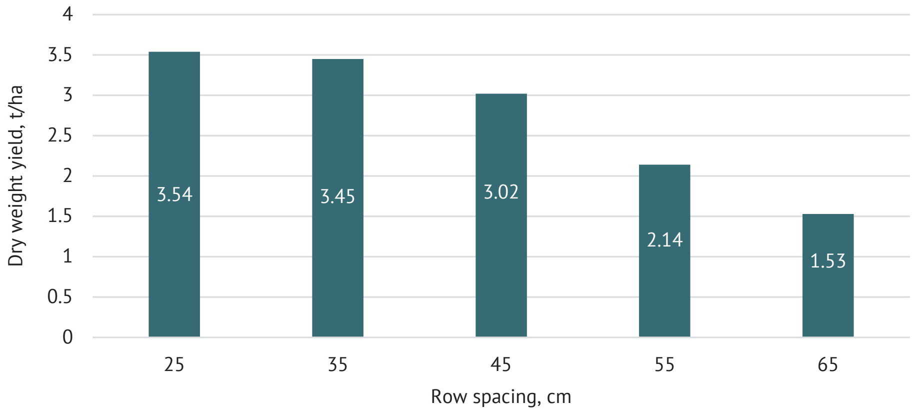

Figure 1. *Effect of row spacing on the yield of dry leaves of Taraxacum officinale, average for 2020-2022*
Source: *compiled by the authors of this study*

When analysing the suitability of *Taraxacum officinale* as an organic fodder additive, the content of biologically active substances in its composition is of significant importance. The study found that the aerial part of the cultivated samples of *Taraxacum officinale* in terms of the content of extractive substances (at least 20%) follows the current regulatory documents of Ukraine and the EU (Table 4).

Table 4. *The content of biologically active substances in the herb of Taraxacum officinale according to the stages of plant development, average for 2020-2022*

Plant development stage	Content of biologically active substances, %				
	extractives	alcohol-soluble carbohydrates	water-soluble carbohydrates	pectin substances	hemicellulose
Budding	21.2±1.6	3.18±0.8	6.45±0.5	4.40±0.9	1.11±0.3
Flowering	24.0±1.4	5.01±1.1	8.57±0.9	4.81±1.5	1.53±0.8
Fruiting	25.5±1.9	4.22±0.9	6.20±0.5	3.45±1.0	3.08±0.9

Source*: compiled by the authors of this study*

The data in the table shows that the cultivated raw materials are characterised by a relatively high content of carbohydrates, the highest amount of which is observed in the phase of mass flowering – 14.92%, which fully meets the requirements of regulatory documents on the timing of harvesting phytopharmaceutical raw materials. The content of extractive substances was slightly higher in samples collected during the fruiting phase. The carbohydrate fraction content was dominated by samples collected during the flowering phase. Moreover, the highest rates were observed in all phases of vegetation in the fraction of water-soluble compounds from 6.20% to 8.57%. The highest levels of hemicellulose content were observed in the fruiting phase, as well as in terms of extractive substances.

One of the key indicators of the content of biologically active substances in *Taraxacum officinale* is the content of other components: essential oils, flavonoids, polysaccharides, bitters, organic acids and vitamins, etc. Studies have shown that the content of essential oils in its composition is low and cannot substantially affect the body of animals. The content of flavonoids in the dry weight of leaves is 0.65%, in roots – 1.08%, polysaccharides in leaves and inflorescences – 5.4% and in roots – 15.8%, bitters in roots and leaves – 7-10%, and vitamins C – 39.8 mg% and PP – 0.82 mg%. That is, the value of *Taraxacum officinale* for the production of organic fodder additives for livestock lies in its high content of polysaccharides (natural probiotics), bitters, flavonoids, vitamins, and nutritional components of fodder inherent in fodder production.

Taraxacum officinale, which is included in most pharmacopoeias around the world, is used in traditional medicine for a wide range of diseases. In official medicine, *Taraxacum officinale* roots and leaves are used to stimulate kidney and liver function, as a sedative, in diseases of the gastrointestinal tract, in the diet of patients with diabetes and other diseases, as noted in Ukrainian pharmaceutical encyclopaedias. Notably, when organising the production of organic fodder additives, there is a need to search for medicinal and fodder herbs for feeding farm animals with single-species fodder or forming phyto-mixtures for the same purpose. Therefore, the uniqueness of the present study lies in the need to introduce *Taraxacum officinale* into the culture as one of the most common grass species on hayfields and pastures, which is currently estimated as an unseeded forb of the Polissia and Forest-Steppe zones. Due to a complex of valuable biologically active substances (polysaccharides, flavonoids, vitamins), this species deserves to be spread in fodder production, and because *Taraxacum officinale* is well-eaten by almost all types of farm animals (cattle, horses, sheep, goats, rabbits, chickens, etc.). In recent years, research on the use of fodder and medicinal herbs for the production of organic fodder additives has been considerably expanded. Specifically, for this purpose, R. Chudak *et al*. (2020) used *Echinacea pallida*. According to the results of these studies, the effectiveness of the use of echinacea photobiotic extract on quail productivity was established. Among other publications, T. Padalko *et al*. (2021) established the prospects of using *Matricaria chamomilla* and *Foeniculum vulgare* to produce biologically active substances and presented technologies for their cultivation.

In the review articles by L. Kryzhak *et al*. (2020), the authors point out the prospects of using *Echinacea purpurea*, *Origanum vulgare* L., *Achillea millefolium*, etc. for this purpose, including for feeding pigs. In general, the Research Station of Medicinal Plants of the Institute of Agroecology and Environmental Management of NAAS of Ukraine has introduced dozens of medicinal herbs into culture and developed technologies for growing them, as well as bred their varieties. I. Komarova (2018) suggests the need for widespread use of *Taraxacum officinale* in medicine, and according to O. Ivashchenko *et al*. (2021) – also in the pharmaceutical, food, and other sectors of the national economy. However, these studies did not aim to grow *Taraxacum officinale* on different types of soils with and without irrigation, using it specifically for the formation of phyto-mixtures as fodder additives and establishing their technological suitability for this purpose and the introduction of *Taraxacum officinale* into culture. For the first time, the effectiveness of including *Taraxacum officinale* in cereal grass stands on drained peat soils and in cereal-legume grass stands on typical chernozems was investigated. The study of the content of biologically active substances in *Taraxacum officinale* leaves and roots was considerably expanded. Therefore, the present study is aimed at solving this problem and is original in this respect.

Current research indicates that *Taraxacum officinale* can be grown for the production of organic fodder additives. Its use in organic phytomixtures has provided a positive effect on the animal body of cattle, which manifested itself in an increase in milk yields and improvement of its quality due to higher fat content. Summarising the literature on solving such an important national economic problem as increasing the productivity of livestock and poultry and obtaining organic livestock products from them, it becomes clear that such data in the modern literature is extremely insufficient. As a result of these studies, it will be possible to introduce *Taraxacum officinale* into production as a single-species raw material and as a component for the formation of phyto-mixtures with the subsequent replacement of existing fodder additives (premixes) in the production of pure organic animal products for the improvement of the nation, as prescribed by the European Green Deal.

CONCLUSIONS

On dried peat soils, the content of *Taraxacum officinale* in grass stands with a dry weight yield of 7.1-8.5 t/ha was 3-4%, and on typical chernozems with a yield of 5.1-6.3 t/ha, respectively, 2%, which is significantly lower than the calculated seeding rate. In this case, the real daily requirement of *Taraxacum officinale* (300-500 g per 1 head of cattle) with roughage is also not met, since no more than 80-150 g are ingested with fodder. The disadvantage of this use is that in this case it is not possible to harvest the roots, which are the main mass of the *Taraxacum officinale*.

A more promising way to use *Taraxacum officinale* in fodder production is to sow it in clean crops and then harvest both the leaves and the root mass. Thus, the total yield of green mass and roots averaged 7.3-10.7 t/ha and 1.5-2.4 t/ha of dry mass in 2020-2022. Therewith, the share of leaves was 0.5-0.8 t/ha or 33-35% and of roots – 1.0-1.6 t/ha or 65-67%. Under irrigation conditions, it was found that the best sowing methods were wide-row with row spacing of 25-35 cm, which provided a yield of dry leaf mass under the condition of threefold mowing during the growing season of 3.45-3.54 t/ha. That is, under irrigation, the yield of leaves of this crop increases significantly. However, irrigation also considerably increases the additional costs of producing fodder additives.

Taraxacum officinale is a valuable crop for feeding animals. Its value lies in the content of the following biologically active substances: 14.92% carbohydrates, 21-25% extractives, 3.45-4.8% pectin, 0.65% flavonoids in the dry mass of leaves and 1.08% in roots, 5.4% polysaccharides in leaves and inflorescences and 15.8% in roots, 7-10% bitters in roots and leaves, and 39.8 mg% vitamins C and 0.82 mg% PP. *Taraxacum officinale* also contains nutrients that are typical for fodder. Specifically, it has a high crude protein content (22.3% in leaves and 18.4% in leaves and roots). In terms of the content of other components of the full zootechnical analysis, it has a sufficient amount of crude fat (2.0-4.9%), crude fibre (22-23%) and REM (42-48%) and is well-supplied with potassium (2.3-2.5%), phosphorus (0.86-0.88%), and calcium (1.3-1.4%), and has good fodder digestibility (55.5-63%).

To increase the production of raw materials containing biologically active substances, it is recommended to introduce *Taraxacum officinale* into the culture by sowing it at a seeding rate of 7 kg/ha in a wide-row method with row spacing of 25-45 cm in spring under irrigation on fertile soils or to include it in cereal-legume mixtures on chernozems and drained peat soils in the amount of 7% of the seeding rate of cereal-legume grasses.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Antosyak, T.M., Kozurak, A.V., & Voloshchuk, M.I. (2023). Medicinal plants on the territory of the Carpathian Biosphere Reserve. *Medicinal plants: Traditions and perspectives of research: Materials of the VI international scientific conference* (pp. 24-26). Lubny: PCF "Inter Park".

[2] Babych, A.O. (1994). *The research technique of forage production*. Vinnitsa.

[3] Babych, A.O. (1998). *The research technique of forage production and feeding animals*. Kyiv: "Agrarna nauka".

[4] Bogovin, A.V., & Ptashnik, M.M. (2018). Influence of agrotechnical measures on the ecobiomorphic structure and productivity of self-renewing meadow ecosystems in the Forest-Steppe zone. *Bulletin of Agricultural Science*, 6(783), 12-18. doi: 10.31073/agrovisnyk201806-02.

[5] Chudak, R.A., Poberezhets, Yu.M., & Vozniuk, O.I. (2020). *Effectiveness of using a phytobiotic from Echinacea palea in quail feeding.* Vinnitsa: "Druk Plus" LLC.

[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] DSTU 4115:2002. (2002). *Soil. Determination of mobile compounds of phosphorus and potassium by the modified Chirikov method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=58863.
[9] DSTU 4117:2007. (2007). *Grain and products of its processing. Determination of quality indicators by infrared spectroscopy*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=85620.
[10] DSTU 4289:2004. (2005). *Soil quality. Method for determination of organic matter*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=56400.
[11] DSTU 7537:2014. (2015). *Soil quality. Determination of hydrolytic acidity*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=62116.
[12] DSTU 7863:2015. (2016). *Soil quality. Determination of easily hydrolyzable nitrogen by the Cornfield method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=62745.
[13] DSTU ISO 10390:2007. (2009). *Soil quality. Determination of pH (ISO 10390:2005, IDT)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=29452.
[14] European pharmacopeia: 7.0. (2010). Retrieved from https://search.worldcat.org/title/european-pharmacopoeia/oclc/662704167.
[15] European Union register of feed additives pursuant to Regulation (EC) No 1831/2003. (2003). Retrieved from http://ec.uropa.eu/comm/food/food/animainutrition/feedadditives/registera dditivts_en.htm.
[16] Ivashchenko, O.I., Rakhmetov, D.B., Kotyuk, L.A., & Sayuk, O.A. (2021). Evaluation of the success and prospects of introduction for cultivation of medicinal aromatic Asteraceae plants in central Polissia (Ukraine). *Ukrainian Journal of Ecology*, 11(9), 1-5. doi: 10.15421/2021_286.
[17] Karbivska, U.M., *et al.* (2021). Peculiarities of botanical composition formation of cereal agrophytocenosis on sod-podzolic soil depending on fertilization. *Modern Phytomorphology,* 15(5), 126-131. doi: 10.5281/zenodo.7715057.
[18] Komarova, I. (2018). *Taraxacum officinale* Wigg as a bioindicator of heavy metals accumulation in soil of the mining and metallurgical region. *Environmental Sciences,* 6(33), 172-177. doi: 10.32846/2306-9716/2020.eco.6-33.26.
[19] Kryzhak, L.N., Gutsol, N.V., & Mysenko, O.O. (2020). The use of medicinal plants as biologically active additives in livestock production. *Feeds and Feed Production*, 90, 134-144. doi: 10.31073/kormovyrobnytstvo202090-12.
[20] Kurhak, V., Šarūnaitė, L., Arlauskienė, A., Karbivska, U., & Tkachenko, A. (2023). The impact of management practices on the stability of meadow communities on a mountain slope. *Diversity*, 15(5), article number 605. doi: 10.3390/d15050605.
[21] Moisiienko, V.V. (2020). *Medicinal plants in veterinary medicine*. Zhytomyr: PP "Ruta".
[22] Novakovska, V.Iu., Chornolapa, L.P., Hutsol, A.V., Hutsol, N.V., & Kylymniuk, O.I. (2022). Quality composition of medicinal herbs used in feeding farm animals. *Fodder and Fodder Production*, 93, 115-123. doi: 10.31073/kormovyrobnytstvo202293-11.
[23] Padalko, T.O., Bakhmat, M.I., Ovcharuk, O.V., & Horodyska, O.P. (2021). Quality of raw material from chamomile inflarescences depending on technological factors. *Ukrainian Journal of Ecology*, 11(1), 234-240. doi: 10.15421/2021_35.
[24] Poberezhec, Yu., Chudak, R., Dobronecka, V., & Voznyuk, O. (2018). Phytobiotic effect on quils meat quality. *Modern Engineering and Innovative Technologies*, 2(06-02), 4-10. doi: 10.30890/2567-5273.2018- 06-02-002.
[25] Shtakal, M.I., & Shtakal, V.M. (2020). Botanical composition of perennial cereal grasses depending on fertilizer on drained peatlands. *Collection of Scientific Papers of the National Scientific Centre "Institute of Agriculture of NAAS"*, 1-2, 162-171.
[26] Slusar, I.T., Solianyk, O.P., Serbenyuk, V.O., Hera, O.M., & Viryovka, V.M. (2017). *Hayfields and pastures on the draining lands*. Kyiv: "KOMPRINT".
[27] State Pharmacopoeia of Ukraine. (2015). Retrieved from https://www.dls.gov.ua/en/news/the-state-pharmacopoeia-of-ukraine-sphu-supplement-4-is-coming-into-force/.
[28] Zaiats, P.S., Drukhal, F.Y., & Ostapyk, B.V. (2023) Features of competitive relationships between plants and weeds of winter wheat agrophytocenose. *Agriculture and Plant Sciences: Theory and Practice,* 1, 99-106. doi: 10.54651/agri.2023.01.11.

Кульбаба лікарська у лучному кормовиробництві

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Анотація. Актуальність проведених досліджень полягає в тому, що вивчення цінності кульбаби лікарської для кормовиробництва вкрай обмежені хоча вона є одним з найпоширеніших видів на природних і сіяних кормових угіддях. Метою досліджень було експериментально встановити біологічну цінність та можливості введення в культуру кульбаби лікарської, її технологічну придатність за вирощування в чистих посівах і сумішах зі злаково-бобовими травами. В дослідженнях використані наступні методи – польовий, лабораторний, аналітичний, статистичний. Встановлені можливості підсіву кульбаби в травостої та способи використання її з зеленими і грубими кормами, оптимальні способи посіву та продуктивність, вміст біологічно активних речовин тощо. Доведено, що підсів кульбаби лікарської в травостої забезпечує її вміст в зелених і грубих кормах на рівні 2-4 %, що є недостатньою кількістю діючої речовини для застосування в якості кормових добавок. Перспективнішим є висівання кульбаби лікарської в чистих посівах. При цьому урожайність сухої маси і коренів кульбаби лікарської без зрошення становила 1,5-2,4 т/га. За зрошення урожайність сухої маси її листків підвищувалася. Кращим способом сівби є широкорядний з міжряддями 25-35 см. Основними біологічно активними речовинами є флавоноїди полісахариди, гіркоти, вітаміни, пектинові речовини та геміцелюлоза. Кульбаба лікарська має в своєму складі і притаманні для кормів поживні речовини повного зоотехнічного аналізу. Зокрема, це високий вміст сирого протеїну (22,3 % в листках і 18,4 % в листках і коренях). За іншими показниками повного зоотехнічного аналізу корм з кульбаби лікарської відповідає зоотехнічним вимогам. Включення до раціону годівлі кульбаби лікарської може забезпечувати отримання органічної продукції тваринництва, що відповідає сучасним вимогам стратегії Європейського зеленого курсу

Ключові слова: урожайність; хімічний склад; зрошення; способи посіву; фітосуміші; біологічно активні речовини; поживність кормів

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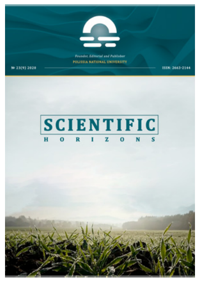

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Microbial activity of dark-chestnut soil in winter wheat crops depending on fertiliser application

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Abstract. Preventing soil degradation is an important task of modern agrarian science. Preservation and increase in beneficial soil microflora are a precondition for satisfactory ecological functioning of soil and its fertility. The purpose of this study was to investigate the dynamics of beneficial soil microflora in winter wheat crops under the impact of mineral fertilisers and *Agrobacterium radiobacter* on the lands of the south of Ukraine. The study was conducted in threefold replication in the conditions of the Kherson region in 2016-2020 in the experimental fields of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine. The study used a systematic design, and the following factors were investigated: no fertiliser and *Agrobacterium radiobacter*; $N_{120}P_{90}$; $N_{90}P_{60}$ + *Agrobacterium radiobacter*; $N_{120}P_{90}$ + *Agrobacterium radiobacter*. The study on the microflora composition in the soil layer at 0-30 cm was carried out in the main stages of winter wheat growth and development through the inoculation of nutritious environment. Statistical analysis was performed using the methods of analysis of variance, correlation, and regression analysis. Dynamic changes in the soil biota composition under the influence of the studied factor were established. The slightest response to mineral fertilisers and bacterial preparation application was in ammonifying bacteria, while the strongest response was in cellulose-degrading microorganisms. The winter wheat harvesting revealed a decrease in the number of ammonifying bacteria in the soil, while the number of nitrifying and cellulose-degrading microflora increased significantly. Regression models for the prediction of the number of nitrifying bacteria and cellulose-degrading microorganisms, developed based on experimental data, have great accuracy (the error is 3.78% and 7.79%), and allow determining the adverse effect of phosphorus fertiliser on the microflora of dark-chestnut soil. The study has no analogues in Ukraine and expands theoretical knowledge about the influence of mineral fertilisers and bacterial preparation, containing *Agrobacterium radiobacter,* on the composition of beneficial microflora of the dark-chestnut soil

Keywords: ammonifying bacteria; bioaugmentation; nitrifying bacteria; cellulose-degrading microorganisms; mathematical modelling

INTRODUCTION

Soil degradation is less discussed and popularised than global warming, but not a less hazardous challenge standing before the humankind in the 21st century. Deterioration of soil quality and poor soil health in some regions reach the peak point and immediate intervention is required to preserve this non-renewable resource for crop production. If no steps are taken, the degraded soils will be abandoned and deserted (Panagos *et al.*, 2018). Assuming that soil is not only an irreplaceable natural resource for food production, but also an important link of the general ecological chain of the biosphere, soil and land degradation is a threat for global food security, biodiversity preservation, and general well-being of the Earth. Current irrational intensification of agricultural land use practices resulted in extreme deterioration of soil quality on the global scale (Kopittke *et al.,* 2019).

It is assumed that the Mediterranean is the most susceptible region in Europe in the context of deterioration of soil quality and desertification. H. Shao *et al.* (2019) proved that some soils of the Mediterranean basin are in critical state, and soon they will be unable to provide not only crop production, but even elementary ecosystem services. According to C.S. Ferreira *et al.* (2022), soils are subjected to degradation on three main levels: biological (loos of soil microbiome diversity, shifts to the prevalence of harmful flora over the beneficial); chemical (decrease in soil organic matter content, contamination with chemical wastes, salinisation); physical (sealing, over compaction, erosion).

A. Drobitko *et al.* (2023) noted that even though Ukraine does not belong to the Mediterranean region of Europe, it is well-known that in recent decades soil degradation processes take place on the entire area of the country. Apart from the negative transformations mentioned above, which are common for the Mediterranean and Ukrainian soils, the latter are subjected to other negative impacts. According to D. Rawtani *et al.* (2022), in the last two years, soil health deterioration has extremely accelerated, especially in the south and in the east of Ukraine, because of military activities, which lead to destruction of the upper fertile soil layers, soil pollution with heavy metals, radioactive trace elements, toxic chemicals and harmful bacteria, diminishment of the number of biologically active beneficial microorganisms, flooding, covering with silt, over-compaction, etc. Combined with irrational agricultural practices of land-use, inherited from the Soviet Union era, extremely high share of arable lands in the structure of croplands, neglection of organic fertilisers application, introduction of high-intense, soil-exhausting short crop rotations with row crops (such as maize, soybeans, sunflower, grain sorghum) and complete replacement of perennial herbs from crop rotations, irrational irrigation and soil tillage practices at the background of adverse effects of natural phenomena, driven by climate change, technogenic impacts connected with current military activities and absence of reliable scientific information support in the sphere of land use and soil regulation are absolutely destructive for the soils of the south and east of the country (Malashevskyi *et al.*, 2020).

P. Pereira *et al.* (2022) note that general land surface topography has been changing since the beginning of the war due to impacts of shelling and military construction, especially trenches and fortification building. Researchers P.V. Lykhovyd and Ye.V. Kozlenko (2018) noted low irrigation water quality (e.g., Ingulets irrigation system, which became the only body to supply irrigation water to the fields of the south after the destruction of Kakhovka dam) and poor land reclamation practices, malfunction of major irrigation and drainage systems, leading to secondary alkalisation and additional structural damage to the soil texture, and the situation starts to look horrible. In this regard, studies on soil health preservation and improvement are of great relevance and importance for current agriculture.

Soil health improvement could be achieved in different ways. As mentioned above, there are three main levels of soil degradation, and there are three corresponding levels of soil quality improvement. One of the crucial but less studied ones is biological level. Soil microorganisms play crucial role in ecosystem services, maintaining soil fertility, balance of organic and mineral matter, and are of great importance for sustainable crop production and ecological stability. This is especially relevant to the arid environments, suffering from rapid climate change, such as of the south of Ukraine, where healthy soil biota composition contributes to ecological sustainability and integrity of total ecosystems (Mishra & Singh, 2020). Therefore, it is necessary to learn about practices that help support a healthy soil biota. P.V. Lykhovyd and S.O. Lavrenko (2017), and B. Futa *et al.* (2021) note that fertilisation practices require robust investigation, because fertiliser application has been shown to lead to significant changes in soil biological and enzymatic activity, measured in different ways.

According to A. Sumbul *et al.* (2020), apart from mineral fertilisers, bacterial preparations, applied during the cultivation of various crops or for the purposes of biological remediation, also have some impact on soil health. Considering current scientific evidence that bioaugmentation in the combination with phytoremediation approach could be extremely beneficial for soil fertility improvement, it is necessary to investigate this question in greater detail for a certain biological agent and soil type (Zanganeh *et al.,* 2022).

The purpose of this study was to reveal the impact of mineral fertilisers and non-symbiotic nitrogen-fixing bacteria application in winter wheat crops on the favourable biota composition of dark-chestnut soil, namely, ammonifying, nitrifying bacteria, and cellulose-degrading microorganisms; to substantiate beneficial and harmful effects of mineral fertilisers and bioaugmentation on the health of the soil.

MATERIALS AND METHODS

Field experiments devoted to the investigation of the effects of mineral fertilisers and bioaugmentation agents on the biota composition of dark chestnut soil were conducted during 2016-2020 at the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine (NAAS). The experimental field was located in Bilozerka district of Kherson region, the south of Ukraine (geographical coordinates: 46°44′33″N 32°42′28″E). In climatological relation, the area of the trials belongs to the dry steppe zone of Ukraine, or BSk (cold semi-arid climate zone) according to M.C. Peel *et al.* (2007). The soil of the experimental field was represented by dark-chestnut middle-loamy soil with humus content in the arable layer averaging 2.2%. The field capacity of the 0-100 cm layer is 22.4%, wilting point is 9.5%. Groundwater is beyond 10 m. The experiment was conducted using the systematic design of the study in threefold replication. The area of the experimental plot of the first grade was 500 m^2, while accountable area was 100 m^2. The area of the second-grade plot was 50 m^2. The scheme of the experiment is presented in the Figure 1.

1 (St.)	2	3	4
4	1 (St.)	2	3
3	4	1 (St.)	2

Figure 1. *The scheme of the experiment, conducted at the field in Bilozerka district of Kherson region during 2016-2020*

Note: *the numbers in the Figure 1 correspond to the variants 1, 2, 3, 4 of the study; St. – standard, control variant of the study*

Source: *created based on the authors' own research*

Winter wheat was sown as the basic crop in the study. Cultivation technology used in the experiment was common for the conditions of the south of Ukraine, except from the factors under study (Domaratskiy *et al.*, 2019). The studied factors, namely fertilisers and bioaugmentation agent application, had the following gradations: variant 1 (St.) – no fertiliser and bioaugmentation agent; variant 2 – $N_{120}P_{90}$; variant 3 – $N_{90}P_{60}$ + non-symbiotic nitrogen-fixing bacteria (NSNFB); variant 4 – $N_{120}P_{90}$ + NSNFB. The NSNFB preparation was represented by Diazophit, which contains 4-6 billion of

Agrobacterium radiobacter strain per 1 g/ml. This bioaugmentation preparation has been developed specifically for wheat, barley, and rice crops (Khomenko *et al.*, 2010).

The number of ammonifying, nitrifying bacteria, and cellulose-degrading microorganisms in the soil was determined in the certified analytical studies laboratory of the Institute of Climate-Smart Agriculture of NAAS. The study was performed for the soil layer at 0-30 cm in three main stages of winter wheat development: start of the growing season (BBCH 10-13), stem elongation (BBCH 31-37), and full ripeness of grain (BBCH 89-91). Soil samples were collected using a special soil auger. The soil suspension was sown in different nutritious environment. To determine the number of ammonifying bacteria, meat-peptone agar (MPA) was used, and to determine the number of nitrifying bacteria, watery agar with ammonium-magnesium salt was used. After inoculation with the nutritious environment, the incubation period (14 days) began, when the temperature was maintained at +28°C. After the incubation period, the number of colonies was accounted for. The number of the soil biota for each species group is represented in the colony-forming units (CFUs) per 1 g of the absolutely dry soil. The moisture content in the soil was calculated using the gravimetric method. All laboratory studies were conducted in threefold replication. Statistical data processing was performed using Microsoft Excel 365 spreadsheets (pairwise linear correlation analysis by Pearson), AgroStat (one-way analysis of variance), BioStat v.7 (multiple linear regression analysis) statistical packages. All calculations were performed at $p<0.05$ using common mathematical procedure (Scheffe, 1999; Sharma, 2005).

RESULTS AND DISCUSSION

As a result of the study, the major regulations on microbiota transformation in dark-chestnut soil were established under the influence of mineral fertilisers and the biological preparation Diazophit (Table 1). First of all, it should be certified that the variants of $N_{90}P_{60}$ + NSNFB and $N_{120}P_{90}$ + NSNFB did not differ significantly at the stage of stem elongation (BBCH 31-37) of winter wheat in terms of the number of ammonifying and cellulose-degrading microflora. These variants were also similar in the latest stage of crop growth in terms of the presence of ammonifying bacteria in the soil. Furthermore, there was no statistically significant difference between the variants without fertilisers and fertilised with $N_{120}P_{90}$ in terms of all microflora species studied in the BBCH 89-91 stage. However, generally, the number of all the studied soil microbiota species was significantly higher in the variants with the application of Diazophit as a bioaugmentation agent. Therefore, it was proved that application of *Agrobacterium radiobacter* is beneficial for preservation of favourable microflora in the dark-chestnut soil under the cultivation of winter wheat. This conclusion is in line with the statements that can be found in the scientific reports of studies on this subject (Kovalenko *et al.*, 2020).

Table 1. *Microbial composition of the dark-chestnut soil in the winter wheat crops depending on mineral fertilisers and the bacterial preparation application (average for 2016-2020)*

Variant	CFU per 1 g of the absolutely-dry soil		
	Ammonifying bacteria, billion	Nitrifying bacteria, billion	Cellulose-degrading microorganisms, thousand
BBCH 10-13			
No fertilisers	28.50a	8.76a	3.36a
$N_{120}P_{90}$	29.37b	9.10b	3.91b
$N_{90}P_{60}$ + NSNFB	35.63c	10.15c	4.30c
$N_{120}P_{90}$ + NSNFB	33.08d	9.89d	4.28c
BBCH 31-37			
No fertilisers	18.97a	8.93a	3.53a
$N_{120}P_{90}$	20.25b	9.40b	3.93b
$N_{90}P_{60}$ + NSNFB	22.86c	10.89c	4.18c
$N_{120}P_{90}$ + NSNFB	21.58c	10.61d	4.20c
BBCH 89-91			
No fertilisers	24.62a	10.49a	3.98a
$N_{120}P_{90}$	25.62a	10.56a	4.00a
$N_{90}P_{60}$ + NSNFB	28.00b	13.12b	4.68b
$N_{120}P_{90}$ + NSNFB	27.22b	12.14c	4.57c

Note: *different letters in the labels of each value certify about statistically significant difference between the variants at p<0.05 according to the ANOVA test results*

Source: *compiled by the authors of this study based on the authors' own research*

Notably, the number of nitrifying bacteria and cellulose-degrading microorganisms gradually increased from the very beginning to the cessation of winter wheat growth in all the variants of the experiment. However, the dynamics for ammonifying bacteria was different: their numbers significantly decreased to the stage of stem elongation (BBCH 31-37) in winter wheat, but then slightly increased before the crop's growth cessation (BBCH 89-91). Despite the increase in the late stages of winter wheat development, the number of ammonifying bacteria had negative balance by the growing season (Table 2).

Table 2. *The dynamics of microbial composition of the dark-chestnut soil in the winter wheat crops depending on mineral fertilisers and the bacterial preparation application (average for 2016-2020; the dynamics is presented relatively to the initial numbers of the bacteria)*

Variant	CFU per 1 g of the absolutely-dry soil		
	Ammonifying bacteria, billion	Nitrifying bacteria, billion	Cellulose-degrading microorganisms, thousand
BBCH 31-37			
No fertilisers	-9.53	0.17	0.17
$N_{120}P_{90}$	-9.12	0.30	0.02
$N_{90}P_{60}$ + NSNFB	-12.77	0.74	-0.12
$N_{120}P_{90}$ + NSNFB	-11.50	0.72	-0.08
BBCH 89-91			
No fertilisers	-3.88	1.73	0.62
$N_{120}P_{90}$	-3.75	1.46	0.09
$N_{90}P_{60}$ + NSNFB	-7.63	2.97	0.38
$N_{120}P_{90}$ + NSNFB	-5.86	2.25	0.29

Source: *compiled by the authors of this study based on the authors' own research*

The highest negative balance was established for $N_{90}P_{60}$ + NSNFB, while the variant with the application of mineral fertilisers at the $N_{120}P_{90}$ rates resulted in the best preservation of the community of ammonifying bacteria in the soil. The best positive balance of nitrifying bacteria was achieved by $N_{90}P_{60}$ + NSNFB, while the best survival and increase rates in cellulose degrading microorganisms were fixed in the variant without applied fertilisers. These results demonstrate that different microflora react differently to the application of mineral fertilisers and bioaugmentation. Notably, established regulations can be unique for the dark-chestnut middle-loamy soil of the steppe zone, as it was shown that there are different patterns of seasonal dynamics and the presence of beneficial microflora under different environmental conditions (Ishaq *et al.*, 2020). Furthermore, as suggested by H. Wang *et al.* (2022), elements of cultivation technology, especially tillage, could also be involved in the regulation of the soil microbiota. Therefore, these specific features should be also considered in the interpretation of the results. The correlation-regression analysis allowed establishing the nature and strength of the relationship between the microbial composition of the dark-chestnut soil in the winter wheat crops and the application of mineral fertilisers (Table 3).

Table 3. *Pairwise relationship between the microbial composition of the dark-chestnut soil in the winter wheat crops and mineral fertilisers and the bacterial preparation application (average for 2016-2020)*

Bacterial community	Correlation coefficient			Determination coefficient		
	Nitrogen fertilisers, kg ha^{-1}	Phosphorus fertilisers, kg ha^{-1}	NSNFB	Nitrogen fertilisers, kg ha^{-1}	Phosphorus fertilisers, kg ha^{-1}	NSNFB
Ammonifying	0.21	0.18	0.36	0.04	0.03	0.13
Nitrifying	0.33	0.29	0.64	0.11	0.09	0.14
Cellulose-degrading	0.63	0.59	0.80	0.39	0.34	0.64

Source: *compiled by the authors of this study based on the authors' own research*

As a result, it was found that there is almost no connection between the application of mineral fertilisers and the number of ammonifying and nitrifying bacteria, while the relationship between the rates of nitrogen and phosphorus application is moderately correlated with the presence of cellulose-degrading microorganisms in the soil. Therewith, it was established that the application of the NSNFB preparation

Diazophit was moderately related to the number of nitrifying bacteria and strongly related to the number of cellulose-degrading microorganisms in the soil. Therefore, ammonifying bacteria were the only one species that were not affected by the factor under study. The results of multiple regression analysis revealed a weak dependence of the presence of ammonifying bacteria on the complex of fertilisers used, while nitrifying bacteria and cellulose-degrading microorganisms demonstrated moderate-to-strong dependence on the complex effects of the factor under study (Table 4).

Table 4. *Multiple relationship between the microbial composition of the dark-chestnut soil in the winter wheat crops and mineral fertilisers and the bacterial preparation application (average for 2016-2020)*

Bacterial community	Correlation coefficient	Determination coefficient
Ammonifying	0.39	0.15
Nitrifying	0.66	0.44
Cellulose-degrading	0.86	0.74

Source: *compiled by the authors of this study based on the authors' own research*

Multiple regression models for the prediction of soil microbiota composition depending on the fertiliser's application and use of Diazophit were developed for the nitrifying and cellulose-degrading microflora (Tables 5 and 6).

Table 5. *Regression statistics and the model for the prediction of nitrifying bacteria numbers in the dark-chestnut soil based on the fertilisation rates and application of the bacterial preparation*

Statistical parameter	Value
Adjusted coefficient of determination	0.23
Predicted coefficient of determination	0.26
Mean absolute percentage error	7.79%
Mean square error	1.30 CFU
Equation	$9.3933E + 1.1933NSNFB - 7.7333\times10^{-2}P + 6.0444\times10^{-2}N$

Note: *N – the dose of Nitrogen fertilisers applied, kg ha^{-1}; P – the dose of Phosphorus fertilisers applied, kg ha^{-1}; NSNFB – application (enter "1") or no application (enter "0") of the bacterial preparation Diazophit*
Source: *compiled by the authors of this study based on the authors' own research*

Table 6. *Regression statistics and the model for the prediction of cellulose-degrading microorganisms' numbers in the dark-chestnut soil based on the fertilisation rates and application of the bacterial preparation*

Statistical parameter	Value
Adjusted coefficient of determination	0.64
Predicted coefficient of determination	0.41
Mean absolute percentage error	3.78%
Mean square error	0.05 CFU
Equation	$3.6233 + 0.4033NSNFB - 1.5667\times10^{-2}P + 1.4444\times10^{-2}N$

Note: *N – the dose of Nitrogen fertilisers applied, kg ha^{-1}; P – the dose of Phosphorus fertilisers applied, kg ha^{-1}; NSNFB – application (enter "1") or no application (enter "0") of the bacterial preparation Diazophit*
Source: *compiled by the authors of this study based on the authors' own research*

The proposed models are the first to provide a mathematical description of the influence of mineral fertilisers and the effects of *Agrobacterium radiobacter* on the beneficial microflora of dark-chestnut soil. According to the regression model coefficients, phosphorus fertilisers have negative impact on both species, while nitrogen fertilisers are favourable for their development.

Other scientists have also investigated this subject, but from other perspectives. However, main conclusions are not contradictory. Thus, M. Sintia *et al.* (2021) have also proven a strong effect of nitrogen fertilisation on nitrifying microbes and net nitrification rates in soils under cereal and leguminous crops. As for cellulose-degrading soil microflora, H. Tang *et al.* (2021) established positive effects of organic manure and crop residue application on the studied group of soil biota. Authors also claimed that the cellulolytic microbial community studied in soils was significantly increased with the long-term application of crop residue (so-called green manure) and the organic manure condition comparing with pure mineral fertilisation practices. However,

Q. Ma *et al.* (2020) do not support this statement and claim that farmyard manure application has no effect on soil microbial community structure. As for the action of bacterial preparations, J. Wang *et al.* (2020) found that some bacterial species, when added into soil community, can enhance cellulose degradation activity in soils under simultaneous increase in the volume of available nitrogen, phosphorus, and potassium, thereby improving soil fertility and crop production.

A. Iminov *et al.* (2020) claimed that application of mineral fertilisers together with nitragin increased the number of ammonifiers, oligonitrophils, and micromycetes in soybean crops. Y. Chen *et al.* (2018) found that mineral fertilisation with nitrogen, phosphorus, and potassium in appropriate proportions is the best approach to improve soil quality and soil bacterial community in non-calcareous fluro-aquic soils of the North China Plain. Z. Liu *et al.* (2021) reported the highest bacterial enzymes activity in the soils of Shaping, Hequ, China, when complex approach to soil fertilisation was implemented, viz., application of appropriate doses of organic manure and mineral fertilisers.

However, meta-analysis on soil microbiota and its relation to fertilisation systems found that manure application is beneficial, while mineral nitrogen, phosphorus, and potassium fertilisers in some soils led to significant loss of microbial biomass (Ren *et al.*, 2019). Y. Kong *et al.* (2019) also support the statement that long-term chemical fertilisation significantly decreases soil nitrifying activity. Finally, in case of different crop rotations and fertilisation practices different changes in soil bacterial diversity and functioning will be observed, as reported by Z. Tong *et al.* (2023). The strongest differences are observed between cereal and leguminous crops, as the latter are the substrate for symbiotic nitrogen-fixing bacteria colonisation, leading to significant shifts in soil microbiome (Zhang *et al.*, 2019).

As for *Agrobacterium radiobacter* application, I. El Attar *et al.* (2022) found beneficial effects of these bacteria on soil fertility and crop production, suggesting the possibility of partial replacement of nitrogen mineral fertilisers with this bacterial agent. L. Tokmakova *et al.* (2019) found that *Agrobacterium radiobacter* improves plants nutrition with phosphorus, providing for the improvement of maize yields. However, caution should be taken when applying *Agrobacterium radiobacter* preparations because these bacteria are pathogens for some agricultural species, e.g., pistachio seedlings (Basavand *et al.*, 2022), while some other crops should be provided with additional protection, especially potato (Borodaj & Parfeniuk, 2019).

Therefore, considering that the presented study is in good agreement with the internationally conducted investigations, even those carried out on other types of soils and in other environmental and agrotechnological conditions, it can be assumed that the mathematical models developed for the prediction of soil microbiome composition depending on the nitrogen, phosphorus, and *Agrobacterium radiobacter* application rates could be applied for scientific purposes not only for the dark-chestnut soils of the south of Ukraine, but for other soils and climate zones as well.

CONCLUSIONS

The findings of this study revealed that the application of *Agrobacterium radiobacter* and mineral fertilisers significantly affects the number of beneficial soil microbiota. A stronger effect was attributed to nitrifying bacteria, while ammonifying bacteria almost did not experience any positive or adverse effect from the application of the substances under study. The strongest effects of the studied factor were observed for the cellulose-degrading microorganisms, which reacted the most on the application of *Agrobacterium radiobacter* – correlation coefficient was 0.80. It was found that the number of ammonifying bacteria in the dark-chestnut soil decreased over the growing season of winter wheat (by 3.75-12.77 CFU/g of the absolutely-dry soil depending on the variant of the study), while the numbers of nitrifying bacteria increased up to 1.46-2.97 CFU/g of the absolutely-dry soil by the end of the study. Statistical analysis allowed multiple regression models to be developed for the prediction of the number of nitrifying bacteria and cellulose-degrading microorganisms in the dark-chestnut soil. The models provide high predictive accuracy (MAPE values are 3.78% and 7.79% for cellulose-degrading and nitrifying microbiota, respectively; correlation coefficients of the models are 0.86 and 0.66 for cellulose-degrading and nitrifying microbiota, respectively) and could be used in scientific purposes for simulation studies of the microbial community of the dark-chestnut soils of the South of Ukraine. It was additionally established that phosphorus application plays negative role in the formation of nitrifying and cellulose-degrading microflora, namely, every kg ha^{-1} of phosphorus mineral fertiliser decreases the number of nitrifying bacteria by 0.077 CFU/g of the absolutely-dry soil, and the number of cellulose-degrading bacteria decreases by 0.016 CFU/g of the absolutely-dry soil, respectively.

More research should be conducted to improve the knowledge on this topic. First of all, additional agrotechnological factors (e.g., tillage, irrigation ways) should be included, as well as it would be beneficial to include other types of crops in the future studies. Furthermore, other soil types (chernozems, greyzems, etc.) should also be investigated in terms of the impacts of agrotechnology on their microbial composition.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Basavand, E., Khodaygan, P., Moradi, M., Mousavi, S.A., Lindström, K., & Sedaghati, N. (2022). Characterization of *Agrobacterium radiobacter*, a new pathogen of pistachio. *Australasian Plant Pathology*, 51(2), 167-174. doi: 10.1007/s13313-021-00831-y.

[2] Borodaj, V., & Parfeniuk, A. (2019). Regulation of phytopathogenic background at use of biological preparations in agro-ecosystems of potato and in conditions of its storage. *Bulletin of Agricultural Science*, 97(10), 37-43. doi: 10.31073/agrovisnyk201910-06.

[3] Chen, Y., Liu, J., & Liu, S. (2018). Effect of long-term mineral fertilizer application on soil enzyme activities and bacterial community composition. *Plant, Soil and Environment*, 64(12), 571-577. doi: 10.17221/658/2018-PSE.

[4] Domaratskiy, Y., Berdnikova, O., Bazaliy, V., Shcherbakov, V., Gamaynova, V., Larchenko, O., Domaratskiy, A., & Boychuk, I. (2019). Dependence of winter wheat yielding capacity on mineral nutrition in irrigation conditions of southern Steppe of Ukraine. *Indian Journal of Ecology*, 46(3), 594-598.

[5] Drobitko, A., Markova, N., Tarabrina, A.M., & Tereshchenko, A. (2023). Land degradation in Ukraine: Retrospective analysis 2017-2022. *International Journal of Environmental Studies*, 80(2), 355-362. doi: 10.1080/00207233.2022.2160079.

[6] El Attar, I., Taha, K., Oubohssaine, M., Diouf, B., Jenk, H.A., Berraho, E.B., Alami, I.T., & Aurag, J. (2022). Phytobeneficial bacterial inoculants for common bean growth and productivity in nitrogen and phosphorus deficient soils. *Pakistan Journal of Agricultural Sciences*, 59(2), 157-163. doi: 10.21162/PAKJAS/22.485.

[7] Ferreira, C.S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of the Total Environment*, 805, article number 150106. doi: 10.1016/j.scitotenv.2021.150106.

[8] Futa, B., Kraska, P., Andruszczak, S., Gierasimiuk, P., & Jaroszuk-Sierocińska, M. (2021). Impact of subsurface application of compound mineral fertilizer on soil enzymatic activity under reduced tillage. *Agronomy*, 11(11), article number 2213. doi: 10.3390/agronomy11112213.

[9] Iminov, A.A., Hatamov, S.R.O., & Khayrullaev, S.S.O. (2020). Effect of nitragine and mineral fertilizers on soil microbiological properties in planted as secondary legume crops. *The American Journal of Agriculture and Biomedical Engineering*, 2(08), 169-172. doi: 10.37547/tajabe/Volume02Issue08-22.

[10] Ishaq, S.L., Seipel, T., Yeoman, C.J., & Menalled, F.D. (2020). Soil bacterial communities of wheat vary across the growing season and among dryland farming systems. *Geoderma*, 358, article number 113989. doi: 10.1016/j.geoderma.2019.113989.

[11] Khomenko, G., Berdnikov, O., Potapenko, L., Gapon, O., & Lavska, V. (2010). The effectiveness of diazophit application in different fertilization systems at cultivation of spring wheat. *Agricultural Microbiology*, 10, 116-123. doi: 10.35868/1997-3004.10.116-123.

[12] Kong, Y., Ling, N., Xue, C., Chen, H., Ruan, Y., Guo, J., Zhu, C., Wang, M., Shen, Q., & Guo, S. (2019). Long-term fertilization regimes change soil nitrification potential by impacting active autotrophic ammonia oxidizers and nitrite oxidizers as assessed by DNA stable isotope probing. *Environmental Microbiology*, 21(4), 1224-1240. doi: 10.1111/1462-2920.14553.

[13] Kopittke, P.M., Menzies, N.W., Wang, P., McKenna, B.A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environment International*, 132, article number 105078. doi: 10.1016/j.envint.2019.105078.

[14] Kovalenko, A.M., Kovalenko, O.A., & Piliarskyi, V.G. (2020). Yield of crops of short-rotation crop rotation under conditions of application of microbial preparations in the Southern Steppe of Ukraine. *Agrarian Innovations*, 1, 52-56. doi: 10.32848/agrar.innov.2020.1.8.

[15] Liu, Z., Xie, W., Yang, Z., Huang, X., & Zhou, H. (2021). Effects of manure and chemical fertilizer on bacterial community structure and soil enzyme activities in North China. *Agronomy*, 11(5), article number 1017. doi: 10.3390/agronomy11051017.

[16] Lykhovyd, P.V., & Kozlenko, Ye.V. (2018). Assessment and forecast of water quality in the River Ingulets irrigation system. *Ukrainian Journal of Ecology*, 8(1), 350-355. doi: 10.15421/2018_221.

[17] Lykhovyd, P.V., & Lavrenko, S.O. (2017). Influence of tillage and mineral fertilizers on soil biological activity under sweet corn crops. *Ukrainian Journal of Ecology*, 7(4), 18-24. doi: 10.15421/2017_81.

[18] Ma, Q., Wen, Y., Wang, D., Sun, X., Hill, P.W., Macdonald, A., Chadwick, D.R., Wu, L., & Jones, D.L. (2020). Farmyard manure applications stimulate soil carbon and nitrogen cycling by boosting microbial biomass rather than changing its community composition. *Soil Biology and Biochemistry*, 144, article number 107760. doi: 10.1016/j.soilbio.2020.107760.

[19] Malashevskyi, M., Palamar, A., Malanchuk, M., & Bugaienko, O. (2020). The possibilities of sustainable land use formation in Ukraine. *Geodesy and Cartography*, 46(2), 83-88. doi: 10.3846/gac.2020.7480.

[20] Mishra, A., & Singh, D. (2020). Role of soil fauna: En route to ecosystem services and its effect on soil health. In *Phytobiomes: Current insights and future vistas* (pp. 105-126). Singapore: Springer. doi: 10.1007/978-981-15-3151-4_5.
[21] Panagos, P., Standardi, G., Borrelli, P., Lugato, E., Montanarella, L., & Bosello, F. (2018). Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. *Land Degradation & Development*, 29(3), 471-484. doi: 10.1002/ldr.2879.
[22] Peel, M.C., Finlayson, B.L., & McMahon, T.A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, 11, 1633-1644. doi: 10.5194/hess-11-1633-2007.
[23] Pereira, P., Bašić, F., Bogunovic, I., & Barcelo, D. (2022). Russian-Ukrainian war impacts the total environment. *Science of the Total Environment*, 837, article number 155865. doi: 10.1016/j.scitotenv.2022.155865.
[24] Rawtani, D., Gupta, G., Khatri, N., Rao, P.K., & Hussain, C.M. (2022). Environmental damages due to war in Ukraine: A perspective. *Science of the Total Environment*, 850, article number 157932. doi: 10.1016/j.scitotenv.2022.157932.
[25] Ren, F., Sun, N., Xu, M., Zhang, X., Wu, L., & Xu, M. (2019). Changes in soil microbial biomass with manure application in cropping systems: A meta-analysis. *Soil and Tillage Research*, 194, article number 104291. doi: 10.1016/j.still.2019.06.008.
[26] Scheffe, H. (1999). *The analysis of variance (Vol. 72)*. New York: John Wiley & Sons.
[27] Shao, H., Chu, L., Lu, H., Qi, W., Chen, X., Liu, J., Kuang, S., Tang, B., & Wong, V. (2019). Towards sustainable agriculture for the salt-affected soil. *Land Degradation & Development*, 30(5), 574-579. doi: 10.1002/ldr.3218.
[28] Sharma, A.K. (2005). *Textbook of correlations and regression*. New Delhi: Discovery Publishing House.
[29] Sintia, M., Rahman, M.M., Khanom, A., Huq, M.A., Ali, M.Y., Rauf, M., Banu, N.A., Biswas, S.K., & Azad, M.A.K. (2021). Differential response of the nitrifying microbes and net nitrification rates (NNRs) between different cereal and legume crop soils with chemical fertilization. *Arabian Journal of Geosciences*, 14, article number 1857. doi: 10.1007/s12517-021-08250-5.
[30] Sumbul, A., Ansari, R.A., Rizvi, R., & Mahmood, I. (2020). Azotobacter: A potential bio-fertilizer for soil and plant health management. *Saudi Journal of Biological Sciences*, 27(12), 3634-3640. doi: 10.1016/j.sjbs.2020.08.004.
[31] Tang, H., Li, C., Xu, Y., Cheng, K., Shi, L., Wen, L., Li, W., & Xiao, X. (2021). Effects of fertilizer practice on fungal and actinobacterial cellulolytic community with different humified particle-size fractions in double-cropping field. *Scientific Reports*, 11, article number 18441. doi: 10.1038/s41598-021-97975-0.
[32] Tokmakova, L., Trepach, A., Shevchenko, L., Larchenko, I., Lepeha, O., & Haitova, N. (2019). Assimilation of phosphorus by plants of corn at presence of phosphate mobilizing bacteria. *Bulletin of Agricultural Science*, 97(7), 14-19. doi: 10.31073/agrovisnyk201907.
[33] Tong, Z., Wang, L., Wang, Y., Li, X., & He, F. (2023). Effects on soil bacterial organisms in an alfalfa monocropping system after corn insertion and nitrogen fertilization. *Agronomy*, 13(1), article number 253. doi: 10.3390/agronomy13010253.
[34] Wang, H., Zhang, D., He, J., Wang, L., Ren, J., Zhang, S., Bai, W., Song, J., Lv, G., & Li, J. (2022). Changes in soil properties, bacterial communities and wheat roots responding to subsoiling in south loess plateau of China. *Agronomy*, 12(10), article number 2288. doi: 10.3390/agronomy12102288.
[35] Wang, J., Li, R., Zhang, H., Wei, G., & Li, Z. (2020). Beneficial bacteria activate nutrients and promote wheat growth under conditions of reduced fertilizer application. *BMC Microbiology*, 20, article number 38. doi: 10.1186/s12866-020-1708-z.
[36] Zanganeh, F., Heidari, A., Sepehr, A., & Rohani, A. (2022). Bioaugmentation and bioaugmentation–assisted phytoremediation of heavy metal contaminated soil by a synergistic effect of cyanobacteria inoculation, biochar, and purslane (Portulaca oleracea L.). *Environmental Science and Pollution Research*, 29(4), 6040-6059. doi: 10.21203/rs.3.rs-439162/v1.
[37] Zhang, P., Sun, J., Li, L., Wang, X., Li, X., & Qu, J. (2019). Effect of soybean and maize rotation on soil microbial community structure. *Agronomy*, 9(2), article number 42. doi: 10.3390/agronomy9020042.

Мікробна активність темно-каштанового ґрунту в посівах озимої пшениці залежно від застосування добрив

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Анотація. Попередження деградації ґрунтів є важливим завданням сучасної аграрної науки. Збереження та примноження корисної ґрунтової мікрофлори є запорукою забезпечення екологічної функції ґрунтів і їх родючості. Метою даної роботи є вивчення динаміки корисної ґрунтової мікрофлори на посівах пшениці озимої під впливом мінеральних добрив та *Agrobacterium radiobacter* на землях півдня України. Дослідження виконували в трьох разовій повторності в умовах Херсонської області у період 2016-2020 рр. на експериментальних полях Інституту кліматично орієнтованого сільського господарства Національної академії аграрних наук України. Розташування варіантів досліду – систематичне, вивчали наступні фактори: без добрив і *Agrobacterium radiobacter*; $N_{120}P_{90}$; $N_{90}P_{60}$ + *Agrobacterium radiobacter*; $N_{120}P_{90}$ + *Agrobacterium radiobacter*. Вивчення складу мікрофлори у шарі ґрунту 0-30 см виконували у основні фази росту і розвитку пшениці озимої в лабораторних умовах шляхом висівання суспензії на живильні середовища. Статистичний аналіз даних виконували методами дисперсійного, кореляційного та регресійного аналізу. Було встановлено динамічні зміни у складі ґрунтової біоти під впливом досліджуваного фактора. Мінімальну відповідь на внесення мінеральних добрив і бактеріального препарату мали амоніфікуючі бактерії, максимальну – целюлозо-розкладаючі мікроорганізми. Встановлено зменшення чисельності амоніфікуючих бактерій у ґрунті до періоду збирання пшениці озимої, у той час як чисельність нітрифікуючих бактерій і целюлозо-розкладаючої мікрофлори істотно зростала. Регресійні моделі прогнозу чисельності нітрифікуючих бактерій і целюлозо-розкладаючої мікрофлори, розроблені на основі експериментальних даних, мають високу точність (похибка склала 3,78 і 7,79 %), і дозволили встановити негативний вплив фосфорних добрив на мікрофлору темно-каштанового ґрунту. Дослідження не має аналогів в Україні та поглиблює теоретичні знанні щодо впливу мінеральних добрив і бактеріального препарату на основі *Agrobacterium radiobacter* на склад корисної мікрофлори темно-каштанового ґрунту

Ключові слова: амоніфікуючі бактерії; біологічне поліпшення; нітрифікуючі бактерії; целюлозо-розкладаючі бактерії; математичне моделювання

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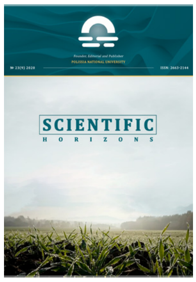

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Molecular and genetic basis for improving the quality of soft wheat grain

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Abstract. The increase in agricultural territories in Azerbaijan can no longer cover the problem of shortage of high-quality baking flour in the domestic market. Thus, there is a need to improve the quality of grain harvested from existing areas to obtain more grain products. The purpose of this study is to review and investigate the physico-chemical and genetic parameters of local and introduced soft wheat varieties to further identify promising areas of breeding. For this purpose, a PCR study of individual loci of the Wx genes responsible for amylose synthesis and electrophoresis of Glu genes encoding gluten quantity and quality were performed. In addition, for the varieties Shafaq 2 and Gonen, which were selected during the research for the test baking of bread, a PCR analysis was performed to compile the gliadin formula of the varieties using a sample of the Bezostaya 1 variety as a marker. The physico-chemical characteristics

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were determined according to quality standards, as well as baking bread sample. During the pilot sowing, one of the varieties – Girmizi Gul1, was sown on plots with various tillage methods – traditional, minimal, and zero. Thus, it was determined that the varieties Gonen and Ekinci 84 contain a zero allele of the Wx-B1 – Wx-B1b gene, which means that their endosperm contains higher-quality starch, and the varieties Askeran, Azemetli 95, Gonen, Kirmizigul, Nurlu 99, Tale 38, and Ugur, in turn, contain a zero allele of the gene GluA1 – GluA1d, which on the contrary worsens the gluten quality of these varieties. As for tillage, the traditional system showed itself to be the best, the minimal tillage was slightly worse, and the zero tillage system turned out to be the least suitable in these conditions. Thus, the obtained data outline further areas for conducting research and open up prospects for targeted selection for alleles of the considered genes

Keywords: flour; starch; gluten; gliadin; baking qualities

INTRODUCTION

The decline in the quality of soft wheat caused by a number of unfavourable yield factors leads to an increase in the agricultural area in Azerbaijan. During 2020-2021, the quality of the crop was most influenced by temperature conditions, in particular abnormally high temperatures, and poor resistance of a number of varieties to infectious diseases – both to brown rust, which spread during the years of observation, and to yellow rust, outbreaks of which were observed for seven years, on the moment when the authors conducted the study.

These trends, which go beyond the years presented, and issues of irrigation and soil erosion, recorded in a number of studies, lead to the fact that as of 2021, about 50% of the republic's wheat needs had to be covered by imports. However, the area of crops has increased by 60% since 2011 (Huseun Oglu, 2021; Mustafayeva *et al.*, 2021). Increasing the amount of grain produced does not fully solve the problem of shortage, because as a result, significantly fewer bread products are obtained from low-quality wheat than from high-quality grain (Tadesse *et al.*, 2019). The suitability of grain for the manufacture of food products, including bread, is mainly determined by its composition. The greatest focus of research in this context is the influence of the physicochemical properties of the constituents of glutens and gliadins (Mirzayeva *et al.*, 2022). These are proteins responsible for the rheological parameters of the dough, since they have the ability to trap air bubbles and form a porous structure of finished products, and also affect the elasticity of the dough (Ospanov *et al.*, 2020). Another significant factor is the influence of the starch content and structure, as well as the ratio of polar and nonpolar lipids, which also affects the volume of bread (Cesevičienė *et al.*, 2022).

The quality of soft wheat, according to E. Hajiyev *et al.* (2021), depends on two groups of factors: environmental and genetic. Environmental factors include weather conditions, soil quality, methods of tillage, method of fertilisation, etc. Genetic factors are currently less investigated, however, the study of genetic control and polymorphism of various enzyme and non-enzyme proteins opens up new opportunities for breeding and selecting varieties with optimal nutritional indicators (Afanasyeva *et al.*, 2023). According to the research by S. Kalenska *et al.* (2023), Glu-type genes are responsible for the synthesis of gluten, which are localised on the long arms of chromosomes of group 1: 1A, 1B, and 1D. At the same time, Glu-D1 genes have the greatest contribution to wheat quality, and Glu-A1 are the least variable. Y. Zi *et al.* (2022), in turn, summarised information on the effect of various genes responsible for starch synthesis on the yield and quality of flour. The Wx genes affect the synthesis of amylose, which reduces the quality of flour and its products. The main effect is provided by the Wx-B1 allele, the smaller one – by Wx-A1. The absence of the first allele significantly improves the quality of flour.

For genes of the Gld group that encode the synthesis of gliadins, as indicated by G. Özer *et al.* (2020), at the moment, no alleles have been identified that have an unambiguous qualitative effect. Alleles Glu-B1d (6+8), Glu-B1h (14+15), and Glu-B1b (7+8) are associated with higher gluten strength and pasta quality. The 1Dx5+1Dy10 alleles determine the level of increase in dough consistency, elasticity, viscosity, and extensibility, baking quality and the corresponding volume of a loaf of bread. Bx7, Bx7 OE, 1Bx17+1By18, 1Bx13+1By16, Bx7+By9 and 1Bx7+By8 in the Glu-B1 and 1Ax2 alleles found on Glu-A1 increase the strength of the dough and positively affect the consistency, extensibility, viscosity, and elasticity of bread dough.

Thus, given the confirmed directional effect of certain groups of genes on the quality of wheat flour, this study is designed to determine whether breeding for these genes really has prospects of becoming one of the ways to overcome the shortage of high-quality baking flour in Azerbaijan.

MATERIALS AND METHODS

Studies on the productivity of 37 local and breeding varieties of soft wheat were conducted in 2020 at the Terter zonal experimental station located in the north-western part of the Karabakh lowland at an altitude of 175 m above sea level. Observations and measurements were carried out three times on the selected plots with an area of 1 m^2. Irrigation was applied at the stage of onset of tube emergence, earing and onset of milk maturity of grain. The agrotechnical practices recommended for the region were also carried out within the framework of the traditional tillage system. The sowing of the Girmizi Gul 1 variety was carried out in the third ten days of November using traditional, minimal, and zero tillage methods.

Thus, the study consisted of three blocks designed to determine the main measures to improve the quality of wheat grain: determining the optimal type of tillage, analysing the grain quality of the main wheat varieties suitable for cultivation in Azerbaijan, and determining the molecular genetic basis of the determining indicators.

As part of the grain quality assessment, weight of 1,000 grains, percentage composition and fibre deformation measurement (FDM), falling number, level of sedimentation, and nitrogen content were determined. The grains were randomly selected, counted and weighed. To determine the gluten content, a sample of medium grain weighing about 50 g was taken. The sample was crushed in a laboratory mill and cleaned of impurities: debris, husks, spoiled and underdeveloped grains by sieving through a series of sieves with holes of different diameters. About 25 g of pure ground grain was taken, 14 cm^3 of distilled water was poured, and a lump of dough was kneaded, which was allowed to settle for 20 minutes. The settled dough was washed under running water until the turbidity of the water stopped and the lump mass decreased. The resulting gluten was squeezed out and wiped with a dry towel during the entire process. They were weighed, recording the results with an accuracy of 0.1. The gluten content was calculated using the equation (1):

$$x = \frac{m_1}{m_2} \times 100. \tag{1}$$

The gluten quality was determined using the IDK-1M and IDK-2 devices. The falling number was determined using a viscometric tube. All stages of grain quality research were carried out using methodological recommendations and Interstate Standard 13586.1-68 (1987). In the study, the Bezostaya 1 variety was used as a marker for electrophoretic analysis. Electrophoresis of spare proteins was performed on gel electrophoresis plates with glycine acetate buffer (pH 3.1). The identification of wheat samples based on the results of electrophoregrams of gliadin coding loci Gld 1A, Gld 1B, Gld 1D, Gld 6A, Gld 6B and Gld 6D was carried out according to the catalogue of allele component blocks of gliadin of the Bezostaya 1 variety (marker), taken as the standard.

The collections were evaluated for the allelic state of the Wx genes using PCR analysis using primers AFC/AR2, Wx-A1b-F-MH/Wx-A1b-R-MH, Sun-1F/Sun1R, BDFL/BRD, 4F/4R, BDFL/BRC1/BRC2/BFC, WxB1L/Wx-B1R, Wx-D1-2F/Wx-D1-2R, Wx-D1-1F/Wx-D1-1R, BDFL/DRSL. In determining the glutenin-coding genes, the UMN19 codominant marker was used to identify allelic variants of the glutenin IUD genes encoded by the Glu-A1 locus. A fragment of 362 pn in size was amplified on samples having subunit 2 (Glu-A1b allele). In samples with a null allele and having subunit 1 (Glu-A1a allele), a fragment of 344 pn was observed.

It was also decided to conduct a test baking of bread to compare varieties with different indicators of the qualitative and quantitative composition of starch. The bread was baked using a straight dough method, dough fermentation, and further baking were carried out on Domino and Arianna devices. The duration of resting was determined organoleptically, baking was carried out at a temperature of 220-230°C. For comparison, the paper presented a comparison of loaves made from flour of varieties Shafaq 2 and Gonen. Statistical processing of the research results was carried out using Microsoft Excel 2010 software suite.

RESULTS

The first stage of the study was the test sowing of one of the varieties – Girmizi Gul 1 – on experimental areas with different types of tillage: traditional, minimal, and zero. The data obtained were highlighted separately (Table 1).

Table 1. *Quality indicators of the Girmizi Gul1 variety under various cultivation methods 2021*

Tillage methods	Weight of 1,000 grains, g.	Vitreousness, %	Gluten, %	FDM, p.p.	Sedimentation, ml	Total nitrogen content, %
Traditional	32.1	50.5	26	76.8	31.5	12.7
Null	32.1	9.5	18.6	95.5	21	11.7
Minimal	32.8	14	28	88	27	10.4

Source: *compiled by the authors*

From the presented results, it can be seen that none of the listed tillage methods revealed statistically significant advantages in terms of the weight of a thousand grains and sedimentation rates. At the same time, the difference in vitreousness indices is noticeable – the highest proportion, more than 50%, is found in grains obtained from plants grown using the traditional method of tillage. This indicator shows a high protein content in the endosperm, compared with the starch content. With zero and minimal treatment, which included less interference with the soil structure, the percentage of vitreousness was in the range of 9-14.

In a separate way, it is worth highlighting the difference in the composition of gluten and the quality of starch. Despite the higher percentage of gluten in grain with traditional and minimal tillage methods – 26-28% versus 18.6% with the zero method. At the same time, the gluten quality expressed through FDM coefficient correlated similarly – the indicator of zero tillage was more than 95 p.p., at minimal tillage – 88, and at traditional tillage method FDM was the lowest – about 77 p.p. Total nitrogen content correlated weakly with tillage method in this case.

The subsequent stages of the study were devoted to determining the molecular soil quality characteristics of the studied wheat varieties. When conducting PCR analysis of 37 local varieties to investigate the allelic diversity of Wx genes, attention was paid to the alleles Wx-B1 – Wx-B1e, Wx-B1 – Wx-B1a, and Wx-B1 – Wx-B1b, where the presence of one of the first or second alleles – “e” or “a” – indicated the presence of active amylose synthesis in the endosperm, in turn, the “b” allele – the so-called null allele, indicates the absence of amylose synthesis. Thus, three samples were found where amplification for the “e” allele according to Wx-B1 – Wx-B1e presumably occurred, these are the varieties Ag Bugda, Berektli 95, and Pervin. Three more samples, according to this analysis, turned out to be presumably heterogeneous and contained both the “a” allele and the “e” allele for this gene. These are wheat varieties Shiraslan 23, Karabakh, and Shafaq 2. The target allele, Wx-B1 – Wx-B1b, is presumably found in the endosperm of two varieties: Gonen and Ekinci 84. All other wheat samples contained the “a” allele of the Wx-B1 gene (Fig. 1).

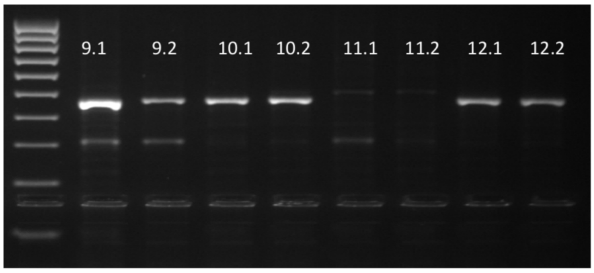

Figure 1. *Example of PCR analysis of the Wx-B1 locus, where sample 11 is the putative “b” allele according to Wx-B1 – Wx-B1b (null allele), and the remaining “a” is the wild type*
Source: *compiled by the authors*

The next group of genes analysed were the Glu group genes responsible for the synthesis of high molecular weight glutenins (HMW-GS) encoded by the Glu-A1, Glu-B1, and Glu-D1 loci localised on the long arms of chromosomes 1A, 1B, and 1D, respectively. Allelic variants Glu-A1a and Glu-A1b encoding subunits 1 and 2, respectively, have a positive effect on baking qualities, whereas the null allele Glu-A1d worsens them. Among all the samples, Glu gene null alleles were detected in seven samples numbered 8, 9, 11, 16, 23, 30, and 34 (Fig. 2). These are the varieties Askeran, Azemetli 95, Gonen, Kirmizigul, Nurlu 99, Tale 38, and Ugur. For the remaining varieties, the presence of the second, Glu-A1b, allele variant was determined to be the most likely, whereas the Glu-A1a allele was not found in any of the samples.

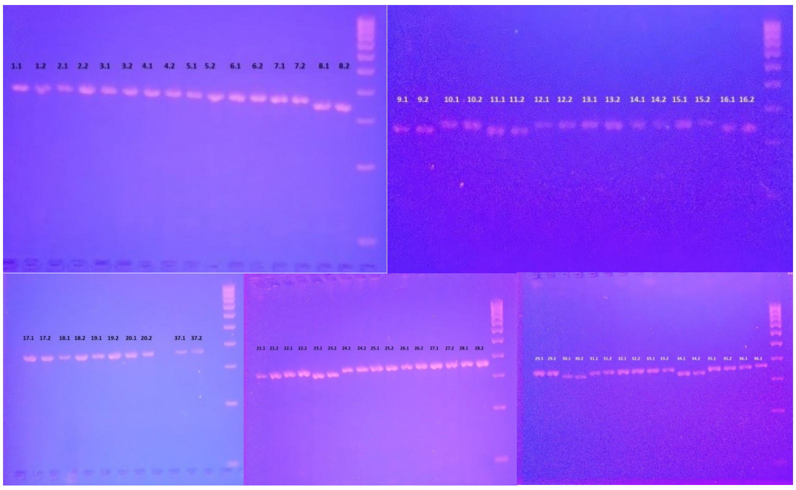

Figure 2. *Determination of the Glu-A1 locus, using the UMN19 codominant marker, where the samples 8, 9, 11, 16, 23, 30, 34 – carry a null allele, and the samples 1-7, 10, 12-15, 17-22, 24-29, 31-33 – carry subunit 2*
Source: *compiled by the authors*

When comparing the physico-chemical parameters determined in the framework of grain quality assessment, varieties with different alleles of Glu group genes, first of all, the indicators involved in the quality of gluten were analysed. Thus, the percentage of gluten for all varieties with a zero allele turned out to be, with minor deviations, about 28 and 30%, only the Azemetli variety showed a result of 24.4%, which is slightly less than the average result of other samples with the same allele. It should be noted that the gluten content of the other varieties containing the coding subunit also ranged from 26-32%. The lowest result in the Ruzi 84 variety is 22.1% gluten, and the highest in the Mirvari variety is 35%. The gluten quality turned out to be average in absolutely all samples, and the FDM was in the range of 90-111 p.a. The best indicators were in the varieties for which the presence of the coding allele of glutenin genes was determined: varieties Azeri – 90; Yagut – 93; Gobustan – 94, and Karakylchyk 2 – 95 p.a. The indices of varieties with a zero allele ranged from 100-109 p.a. There were no clear traceable patterns with the considered genetic factors for the indicators of total nitrogen content, sedimentation, and falling number (Table 2).

Table 2. *Results of the analysis of grain quality of local and introduced varieties (2020)*

No.	Varieties	Weight of 1,000 grains, g	Gluten, %	FDM, p.a.	Sedimentation, ml	Total nitrogen, %	Falling number, seconds	Baking quality, in points
1	Agali	46.1	32.1	110	34.7	13.8	190	4.5
2	Ag bugda	41.9	28	109	21	14	145	4.5
3	Aran	50.2	31.4	100	34.8	14	232	4.7
4	Azeri	49	32.8	90	30	14	177	4.6
5	Berektli 95	37.7	24.5	110.6	-	12.4	123	4.4
6	Ekinci 84	38.2	28.2	100.6	24.4	12	120	4.4
7	Elinge84	56	32.6	100	-	13.4	200	4.5
8	Askeran	45.7	28	105.4	30.5	14.2	180	4.6
9	Azemetli 95	46.2	24.4	100.3	25.7	14	200	4.5
10	Fatima	50	28	95.6	30	13.9	264	4.5
11	Gonen	47.7	30.6	100	33.1	14.4	218	4.8
12	Guneshli	51.2	26.8	112	29.7	14.4	205	4.7
13	Kehraba	49.6	28.4	103.8	-	14.3	189	4.6
14	Karabakh	51.8	28.6	111	-	14.6	244	4.7
15	Karakylchyk 2	47.5	30	95	-	13.6	174	4.5
16	Kirmizigul	52.2	30	97.8	40	14.8	222	4.9
17	Gobustan	50	30.8	94	40	14.9	220	5
18	Ləyaqətli	42.6	30	106.6	33	14.5	190	4.7
19	Mirbeshir50	49.0	32	96.6	-	14.4	138	4.6
20	Mirvari	39.8	35	109.9	-	13.6	144	4.5
21	Mugan	48.8	30	111	-	12.7	200	4.5
22	Murov 2	51.4	33	101.5	33.4	14.3	197	4.6
23	Nurlu 99	37.5	28	109.3	27.7	13	156	4.4
24	Pervin	40	26.4	106	33	13.4	177	4.6
25	Ruzi 84	33.9	22.1	109.9	29	12.4	159	4.4
26	Shafaq 2	50.4	28.4	109	30.3	14	232	4.8
27	Sheki 1	42	30.2	100.4	33.3	13.9	179	4.7
28	Shark	40	28.8	110.5	32.8	14.6	188	4.7
29	Shiraslan 23	50.1	28.6	108.8	32.4	13.9	177	4.6
30	Tale 38	52	30.4	104.1	33.3	13.9	163	4.6
31	Tereggi	48.8	32.6	109.5	30	14.4	190	4.6
32	Terter	49.5	32.1	105	-	13.9	166	4.5
33	Terter 2	50.8	32.6	106.6	-	14	169	4.4
34	Ugur	43.6	30	108.3	33.1	13.4	154	4.5
35	Vugar	52.7	28.8	102	-	14.5	200	4.7
36	Yagut	50.9	28.8	93	-	14.5	196	4.7
37	Peringe (tetraploid)	54.2	26.4	109.4	-	13.0	134	4.3

Source: *compiled by the authors*

For a more detailed comparison of the baking properties and quality of the finished bread product, two varieties were selected: Gonen and Shafaq 2. The Gonen variety was the only one of the studied ones containing two target null alleles: Wx-B1 – Wx-B1b, which led to the absence of amylose synthesis in the endosperm of the grain of this variety, and the Glu-A1d allele of glutenin-synthesising genes, which leads to lower gluten quality. For comparison, the Shafaq 2 variety is heterogeneous in the Wx-B1 gene, and contained both the Wx-B1 – Wx-B1a and Wx-B1–Wx-B1e alleles, but, on the contrary, the Glu-A1b allele of glutenin-synthesising genes turned out to be characteristic of it. Thus, potentially, the starch composition in the Gonen variety should have been more suitable for baking, and in the Shafaq 2 variety, on the contrary, the gluten quality was more optimal. An important factor in choosing varieties was that both samples received a final score for baking properties at the same level – 4.8.

The physico-chemical properties of flour of these varieties turned out to be quite comparable, such as the weight of 1,000 grains, level of nitrogen, FDM, and percentage of gluten (Table 3). The Shafaq variety is slightly superior in terms of the falling number and is inferior in terms of gluten content and sedimentation rate, however, the difference between these indicators is not statistically significant.

***Table 3**. Results of the analysis of the grain quality of the Gonen and Shafaq 2 varieties*

No.	Varieties	Weight of 1,000 grains, g.	Gluten, %	FDM p.a.	Sedimentation, ml	Total nitrogen, %	Falling number, seconds	Baking quality, in points
1	2	3	4	5	6	7	8	9
11	Gonen	47.7	30.6	100	33.1	14.4	218	4.8
26	Shafaq 2	50.4	28.4	109	30.3	14	232	4.8

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

The obtained bread samples, despite the fact that the varieties received an equal score in baking properties, differed visually and organoleptically (Fig. 3 and 4).

***Figure 3.** Laboratory baking of bread from the variety Gonen*

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

***Figure 4.** Laboratory baking of bread from the variety Shafaq 2*

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

The photo shows that the colour and porosity of the bread are different: the pulp of bread made from flour of the Gonen variety is lighter, has a whiter shade and is less porous, the rise of the bread on the side section is smooth, high, arched. The flesh of bread made from Shafaq 2 flour is, accordingly, more porous, has an even texture, a dark colour, and a more yellowish shade. The rise of this sample is low and smooth, the volume is somewhat smaller. The taste properties of both samples are satisfactory, the texture of the second one is softer, moist and elastic, whereas the first sample is denser.

Gluten-coding genes were additionally analysed for the selected varieties. The compilation of the genetic formula of the electrophoregrams of the glutein-coding loci Gld 1A, Gld 1B, Gld 1D, Gld 6A, Gld 6B, and Gld 6D was carried out according to the catalogue of allele-component blocks of gluten of the Bezostaya 1 variety, as a result of which it turned out that the gluten components of the Gonen variety differ from the Bezostaya 1 marker variety in the following blocks: Gld 1D2, Gld 6B2, Gld 6A12; the block components: Gld 1D4, Gld 1A7 of Shafaq 2 variety differ in five blocks: Gld 1B, Gld 6A3, Gld 6D9 (Fig. 5).

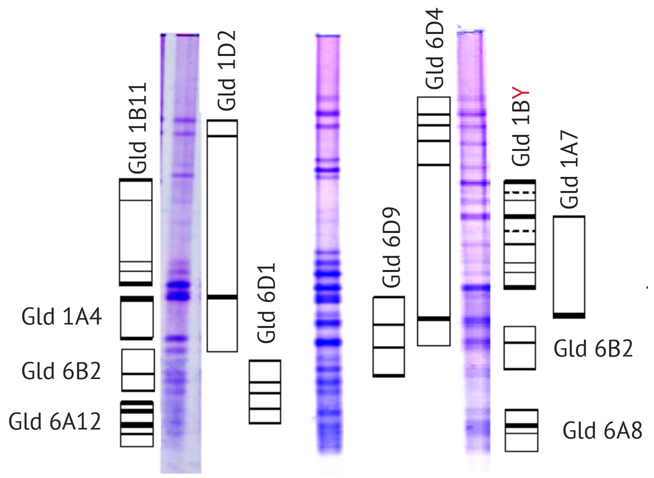

Figure 5. *Gliadin formula of varieties 1 – Gonen (a variety of Turkish origin); 2 – Bezostaya 1 (marker); 3 – Shafaq 2*
Source: *compiled by the authors*

Since gliadin-coding genes are responsible for the porosity of bread products, this information can be used in further studies aimed at investigating the desired texture of bread. Targeted selection of target alleles of genes encoding the synthesis of starch, gluten, and gliadin may be a promising area in improving the quality of wheat.

DISCUSSION

Improving the quality of wheat and the yield of flour from it for the production of high-quality bakery products in quantities capable of meeting demand is a goal that can potentially be achieved by a set of measures. First of all, it is reasonable to consider the factors affecting soil preparation for sowing, namely the tillage system. Despite evidence of the effectiveness of zero tillage for some crops, such as cotton, legumes, or vineyards, the impact of this system is currently only beginning to be actively studied (Fan *et al.*, 2020). B. Barna *et al.* (2023) in their studies note an improvement in the quality and yield of grain with zero tillage. In the study by Z. Peng *et al.* (2020), this tillage system has been identified as one of the most promising in the context of arid or semi-arid climate conditions. In turn, Z.R. Kan *et al.* (2020) are somewhat more skeptical about the prospects of using zero tillage, and note the difficulty of absorbing moisture and developing roots in the absence of loosening the soil, but they still define this system as more promising than the traditional one. Moreover, the conclusions of these researchers are close to the results obtained in this study, regarding the fact that the best indicators were obtained during minimal or rotational tillage.

Very simillar results were obtained by M. Yousefian *et al.* (2021). The researchers noted that the zero tillage system reduces the average physical and chemical properties of grain, increases the amount of fibre and water, while reducing the protein and ash content, while rotary tillage was close in its results to the traditional one and is defined by the researchers as an equivalent replacement. It is noteworthy that the climatic conditions of the region in which the study took place are quite comparable to those in Azerbaijan. The next group of factors that could improve the situation with wheat quality, and which at the same time would be weakly dependent on unfavourable external factors, were genetic (Litvinov & Olefirenko, 2023). E. Filip *et al.* (2023) note three key factors for the selection of varieties containing high-quality starch: the baking potential of flour depends on the amylose content in starch, a decrease in the amylose content improves the quality of flour and the fact that the amylose content is most influenced by the Waxy-B1 locus.

Z. Maryami *et al.* (2020), during the analysis of 160 Iranian wheat varieties, found a pattern to the situation with Azerbaijani varieties reflected in this paper.

Most varieties contained the Wx-B1 – Wx-B1a allele, which corresponds to the so-called "wild type" – that is, it occurs mainly in free-growing, non-selective wheat varieties. Only 2 samples, as well as among Azerbaijani varieties, contained the allele Wx-B1 – Wx-B1b – which has the greatest effect on reducing the synthesis of amylose in the wheat endosperm. For Iranian realities, this is only 1.25% of all the varieties studied, whereas among the varieties considered in this study, there are more than four times as many – 5.4%. The researchers, despite the fact that they did not bake bread and were not involved in the production and study of physical and chemical properties of flour of the identified varieties, see prospects for breeding wheat varieties based on minimisation of amylose content.

Target study by Y. Li *et al.* (2022), in turn, confirms that the expression of the null allele of the Wx-B1 locus affects the content of amylose, reducing it, and its blocking, respectively, increases the proportion of this polysaccharide residue in the composition of starch granules. Accordingly, the type of starch granules, their microstructure, size, thermal properties, etc., and how they affect the baking qualities of flour obtained from this wheat, change. Thus, with the expression of the Wx-B1 – Wx-B1b gene and a decrease in the amylose content, the researchers noted such an effect on the quality of bread as a more homogeneous porous structure, an increase in the volume of bread and its storage time. Y. Sung *et al.* (2023) recorded an increase in the protein content and a greater ability to swell in flour products of the so-called "glass" varieties, which were characterised by a reduced content of amylose in the starch composition. The bread sample obtained by baking from Gonen flour generally corresponds to the characteristics given in other works, especially with regard to volume increase. Indeed, it turned out to be larger in volume than bread made from a similar sample of flour obtained from Shafaq 2 grain, which contained alleles responsible for encoding amylose in significant quantities (Figs. 3, 4).

However, when evaluating the baking qualities and other physico-chemical properties of flour from different wheat varieties, there was no fundamental distinguishable difference between varieties with zero allele and "a" or "e" alleles. This is probably due to differences in the quality of the varieties themselves, which are conditioned by a combination of other genes not considered in this study, and their interaction with climatic and other external factors, which also significantly and differently affect the properties and characteristics of the grain (Panfilova *et al.*, 2019). Another equally important factor affecting the baking potential of wheat is the content and quality of gluten, which is part of it. M.E. Bayram and K.Z. Korkut (2020) identify three main groups of genes important for the optimal state of gluten: Glu-A1, Glu-B1, and Glu-D. They associate the absence of these genes, or rather their zero alleles, with a deterioration in the quality of bread products made from such flour.

C. Guzmán *et al.* (2022) clarify that high-molecular-weight glutenins encoded, in particular, by the Glu–A1 locus, mainly affect the increase in gluten strength, dough extensibility, and also, like the considered allele of the Wx-B1 – Wx-B1b gene, contribute to an increase in the volume of finished baking. The researchers associate zero alleles of the Glu-A gene with a decrease in the quality of finished products. Similar conclusions were obtained by M.H. Lee *et al.* (2022), and they additionally investigated the effect of these loci on some physico-chemical factors of flour quality and found that the Glu-A1 allele positively affects the sedimentation coefficient and an increase in protein content. They also noted the prospects for the selection and use of varieties obtained as a result of targeted breeding for these genes to increase yields in an unfavourable or unstable climate. The Gonen variety, which contains a zero allele for the Glu-A1d gene, is slightly inferior to bread made from Shafaq 2 grain in elasticity and porosity when baked, which may probably be due to differences in the alleles of Glu genes.

Currently, there are not enough studies on the effect of specific gluten-coding genes on certain baking qualities of wheat, since, as noted by K. Pourmohammadi *et al.* (2023), the variability of these genes is very large. However, this opens up space for further work with genotyping and the study of the correlation of the ratio of certain loci and physico-chemical and organoleptic parameters of wheat and its product. In general, this study outlines the way to further work on both a more detailed study of the genome of existing varieties, and breeding work to create new ones that are more stable, productive, and of high quality. Currently, the qualitative analysis was hampered by the fact that the assessment was carried out between different characteristics of different varieties, which led to a more overview character of the article. However, the data obtained can become the basis for a number of studies focused on more narrow aspects.

CONCLUSIONS

Currently, there is a problem in Azerbaijan related to the shortage of grain capable of meeting the needs of the domestic market. Climate change, which has been accompanied by abnormally high temperatures in recent years, has significantly reduced wheat yields. In the part of the study related to determining the optimal tillage for the Girmizi Gul1 variety, it was determined that the most optimal option is minimal tillage, and zero intervention gives results noticeably worse than traditional and minimal tillage methods.

In the main part of the study, 37 local and introduced wheat varieties were analysed, and their quality was determined: weight of 1,000 grains, level of nitrogen and sedimentation, gluten percentage, FDM, and baking quality. Further, samples of each variety were analysed for Waxy-B1 and Glu-A1 gene loci to determine which varieties have a prospect for selective selection based on these genes. As a result, the target null allele of starch-synthesising genes was probably found only in two varieties: Gonen and Ekinci 84. Starch of these varieties has a reduced amylose content, which increases the baking potential of flour from grains of these varieties. The null allele of the Glu-A1 – Glu-A1d gene, on the contrary, worsens the quality of gluten and the baking potential of the variety. Such an allele is probably found in the varieties Askeran, Azemetli 95, Gonen, Kirmizigul, Nurlu 99, Tale 38, and Ugur.

The test baking of bread from grain varieties Gonen and Shafaq 2, as carriers of opposite alleles at both target loci, showed that, in general, the quality of gluten is more important for the texture and porosity of bread than the quality of starch, whereas the reduced amylose content, in turn, contributes more to the volume of baking. However, the clarity and validity of comparisons in this study was not helped by the fact that different varieties were compared that had different traits not only for the target genes. Thus, it seems logical further steps to identify separate lines of research that will be conducted in parallel: determining the effect of the genes in question on specific baking parameters; determining several varieties for experimental work and further breeding; also separately, research related to the influence of specific loci of glutenin-coding genes can be continued.

At the moment, the varieties Kirmizigul and Gobustan, which received the highest scores for baking properties, are promising. It is also rational to involve Gonen and Ekinci 84 varieties in breeding, which are carriers of the zero allele of the Waxy-B1 locus and require modification of glucan-coding genes. The Shafaq 2 variety also demonstrated good baking qualities. Thus, further research will be able to provide a more constructive and measurable answer to the question to what extent the study of the considered genes and the selection work aimed at them can contribute to an increase in the production of bakery products and cover the domestic demand of the Azerbaijani market.

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CONFLICT OF INTEREST

None.

REFERENCES

[1] Afanasyeva, O., Golosna, L., Lisova, G., Kryvenko, A., & Solomonov, R. (2023). Use of effective sources of winter wheat resistance in breeding for immunity. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 52-59. doi: 10.56407/bs.agrarian/4.2023.52.

[2] Barna, B., Torres, N., & Rogiers, S.Y. (2023). Editorial: Improving the sustainability of winegrape vineyards during climate change. *Frontiers in Plant Science*, 14, article number 1314923. doi: 10.3389/fpls.2023.1314923.

[3] Bayram, M.E., & Korkut, K.Z. (2020). Effect of the glutenin genes on quality parameters in common wheat. *Journal of Central European Agriculture*, 21(1), 62-76. doi: 10.5513/JCEA01/21.1.2422.

[4] Cesevičienė, J., Gorash, A., Liatukas, Ž., Armonienė, R., Ruzgas, V., Statkevičiūtė, G., Jaškūnė, K., & Brazauskas, G. (2022). Grain yield performance and quality characteristics of waxy and non-waxy winter wheat cultivars under high and low-input farming systems. *Plants,* 11(7), article number 882. doi: 10.3390/plants11070882.

[5] Fan, J., McConkey, B.G., Luce, M.S., & Brandt, K. (2020). Rotational benefit of pulse crop with no-till increase over time in a semiarid climate. *European Journal of Agronomy*, 121, article number 126155. doi: 10.1016/j.eja.2020.126155.

[6] Filip, E., Woronko, K., Stępień, E., & Czarniecka, N. (2023). An overview of factors affecting the functional quality of common wheat (*Triticum aestivum* L.). *International Journal of Molecular Sciences,* 24(8), article number 7524. doi: 10.3390/ijms24087524.

[7] Guzmán, C., Crossa, J., Mondal, S., Govindan, V., Huerta, J., Crespo-Herrera, L., Vargas, M., Singh, R.P., & Ibba, M.I. (2022). Effects of glutenins (Glu-1 and Glu-3) allelic variation on dough properties and bread-making quality of CIMMYT bread wheat breeding lines. *Field Crops Research*, 284, article number 108585. doi: 10.1016/j.fcr.2022.108585.

[8] Hajiyev, E.S., Mammadova, A.D., Abbasov, M.A., & Aliyev, R.T. (2021). Study of genetic polymorphism and adaptation potential to drought stress of bread wheat (T. *aestivum* L.) of Azerbaijan. *European Journal of Natural History*, 4, 2-7. doi: 10.17513/ejnh.34189.

[9] Huseun Oglu, A.Z. (2021). Study of the soil-ecological state of the soils of the objects of study on the example of the foothill zones of Azerbaijan in the lesser Caucasus under various crops. *American Journal of Plant Biology*, 6(2), 28-33. doi: 10.11648/j.ajpb.20210602.12.

[10] Interstate Standard 13586.1-68. (1987). Retrieved from http://vsegost.com/Catalog/27/27132.shtml.

[11] Kalenska, S., Falko, G., Antal, T., Hordyna, O., & Fediv, R. (2023). Iodine-containing preparations in grain growing technologies. *Plant and Soil Science*, 14(2), 33-45. doi: 10.31548/plant2.2023.33.

[12] Kan, Z.R., Liu, Q.Y., He, C., Jing, Z.H., Virk, A.L., Qi, J.Y., Zhao, X., & Zhang, H.L. (2020). Responses of grain yield and water use efficiency of winter wheat to tillage in the North China Plain. *Field Crops Research*, 249, article number 107760. doi: 10.1016/j.fcr.2020.107760.

[13] Lee, M.H., Choi, C., Kim, K.H., Son, J.H., Park, J., Lee, G.E., Choi, J.Y., Kang, C.S., Shon, J., Ko, J.M., & Kim, K.M. (2022). Analysis of protein properties and gluten protein composition evaluation of wheat genetic resources. *Korean Society of Breeding Science*, 54(4), 245-259. doi: 10.9787/KJBS.2022.54.4.245.

[14] Li, Y., Karim, H., Wang, B., Guzmán, C., Harwood, W., Xu, Q., Zhang, Y., Tang, H., Jiang, Y., Qi, P., Deng, M., Ma, J., Lan, J., Wang, J., Chen, G., Lan, X., Wei, Y., Zheng, Y., & Jiang, Q. (2022). Regulation of amylose content by single mutations at an active site in the Wx-B1 gene in a tetraploid wheat mutant. *International Journal of Molecular Sciences*, 23(15), article number 8432. doi: 10.3390/ijms23158432.

[15] Litvinov, D., & Olefirenko, O. (2023). Assessment of the tillage impact on soybean productivity. *Plant and Soil Science*, 14(3), 75-83. doi: 10.31548/plant3.2023.75.

[16] Maryami, Z., Azimi, M.R., Guzman, C., Dreisigacker, S., & Najafian, G. (2020). Puroindoline (Pina-D1 and Pinb-D1) and waxy (Wx-1) genes in Iranian bread wheat (*Triticum aestivum* L.) landraces. *Biotechnology & Biotechnological Equipment*, 34(1), 1019-1027. doi: 10.1080/13102818.2020.1814866.

[17] Mirzayeva, G., Ibrahimov, E., & Ahmedova, F. (2022). Studying the resistance of introduced wheat samples to diseases and other parameters, selecting the primary material for breeding. In *Proceedings of symposium "Advanced biotechnologies – achievements and perspectives"* (pp. 196-198). Chisinau: Instrument Bibliometric National. doi: 10.53040/abap6.2022.66.

[18] Mustafayeva, R., Abbasova, Y., & Qambarova, R. (2021). Economic assessment of agriculture development and prospective directions of agrarian reforms in the Republic of Azerbaijan. *Scientific Papers Series Management Economic Engineering in Agriculture and Rural Development*, 21(1), 525-536.

[19] Ospanov, A.A., Muslimov, N.Z.H., Timurbekova, A.K., Mamayeva, L.A., & Jumabekova, G.B. (2020). The effect of various dosages of poly-cereal raw materials on the drying speed and quality of cooked pasta during storage. *Current Research in Nutrition and Food Science*, 8(2), 462-470. doi: 10.12944/CRNFSJ.8.2.11.

[20] Özer, G., Paulitz, T.C., Imren, M., Alkan, M., Muminjanov, H., & Dababat, A.A. (2020). Identity and pathogenicity of fungi associated with crown and root rot of dryland winter wheat in Azerbaijan. *Plant Disease*, 104(8), 2149-2157. doi: 10.1094/PDIS-08-19-1799-RE.

[21] 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.

[22] Peng, Z., Wang, L., Xie, J., Li, L., Coulter, J.A., Zhang, R., Luo, Z., Cai, L., Carberry, P., & Whitbread, A. (2020). Conservation tillage increases yield and precipitation use efficiency of wheat on the semi-arid Loess Plateau of China. *Agricultural Water Management*, 231, article number 106024. doi: 10.1016/j.agwat.2020.106024.

[23] Pourmohammadi, K., Abedi, E., & Hashemi, S.M.B. (2023). Gliadin and glutenin genomes and their effects on the technological aspect of wheat-based products. *Current Research in Food Science*, 7, article number 100622. doi: 10.1016/j.crfs.2023.100622.

[24] Sung, Y., Kim, K., Park, J., Kang, S., Park, C., Cho, S., & Kim, C. (2023). *Identification and characterization of waxy bread wheat carrying a novel Wx-B1 allele*. Retrieved from https://www.preprints.org/manuscript/202305.1468/v1

[25] Tadesse, W., Sanchez-Garcia, M., Assefa, S.G., Amri, A., Bishaw, Z., Ogbonnaya, F.C., & Baum, M. (2019). Genetic gains in wheat breeding and its role in feeding the world. *Crop Breeding, Genetics and Genomics*, 1, article number e190005. doi: 10.20900/cbgg20190005.

[26] Yousefian, M., Shahbazi, F., & Hamidian, K. (2021). Crop yield and physicochemical properties of wheat grains as affected by tillage systems. *Sustainability*, 13(9), article number 4781. doi: 10.3390/su13094781.

[27] Zi, Y., Cheng, D., Li, H., Guo, J., Ju, W., Wang, C., Humphreys, D.G., Liu, A., Cao, X., Liu, C., Liu, J., Zhao, Z., & Song, J. (2022). Effects of the different waxy proteins on starch biosynthesis, starch physicochemical properties and Chinese noodle quality in wheat. *Molecular Breeding,* 42, article number 23. doi: 10.1007/s11032-022-01292-x.

Молекулярно-генетичні основи підвищення якості зерна м'якої пшениці

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Анотація. Збільшення сільськогосподарських територій в Азербайджані вже не може покрити проблему нестачі високоякісного хлібопекарського борошна на внутрішньому ринку. Таким чином, існує потреба в поліпшенні якості зерна, зібраного з існуючих площ, для отримання більшої кількості зернових продуктів. Метою даного дослідження є огляд та вивчення фізико-хімічних та генетичних параметрів місцевих та інтродукованих сортів м›якої пшениці для подальшого визначення перспективних напрямків селекції. Для цього було проведено ПЛР-дослідження окремих локусів генів Wx, що відповідають за синтез амілози, та електрофорез генів Glu, що кодують кількість і якість клейковини. Крім того, для сортів Shafaq 2 і Gonen, які були відібрані в ході досліджень для тестового випікання хліба, був проведений ПЛР-аналіз для складання гліадинової формули сортів з використанням зразка сорту Безоста 1 в якості маркера. Фізико-хімічні показники визначали за стандартами якості, а також за результатами випікання зразків хліба. Під час дослідного посіву один із сортів – Girmizi Gul1 – висівали на ділянках з різними способами обробітку ґрунту – традиційним, мінімальним та нульовим. Так, було визначено, що сорти Gonen і Ekinci 84 містять нульовий алель гена Wx-B1 – Wx-B1b, що означає, що їх ендосперм містить крохмаль більш високої якості, а сорти Askeran, Azemetli 95, Gonen, Kirmizigul, Nurlu 99, Tale 38 і Ugur, в свою чергу, містять нульовий алель гена GluA1 – GluA1d, що навпаки погіршує якість клейковини цих сортів. Щодо обробітку ґрунту, то найкраще себе показала традиційна система, дещо гірше – мінімальний обробіток, а найменш придатною в даних умовах виявилася система нульового обробітку. Таким чином, отримані дані окреслюють подальші напрями проведення досліджень і відкривають перспективи для цілеспрямованої селекції на алелі розглянутих генів

Ключові слова: борошно; крохмаль; клейковина; гліадин; хлібопекарські властивості

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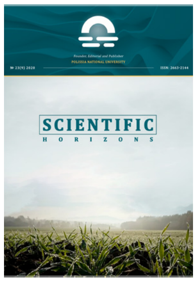

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Effect of an ultra-high frequency electromagnetic field on the physical properties of spelt grain

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Abstract. Since spelt grain is one of the most promising non-conventional types of plant material for healthy food products, it is important to investigate environmentally friendly technologies for post-harvest processing of this crop. The purpose of this study was to determine the physical changes in spelt wheat grain under the influence of microwave electromagnetic radiation. The study presented the results of research on how the electromagnetic field of ultra-high frequencies and the duration of processing

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affect the quality characteristics of spelt grain of the Holikovska wheat variety harvested in Cherkasy region in 2020 and 2021. During the experimental study, physical methods of grain quality research were used following the developed and existing methods and industry standards. The complex structural changes in spelt grains during their treatment with an ultra-high frequency electromagnetic field with an increase in grain size, shape, and volume were investigated. Analysis found that the grain fractional composition changed towards reducing the passage depending on the processing time by 1.5-4.0 times. It was found that the treatment of spelt grain with high-frequency waves for 20-180 s reduces grain moisture content by 2-36% compared to the control, with a significant decrease after the first minute of exposure. Moreover, during the first minute of intensive grain heating, the grain temperature increased, while during the next two minutes, the intensity of grain heating decreased by 1.5-3 times. It was also proved that irradiation with ultra-high frequencies decreased the number of vitreous grains, while the number of floury grains, on the contrary, increased. The analysis also found that the vitreousity of treated spelt wheat grain by electromagnetic waves of ultra-high frequency decreases by 1.3-1.5 times during the last 2-3 minutes of treatment. The developed recommendations for the use of ultra-high frequency electromagnetic waves in the technological processes of storage and processing of spelt grain can be used by enterprises to intensify the production of environmentally friendly products

Keywords: spelt grain processing; ultra-high frequencies; grain heating; quality; vitreousity; fractional composition

INTRODUCTION

The use of high and ultra-high frequency electromagnetic waves opens new opportunities for creating environmentally friendly grain storage and processing. The influence of the electromagnetic field of ultra-high frequency on the technological quality of spelt grain needs to be investigated to understand the nature of its further use. Microwave heating processes are currently used in many areas: from environmental remediation processes (Stanislavov *et al.*, 2018); in the food industry (Demir *et al.*, 2023), to new pharmaceutical technologies (Kumeda & Sukhodub, 2021). According to researchers, spelt wheat grain is a valuable source of protein, fibre, and many useful components, and has a special flavour with nutty notes, making it a valuable raw material for the food industry. L.A. Vecherska *et al.* (2018) emphasise the key problem of the agro-industrial complex – increasing the nutritional value, digestibility, and assimilation of grain as a component of food and feed production. Y. Kretova *et al.* (2018) recommend grain treatment by microwave irradiation to stabilise the product and as an effective alternative to chemical insect deinfestation methods.

In experiments on irradiation of plant seeds with an ultra-high frequency electromagnetic field (UHF EMF) (Zhong *et al.*, 2018), two effects are described: one is stimulation of germinating ability and germination energy of seeds, increase in the biomass of the crop, improvement of its structure (increase in the content of carotene and sugar in roots, protein in grain, starch in potatoes), and the second is lethality to living organisms. The most widespread processing of grain raw materials with UHF waves in the food industry is in the bakery, confectionery, and oil industry (Osadchuk, 2019).

Y. Kovra *et al.* (2022) found the influence of the ultra-low frequency electromagnetic field (ULF EMF), electromagnetic induction (EMI), processing duration, conditions and duration of storage of the treated grain on the quality characteristics of wheat grain. Microwave treatment is widely used to disinfect and improve the value of grain. Thus, M. Sarraf *et al.* (2020) investigated the bactericidal effect of UHF treatment, inhibiting and destroying existing fungi, bacteria, and insects, ensuring this without any chemicals, which is extremely relevant today. V. Liubych *et al.* (2019) argue that intensive and environmentally friendly technologies are increasingly used for grain cultivation. Therewith, the requirements for alternative methods of replacing chemical processing include competitiveness, environmental friendliness, and safety for humans. That is why such a method of exposure as irradiation with UHF waves was recommended. The specific feature of heating bulk material with UHF is its penetration of the electromagnetic field into the grain without an intermediate gas medium, while the amount of heat generated in it and its distribution throughout the grain depended on the humidity. Where the humidity was higher, the temperature was also higher. Since the moisture content in the centre of the kernel is always higher, the temperature and pressure in the centre of the kernel are also consistently higher than in the shell. Due to this effect, moisture from the inside of the kernel is forced to the surface of the kernel, from where it can be easily removed, which is an advantage of this method of hydrothermal treatment.

A. Zykov *et al.* (2019) states that considerable advantages in drying bulk materials are provided by the use of UHF electromagnetic field energy. Thus, since electromagnetic waves penetrate each particle of raw material, heating it from the inside, and the heating is more intense the higher its moisture content, the release of moisture is much more intense due to an increase in internal steam pressure; this is especially true for grains with hard shells. Therewith, energy consumption and material intensity of production lines reduced, while the consumer received a high-quality product. The purpose of this study was to establish the effect of microwave oven electromagnetic radiation at different exposure times on the physical properties of spelt grain.

MATERIALS AND METHODS

The principal research was conducted at the educational and scientific laboratory "Quality Assessment of Grain and its Processed Products" of the Department of Food Technologies of the Faculty of Engineering and Technology of Uman National University of Horticulture in 2020-2022. For UHF treatment, the study used spelt wheat grain of the Holikovska variety. The theoretical research was based on the methods of the theory of heat and mass transfer and drying, mathematical modelling of technological processes, and was carried out using the basic principles of higher mathematics, while experimental studies were carried out following the developed and existing methods and industry standards (DSTU 3355-96, 1996; DSTU 4138-2002, 2003; DSTU ISO 712:2015, 2016) in laboratory conditions on the developed experimental microwave oven unit using the planning of a multivariate experiment and the application of statistical processing methods.

The study was conducted according to the following scheme:

- processing grain in a microwave oven;
- determination of temperature rise under the influence of an electromagnetic field;
- determination of changes in grain size using laboratory sieves;
- investigation of the effect of grain temperature on their vitreousity.

During the experiment, physical research methods were used to treat the grain with UHF waves, determine the temperature of the grain, its fractional composition, and vitreousity. The grains were treated with the electromagnetic field of a kitchen microwave oven (P=1.0 kW). The prototypes were exposed to an electromagnetic field from 20 to 180 s (periods with an interval of 20 s).

An increase in temperature above 40°C in the initial stages inactivates the enzymatic activity of the grain, and above 60°C leads to coagulation and protein denaturation. At 50-60°C grain starts losing its viability. The temperature was measured immediately after grain processing with a compact pyrometer. The moisture content of spelt grain was determined by drying in an electric drying oven (SES-3MC, Ukraine) at 130°C for 40 min.

The total vitreousity of the grain is determined in a 50 g sample of wheat grains, free from debris and grain impurities. The total vitreousity is the sum of the fully vitreous and half of the partially vitreous grains. The analysis is performed using a DSZ-3 diaphanoscope (OLISLAB 1100, Ukraine). The total vitreousity of spelt grain was determined according to the following formula:

$$\text{Vitreousity (\%)} = 0.5\times C - 0.5\times B + 50\%, \quad (1)$$

where C is the number of fully vitreous grains, pcs; B is the number of fully mealy grains, pcs.

Generally accepted methods for determining grain moisture and vitreous content were used, as described in Methods of determining product quality indicators of crop production (2016), approved by Working instruction No. 04 (NIBULON LLC, 2021). The size of wheat grains was determined using sieves with different diameters, namely ø2.0, ø2.2, ø2.4, ø2.6, ø2.8, and ø3.0. The sieves were placed on a universal laboratory sieving machine RLU-1 (OLISLAB 5100, Ukraine). The sieving time was 2 min. After sieving, grain fractions were selected from each sieve and weighed using a KERN 440-21N laboratory balance (KERN&SOHN, Germany).

RESULTS AND DISCUSSION

Temperature of spelt wheat grain after UHF treatment. When spelt grain was treated with microwave beams, it was heated, which led to the evaporation of moisture and drying of the grain. It is important to establish regularities in the temperature and moisture content of the grain. The dynamics of these indicators was recorded for 180 s (3 min) in increments of 20 s (Table 1).

Table 1. *Temperature of spelt wheat grain after UHF treatment*

Duration of exposure to UHF EMF, s	Temperature, °C			Humidity, %
	minimum	maximum	average	
0	–	–	15.5	11.9
20	29.8	48.6	39.2	11.7
40	45.2	82.5	63.8	11.4
60	56.6	109	82.8	11.0
80	64.8	125.1	94.9	10.5
100	77.5	135.5	106.5	10.1
120	93.6	138.4	116	9.4
140	97.8	146.5	122.1	8.9
160	102.1	144.3	123	8.0
180	112.2	142.8	127.5	7.6
LSD_{05}	*6.1*	*9.7*	*7.7*	*0.7*

Note: *the temperature before grain processing was 15.5°C*
Source: *developed by the authors of this study based on (Qu et al., 2017; Osokina et al., 2020)*

Table 1 shows that after 20 s of heating, the grain temperature increased: at the minimum, from 15.5°C to 29.8°C, and at the maximum, up to 48.6°C, which is on average 2.5 times higher than the initial temperature of the spelt grain. After 40 s of heating, the minimum grain temperature increased by 3 times, and the maximum by 5 times, or 4 times on average. After 60 s of heating, the rate of temperature increase decreased slightly, but the minimum temperature increased 3.7 times, while the maximum temperature increased 7 times, or 5.3 times on average. In other words, after 1.0 min of heating the grain, the temperature increased to 57-109°C or an average of 83°C.

During the second minute of heating for 80-120 s, the minimum temperature of the spelt grain increased 5-6 times and reached 93.6°C, the maximum temperature increased 8-9 times and reached 108.4°C. Therewith, the average temperature crossed the 138°C mark, i.e., it averaged 116°C, a 7.5-fold increase. During the third minute of heating, the intensity of the process slowed down and the minimum temperature increased to 112°C or 6.7 times, the maximum temperature to almost 143°C or slightly more than 9 times. The average temperature reached 127°C, while the increase was 9.3 times higher.

Thus, a sharp increase in grain temperature (min – 60°C, max – 109°C, average – 83°C) occurred during the first minute of heating, which was 4.7 and 5 times higher than the initial temperature, respectively. During the second minute, the heating rate was 1.5 times higher compared to the first minute. Therefore, the grain temperature was min up to 94°C, max up to 134°C, and an average of 116°C, which corresponded to an increase of 6.6-7.5 times. During the third minute, the grain continued to heat, but the intensity decreased by a third compared to the second minute, and therefore the grain temperature was: min – 112°C, max – 144°C, and on average – 127°C, which corresponds to an increase of 7.7, 9.3, and 8.2 times, respectively. At the same time, a decrease in grain moisture content was observed during heating. However, the changes had a slightly different trend.

During the first minute of heating, the moisture content of the grain decreased by almost 1% – from 11.9% to 11%, which was only 10% of the initial moisture content. In the second minute (within 100 s), the humidity decreased and reached 1.8% (only 12%). Over the next 120-140 s, these indicators increased, while the humidity decreased to 8.9%, or a 1.3-fold decrease by 3 relative percent. By the end of the third minute, the grain moisture content had decreased by 4.3%, or 1.5 times, to 7.6%. This trend could be explained by the fact that the grain sample at the beginning of the experiment had a low moisture content of 11.9% (dry grain). There is no free moisture in this grain. During the energy, bound moisture was released from the grain – hygroscopic moisture. The process started with external heating and then moved to the centre of the kernel. Based on the analysis, it can be concluded that microwave rays had a specific effect on the heating intensity of spelt grain and changes in its moisture content. The moisture content of dry grain (11.9%) decreases by only 10% in the first minute, by 12% in the second minute, and by 1.5 times by the end of the third minute. In total, the grain lost 4.6% of its moisture, with a significant deepening by the end of the process.

Fractional composition of spelt wheat grain after UHF EMF treatment. The grain arriving at the elevator often differed substantially in quality. To improve them, it is advisable to fractionate grain and seeds by different properties (geometric dimensions, density, etc.) (Kostetska & Herasymchuk, 2022). Having quantified the distribution of grains by their geometric structure (in %), the fractional composition of the grain was obtained. In this case, the fines and tails of grains from sieves of different diameters. For the study, 200 g of grain was used with different duration of exposure to UHF EMF. The grain fractional composition after UHF treatment is presented in Table 2.

Table 2. *Fractional composition of spelt grain after UHF treatment, %*

Duration of action UHF EMF, s	Sieve fines ø					Sieve tails ø
	2.2 mm	2.4 mm	2.6 mm	2.8 mm	3.0 mm	3.0 mm
0	4.4	9.5	26.7	28.0	21.6	8.5
20	2.6	10.5	25.9	27.5	23.9	8.7
40	2.8	9.2	26.0	28.1	24.0	8.9
60	2.0	8.5	22.8	29.4	26.0	10.3
80	2.4	8.9	23.8	27.0	26.2	10.1
100	2.3	8.8	23.0	25.9	27.0	10.6
120	2.5	8.2	22.1	26.7	26.6	12.2
140	1.4	4.8	12.8	20.3	27.8	29.30
160	1.1	4.3	11.2	16.5	24.9	38.4
180	1.2	4.4	14.1	17.6	28.3	29.6

Source: *developed by the authors of this study based on (Qu et al., 2017; Kostetska & Herasymchuk, 2022)*

During prolonged treatment with UHF EMF, the grain deformed, increased in size, and swelled. The data in Table 2 show that the treatment of spelt wheat with UHF EMF substantially affects the grain size. Since the number of fines decreased when the grain was sieved through a 2.2 mm sieve, it can be assumed that the shape of the grains became more rounded. If the amount of sifted untreated grain was 4.4%, then with the duration of exposure to UHF EMF, this amount decreased by 1.6-3.6 times. Moreover, for the duration of UHF exposure – 20-40 s – the indicator decreased by 1.6-1.8% or 1.6 times, and for the duration of 60-120 s – by 2.0% or almost 2 times compared to untreated grain. With a processing time of 140-180 s, it increases by 3.1-3.3% or 3.6-4.0 times. That is, the most critical moments in the change in grain size are during processing for 40-60 s and after 120 s.

An analogous trend was observed with grain sieved through a 2.4 mm sieve. The critical limit for a sharp decrease in the number of grains after sieving is wheat at a processing time of 140 s. Thus, the figure dropped from 8.2% (120 s duration) to 4.8%, which is almost 2 times lower. When the grain was sieved through a 2.6 mm sieve, an analogous decrease in the number of grains was observed at the critical limit of the treatment time of 140 s. That is, after 120 s, the number of grains decreased by almost 2 times or 9.3%. A less drastic reduction in grain was observed when sieving on a 2.8 mm sieve. However, after a treatment duration of 120 s, the indicator decreased by 6.7%, which is only 5% relative; after 180 s, it decreased by 10.4%, or 1.6 times.

That is, it was found that with an increase in the fraction of sifted grain, the number of fines decreased. This confirms the conclusion that the bulk grain size increased after irradiation. This pattern is also confirmed by the fact that if one combines the largest fractions of the fines through the ø2.6, 2.8, and ø3.0 mm sieves, their sum is 76.3% for untreated grain, and after treatment up to 180 s, the figures are 77% and 75%, i.e., they did not differ significantly. However, during further processing, the amount of sifted grain decreased to 60% and 57.7%, i.e., there was less sifted grain because its size increased and it stayed on the sieve surface. This is especially evident when looking at the passage and descent of grain through a 3.0 mm sieve. The number of fines and tails through the ø3.0 mm sieve increased during processing. However, the trends were different.

The passage through the 3.0 mm sieve increased slightly by 4.4% after 60 s of processing and stayed at 5% after 120 s, while after 180 s the increase was 6.2-6.7%. In other words, the overall increase was 1.2 times, and 1.3 times in 180 s. The tails from a ø3.0 mm sieve increased only to 2-3% in 120 s, and during the third minute of treatment, the excess reached 20-30%, or 1.2-1.4 times and 3.4-4.5 times, respectively. The data obtained confirm that during the irradiation treatment of grain, the fraction of grain with a larger volume and size increased during the grain sieving and the volume of grain increased significantly during its treatment for three minutes. Thus, it can be concluded that complex structural changes in the grains occurred during the treatment of spelt grain with UHF EMF. This led to an increase in their size, shape, and volume. The grain fractional composition during sieving through ø2.2, ø2.4, ø2.6, and ø2.8 mm sieves changed towards reducing the passage by 1.5-2.0 times and even 3.6-4.0 times, respectively. On the other hand, the fines and tails of a ø3.0 mm grain increased by 1.2-1.3 times and 1.4-3.4 times, respectively.

Vitreousity of spelt grain after UHF treatment. Vitreousity affects the structural and mechanical properties of the grain, which determine the modes of preparation for processing. Wheat grain is divided into three groups according to its vitreousity: ⩾40% – floury, 40-60% – semi-glazed, ⩽60% – vitreous. The vitreous spelt grains had a transparent consistency with a horn-shaped structure in the section, and the floury grains had an opaque consistency, loose, white in the section. It is known (Osokina *et al.*, 2020) that vitreous characterises certain technological properties of grain, its intended use, and usually vitreous grain contains more proteins than floury grain. The data are presented in Table 3.

Table 3. *Vitreousity of spelt grain after UHF treatment*

Duration of action UHF EMF, s	Number of grains pieces		Vitreousity, %
	vitreous	mealy	
0	69	2	83.5
20	59	6	76.5
40	53	4	74.5
60	54	4	75.0
80	46	5	70.5
100	33	10	61.5
120	35	11	62.0
140	28	16	56.0
160	17	26	45.5
180	20	30	45.0
LSD_{05}	–	–	*3.25*

***Source**: developed by the authors of this study based on (Liubych et al., 2019; Osokina et al., 2020)*

Table 3 shows substantial changes in the vitreous content of spelt grain. With increasing irradiation time, the number of vitreous grains decreased: in the first minute of treatment – by 1.3 times, in the second minute – by 2 times, and in the third minute – by 3.5 times. At the same time, the amount of floury grains increased significantly: in the first minute of processing – by 3 times, in the second minute – by 5.5 times, and in the third minute – by 15 times. These changes have a substantial impact on the grain's vitreousity. As Table 3 shows, unprocessed spelt wheat grain is highly vitreous, with a vitreousity of 83.5%. However, in the first minute of grain processing, the figure dropped substantially – by 8-10% but was still high – up to 75%. After the second minute of processing, the grain vitreousity decreased by 26% to 62%, but the grain stayed in the highly vitreous group. However, during the third minute of grain processing, its vitreousity decreased by 1.3-1.5 times and dropped to 46%. As a result, the grain has moved into the medium-vitreous group.

Changes in the vitreous quality of the grain are natural and are associated with a decrease in protein and starch content and a disruption in the grain structure, which changed the monolithic bond between protein and starch. Thus, the number of vitreous grains decreased within three minutes of processing by 1.3, 2, and 3.5 times, and the number of flour grains increased by 3, 5.5, and 15 times during the same time. This was reflected in the vitreousity of the grain, which decreased from 83.5% to 45%, or by 10%, 26%, 46%, or 1.3-1.5 times in the last 2-3 minutes of treatment. The positive experience in reducing moisture content as a result of the UHF EHF confirmed in this study confirms the possibility of using these technologies for drying spelt grain. However, among other microwave conditions, heating spelt grain shows significant results in terms of increasing the floury grain in these samples already after 20 s.

Research confirms the conclusions of A. Zykov *et al*. (2019) about effective microwave drying of grain, which allows ensuring the supply of powerful energy flows to the drying object and obtaining a significant intensification of moisture evaporation. The use of microwave irradiation in the heat treatment of grain is relevant and of practical importance for modern industrial grain processing. The revealed effects of grain irradiation before processing indicate the prospects of introducing the proposed processing methods into production. The shortcomings of the study include the lack of technical and economic indicators of grain production using UHF irradiation. It is advisable to conduct further research on the energy intensity of the microwave irradiation process and compare it with conventional drying methods for existing enterprises. Furthermore, a detailed investigation of the reduction of investment risks resulting from the integration of microwave irradiation into the design of new grain mills of various capacities is required. It is advisable to further study the effect of UHF irradiation on the yield and quality of grain processing products. The safety indicators of finished products, specifically microbiological changes in spelt grain and the quality of finished products as a result of UHF irradiation before hulling, grinding, grinding, etc., need to be clarified.

The obtained results of the effect of such treatment on reducing the vitreousity of spelt grain necessitate the development of recommendations for the use of UHF EMF treatment for milling or feed grain, where the highly vitreous characteristics of grain are of less technological importance. The study by V. Liubych *et al*. (2019) on the use of alternative methods of hydrothermal treatment to further improve the hulling of cereal grain is for spelt grain, which the authors recommend to be used for flattening. Considering the findings of S.S. Biradar *et al*. (2021) on the value of spelt grain as a source of useful components, it is relevant to use UHF EMF to process raw materials processed into functional foods. Moreover, according to H. Zhong *et al*. (2018), the application of electric field and electromagnetic waves can cause conformational changes in the protein by creating free radicals or larger or smaller molecules that damage the primary, secondary, tertiary, and quaternary structure of the protein and thus affect the functional properties of the product. Therefore, electric fields and electromagnetic waves are useful methods for changing the structure of food products, but the changes in protein structure modification of spelt grain are still understudied. Furthermore, research by A. Arzani (2019) confirm that the sustainable use of natural genetic resources is important for achieving the goals of using biological diversity, ensuring the reproduction of ecological integrity and environmental sustainability. Therefore, reviving the unfulfilled potential of ancestral species such as spelt, which is the domesticated ancestor of modern bread and durum wheat, should include multidimensional measures of genetic resources, food diversity, and ecosystem benefits. This creates the preconditions for growing this crop through organic farming. The recommended regimes can be applied to spelt wheat grain of the Holikovska variety or other wheat varieties with comparable technological characteristics. The processing of spelt grain with other technological properties requires a separate investigation.

CONCLUSIONS

Based on the analysis, it can be concluded that UHF rays have a specific effect on the heating intensity of spelt grain. Within the first minute of heating, the grain temperature increases to an average of 83°C. During the second minute, the grain heating intensity decreases by 1.5 times, while the grain temperature is 6.6-7.5 times higher than the initial one. After the third minute of heating the grain, the temperature decreases by three times, with an average grain temperature of 127°C. It can be concluded that complex structural changes occur in spelt grains during microwave EMF treatment. This leads to an increase in their size, shape, and volume. The grain fractional composition during sieving through ø2.2, ø2.4, ø2.6, and ø2.8 mm sieves changes towards reducing the passage by 1.5-2.0 times and even 3.6-4.0 times, respectively. In contrast, the fines and tails of a ø3.0 mm grain increase by a 1.2-1.3 times and 1.4-3.4 times, respectively.

The UHF irradiation caused considerable changes in the grain vitreousity. Thus, the number of vitreous grains decreases within three minutes of processing by 1.3, 2.0, and 3.5 times, while the number of mealy grains increases by 3.0, 5.5, and 15.0 times during the same time. This had an impact on the grain's vitreousity. It decreased from 83.5% to 45%, or by 10%, 26%, 46% in three minutes of processing, or by 1.3-1.5 times in the last 2-3 minutes.

Thus, studies established a substantial effect of UHF electromagnetic radiation of the exposure duration on the physical properties of spelt wheat grain, namely an increase in grain size, its mealiness and temperature with a significant decrease in grain moisture content after the first minute of exposure. It is recommended to investigate the impact of UHF EMFs on the technological properties of grain, including the nutritional value of the finished product, in greater detail with regard to quality and safety indicators for the further use of such grain for agricultural (sowing) or food (processing) purposes. Having reviewed and investigated the study conducted by scientists on the effects of electromagnetic radiation on food, and having drawn conclusions regarding the current research, the authors of this study recommend that further clinical and biochemical studies be conducted.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Arzani, A. (2019). Emmer (T. turgidum ssp. dicoccum). In V.R. Preedy & R.R. Watson (Eds.). In *Flour and breads and their fortification in health and disease prevention* (pp. 89-98). Cambridge: Academic Press. doi: 10.1016/B978-0-12-814639-2.00007-1.

[2] Biradar, S.S., Yashavanthakumar, K.J., Navathe, S., Reddy, U.G., Baviskar, V.S., Gopalareddy, K., Lamani, K., & Desai, S.A. (2021). Dicoccum heat: Current status and future perspectives. In P.L. Kashyap *et al.* (Eds.), *New horizons in wheat and barley research.* Singapore: Springer. doi: 10.1007/978-981-16-4449-8_21.

[3] Demir, E., Tappi, S., Dymek, K., Rocculi, P., & Galindo, F.G. (2023). Reversible electroporation caused by pulsed electric field – opportunities and challenges for the food sector. *Trends in Food Science & Technology,* 139, article number 104120. doi: 10.1016/j.tifs.2023.104120.

[4] DSTU 3355-96. (1996). *Agricultural plant products. Methods of sampling in the process of quarantine inspection and examination.* Retrieved from http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=91446.

[5] DSTU 4138-2002. (2003). *Seeds of agricultural crops. Methods of determining quality.* Retrieved from https://www.agrodialog.com.ua/wp-content/uploads/2018/04/dstu-4138_2002.pdf.

[6] DSTU ISO 712:2015. (2016). *Grain and grain products. Determination of moisture content. Control method.* Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=83685.

[7] Kostetska, K.V., & Herasymchuk, O.P. (2022). Improving soybean quality by seed fractionation. *Bulletin of Uman National University of Horticulture,* 1, 70-76. doi: 10.31395/2310-0478-2022-1-70-76.

[8] Kovra, Y., Stankevych, G., & Borta, A. (2022). The effect of the electromagne tic field of extremely low frequencies on the quality of wheat grain. *Technology and Safety of Food Products*, 16(1), 71-82. doi: 10.15673/fst.v16i1.2292.

[9] Kretova, Y., Tsirulnichenko, L., Naumenko, N., Popova, N., & Kalinina, I. (2018). The application of micro-wave treatment to reduce barley contamination. *Agronomy Research*, 16(5), 2079-2087. doi: 10.15159/AR.18.198.

[10] Kumeda, M.O., & Sukhodub, L.F. (2021). The effect of microwave irradiation on the synthesis of hydroxyapatite/biopolymer nanocomposites. *Chemistry, Physics and Surface Engineering*, 12(3), 201-215. doi: 10.15407/hftp12.03.201.

[11] Liubych, V., Novikov, V., Polianetska, I., Usyk, S., Petrenko, V., Khomenko, S., Zorunko, V., Balabak, O., Moskalets, V., & Moskalets, T. (2019). Improvement of the process of hydrothermal treatment and peeling of spelt wheat grain during cereal production. *Eastern-European Journal of Enterprise Technologies*, 3(11(99)), 40-51. doi: 10.15587/1729-4061.2019.170297.

[12] Methods determination of product quality indicators crop production. (2016). Retrieved from https://sops.gov.ua/uploads/page/5a5f41997447d.pdf.

[13] Osadchuk, P. (2019). Use of electromagnetic field in hydration of vegetable oils. *Scientific Works*, 83(1), 98-102. doi: 10.15673/swonaft.v83i1.1425.

[14] Osokina, N.M., Liubych, V.V., Novikov, V.V., & Leshchenko, I.A. (2020). Yield of spelt wheat rolled grits depending on exposure time to microwave EMF (electromagnetic field of high-frequency current) and water treatment. *Journal of Uman NUH*, 96(1), 52-71. doi: 10.31395/2415-8240-2020-96-1-52-71.

[15] Qu, C., Wang, H., Liu, S., Wang, F., & Liu, C. (2017). Effects of microwave heating of wheat on its functional properties and accelerated storage. *Journal of Food Science and Technology*, 54(11), 3699-3706. doi: 10.1007/s13197-017-2834-y.

[16] Sarraf, M., Kataria, S., Taimourya, H., Santos, L.O., Menegatti, R.D., Jain, M., Ihtisham, M., & Liu, S. (2020). Magnetic field (MF) applications in plants: An overview. *Plants*, 9(9), article number 1139. doi: 10.3390/plants9091139.

[17] Stanislavov, A.S., Sukhodub, L.F., Sukhodub, L.B., Kuznetsov, V.N., Bychkov, K.L., & Kravchenko, M.I. (2018). Structural features of hydroxyapatite and carbonated apatite formed under the influence of ultrasound and microwave radiation and their effect on the bioactivity of the nanomaterials. *Ultrasonics Sonochemistry*, 42, 84-96. doi: 10.1016/j.ultsonch.2017.11.011.

[18] Vecherska, L.A., Relina, L.I., & Golik, O.V. (2018). Emmer: Benefits, drawbacks and prospects. *Bulletin of Uman National University of Horticulture*, 2, 10-16. doi: 10.31395/2310-0478-2018-21-10-16.

[19] Working instruction No. 04. (2021). *Grain. Methods of determining vitreousness*. Retrieved from https://nibulon.com/uploads/files/c25893d7aea930fc1be716d0797b9368025d15b0.pdf.

[20] Zhong, H., Meng-jie, C., Jun-Hu, Ch., & Da-Wen, S. (2018). Effects of electric fields and electromagnetic wave on food protein structure and functionality: A review. *Trends in Food Science & Technology*, 75, 1-9. doi: 10.1016/j.tifs.2018.02.017.

[21] Zykov, A., Orlova, S., & Ovsiannykova, L. (2019). The energy efficiency technique of thermal processing of grain. *Agrarian Bulletin of the Black Sea Littoral*, 94, 176-182. doi: 10.37000/abbsl.2019.94.23.

Вплив електромагнітного поля надзвичайно високої частоти на фізичні властивості зерна полби

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Анотація. Оскільки зерно полби є одним із найбільш перспективних нетрадиційних видів рослинної сировини для продуктів здорового харчування є актуальним вивчення екологічно чистих технологій післязбирального оброблення зерна цієї культури. Метою роботи було встановлення фізичних змін зерна пшениці полби під дією електромагнітного випромінювання мікрохвильової печі. У статті представлені результати досліджень того, як електромагнітне поле надзвичайно високих частот, а також тривалість обробки впливають на якісні характеристики зерна пшениці полби сорту Голіковська зібраної в Черкаській області у 2020 та 2021 роках. Під час експериментальної роботи були використані фізичні методи дослідження якості зерна згідно розроблених та існуючих методик і галузевих стандартів.Досліджено складні структурні зміни в зернівках полби під час його оброблення електромагнітним полем надзвичайно високої частоти із підвищенням розміру, форми та об'єму зернівки. Було проаналізовано, що фракційний склад зерна змінювався вбік зменшення проходу залежно від тривалості оброблення в 1,5-4,0 рази. Встановлено, що обробка зерна полби високочастотними хвилями впродовж 20-180 с знижує вологість зерна порівняно з контролем на 2-36 % зі суттєвим її зменшенням уже після першої хвилини впливу. При чому, відразу впродовж першої хвилини за інтенсивного нагрівання зерна відбувалося збільшення температури зерна, тоді як протягом двох наступних хвилин встановлено зменшення інтенсивності нагрівання зерна в 1,5-3 рази. Також, доведено, що опромінення надзвичайно високих частот впливало на зменшення кількості склоподібних зерен, а кількість борошнистих зерен, навпаки, збільшувалась. Було проаналізовано, що склоподібність обробленого зерна пшениці полби електромагнітними хвилями надзвичайно високої частоти знижується в 1,3-1,5 рази за останні дві-три хвилини оброблення. Розроблені рекомендації використання електромагнітних хвиль надвисокої частоти у технологічних процесах зберігання і перероблення зерна полби можуть бути використані підприємствами для інтенсифікації виробництва екологічно чистих продуктів

Ключові слова: оброблення зерна полби; вкрай високі частоти; нагрівання зерна; якість, склоподібність; фракційний склад

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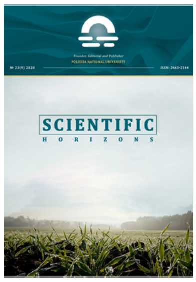

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Mulching as a restoration method of revegetation at ash and slag dumps of Burshtyn TPP

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Abstract. The study of the effect of mulching to establish vegetation cover at industrial sites is promising and relevant in terms of environmental restoration and reduction of environmental risks in the area of influence of industrial facilities. The study aims to investigate and evaluate the effectiveness of mulching and sowing seed mixtures as a method of establishing vegetation cover at ash and slag dumps of thermal power plants. To conduct the study, the soil cover of ash and slag dumps was assessed, and experimental plots were laid out for mulching and sowing seed mixtures. The study revealed that ash and slag dumps ecotopes are characterised by a high concentration of pollutants, namely heavy metals, which makes it difficult for vegetation to grow there. In the course of studying the ecological features of the ecotopes and phytodiversity of the territory, a list of species of native flora for seed mixtures was proposed. Mulching was done on the experimental plots and seed mixtures were sown. Mulching has proven to be an effective method for accelerating the processes of natural regeneration of vegetation in areas affected by anthropogenic impact. The results of the study can be used in practice by ecologists, environmental organisations, and a wide range of specialists to develop and implement measures to restore the ecological balance of degraded and technologically transformed ecosystems

Keywords: pollution; degradation; solid waste; reclamation; mulching; seed mixtures

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INTRODUCTION

The environmental risks caused by the accumulation of multi-tonne waste generated by thermal power plants are of particular concern, as the accumulation of ash and slag in solid waste landfills leads to the transformation of natural geochemical cycles, aerogenic pollution and changes in the chemical parameters of surface and groundwater and leads to the withdrawal of significant areas. One of the largest thermal power plants in West Ukraine is the Burshtyn Thermal Power Plant (TPP), whose ash and slag dumps cover about 200 ha with an annual increase of 0.5 million tonnes. Ash and slag dumps as objects of increased environmental hazard require the development of measures to reduce environmental risks, reclamation, and rehabilitation of these lands to restore and maintain a favourable environmental balance at the regional and national levels.

The current state of the soil cover, which has undergone large-scale transformational changes due to human activity, requires environmental assessment and monitoring (Pichura *et al.*, 2023). The results of a study of the genetic and geographical features of degradation processes in the soils of Lviv region, as presented by N.M. Lemega (2020), indicate the need to implement comprehensive measures to preserve soil fertility. A more challenging issue is the rehabilitation of soils of anthropogenic origin – the so-called techno-soils, which include ash and slag mixtures. A possible way to solve the problem of soil degradation, in particular erosion, may be phytoreclamation, which, in addition to soil protection crop rotations, involves sowing buffer strips and backstage crops, strip or continuous mulching, leaving plant residues on the soil surface, as well as sowing crops in strips and sowing perennial grasses or annual crops between rows of perennial plantations (Tokhetova *et al.*, 2020).

A.O. Bozhenko (2020) analysed erosion processes in the Smotrytskyi Canyon and identified the need to implement a set of anti-erosion measures that would help stop the action of erosion factors. The research was moving from considering erosion processes in a specific area of the canyon to possible measures to reduce the impact of erosion factors on natural objects in a larger context. O.O. Svitlychnyi and A.V. Piatkova (2021) assessed the intensity of soil loss due to erosion in three main areas located within the right-bank Forest-Steppe of Ukraine. The researchers proposed to address the issue of rational land use by implementing soil conservation measures and establishing vegetation cover that helps to retain soil. Considering biological reclamation as an effective method of controlling water and wind erosion, a possible solution to the problem of ash and slag dumps may be the use of plants to create a protective cover at industrial sites exposed to erosion (Fedoniuk *et al.*, 2021). The study of the level of soil erosion degradation in the Western region of Ukraine by V.G. Gaskevych *et al.* (2023) provided valuable conclusions for the application of erosion control measures in various ecosystems. The anti-erosion measures identified by the researchers, such as conservation of highly erodible lands, and soil protection tillage techniques can be implemented in the practice of reclamation of man-made landscapes, in particular, ash and slag dumps of Burshtyn TPP.

In the context of erosion control measures, vegetation occurrence patterns and development on the territories of anthropogenic origin should be addressed. The vegetation formation on the territory of anthropogenic ecotopes, including ash and slag dumps, is a process of natural colonisation of plants from the surrounding ecosystems. Even though this process is long and can take several decades, it is a natural recovery that leads to the formation of plant communities with a high level of biodiversity. In addition, due to the remediation properties of plants, the development of vegetation within the framework of near-natural recovery plays the role of a meliorative and remediation factor that mitigates and reduces the toxic effects of pollutants (Gajic *et al.*, 2018; Guo *et al.,* 2024). Several studies have shown that the best plants for phytoremediation are indigenous species of local flora. Therefore, those native species identified on the targeted sites before the start of reclamation should be included in the phytoremediation project. Effective revegetation measures include sowing seed mixtures with regional species, as well as various agronomic methods of introducing target plant species to restoration sites: fresh hay transfer (mulching) and plants biomass or soil transfer containing seeds (Wagner *et al.*, 2020). Sowing seed mixtures of regional species, reforestation, and agricultural practices such as mulching, mowing, and other management measures are effective approaches to revegetation.

In previous studies, the effectiveness of mulching with natural materials such as sawdust, straw, and black and white agricultural fibres was noted for creating litter under fruit trees in difficult hydrothermal conditions due to the climatic regime (Malyuk, 2023). Burshtyn TPP is the main source of environmental pollution in the Carpathian region. The residual waste is stored in three ash and slag ponds, the total volume of which is currently almost filled (Zhumadilova & Zhigitova, 2023). These facilities are characterised by increased environmental hazards and therefore require particular consideration, reclamation, and remediation to reduce ecosystem risks in the region (Bidolakh, 2023). The study of plant communities at the Burshtyn TPP ash dumps provided an important theoretical basis for the development of revegetation measures in the study area, in particular, the phytodiversity and ecological and genetic features of the ash dumps' vegetation cover were assessed (Semak *et al.*, 2023).

Given the effectiveness of mulching for the restoration of vegetation cover, the testing of the technique in anthropogenic ecotopes is of considerable scientific interest. The study aims to investigate the application of mulching for the restoration of anthropogenic ecotopes, namely ash and slag dumps of thermal power plants.

MATERIALS AND METHODS

The study used research methods to assess the intensity of soil erosion losses in key areas, the use of which is established by Law of Ukraine No. 962-IV "On Land Protection" (2003). The study used methods of analysing the content of heavy metals, as well as methods of mulching with hay and sowing seed mixtures to increase soil fertility and preserve moisture, which helps to improve yields and reduce the risk of erosion and is also important for biodiversity conservation. The object of the study was the territory of ash and slag dumps of Burshtyn TPP (Halych district, Ivano-Frankivsk region).

The anthropogenic ecotopes of ash and slag dump of Burshtyn TPP are characterised by special physical and chemical properties and a certain concentration of radioactive substances (Kovaliv, 2013; Levchenko *et al*., 2013; Gneushev, 2013). The humus content in the 0-20 cm layer in the ecotope of the closed and operating ash and slag dumps ranges from 2.17-5.43%, and in the 20-60 cm layer – from 1.5-4.87%. A characteristic feature of ash and slag dumps soils is their salt acidity, which is 6.2-8.2; affecting the mobility of heavy metals, the acidity of the environment largely determines their phytotoxicity. The 0-60 cm substrate layer of the existing ash and slag dump at Burshtyn TPP contains many heavy metals: zinc, manganese, nickel, lead, copper, cobalt, cadmium and iron. These elements are classified as hazardous compounds of class I and II. When the content of these elements exceeds the maximum permissible concentration, environmental hazards arise for biotic components of ecosystems. Slag is also a source of heavy metals, with heavy metals being leached from slag. The behaviour of heavy metals and their localisation in soil horizons varies and depends on both external (agrochemical) conditions and the migration properties of the element.

The background gamma of ash and slag dumps is characterised by elevated levels of radioactivity and exceeds background levels by 2-3 times (Levchenko *et al*., 2016). Moreover, in combustion products, the concentration of radioactive compounds increases several times compared to the initial fuel – the specific activity of radionuclides in slag is twice as high as in coal. The storage of coal combustion products in ash and slag dumps creates a risk of wind erosion, which can carry dry ash. The main characteristics of ash in terms of its environmental impact are dispersion, miscibility, flowability, density, abrasiveness, and electrical conductivity. Ash dispersion of ash causes its dusting, with polluting particles being carried by wind currents and deposited in the surrounding areas in the form of spots (Penderetskyi, 2005).

The study analysed the content of heavy metals in ash and slag dumps soil mixtures. To assess the level of heavy metal contamination of ash and slag dumps' ecotopes of Burshtyn TPP, their content in the technogenic soils of the study area was analysed. Soil sampling was carried out by DSTU ISO 10381-2:2004 "Soil quality. Sampling. Part 2. Guidelines for sampling methods" (2006). The soil sampling was preceded by the preparation of a map of the study area with the indication of sampling points. Soil was sampled from a depth of 5-20 cm using the envelope method. The content of mobile metal forms in the soil was determined by DSTU 4770.1:2007 "Soil quality. Determination of the content of mobile manganese compounds in the soil in a buffered ammonium acetate extract with a pH of 4.8 by atomic absorption spectrophotometry" (2009).

Field studies were carried out on the territory of the ash and slag dump No. 1-2 of the BTPP. The study of the territory and the laying of experimental plots was carried out in 2021-2023. The study developed recommendations for restoring the vegetation cover of ash and slag dumps, compiled a list of species recommended for sowing on the territory, and tested the mulching methodology. In the course of testing the mulching and seed mixtures methodology, 6 experimental plots with a total accounting area of 140 m^2 were created (Fig. 1).

Figure 1. *Experiment sites*

Source: *photographed by the authors*

Mulching and seed mixtures were tested on the experimental plots.

The seed mixtures used are presented in Table 1 and Figure 2.

Table 1. *Seed mixtures for phytoremediation of ash and slag heaps*

Type	Grams	% in mixture
Seed mixture No. 1		
Perennial ryegrass (*Lolium perenne*)	100	18.2
Annual ryegrass (*Lolium multiflorum*)	50	9.1
Meadow fescue (*Festuca pratensis*)	50	9.1
Red clover (*Trifolium pratense*)	120	21.8
White clover (*Trifolium repens*)	50	9.1
Sweet yellow clover or common melilot (*Melilotus officinalis*)	50	9.1
White melilot (*Melilotus albus*)	50	9.1
Alfalfa (*Medicago sativa*)	80	14.5
Seed mixture No. 2		
Perennial ryegrass (*Lolium perenne*)	100	19.23
Annual ryegrass (*Lolium multiflorum*)	50	9.61
Meadow fescue (*Festuca pratensis*)	50	9.61
Red clover (*Trifolium pratense*)	120	23.07
White clover (*Trifolium repens*)	50	9.61
Sweet yellow clover or common melilot (*Melilotus officinalis*)	50	9.61
White melilot (*Melilotus albus*)	50	9.61
Alfalfa (*Medicago sativa*)	50	9.61
Seed mixture No. 3		
Perennial ryegrass (*Lolium perenne*)	100	21
Annual ryegrass (*Lolium multiflorum*)	50	9.1
Meadow fescue (*Festuca pratensis*)	50	9.1
White melilot (*Melilotus albus*)	50	9.7
Alfalfa (*Medicago sativa*)	80	14.5

Source: *compiled by the authors*

Figure 2. *Seed mixtures for phytoremediation of ash and slag dumps*
Source: *photographed by the authors*

The mixtures are based on grains: *Lolium perenne*, *Lolium multiflorum* and *Festuca pratensis*. Among the beans are *Melilotus albus*, *Melilotus officinalis*, *Trifolium pratense*, *Trifolium repens* and *Medicago sativa*. The area where plant biomass was harvested for mulching was the Druzhba Dendrological Park of Vasyl Stefanyk Precarpathian National University. Hay was harvested here from June to September. The fresh hay was dried and put into plastic bags on the day of transport. For mulching with fresh hay, the material was stored on the day of transport and brought to the study area.

RESULTS

The first step in the phytoremediation techniques is an environmental analysis, site inspection and planning. The territory of the mulching technology selected for testing was inspected during the growing season. A description of the phytodiversity of the study site was carried out, as well as an analysis of soil mixtures.

Among the analysed elements in the soils test samples, the exceedance of the permissible level was recorded for lead in four test samples. In general, the concentration of lead in the sample ranged from 0.7 to 8.9 mg/kg. The concentration of cadmium exceeded the permissible levels in two samples, with the concentration ranging from 0.21 to 0.83 mg/kg. One of the samples exceeded the permissible levels of copper. The concentration of copper in the test samples ranged from 0.14 to 7.35 mg/kg. Nickel and zinc do not exceed the permissible levels, their concentrations range from 1 to 8.4 mg/kg and from 0.4 to 2.4 mg/kg, respectively. For such elements as manganese and iron, no permissible concentration levels were established; the concentration of elements in the test samples ranges from 6 to 148.7 mg/kg and 9.5 to 124.6 mg/kg, respectively.

The content of mobile forms of heavy metals (mg/kg) in the substrates of ash and slag dump No. 3 is as follows: Fe(64.06)>Mn(50.28)>Zn(3.37)>Pb(3.18)>Cu (1.65)>Ni(1.35)>Cd(0.51). The average concentration of mobile forms of heavy metals (mg/kg) in the test samples compared to the permissible levels is shown in the diagram (Fig. 3).

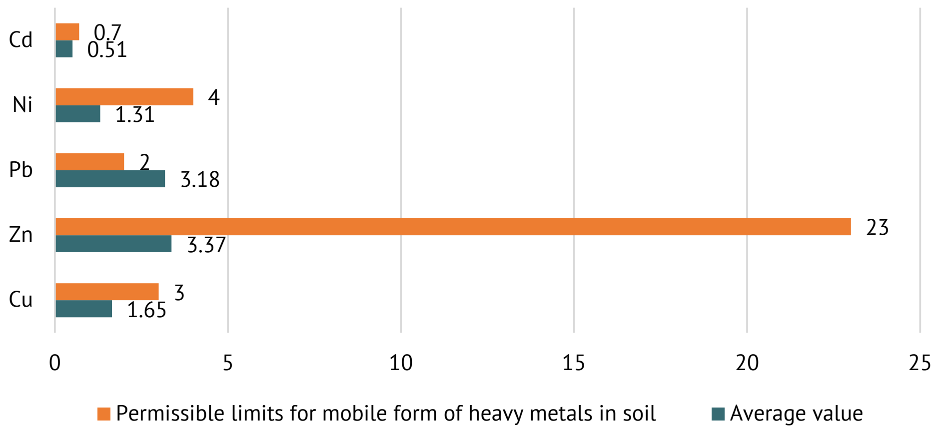

Figure 3. *The content of mobile forms of heavy metals (mg/kg) on the territory of ash and slag dump No. 3 of BTPP*
Source: *compiled by the authors*

As for the analysis of the phytodiversity, previous studies have shown that the representatives of the families *Asteraceae*, *Poaceae* and *Fabaceae* predominate in the flora diversity. A significant proportion of species belong to the *Brassicaceae* and *Rosaceae*. In terms of life cycle, the dominant species are perennial herbs that are pollinated by insects, and their seeds are also spread by insects. Thus, the key role of plant-insect interaction in the formation of the vegetation cover of the study area and its restoration has been shown earlier (Semak *et al*., 2023).

However, the presented study was conducted on the territory of ash and slag dumps 1 and 2, which were decommissioned more than 10 years ago. The study area revealed herbaceous vegetation with shrubs growing along the periphery of the ash dump. The area allocated for mulching is a former ash dump bowl. The vegetation here is formed on ash and is characterised by a continuous cover of *Calamagrostis epigejos* (L.) Roth. Other identified species include *Onagra biennis* Scop., *Trifolium pratense* L., *Inula hirta* L., *Medicago lupulina* L., *and Galium verum* L. There were also some young trees – *Betula pendula* Roth., *Salix* spp. The vegetation was a monodominant plant community dominated by *Calamagrostis epigejos*. The dense sod of *C. epigejos* did not allow other species to settle, which led to the blocking of succession for more than ten years. This situation is typical for neo-ecotopes of anthropogenic lands – the danger of blocking succession with the subsequent formation of monospecies communities was described earlier for post-mining sites (Řehounkova *et al*., 2011). For a comprehensive understanding of the state of phytocoenosis, it is important to assess the density and abundance of species, which requires further research.

A preliminary measure before mulching is the removal of unwanted vegetation in the study area or control of existing plant communities. It has been observed that establishment rates were higher in restoration plots where mowing was carried out than without mowing (Kiehl *et al*., 2010). Mowing, as well as mulching, suppresses competition from the herbaceous layer and promotes the establishment of other species (Wagner *et al*., 2020). Mowing is especially important in the presence of ruderal and invasive species. Areas with sparse vegetation or single plants do not require mowing. Guided by this approach, the grass was mowed on the territory of the experimental plots, followed by sowing seed mixtures and mulching.

Typically, commercial seed mixtures are low-species mixtures of cultivated grasses, often including annuals and perennials, as well as nitrogen-fixing legumes. The use of low-species seed mixtures leads to the formation of unstable, low-productive communities with reduced biodiversity (Kirmer *et al.*, 2011). Such communities are vulnerable to invasion by unwanted species and phytopathogens. In contrast, multi-species plant communities are more stable and resistant to invasion by undesirable species and other environmental impacts. The study proposed a list of species for seed mixtures from local species of native flora. The following criteria were used to select species:

- floristic status;
- ability to survive in the difficult microclimatic and edaphic conditions of ash and slag dumps;
- low nutrient requirements;
- resistance to heavy metals and pollutants;
- well-developed root system;
- long life cycle and herbaceous life form;
- competitive strategy.

The study of the area's phytodiversity resulted in the development of a seed mix. The list includes 20 perennials and 2 biennials, including 7 grass species and 5 legumes (Table 2). Despite the obvious advantages of annual species – habitat function for perennials and formation of organic matter after decaying, the authors did not include annual species in the list to avoid the risk of phytoinvasions and formation of low-value communities, since all identified annual species in the study area have the status of alien species. Grass species are widely used to restore vegetation cover during reclamation activities. The use of grass is explained by their potential to establish vegetation cover quickly and efficiently. In addition, the ability of some to withstand high concentrations of heavy metals when growing on ash and slag mixtures has been previously identified, and a species such as *Phleum pratense* is resistant to high acidity, and due to its ability to form deep and dense roots, it prevents erosion processes (Anca *et al.*, 2011).

***Table 2**. Seed mix for revegetation of ash and slag dumps*

No.	Type	Lifeform	Lifecycle
1	*Achillea millefolium L.*	Herbaceous species	Perennial
2	*Arrhenatherum elatius (L.) P.Beauv. ex J.Presl & C.Presl*	Grain	Perennial
3	*Campanula rotundifolia L.*	Herbaceous species	Perennial
4	*Centaurea jacea L.*	Herbaceous species	Perennial
5	*Dactylis glomerata L.*	Grain	Perennial
6	*Daucus carota L.*	Herbaceous species	Biennial
7	*Echium vulgare L.*	Herbaceous species	Perennial
8	*Festuca rubra L.*	Grain	Perennial
9	*Festuca pratensis (Huds.)*	Grain	Perennial
10	*Holcus lanatus L.*	Grain	Perennial
11	*Leucanthemum vulgare Lam.*	Herbaceous species	Perennial
12	*Melilotus albus L.*	Herbaceous species (legumes)	Perennial
13	*Melilotus officinalis L.*	Herbaceous species (legumes)	Perennial
14	*Phleum pratense L.*	Grain	Perennial
15	*Plantago lanceolata L.*	Herbaceous species	Perennial
16	*Poa trivialis L.*	Grain	Perennial
17	*Prunella vulgaris L.*	Herbaceous species	Perennial
18	*Securigera varia (L.) Lassen*	Herbaceous species (legumes)	Perennial
19	*Tragopogon pratensis L.*	Herbaceous species	Biennial
20	*Trifolium pratense L.*	Herbaceous species (legumes)	Perennial
21	*Trifolium repens L.*	Herbaceous species (legumes)	Perennial
22	*Veronica chamaedrys L.*	Herbaceous species	Perennial

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

However, when selecting grass species for colonisation of devastated areas, their cenotic impact, especially their competitive ability, should be considered, since highly competitive grass species (*Festuca rubra, Arrhenatherum elatius* and *Calamagrosti epigejos*), when colonised by spontaneous succession, form mono-dominant communities and prevent other species from colonising the area. In the proposed mixture, the most competitive species are *Poa pratensis*, *Dactylis glomerata*, *Arrhenatherum elatius* and *Elymus repens*. The distribution of these species and their competitive impact should be controlled through regular monitoring of the restored areas and appropriate technical biodiversity management measures, which will be described in the next section. In general, the assessment of the competitive strategy by J. Grime (1974) shown that most of the proposed species for the seed mixture are competitors/stress-tolerators, competitors/stress-tolerators/ruderals and competitors/ruderals – this reflects a highly competitive potential and at the same time tolerance to environmental factors, and therefore these species have the promising potential to grow in adverse conditions of ash and slag dumps.

Favourable soil conditions are an important condition for species settlement, which can be improved by nitrogen-fixing legumes. The authors included such legumes as *Trifolium* spp., *Melilotus* spp. and *Securigera varia* in the seed mixture. *Trifolium repens* is widely used in seed mixtures, in particular for revegetation after intensive grazing (Skousen & Zipper, 2018). Due to its deep roots with a tasselled root system that develops near the surface, *Trifolium pratense* prevents erosion. Representatives of the *Melilotus* genus also play a positive role in the formation of vegetation cover. The authors included such species as *Melilotus officinalis* and *Melilotus albus* in the proposed mixture – these species are widely used in phytoremediation due to their drought resistance and soil formation ability. One of the most popular species for phytoremediation is seed alfalfa (*Medicago sativa*). Considering the reclamation properties and potential of *Medicago* spp., the use of *Medicago sativa* and other species of the genus in the experimental plots is a desirable measure. In the course of the experiment, seed mixtures were sown, and mulching technology was applied to the experimental area. In total, the following experimental plots were established: 25 m^2 – mulching with dry hay + seed mix No. 1; 20 m^2 – seed mix No. 1, mulching with fresh hay; 25 m^2 – mulching without sowing seeds; 25 m^2 – mulching with dry hay. Hay + Seed Mixture No. 2; 20 m^2 – mulching with dry hay (without sowing seeds); 25 m^2 – Seed Mixture No. 3 + mulching with fresh hay (without mowing).

The authors of this study believe that mulching and sowing seed mixtures is a promising method for restoring vegetation of anthropogenically transformed ecotopes. The results of the impact of seed mixtures and mulching within the experimental plots can be assessed in the long term. However, the applied methodology had an immediate impact, which consists of reducing erosion, introducing organic matter, and preserving moisture in the experimental sites.

DISCUSSION

Analysing the obtained results, the authors of this study concluded that the presence of such pollutants as heavy metals in the soil cover significantly complicates the plant survival and formation of vegetation cover. At the same time, mulch improves seed germination and plant survival. Given the environmental hazard posed by ash and slag dumps, the assessment of environmental risks, in particular soil erosion, in these ecotopes is a topical issue.

S. Stefanidis *et al.* (2023) analysed changes in the average annual rate of soil erosion due to rainfall erosion over the period 1980-2018. This study used hay mulching to create vegetation cover on ash and slag dumps and focused on the use of mulching as a means to prevent soil and water erosion, improve local environmental conditions and maintain biodiversity. The results show that mulching is effective in preventing erosion. A study by A. Kavian *et al.* (2020) analysed the impact of two types of straw mulch rapeseed and corn to reduce the activation of soil loss and runoff in sandy loam soils. The researchers determined that straw mulching reduced soil loss and sediment concentration by 99%, especially under certain moisture conditions and mulch types. R. Li *et al.* (2021) analysed the impact of organic mulching on soil and water loss. It should be noted that the study conducted by the researchers used the straw mulch method and the method of measuring the rate of reduction of soil loss and runoff. The study focused on aspects such as maintaining soil structure, reducing erosion, and the impact on water resources through reduced soil and runoff losses.

In addition, mulching has an important impact on soil moisture, which has also been shown in several studies (Prysiazhniuk *et al.*, 2022). J. Liu *et al.* (2023a) analysed the dual effect of the amount of straw mulching and mulching periods on moisture gain and loss. According to the results of the analysis, it was found that mulching with straw in the amount of 0.8 kg/m^2 at the three-leaf stage had a positive effect on moisture characteristics. The effectiveness of the double effect analysis method is confirmed by the fact that this method addresses the interaction between the amount of straw mulching and the periods of mulching and determine its impact. T. Singh *et al.* (2024) determined the optimal level of irrigation in conjunction with mulching for spring corn. The results show that the dry hay (seedless) mulching method can retain moisture well, prevent weed growth and protect the soil from erosion. However, it has the disadvantage of decomposition of densely packed hay, which can lead to reduced air access to the soil.

H. Duanyuan *et al.* (2023) investigated the effect of rice straw mulching on soil fertility in agroforestry systems, soil carbon (C) and nitrogen (N) content, and enzyme activity. The researchers employed straw powder mulching, straw segment mulching, and mulching without straw as control. The results show that the organic carbon content in the soil increased significantly due to the use of mulching with straw powder and mulching of straw segments in the upper 0-10 cm soil layer compared to the method of mulching without straw. Y. Yang *et al.* (2023) conducted a field experiment using the long-term deep tillage method and straw mulching.

The long-term deep tillage method can have a positive effect on soil quality and stability over a long period. In addition, deep tillage improves plant access to nutrients and water. However, there is also an advantage to the method of the study, which is that hay mulching can be less costly than deep tillage.

It should be noted that mulch can be a different material, both of plant and artificial origin. S. Liu *et al.* (2023b) conducted a study of straw mulching, co-cultivation, and their interaction. This study found that the hay mulching method was more effective than the straw mulching method because hay decomposes faster than straw, which can lead to faster nutrient delivery to plants. This indicates a significant advantage of hay material compared to other organic materials. In addition to plant material, the use of biodegradable film has significant prospects. Y. Zhao *et al.* (2023) studied fields with film mulching over the past 10 years (mainly from 2019 to 2023). The results of the study of plastic film mulching demonstrated a positive impact on improving water, temperature, and nitrogen in the soil. However, it is worth noting that the method used in mentioned study, namely hay mulching, had a positive effect on the activity of microorganisms in the soil, which is beneficial for its biological activity.

W. Sun *et al.* (2022) studied the production of biodegradable mulching film from biomass materials to reduce environmental pollution caused by plastic. Thus, the results of the study indicate that the liquid mulch film and solid mulch film showed high mechanical properties, UV resistance, water resistance, ageing resistance and biodegradation. P. Kumar and V.P. Usadadiya (2023) examined the impact of plastic and organic mulching materials and methods on soil and the environment, which affects crop productivity. The researchers' results showed that organic mulching materials are inexpensive and environmentally friendly. In the study conducted, hay mulching was used, while in the study by the researchers, mulching methods were applied with grass clippings to preserve soil moisture and suppress weed growth, as well as plastic biodegradable film to control the soil environment and increase yields.

A common practice is to use seed mixtures together with mulching. G.L. Wu *et al.* (2023) conducted an experiment on field restoration that combined the sowing of three types of grasses, using grass clippings as mulch, to restore alpine meadow vegetation. According to the results of the study, soil moisture, plant germination density and vegetation cover density increased in the soils and seed plots. In both studies, the method of sowing several types of grasses using grass clippings as mulch was used. The herbaceous plants selected in the study were legumes: meadow clover, sweet clover and seed alfalfa. The advantages of using the grasses used in this study were their ability to interact with bacteria, fixing nitrogen in the soil and improving its fertility. Regarding the advantages of herbaceous plants such as wheatgrass, annual bluegrass and fescue used in the study by the researchers (Robins & Bushman, 2020).

Thus, numerous studies have confirmed the effectiveness of mulch in enhancing the development of vegetation cover and plant establishment. The additional use of seed mixtures will enhance the process of establishing vegetation cover and enriching biodiversity. Despite the pollutants present in the soil, this method will allow for the formation of vegetation cover in ash and slag dumps and thus help reduce the environmental risks of the industrial facility.

CONCLUSIONS

The study assessed the territory, including the condition of the soil cover and phytodiversity. The results of the study showed that the man-made ecotopes of ash and slag dumps were contaminated with hazardous pollutants, particularlyheavy metals. This fact indicates the potential environmental hazard of these facilities, as the fine dispersion and dusting of ash and slag heaps cause the dispersion of pollutants in the surrounding ecosystems. The presence of heavy metals in soilsmakes it difficult for vegetation to grow here, which is a factor in erosion protection. The results of the assessment of the phytodiversity of the studied areas showed the presence of monodominant communities with *Calamagrostis epigejos*, which indicates the blocking of succession and makes it impossible for other species to appear here. Considering the phytodiversity of the territory, a list of native species for the preparation of seed mixtures was proposed.

The study examined mulching and seed mixtures. The results showed that the using mulch without ruderal and invasive species contributes to the formation of plant communities by creating favourable conditions for seed germination: it reduces soil erosion and retains moisture, creates a physical substrate and protection for seeds, and is a source of seeds and diasporas. The use of green hay accelerates the development of vegetation and leads to the formation of species-rich plant communities. Thus, the use of mulching as a step towards natural restoration proved a successful strategy for ash and slag dumps at Burshtyn TPP. Areas for further research on the mulching and seed mixtures method may include studying the impact of different types of mulch (organic, inorganic, biodegradable) on improving soil quality, evaluating the effectiveness of different combinations of seed mixtures, and growing conditions, analysing the impact of the mulching and seed mixtures method on soil microbial biodiversity and microbiological processes in the soil to restore the soil cover of a potentially hazardous site.

The algorithm for applying the restorative methodology of mulching and seeds mixtures in anthropogenic ecotopes is as follows: assessment of environmental risks of the territory – preparation of the territory for mulching and/or sowing of seed mixtures – mulching and/or sowing of seed mixtures – monitoring of the experimental plots. It would also be advisable to introduce clear coordination of soil erosion monitoring programmes between the main technosphere objects at the regional (local) and national levels, unification of the regulatory framework and measurement methods, and scientifically based adjustment of the programme and observation sites depending on specific local conditions.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Anca, P., Mâşu, S., Lixandr, B., Morariu, F., Dragomir, N., Laffont-Schwob, I., & Popescu, D. (2011). Strategies for covering fly ash dumps with plant species suitable for phytostabilization. *Scientific Papers: Animal Science and Biotechnologies*, 44(2), 229-234.

[2] Bidolakh, D. (2023). Assessment of ecosystem functions of green spaces as an important component of their inventory in the context of sustainable development of urban landscapes. *Ukrainian Journal of Forest and Wood Science*, 14(1), 8-26. doi: 10.31548/forest/1.2023.08.

[3] Bozhenko, A.O. (2020). *Study of the impact of enterprises on the ecological state of the Podilski Tovtry National Nature Park*. Kyiv: National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute".

[4] DSTU 4770.1:2007. (2009). "Soil quality. Determination of the content of mobile manganese compounds in soil in a buffered ammonium acetate extract with a pH of 4.8 by atomic absorption spectrophotometry". Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=58849.

[5] DSTU ISO 10381-2:2004. (2006) "Soil quality. Sampling. Part 2. Guidelines for sampling methods". Retrieved from https://www.ksv.biz.ua/GOST/DSTY_ALL/DSTY1/dsty_iso_10381-2-2004.pdf.

[6] Duanyuan, H., Zhou, T., He, Z., Peng, Y., Lei, J., Dong, J., Wu, X., Wang, J., & Yan, W. (2023). Effects of straw mulching on soil properties and enzyme activities of camellia oleifera-cassia intercropping agroforestry systems. *Plants*, 12(17), article number 3046. doi: 10.3390/plants12173046.

[7] Fedoniuk, T., Fedoniuk, R., Klymenko, T., Polishchuk, O., & Pitsil, A. (2021). Bioindication of aerotechnogenic pollution of agricultural landscapes caused by the activities of industrial hubs. *Ekologia Bratislava*, 40(2), 115-123. doi: 10.2478/eko-2021-0013.

[8] Gajic, G., Djurdjević, L., Kostic, O., Jarić, S., Mitrović, M., & Pavlović, P. (2018). Ecological potential of plants for phytoremediation and ecorestoration of fly ash deposits and mine wastes. *Frontiers in Environmental Science*, 6, article number 124. doi: 10.3389/fenvs.2018.00124.

[9] Gaskevych, V.G., Lemega, N.M., & Vitvitsky, J. (2023). Erosion degradation of soils in the western region of Ukraine. In *Theory and practice of genetic soil science* (pp. 114-129). Lviv: Ivan Franko National University of Lviv.

[10] Gneushev, V.O. (2013). *Formation and development of technogenic deposits*. Rivne: Volynski Oberehy.

[11] Grime, J.P. (1974). Vegetation classification by reference to strategies. *Nature*, 250, 26-31. doi: 10.1038/250026a0.

[12] Guo, G., Xiao, L., Jie, K., Zhang, X., Peng, X., Xu, Y., Zeng, G., Liu, J., Zhang, C., & Lin, J. (2024). Estimation of annual soil CO_2 efflux under the erosion and deposition conditions by measuring and modeling its respiration rate in southern China. *Journal of Environmental Management*, 351, article number 119686. doi: 10.1016/j.jenvman.2023.119686.

[13] Kavian, A., Kalehhouei, M., Gholami, L., Jafarian, Z., Mohammadi, M., & Rodrigo-Comino, J. (2020). The use of straw mulches to mitigate soil erosion under different antecedent soil moistures. *Water*, 12(9), article number 2518. doi: 10.3390/w12092518.

[14] Kiehl, K., Kirmer, A., Donath, T.W., Rasran, L., & Hölzel N. (2010). Species introduction in restoration projects – Evaluation of different techniques for the establishment of semi-natural grasslands in Central and Northwestern Europe. *Basic and Applied Ecology*, 11(4), 285-299. doi: 10.1016/j.baae.2009.12.004.

[15] Kirmer, A., Baasch, A., & Tischew, S. (2011). Sowing of low and high diversity seed mixtures in ecological restoration. *Applied Vegetation Science*, 15(2), 198-207. doi: 10.1111/j.1654-109X.2011.01156.x.

[16] Kovaliv, L.M. (2013). Environmental problems of thermal power plants. *Scientific Bulletin of the National Technical University of Ukraine*, 23(18), 57-61.

[17] Kumar, P., & Usadadiya, V.P. (2023). Mulching: An efficient technology for sustainable agriculture production. *International Journal of Plant and Soil Science*, 35(20), 887-896. doi: 10.9734/IJPSS/2023/v35i203880.

[18] Law of Ukraine No. 962-IV "On Land Protection". (2003). Retrieved from https://zakon.rada.gov.ua/laws/show/962-15#Text.

[19] Lemega, N.M. (2020). *Genetic and geographical features of soil degradation in the Lviv region.* Lviv: Ivan Franko National University of Lviv.

[20] Levchenko, A.E., Ignatenko, M.I., & Khobotova, E.B. (2013). The heavy metal pollution of soil near thermal power plants. *Energy. Ecology. People*, 6, 462-468.
[21] Levchenko, V.A., Vakaliuk, I.P., Karabanovych, M.M., Svystun, I.I., Ovchar, A.I., & Krul, M.Z. (2016). Analysis of the radiation situation in the area of anthropogenic impact Burshtyn TPP. *Ukrainian Journal of Radiology*, 24(2), 27-29.
[22] Li, R., Li, Q., & Pan, L. (2021). Review of organic mulching effects on soil and water loss. *Archives of Agronomy and Soil Science*, 67(1), 136-151. doi: 10.1080/03650340.2020.1718111.
[23] Liu, J., Liu, Q., Li, J., Zhang, L., Cao, X., Li, J., Cao, R., Lv, H., Wang, Z., & Dong, Z. (2023a). Response of soil moisture and water use efficiency to straw mulching amount and mulching period in black soil zone of northeast China. *Canadian Journal of Soil Science*, 103(4), 634-641. doi: 10.1139/cjss-2023-0018.
[24] Liu, S., Wang, L., Chang, L., Khan, I., Nadeem, F., Rehman, A., & Suo, R. (2023b). Evaluating the influence of straw mulching and intercropping on nitrogen uptake, crop growth, and yield performance in maize and soybean. *Frontiers in Plant Science*, 14, article number 1280382. doi: 10.3389/fpls.2023.1280382.
[25] Malyuk, T.V. (2023). Soil mulching as an agronomic measure in the cultivation of sweet cherries in the South of Ukraine. In *Proceedings of the all-Ukrainian scientific and practical conference "actual issues of crop production and horticulture"* (pp. 46-48). Zaporizhzhia: Dmytro Motornyi Tavria State Agrotechnological University.
[26] Penderetskyi, O.V. (2005). *The evaluation of ecological situation in the affected zone of Burshtyn power station*. Ivano-Frankivsk: Ivano-Frankivsk National University of Oil and Gas.
[27] Pichura, V., Potravka, L., Domaratskiy, Ye., & Petrovas, S. (2023). Spatiotemporal patterns and vegetation forecasting of sunflower hybrids in soil and climatic conditions of the Ukrainian Steppe zone. *Ukrainian Black Sea Region Agrarian Science*, 27(3), 31-45. doi: 10.56407/bs.agrarian/3.2023.31.
[28] Prysiazhniuk, O., Storozhyk, L., Humentyk, M., Sviridov, A., & Svyrydova, L. (2022). Optimal time of plant growth regulator application to Sorghum canopy according to BBCH and Kuperman crop growth scales. *Plant and Soil Science*, 13(4), 46-56. doi: 10.31548/agr.13(4).2022.46-56.
[29] Řehounkova, K., Řehounek, J., & Prach, K. (2011). *Near-natural restoration vs. technical reclamation of mining sites in the Czech Republic*. Ceske Budejovice: University of South Bohemia in Česke Budějovice.
[30] Robins, J.G., & Bushman, B.S. (2020). Turfgrass performance of perennial wheatgrass species when grown as monocultures and mixtures. *Agronomy Journal*, 112(5), 3567-3578. doi: 10.1002/agj2.20346.
[31] Semak, U., Mylen'ka, M., & Fischer, L.K. (2023). Vegetation description and functional traits of technogenic ecotopes at a thermal power plant in Western Ukraine. *Urban Naturalist*, 10(68), 1-18.
[32] Singh, T., Barkha, Kumari, G., & Bokado, K. (2024). Response of spring maize to irrigation scheduling and mulching in Punjab. *Journal of Environmental Biology*, 45(1), 117-123. doi: 10.22438/jeb/45/1/MRN-5159.
[33] Skousen, J.G., & Zipper, C.E. (2018). *Revegetation species and practices*. Retrieved from https://vtechworks.lib.vt.edu/server/api/core/bitstreams/88b13a86-fc1f-4225-93a5-8fa5d35c1a64/content
[34] Stefanidis, S., Mallinis, G., & Alexandridis, V. (2023). Multi-decadal monitoring of soil erosion rates in South Europe. *Environmental Sciences Proceedings*, 26(1), article number 138. doi: 10.3390/environsciproc2023026138.
[35] Sun, W., Liu, X., Li, X., Wang, S., Li, Q., & Sun, Z. (2022). A method for the treatment of black tea waste: Converting it into liquid mulching film and solid mulching film. *Journal of Applied Polymer Science*, 140(7), article number e53481. doi: 10.1002/app.53481.
[36] Svitlychnyi, O.O., & Piatkova, A.V. (2021). Water soil erosion in right-bank Ukrainian forest-steppe zone. *Bulletin of I.I. Mechnikov Odesa National University*, 2(39), 51-63. doi: 10.18524/2303-9914.2021.2(39).246191.
[37] Tokhetova, L.A., Umirzakov, S.I., Nurymova, R.D., Baizhanova, B.K., & Akhmedova, G.B. (2020). Analysis of economic-biological traits of hull-less barley and creation of source material for resistance to environmental stress factors. *International Journal of Agronomy*, 2020, article number 8847753. doi: 10.1155/2020/8847753.
[38] Wagner, M., Hulmes, S., Hulmes, L., Redhead, J.W., Nowakowski, M., & Pywell, R.F. (2020). Green hay transfer for grassland restoration: Species capture and establishment. *Restoration Ecology*, 29(1), article number e13259. doi: 10.1111/rec.13259.
[39] Wu, G.L., Li, M., Leite, P.A.M., Dang, Z., & Zhao, J. (2023). Restoration approach for alpine extremely degraded landscapes: Testing direct seeding and mulching with grass clippings. *Restoration Ecology*, 32(3), article number e14074. doi: 10.1111/rec.14074.
[40] Yang, Y., Liu, H., Wu, J., Gao, C., Zhang, S., & Tang, D.W.S. (2023). Long-term combined subsoiling and straw mulching conserves water and improves agricultural soil properties. *Land Degradation & Development*, 35(3), 1050-1060. doi: 10.1002/ldr.4969.
[41] Zhao, Y., Mao, X., Li, S., Huang, X., Che, J., & Ma, C. (2023). A review of plastic film mulching on water, heat, nitrogen balance, and crop growth in farmland in China. *Agronomy*, 13(10), article number 2515. doi: 10.3390/agronomy13102515.
[42] Zhumadilova, A., & Zhigitova, S. (2023). Features of modern areas of solid waste disposal. *Evergreen*, 10(2), 640-648. doi: 10.5109/6792809.

Мульчування як екологічний метод відновлення рослинного покриву на золошлаковідвалах Бурштинської ТЕС

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Анотація. Дослідження ефекту мульчування для встановлення рослинного покриву на промислових майданчиках є перспективним та актуальним з погляду екологічного відновлення та зменшення зниження екологічних ризиків в зоні впливу промислових об'єктів. Метою дослідження є вивчення та оцінка ефективності мульчування та висівання насіннєвих сумішей як способу встановлення рослинного покриву на золошлаковідвалах теплових електростанцій. Для проведення дослідження попередньо здійснено оцінку ґрунтового покриву золошлаковідвалів та закладено експериментальні ділянки, на яких здійснювалося мульчування та посів насіннєвих сумішей. Під час проведення дослідження було виявлено, що екотопи золошлаковідвалів характеризуються підвищеною концентрацією полютантів, а саме важких металів, що ускладнює появу тут рослинного покриву. У ході вивчення екологічних особливостей едафотопів та фіторізноманіття території запропоновано перелік видів аборигенної флори для насіннєвих сумішей. Здійснено мульчування на експериментальних ділянках та висівання насіннєвих сумішей. Мульчування зарекомендувало себе як ефективний метод для прискорення процесів природного відновлення рослинності територій що зазнали антропотехногенного впливу. Результати дослідження можуть бути використані на практиці екологами, екологічними організаціями та широким колом спеціалістів з метою розробки та впровадження заходів що сприяють відновленню екологічного балансу деградованих та техногенно трансформованих екосистем

Ключові слова: забруднення; деградація; тверді відходи; рекультивація; мульчування; насіннєві суміші

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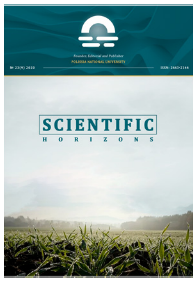

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Technical efficiency in several levels of adoption of garlic farming standard operating procedures in production centre in Indonesia

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Abstract. The relevance of this study lies in overcome obstacles to garlic development in Indonesia, such as low productivity and limited use of technology, which can hinder self-sufficiency and import-reducing programs. The purpose of this study was to identify the technical efficiency, the determinants of technical inefficiency, and the level of technical efficiency at various levels of adoption of the standard operating procedures of garlic farming in production centres in Indonesia. The cross-sectional data was gathered through interviews with 227 farmers chosen using a simple random selection technique. The Cobb-Douglass production function and the stochastic frontier analysis were used to determine the factors influencing garlic production, the technical efficiency level, and the determinants of technical inefficiency. The Maximum Likelihood Estimation was used

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to analyse the data. The level of technical efficiency at various levels of standard operating procedures adoption was measured using descriptive statistical analysis. Farm size, seeds, urea and NPK fertiliser, herbicides, yellow sticky traps, family labour, mulch, and farmers' participation in garlic development programs significantly affected garlic production. The technical efficiency varied within 0.37-0.99, with a mean of 0.71. Farmers' practices and standard operating procedure adoption significantly reduced technical inefficiency. Generally, the level of standard operating procedure adoption is moderate. In the high standard operating procedure adoption group, the mean technical efficiency is 0.77, while in the moderate level group, it is 0.68. The findings of this study can be used as a model for other garlic-importing countries to enhance production and strengthen food security

Keywords: inefficiency; self-sufficiency; stochastic frontier analysis; technology adoption

INTRODUCTION

Garlic is essential in developing economic, culinary, and traditional medicine in Indonesia. Indonesia's garlic production does not meet the national consumption, leading the government to import garlic. Conversely, dependence on imports can threaten social, economic, and political stability. Increasing national garlic production can be challenging due to various problems that may arise, including efficiency and technology adoption problems. Hence, problems of technical efficiency and technology adoption must be analysed comprehensively to avoid a bias in identifying the root causes of garlic productivity.

Due to the global food crisis, every country is considering strengthening domestic food security policies instead of relying on imports (Falkendal *et al.*, 2021; Hellegers, 2022). According to the data of Center for Agricultural Data and Information (2020), the average national garlic productivity reaches 7.48 t/ha, while the average world productivity reaches 17.07 t/ha. As the biggest garlic production centre in Indonesia, Central Java Province only has an average productivity of 6.75 t/ha.

The principal issues are that the seed industry is not well-developed yet, the cultivation area tends to be narrow and scattered, the low adoption of SOP, and high inputs prices (Ricky *et al.*, 2022). Leveraging agriculture productivity can be achieved through extensification and intensification (Coomes *et al.* 2019). Extensification directly impacts agricultural production but causes deforestation and biodiversity loss. Intensification can enhance food production by increasing technical efficiency and technology adoption (Kamau *et al.,* 2023).

Technical efficiency measurement is required for policymakers to determine the strategic programs to increase productivity (Workneh & Kumar, 2023). Technologies play an important role in enhancing production, efficiency, reducing risks, and ensuring the delivery of high-quality agricultural products (Kale *et al.*, 2022). SOP of garlic cultivation consists of technology components from 11 aspects of cultivation, i.e., land preparation, land management, plant spacing determination, use of seed, planting and basic fertilisation, mulch, follow-up fertilisation, water irrigation, plant maintenance, pest control, and harvest and post-harvest handling (Directorate General of Horticulture, 2016).

The Stochastic Frontier Analysis (SFA) and the Cobb Douglass production function are most widely used to measure technical efficiency (Hakim *et al.*, 2021). Previous study using this approach mentioned that the value of technical efficiency of garlic was below 100%. G. Rabbani and B. Ahmad (2021) found that the average of technical efficiency of garlic production in Ethiopia and Bangladesh were 73%, and 69% respectively. These results imply opportunities to increase outputs by 7-31% using the available technology. S. Kune and A. Hutapea (2018) and K. Seran *et al.* (2020) conducted a technical efficiency research of garlic farming in East Nusa Tenggara Province. Technical efficiency values were above 90%. These studies only provide information regarding the estimation of technical efficiency. The determinants of technical inefficiency and how technology impacts technical efficiency were not provided.

The study of technical efficiency in Central Java Province conducted by W. Prayogo and L. Wihastuti (2023) found that the technical efficiency of garlic farming is above 0.60. Factors detrimental to technical efficiency included farmers' age, education, farmer experience, family size, and training. The information about technology adoption was not provided. Moreover, the information about distribution of technical efficiency at each level of SOP adoption was not provided.

This study fills this information gap, allowing decision-makers to get a comprehensive description of productivity problems. Based on the description above, the purpose of this study was to establish the technical efficiency of garlic farming, the variables that affect the technical inefficiency, and the technical efficiency of garlic farming at different stages of standard operating procedure adoption in Temanggung Regency, Central Java Province, Indonesia.

MATERIALS AND METHODS

Sample size, sampling methods, and data collection. The study was conducted in Temanggung Regency, Central Java Province, Indonesia, from October to November 2022. The selection of sample areas and farmer groups was carried out purposively. Temanggung Regency is the largest garlic production centre in Indonesia, which contributes 27.52% to national production (Centre for Agricultural Data and Information, 2020). The research was conducted in seven sub-districts. One village with the largest amount of production was purposively selected from each sub-district. From each village, two farmer groups with garlic as their primary business were selected. The number of farmer samples in this study was determined based on the Krejcie and Morgan formula. The formula is as follows:

$$n = \frac{X^2NP(1-P)}{e^2(N-1)+X^2P(1-P)}, \tag{1}$$

where n is the sample size; X^2 is the chi-square table value for 0.5 degree of freedom at the specified confidence level (3.841); N is the population size; P is the population proportion (assumed to be 0.50); e is the degree of precision (0.05).

The population of selected farmer group members is 550, and therefore the required sample size was 227 farmers. Simple random sampling technique was applied to choose sample farmers from each farmer group. The survey was anonymous and did not mention any institutions. Data was collected from farmers through structured questionnaires administered by enumerators. Interviews were conducted offline. This study also protected the privacy of respondents and their confidential personal information following the Declaration of Helsinki (2013). The respondents provided prior informed consent to fulfil the ethical requirements of scientific research in social sciences.

Analysis method of estimation of production function, technical efficiency, and technical inefficiency. The SFA method was applied to analyse the technical efficiency of garlic production. The stochastic production function assumes that the production function's error component is not simply attributable to random and unmeasured factors. It divides the error term into random and non-random components. The difference between actual production and the production frontier is attributed to inefficiency. This inefficiency can take many forms, including inefficient resource allocation, poor management practices, inadequate technology utilisation, and inefficient manufacturing processes. The SFA is given as follows:

$$Yi = \beta_0 + \beta_i X_i + \varepsilon_i, \tag{2}$$

where Yi is the outputs; β_0-β_i is the model parameters to be estimated; X_i is the production inputs; ε_i is the error term, $\varepsilon_i = -u_i + v_i$. vi is an error term that indicates a production uncertainty, assumed by i.i.d (0,); u_i is an error term that shows the effect of technical inefficiency, assumed by i.i.d (0,) and u>0, u_i is independent of v_i. Equation 2 can be modified as follows:

$$Yi = f(X_i;\beta)\exp(v_i - u_i), \tag{3}$$

where f(.) is production function.

This study uses the Cobb-Douglass production function to estimate the determinants of garlic production and its technical efficiency. The Cobb Douglass production function estimates the elasticity of production inputs (Adzawla & Alhassan, 2021). The Stochastic Frontier production function can also be used to measure the estimated value of technical efficiency according to the following formula:

$$TE_i = \frac{Y}{Y^*} = \frac{f(X_i;\beta)\exp(v_i - u_i)}{f(X_i;\beta)\exp(v_i)} = \exp(-u_i), \tag{4}$$

where TE_i is the farmers' technical efficiency; Y is the frontier output; Y^* is the farmers' observed output. Technical efficiency is typically expressed as a ratio between 0 and 1, where 0 stands for no efficiency or complete inefficiency, and 1 stands for perfect efficiency or optimal use of inputs. The next analysis is regressing a set of factors on $-u_i$ as follows:

$$-u_i = \delta_0 + \sum_{n=1}^{k} \delta_i Z_i + e_i, \tag{5}$$

where Z_i is the vector of determinants of technical inefficiency; δ_0 is the parameter estimates of the model; δ_i is the coefficient estimates of Zi; and e_i is the error term.

Parameter estimation in the SFA model and technical inefficiency using the Maximum Likelihood Estimation (MLE) method in the Frontier 4.1 program. An empirical model of SFA that is converted into a natural logarithm is given as follows:

$$\begin{gathered} LnY=\beta_0+\beta_1\,LnX_1+\beta_2\,LnX_2+\beta_3\,LnX_3+\beta_4\,LnX_4+\beta_5\,LnX_5+\beta_6\,LnX_6+\beta_7\,LnX_7+\beta_8\,LnX_8+\beta_9\,LnX_9+ \\ +\beta_{10}\,LnX_{10}+\beta_{11}\,LnX_{11}+\beta_{12}\,LnX_{12}+\beta_{13}\,LnX_{13}+\beta_{14}\,LnX_{14}+\beta_{15}\,D_1+\beta_{16}\,D_2+(vi\text{-}ui), \end{gathered} \tag{6}$$

where Y_i is the garlic output (kg); $\beta_1 - \beta_{18}$ are the parameters to be estimated in the model; X_1 is the Farm size (ha); X_2 is the seeds (kg); X_3 is the urea (kg); X_4 is the ZA (kg); X_5 is the NPK (kg); X_6 is the SP36 (kg); X_7 is the organic fertiliser (kg); X_8 is the dolomite (kg); X_9 is the pesticides (l); X_{10} is the fungicides (l); X_{11} is the herbicides (l); X_{12} is the yellow sticky trap (pcs); X_{13} is the family labour (man days of work); X_{14} is the hired labour (man days of work); D_1 is the dummy of plastic mulch (1 if yes, 0 if no); D_2 is the dummy of farmers' participation in government and importer programs (1 if yes, 0 if no).

Empirical model of technical inefficiency was calculated as follows:

$$u_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 + \delta_9 Z_9 + e_i, \tag{7}$$

where u_i is the technical inefficiency; $\delta_0 - \delta_9$ are the parameters to be estimated in the model; Z_1 is the farmers' age (years); Z_2 is the education level (years); Z_3 is the farmers' experience in garlic farming (years); Z_4 is the perception of activeness in the farmer group (pts); Z_5 is the perception of extension activity (pts); Z_6 is the adoption level of SOP (pts); Z_7 is the dummy of land ownership (1 if owned by farmer, 0 if rented); Z_8 is the dummy of credit access (1 if there is an access, 0 if there is no access); Z_9 is the dummy of gender (1 if male, 0 if female).

Determination of the level of adoption of SOP and other social variables with a Likert scale score. Social variables such as adoption level of SOP, participation in farmer groups, and perception of extension performance were also collected. The Likert scale was used in the questionnaires to measure farmers' attitudes, opinions, perceptions, or behaviours. The data obtained from the questionnaire with a Likert scale is ordinal and must be converted into interval data through a successive application. Classification of the adoption level of SOP, participation in farmer groups, and perceptions of extension performance were determined by formula as follows:

$$Class\ Interval = \frac{Highest\ value\ (HV) - Lowest\ value\ (LV)}{Number\ of\ classes}. \quad (8)$$

In this study, the accumulative scores achieved in social variables were classified into three classes: High, moderate, and low, as presented in Table 1.

Table 1. *Score classification of social variables*

Variables	Number of questions	Number of point scales	Accumulative Score		Classification		
			Min	Max	Low	Moderate	High
Adoption of SOP	52	*3-point scales* 3: Always apply; 2: Apply sometimes; 1: Never apply	52	171	52-91.6	91.7-131.3	131.4-171
Perception of activeness in farmers' group	8	*5-point scales* 1: Strongly disagree; 2: Disagree; 3: Neither agree nor disagree; 4: Agree; 5: Strongly agree	8	36	8-18.6	18.7-29.3	29.4-36
Perception of extension performance	16	*5-point scales* 1: Strongly disagree; 2: Disagree; 3: Neither agree nor disagree; 4: Agree; 5: Strongly agree	16	89	16-40.3	40.4-64.7	64.8-89

Source: *compiled by the author of this study*

According to Table 1, farmers are classified as having high SOP adoption when they score 131.4-171 pts, medium adoption when they score 91.7-131.3 pts, and low adoption when they score 52-91.6 pts. The perception of activeness in the farmers' group is categorised as high when farmers score 29.4-36 pts, medium when they score 18.7-29.3 pts, and low when they score 8-18.6 pts. The perception of extension performance is categorised as high when farmers score 64.8-89 pts, moderate when they score 40.4-64.7 pts, and low when they score 16-40.3 pts.

Definitions and measurements of variables. Table 2 presents potential explanatory variables for production and inefficiency functions, along with the expected outcome sign for each variable.

Table 2. *Summary of variables and expected outcome*

Variables	Definition	Measurements	Expected outcome
Production Function			
Output	Amount of garlic production	Kilogram (kg)	
Farm size	Total area cultivated of garlic	Hectare (ha)	+
Seeds	Amount of garlic seed	Kilogram (kg)	+
Urea fertiliser	Amount of garlic urea fertiliser	Kilogram (kg)	+
ZA fertiliser	Amount of ZA	Kilogram (kg)	+
NPK fertiliser	Amount of NPK	Kilogram (kg)	+
SP36 fertiliser	Amount of SP36	Kilogram (kg)	+
Organic fertiliser	Amount of organic	Kilogram (kg)	+
Dolomite	Amount of dolomite	Kilogram (kg)	+
Pesticides	Volume of pesticides liquid	Litre	+

Table 2. Continued

Variables	Definition	Measurements	Expected outcome
Fungicides	Volume of fungicide liquid	Litre	+
Herbicides	Volume of herbicide liquid	Litre	+
Yellow sticky trap	Amount of yellow sticky trap	Sheet	+
Family labour	Amount of family labour	Man-days	+
Hired labour	Amount of hired labour	Man-days	+
Mulch	1 if use mulch, 0 otherwise		+
Participation in gov. or importer program	1 if participate, 0 otherwise		+
Inefficiency Function			
Age	Length of time the farmer has lived	Years	-
Level of education	Number of years of formal education	Years	-
Farmer experience in garlic farming	Number of years of farming	Years	-
Perception of activeness in farmers group	Farmer perception of activeness in group	Points	-
Perception of extension performance	Farmer perception of extensionist performance	Points	-
Adoption of SOP	SOP adoption by farmer	Points	-
Land ownership	1 if landowner, 0 otherwise		-
Credit access	1 if farmer has an access, 0 otherwise		-

Source: *compiled by the authors of this study*

Definition and measurement variables provide a clear understanding of the data and the methods used for measurement. The mean and standard deviation of each variable, except for the dummy variable, are determined. The mean value indicates the equal distribution of values in a particular data set, while the standard deviation helps to understand the distribution and variability of measurement variables.

RESULTS AND DISCUSSION

Distribution of outputs, inputs, and socioeconomic characteristics. Table 3 presents the distribution of output and inputs in one garlic planting season in Temanggung Regency. Table 3 shows that farmers produced an average of 6.87 kg/ha of dry garlic. The average seeds used is 854.75 kg. The fertilisers used by the farmers were 257.66 kg of urea, 429.25 kg of ZA fertiliser, 331.25 kg of NPK fertiliser, 132.81 kg of SP36 fertiliser, and 13,601.31 kg of organic fertiliser. The dolomite used was 1,289.59 kg. Farmers use pesticides at 7.25 l and fungicides at 6.38 l.

The average number of yellow sticky traps used was 42.03 sheets per ha. The number of family labourers is 621.81, and the hired labour is 135.03 man-days per ha. The use of inputs for fertiliser production is generally still inadequate compared to the amount recommended in the SOP. Meanwhile, Table 4 shows data on the socio-economic characteristics of farmers.

Table 3. *Descriptive statistics of the distribution of output and inputs of garlic farming in Temanggung Regency*

Variables	Sample Distribution				Conversion per ha
	Mean	Standard Deviation	Min	Max	
Output	2,198.85	1,175.39	500.00	4,980.00	6,871.41
Farm size	0.32	0.14	0.10	0.70	1.00
Seeds	273.52	182.25	40.00	775.00	854.75
Urea fertiliser	82.45	41.60	17.00	175.00	257.66
ZA fertiliser	137.36	75.75	25.00	350.00	429.25
NPK fertiliser	106.00	55.52	25.00	290.00	331.25
SP36 fertiliser	42.50	22.69	8.00	100.00	132.81
Organic fertiliser	4,352.42	1,997.58	1,500.00	8,000.00	13,601.31
Dolomite	412.67	190.37	100.00	850.00	1,289.59
Pesticides	2.32	0.81	1.10	4.50	7.25
Fungicides	2.04	1.14	0.01	5.00	6.38
Herbicides	2.32	1.25	0.50	5.00	7.25
Yellow sticky trap	13.45	7.30	3.00	35.00	42.03
Family labour	198.98	99.79	25.00	421.00	621.81
Hired labour	43.21	36.05	5.00	127.00	135.03

Source: *the results of the authors' own research*

Table 4. Descriptive statistics of the distribution of social characteristics of garlic farmers in Temanggung Regency				
Variable	**Sample Distribution**			
	Mean	**Standard Deviation**	**Min**	**Max**
Age	43.99	9.76	21.00	84.00
Level of education	8.19	2.71	3.00	16.00
Farmer experience in garlic farming	9.89	7.08	2.00	31.00
Perception of activeness in farmers group	24.03	4.62	8.00	35.98
Perception of extension performance	59.47	11.84	22.00	87.84
Adoption of SOP	124.61	97.87	97.87	160.49

Source: *the results of the authors' own research*

Table 4 shows that the average garlic farmer is 43 years old, which is considered a productive age for managing their farm effectively. On average, farmers have 8 years of education and a relatively extensive experience in garlic farming, spanning almost a decade. The mean score for the perception of activeness in the farmers' group variable is 24.03, indicating a moderate level. However, there is still room for improvement in farmers' participation, particularly in terms of attending regular group meetings. Most farmers do not hold group administrative positions. Unfortunately, farmers rarely can attend government-organized training sessions. The mean score attained by farmers for the perception of extension performance variable is 59.47, which falls within the moderate category as presented in Table 1. Farmers perceive extension workers to be effective communicators, motivators, and educators, but they still need to improve their facilitation skills. The average score for the SOP adoption variable is 124.61, which is also classified as moderate in Table 1. Farmers have not yet fully implemented the technological components of the SOP.

Maximum likelihood estimation results for production function model parameters. Due to the stochastic frontier production function using the MLE method estimation as presented in Table 5, the value of MLE Log Likelihood (132,662) is greater than the value of OLS Log Likelihood (116,118). This suggests that estimating the production function using the MLE method is better at describing conditions in the field than the OLS method. The Sigma Squared coefficient obtained is 0.0192, which is indicating that the error term inefficiency (μi) is normally distributed. The value of Gamma (γ) of 0.999 indicates that 99.99% of the variation of residual in the model comes from inefficiency (μi), which farmers can control. The remaining 0.01% is caused by a random error in measurement/noise (vi) in the form of production risks that farmers cannot control, such as weather and pest attacks. This finding shows that technical inefficiency is vital in explaining the garlic production level farmers in Temanggung Regency achieved. The LR test value for the one-sided error (number of restrictions = 10) obtained from the model is 33,088. This value is greater than the value of the mixed chi-square distribution X^2 (0.01,10)=28.856, which is contained in the Upper and Lower Bounds Table for The Critical Value for Jointly Testing Equality and Inequality Restriction (Shi, 2020). It means that the model can describe the effect of technical inefficiency in garlic farming.

Table 5. Results of Stochastic Frontier Analysis Production Function with MLE				
Variables	**Parameters**	**Coefficients**	**Standard Error**	**T ratio**
Production Function				
Constanta	β_0	4.042	0.234	17.310[a]
Farm size	β_1	0.113	0.042	2.680[a]
Seeds	β_2	0.098	0.032	3.036[a]
Urea fertiliser	β_3	0.100	0.031	3.266[a]
ZA fertiliser	β_4	0.044	0.030	1.476[ns]
NPK fertiliser	β_5	0.402	0.037	10.884[a]
SP36 fertiliser	β_6	0.014	0.028	0.500[ns]
Organic fertiliser	β_7	0.023	0.032	0.724[ns]
Dolomite	β_8	0.023	0.023	1.016[ns]
Pesticides	β_9	0.036	0.038	0.936[ns]
Fungicides	β_{10}	0.016	0.015	1.070[ns]
Herbicides	β_{12}	-0.045	0.022	-2.069[b]
Yellow sticky trap	β_{12}	0.077	0.028	2.721[a]
Family labour	β_{13}	0.066	0.030	2.210[b]

Table 5. Continued

Variables	Parameters	Coefficients	Standard Error	T ratio
Hired labour	β_{14}	0.009	0.018	0.514 [ns]
Dummy of mulch	β_{15}	0.045	0.027	1.698[c]
Dummy of participation in gov. and importer programs	β_{16}	0.091	0.023	3.939[a]
Sigma squared (σ^2)		0.0192		7.086
Gamma (γ)		0.9999		14.295
Log Likelihood function-OLS				116,118
Log Likelihood function-MLE				132,662
LR test for the one-sided error				33.088

Note: *a: statistically significant at 1% (2.601); b: statistically significant at 5% (1.972); c: statistically significant at 10% (1.652); ns: not statistically significant*
Source: *the results of the authors' own research*

Table 5 shows that farm size significantly affects garlic production with an elasticity of 0.113, which means that a 1% increase in the land area can increase garlic production by 0.113% (ceteris paribus). Land has a relatively large production elasticity indicating that land expansion is an effective strategy for increasing garlic production. The average land ownership by farmers is only 0.32 hectares. Even though garlic is cultivated in narrow and scattered areas, farm size significantly impacts production because farmers grow garlic on the slopes of the Sindoro and Sumbing mountains, which are rich in humus. This result contradicts the findings of I. Ali *et al.* (2019), who state that fragmented land has a negative impact on production. The study mentioned that farmers did not use best fertilisation and land processing technology, which is causing a soil infertility. Seeds significantly affect garlic production, with an elasticity of 0.098. Every 1% increase in seed usage can increase production by 0.098% (ceteris paribus). This finding supports previous research from F. Rahmawati and Jamhari (2018) that shows that increased garlic production in Karanganyar Regency can be achieved by using more quality seeds. Both studies found that farmers often produce seeds from their previous harvests, which can affect the quality of the seeds. The quality of seeds depends on a range of factors, including their physical appearance, genetic purity, and freedom from pests and diseases.

The production factor of urea fertiliser has a significant impact. Every 1% increase in urea use can increase production by 0.1% (ceteris paribus). This finding supports the results of C. Mina *et al.* (2021) on garlic commodities in Pakistan and F. Chekol *et al.* (2023) in Northwest Ethiopia. The nitrogen content in Urea fertiliser is vital in vegetative growth because it can increase the ratio of shoots to roots, determining tuber formation. However, using elemental N in conditions that exceed the requirements can cause the thickening of the stems and rotting of the tubers during storage (Geisseler *et al.*, 2022). NPK fertiliser has a positive impact. Increasing 1% of NPK, production will increase 0.402% (ceteris paribus). The content of the macro elements Nitrogen, Phosphorus, and Potassium in NPK fertiliser plays a role in the formation of bulbs of up to 80% in garlic and shallots (Shukla *et al.*, 2018). These findings contradict the results of F. Rahmawati and Jamhari's (2018) study, which mentioned that no fertiliser significantly increased garlic production. The variables that impacted garlic production were land, seed, and liquid pesticides.

In this study, herbicides significantly adversely affect garlic production, with an elasticity of -0.045. Adding 1% herbicide will reduce production by 0.045% (ceteris paribus). The negative effect of herbicides on production output is caused by farmers' use in the long term and the amount that exceeds the threshold, causing resistance. This result differs from the results of C. Mina *et al.* (2021) who stated the positive impact of using herbicides. The herbicide will increase production yield by up to 10%. The use of yellow sticky traps to reduce fly pest populations affecting production with an elasticity of 0.077. Increasing yellow sticky traps by 1% can increase production by 0.077% (ceteris paribus). This results aligned with M. Pobozniak *et al.* (2020). Yellow sticky traps are effective in reducing the population of leafminer flies, fruit flies, whitefly, aphids, and thrips which can reduce the yield potential of garlic by up to 80%.

Family labour input has a positive impact with an elasticity of 0.066. Increasing the number of family labour by 1% can increase production by 0.066% (ceteris paribus). I. Ali *et al.* (2019) also found that family labour has a positive relation with garlic production, but not at a significant level. The positive influence of family labour is caused by a high availability level in each garlic cultivation phase compared to hired labour. The commitment and responsibility of family labour are also higher than that of workers outside the family because of a greater sense of belonging.

Plastic mulch significantly affects garlic production, with a coefficient of 0.045. Silver and black plastic mulch function to maintain soil moisture, prevent soil erosion and compaction, regulate soil temperature, and suppress the growth of weeds that disturb plants. The study of R. Iqbal *et al.* (2020) on 13 agricultural commodities stated that mulch could increase yields by up to 20%. The dummy variable of farmer participation in government programs and importers was proved give a positive impact on garlic production with a coefficient of 0.091. Farmers taking part in government programs and importers receive seeds, fertilisers, pesticides, mulch, capital, and technical assistance. This finding corroborates the study of B. Septiana *et al.* (2022) and S. Saraswati *et al.* (2022) which state that input and output policies simultaneously increase farmers' production and income.

Estimation of technical efficiency. The MLE method with the Frontier 4.1 application estimates the value of technical efficiency the farmer achieves, as shown in Table 6.

Table 6. *Level of technical efficiencies*

Technical efficiency level	Frequency	Percentage (%)
0.00-0.40	1	0.4
0.41-0.50	4	1.8
0.51-0.60	25	11.0
0.61-0.70	95	41.9
0.71-0.80	59	26.0
0.81-0.90	32	14.1
0.91-1.00	11	4.8
Total farmers	227	100
Mean	0.71	
Min	0.37	
Max	0.99	

Source: *the results of the authors' own research*

The farmers achieved a mean of technical efficiency of 0.7. The lowest value of 0.37 and the highest value of 0.99. Most farmers achieve technical efficiency values of 0.61-0.70 and 0.71-0.80. The average value achieved shows that there is still a 29% chance for farmers to increase their frontier production limits with the same technology. Variations in the values for achieving technical efficiency illustrate the level of adoption of different technologies. The study from F. Rahmawati and Jamhari (2018) in Karanganyar Regency produced a technical efficiency value of 0.61 in garlic farming with intercropping patterns. A. Wardani and D. Darwanto (2018) using the SFA method, found an average value of technical efficiency for garlic farmers in the Kledung sub-district, Temanggung Regency of 0.81. The technical efficiency of garlic studies using the SFA method in other countries shows varying results. P. Kumar *et al.* (2018) reported that the technical efficiency of garlic farmers in Madhya Pradesh, India reached 0.72. C. Mina *et al.* (2021) found that garlic farmers in the Philippines reached a technical efficiency 0.8.

Determinants of the technical inefficiency of garlic farming. Technical inefficiency was identified simultaneously through the MLE method on the Cobb-Douglas production function. Table 7 shows that only the variables of farming experience and the level of SOP adoption significantly affect the technical inefficiency of garlic farming.

Table 7. *Estimation of the determinants of technical inefficiency of garlic farming*

Variables	Parameters	Coefficients	Standard Error	T ratio
Constanta	δ_0	3.412	0.690	4.945^{a}
Age	δ_1	0.012	0.066	0.178^{ns}
Level of education	δ_2	-0.006	0.036	-0.165^{ns}
Farmer experience	δ_3	-0.033	0.019	-1.756^{c}
Perception of activeness in farmers group	δ_4	0.033	0.082	0.403^{ns}
Perception of extension performance	δ_5	0.017	0.070	0.245^{ns}
Adoption of SOP	δ_6	-0.654	0.156	-4.194^{a}
Dummy of land ownership	δ_7	0.017	0.042	0.408^{ns}
Dummy of credit access	δ_8	-0.018	0.027	-0.660^{ns}
Dummy of gender	δ_9	-0.058	0.090	-0.648^{ns}

Note: *a: statistically significant at 1% (2.599); b: statistically significant at 5% (1.971); c: statistically significant at 10% (1.652); ns: not significant*

Source: *the results of the authors' own research*

The farmer experience in garlic farming significantly impacts the technical inefficiency. The negative sign indicates that the longer the farmer's experience running garlic farming, the less technical inefficiency or more efficient farming. This finding corroborates the finding of F. Rahmawati & Jamhari (2018) and S. Attipoe *et al*. (2020). Based on Table 4, the average experience of garlic farmers is nine years. Experience teaches farmers the best cultivation practices so that farmers have the most efficient input use combinations to produce maximum output. In addition, farmers who have been cultivating garlic for a long time have a more open attitude towards ever-evolving technologies that allow them to produce a better yield.

The variable of adoption of SOP for garlic cultivation also significantly affects technical inefficiency at the 99% confidence level with a coefficient of -4.194. The negative sign describes that the higher the adoption rate of SOP, the lower the technical inefficiency. These results aligned with research results study of A. Wardani and D. Darwanto (2018). The adoption of technological components contained in SOPs can increase the efficiency of using production inputs. Table 3 indicates that the average garlic farmer adopts SOP at a moderate level with a value of 124 points. Technological aspects of SOP, especially in land management, variety selection, use of seeds, fertilisation, plant maintenance, pest control, and harvest and postharvest, can increase the potential productivity of the varieties used. Variables of age, education level, activeness in farmer groups, farmers' perceptions of extension performance, land ownership, credit access, and gender do not significantly affect technical inefficiency.

Technical efficiency at various levels Adoption of Standard Operating Procedures. Standard operating procedure for garlic cultivation consists of 11 stages of cultivation, each of which has specific technological components recommended by the government. In general, the adoption of SOP for garlic cultivation in Temanggung Regency is in the moderate category. The total score obtained is 124 from a score range of 52-171. In detail, the classification of SOP adoption by farmers at each stage of garlic cultivation is presented in Table 8.

Table 8. *Adoption of SOP by Farmers*

Cultivation component	Number of technologies	Measuring tool scores interval		Adoption level		
		Min	Max	Achieved scores	(%)	Category
Land preparation	3	3	10	7	70	moderate
Land ploughing	5	5	16	12	75	moderate
Plant spacing	2	2	6	4	67	moderate
Seeds	5	5	16	12	75	moderate
Planting and basic fertilising	4	4	13	10	77	moderate
Mulch installation	2	2	6	5	83	high
Follow-up fertilising	6	6	19	13	68	moderate
Irrigation	2	2	7	3	43	low
Weed and soil management	3	3	10	9	90	high
Pest control	15	15	50	35	70	moderate
Harvest and post-harvest	5	5	18	14	78	high
All SOP components	**52**	**52**	**171**	**124**	**73**	**moderate**

Source: *the results of the authors' own research*

The technology components adopted by farmers in the high category are mulch use, plant maintenance, harvest, and postharvest. Farmers obtain plastic mulch both from government programs and importers programs. In the Horticultural Product Import Recommendations regulated by the Ministry of Agriculture, importers must plant as much as 5% of the proposed amount of garlic imports (Regulation of The Ministry of Agriculture, 2017). Therefore, importers collaborate with farmers to achieve the required outcome. At the maintenance stage, farmer adoption is included in the high category. Farmers regularly cultivate the land, remove weeds, and clear away plant debris. Farmers adopt technological components to facilitate uprooting in damp conditions. The subsequent process involves drying and cleaning the tubers of crop residue. Additionally, farmers sort the tubers based on quality and size, storing them with special treatment to maintain their quality.

The adoption of SOP by farmers is categorized as a moderate level at the stage of land preparation, determination of plant spacing, use of seeds, planting and basic fertilisation, follow-up fertilisation, and pest control. Garlic in Temanggung Regency can only be planted once a year during the rainy season (November-April). The type of land limit is rainfed with high humidity levels. It causes garlic farming more vulnerable to various production risks, such as excessive rainfall and pest attacks. Land preparation does not carry out intensively by farmers as well. They hack the land only once, whereas the SOP suggests that the field should be deeply ploughed and disked properly to eliminate debris and soil clods. Farmers planted garlic on the slopes of Mount Sumbing and Sindoro but disobeyed SOP's recommendation. They make broad beds of garlic aligned to the slope of the land, not across the slope. It is certainly dangerous for the sustainability of the land because it has the potential to cause erosion.

Many farmers use spacing that is not recommended in the SOP. The intercropping cultivation system of garlic with tobacco and other vegetables causes farmers to be unable to apply spacing according to the SOP recommendations. They have yet to use certified seeds as well. They use seeds from superior, high-yielding varieties such as Lumbu Hijau and Lumbu Kuning, but the quality cannot be guaranteed because they got the seeds from previous harvests. Certified seed availability is one of the obstacles for farmers trying to increase garlic productivity. Farmers still rely heavily on chemical pesticides compared to natural ingredients during the pest control phase, as recommended in the SOP. The lowest level of SOP adoption is in the watering phase. As explained previously, the garlic field in Temanggung Regency is rainfed. Farmers depend on rainfall to water their plants. Irrigation technology is needed so garlic can be planted during the off-season. Drip or sprinkler irrigation is a strategic technique to increase the cropping index to generate national garlic production. Many farmers, especially small-scale farmers, may not have the financial resources to invest in such infrastructure. A comprehensive approach that combines financial aid, infrastructure development, research, and supportive policies can help make technical irrigation more accessible and affordable for farmers, ultimately enhancing agricultural productivity and sustainability.

The previous discussion in this study stated that the adoption rate of SOP for garlic had a significant impact on the level of technical inefficiency of farmers. The coefficient with a negative sign means that the higher the level of SOP adoption, the lower the technical inefficiency of the farmers or the higher the technical efficiency. This study categorizes the technical efficiency values obtained by farmers based on their level of adoption of the SOP for garlic cultivation, as presented in Table 9.

Tabel 9. *Farmers' technical efficiency at various levels of SOP adoption*

SOP adoption level	Score intervals	Number of farmers	%	Mean of Technical Efficiency
High	131.4⩽score achieved⩽171	66	29	0.77
Moderate	91.7⩽score achieved ⩽131.3	161	71	0.68
Low	52⩽score achieved⩽91.6	0	0	0

Source: *the results of the authors' own research*

This table shows that 71% of farmers have an SOP adoption level in the medium category. The average technical efficiency achieved by this group is 0.68. Meanwhile, 29% of farmers have a relatively high SOP adoption rate. The mean of technical efficiency achieved is 0.77. The higher the adoption rate of SOP, the higher the value of technical efficiency. The technological components included in SOP for garlic cultivation can help farmers in allocating production inputs as efficiently as possible to produce greater production. The application of SOP can encourage the achievement of productivity targets above 12 t/ha, reduce yield loss to below 10%, and improve the quality of dry tubers according to market standards, namely quality level I (50%), quality II (30%) and quality III (20%) (Directorate General of Horticulture, 2016).

However, the adoption rate of SOP-GAP for garlic still needs to be improved. Based on this research, the adoption rate of SOP for garlic cultivation in Temanggung Regency is in the moderate category. The mean of technical efficiency obtained by farmers only reaches 0.71. The results of this study aligned with the findings of A. Wardani and D. Darwanto (2018), which state that the application of SOP and GAP for garlic cultivation in various production centres in Indonesia still needs to be improved. The government and other stakeholders were challenged to increase the implementation of SOP garlic through various programs and policies.

CONCLUSIONS

The key to achieving food security lies in increasing production to ensure physical and financial access to food according to people's consumption needs. However, national garlic production has not been sufficient to meet national demand, leading to price increases if the government does not implement import policies. Low production is also affected by the inefficient use of factor inputs, which can be attributed to the lack of technology application. The study discovered that the input factors that had a significant impact on garlic production were land area, seeds, urea, NPK fertiliser, herbicides, yellow lick traps, family labour, use of plastic mulch, and participation in government and importer programs. The technical efficiency level of garlic farmers has only reached 0.71, indicating that there is still room for improvement in production using the same technology.

Efficiency in farming is intricately linked to the managerial ability of farmers. Therefore, the socio-economic factors of farmers play a crucial role in reducing opportunities for inefficiency. This study proved that the experience of farmers and the adoption rate of SOPs are significant variables in reducing technical inefficiency. Farmers with more experience have greater exposure to information and technology, providing them with valuable references for their farming practices. This study showed a clear correlation between the rate of technology adoption and technical efficiency. Therefore, to develop successful garlic production programs, the government must ensure that farmers have strong managerial skills, distribute inputs efficiently, and have a mastery of technology.

At the medium level of SOP adoption, farmers achieve a technical efficiency of 0.68. At the medium level of SOP adoption, farmers achieve a technical efficiency of 0.68. This increases to 0.77 at higher levels of adoption. These findings suggest the possibility of formulating several exit strategies to enhance production and technical efficiency. The study's results are important for the Indonesian government and stakeholders in developing garlic policies within the province. This includes expanding the planting area, using quality seeds, adopting fertilisation technology and pest/disease control, improving labour skills within families, applying standard operating procedures by farmers, increasing the role of extension as a facilitator, and improving programs to empower farmers and their businesses. The focus is on increasing production, technical efficiency, and the adoption of technology. To determine national policies for garlic development in Indonesia, it is necessary to scale up this research and broaden the research locus to include all production centres in the country.

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None

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Adzawla, W., & Alhassan, H. (2021). Effects of climate adaptation on technical efficiency of maize production in Northern Ghana. *Agricultural and Food Economics*, 9, article number 14. doi: 10.1186/s40100-021-00183-7.

[2] Ali, I., Xue-xi, H.U.O., Khan, I., Ali, H., Baz, K., & Khan, S.U. (2019). Technical efficiency of hybrid maize growers: A stochastic frontier model approach. *Journal of Integrative Agriculture,* 18(10), 2408-2421. doi: 10.1016/S2095-3119(19)62743-7.

[3] Attipoe, S.G., Jianmin, C., Opoku-Kwanowaa, Y., & Ohene-Sefa, F. (2020). The determinants of technical efficiency of cocoa production in Ghana: An analysis of the role of rural and community banks. *Sustainable Production and Consumption*, 23, 11-20. doi: 10.1016/j.spc.2020.04.001.

[4] Center for Agricultural Data and Information. (2020). Retrieved from https://satudata.pertanian.go.id/assets/docs/publikasi/Outlook_Komoditas_Hortikultura_Bawang_Putih_Tahun_2020.pdf.

[5] Chekol, F., Abetie, K., & Sirany, T. (2023). Technical efficiency of garlic production under rain fed agriculture in Northwest Ethiopia: Stochastic frontier approach. *Cogent Economics and Finance,* 11(2), 1-24. doi: 10.1080/23322039.2023.2242177.

[6] Coomes, O.T., Barham, B.L., MacDonald, G.K., Ramankutty, N., & Chavas, J.P. (2019). Leveraging total factor productivity growth for sustainable and resilient farming. *Nature Sustainability,* 2, 22-28. doi: 10.1038/s41893-018-0200-3.

[7] Declaration of Helsinki. (2013). Retrieved from https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/.

[8] Directorate General of Horticulture. (2016). Retrieved from https://hortikultura.pertanian.go.id/wp-content/uploads/2020/06/Renstra-Horti-2020-2024.pdf.

[9] Falkendal, T., Otto, C., Schewe, J., Jagermeyr, J., Konar, M., Kummu, M., Watkins, B., & Puma, M.J. (2021). Grain export restrictions during COVID-19 risk food insecurity in many low- and middle-income countries. *Nature Food,* 2, 11-14. doi: 10.1038/s43016-020-00211-7.

[10] Geisseler, D., Ortiz, R.S., & Diaz, J. (2022). Nitrogen nutrition and fertilisation of onions (*Allium cepa* L.) – a literature review. *Scientia Horticulturae,* 291, article number 110591. doi: 10.1016/j.scienta.2021.110591.

[11] Hakim, R., Haryanto, T., & Sari, D.W. (2021). Technical efficiency among agricultural households and determinants of food security in East Java, Indonesia. *Scientific Reports*, 11, article number 4141. doi: 10.1038/s41598-021-83670-7.

[12] Hellegers, P. (2022). Food security vulnerability due to trade dependencies on russia and Ukraine. *Food Security*, 14, 1503-1510. doi: 10.1007/s12571-022-01306-8.

[13] Iqbal, R., Raza, M.A.S., Valipour, M., Saleem, M.F., Zaheer, M.S., Ahmad, S., Toleikiene, M., Haider, I., Aslam, M.U., & Nazar, M.A. (2020). Potential agricultural and environmental benefits of mulches – a review. *Bulletin of the National Research Centre*, 44, article number 75. doi: 10.1186/s42269-020-00290-3.

[14] Kale, R.B., Gadge, S., Rao, B.V., Mahajan, V., & Sigh, M. (2022). *Good agricultural practices in onion and garlic production*. Retrieved from https://dogr.icar.gov.in/images/ebook/ebookdogr.pdf.

[15] Kamau, H., Roman, S., & Biber-freudenberger, L. (2023). Farming for sustainable intensification. *Communications Earth & Environment*, 4, article number 446. doi: 10.1038/s43247-023-01062-3.
[16] Kumar, P.P., Khan, N., & Kumar, S. (2018). An economic analysis of garlic cultivation in Ratlam district of Madhya Pradesh. *International Journal of Agriculture, Environment and Biotechnology,* 11(2), 371-377. doi: 10.30954/0974-1712.04.2018.19.
[17] Kune, S.J., & Hutapea, A.N. (2018). Efficient use farm input of Eban local garlic in Western Miomaffo Timor Tengah Utara district. *Journal Management of Agribusiness*, 6(1), 26-33. doi: 10.24843/JMA.2018.v06.i01.p05.
[18] Mina, C.S., Catelo, S.P., & Jimenez, C.D. (2021). Productivity and competitiveness of garlic production in Pasuquin, Ilocos Norte, Philippines. *Asian Journal of Agriculture and Development,* 18(1), 50-63. doi: 10.37801/ajad2021.18.1.4.
[19] Pobozniak, M., Tokarz, K., & Musynov, K. (2020). Evaluation of sticky trap colour for thrips (*Thysanoptera*) monitoring in pea crops (*Pisum sativum* L.). *Journal of Plant Diseases and Protection,* 127, 307-321. doi: 10.1007/s41348-020-00301-5.
[20] Prayogo, W., & Wihastuti, L. (2023). *Technical efficiency analysis of the use of production factors in garlic farming for the 2022 state budget assistance program (case study of Petarangan Village, Kledung District, Temanggung regency).* Retrieved from https://etd.repository.ugm.ac.id/penelitian/detail/227909.
[21] Rabbani, G.M., & Ahmad, B. (2021). An analysis of economic efficiency of garlic production in selected upazila of Dinapur District in Bangladesh. *BAUET Journal*, 3(1), 144-153.
[22] Rahmawati, F., & Jamhari. (2018). Technical efficiency of garlic farming with intercropping pattern in Karanganyar regency, Central Java Province. *Jurnal Agro Ekonomi,* 36(2), 135-147. doi: 10.21082/jae.v36n2.2018.135-147.
[23] Regulation of The Ministry of Agriculture. (2017). Retrieved from https://peraturan.bpk.go.id/Details/160968/permentan-no38permentanhr060112017-tahun-201.
[24] Ricky, R., Suminah, S., & Rusdiyana, E. (2022). Partnership of garlic farmers and importers in Karanganyar Regency. *International Journal of Social Science*, 1(6), 897-906. doi: 10.53625/ijss.v1i6.1913.
[25] Saraswati, S.R., Iswandi, M., & Alwi, L.O. (2022). Analysis of competitiveness and impact of government policy on shallot farming in south Buton Regency. *Jurnal Sosio Agribinis,* 7(1), 22-32. doi: 10.33772/jsa.v7i1.23226.
[26] Septiana, B., Kusnadi, N., & Fariyanti, A. (2022). Garlic competitiveness in Indonesia. *Journal of Indonesian Agribusiness*, 10(1), 40-52. doi: 10.29244/jai.2022.10.1.40-52.
[27] Seran, K.I., Kapa, M.M.J., & Pudjiastuti, S.S.P. (2020). Production efficiency of local garlic farming in west Miomaffo sub-district, East Central Timor Regency. *Buletin Ilmiah IMPAS,* 21(3), 245-252.
[28] Shi, X. (2020). *Uniform inference when parameters are subject to linear inequality constraints.* Washington: University of Washington.
[29] Shukla, Y.R., Kaushal, M., & Bijalwan, P. (2018). Studies on the effect of macro and micro nutrients on yield and nutrient uptake in Garlic (*Allium sativum* L.). *International Journal of Current Microbiology and Applied Sciences,* 7(10), 1201-1204. doi: 10.20546/ijcmas.2018.710.133.
[30] Wardani, A., & Darwanto, D. (2018). The impact of GAP-SOP on the production and technical efficiency of garlic in Temanggung Regency. *Jurnal Agro Ekonomi*, 29(2), 299-309. doi: 10.22146/ae.36468.
[31] Widyastutik, W., Setyawati, D., Dewi, F.R., & Nugraheni, S.R.W. (2022). Garlic business model development strategy: Canvas model business approach. *Jurnal Manajemen Dan Agribisnis,* 19(2), 239-250. doi: 10.17358/jma.19.2.239.
[32] Workneh, M.W., & Kumar, R. (2023). The technical efficiency of large-scale agricultural investment in Northwest Ethiopia: A stochastic frontier approach. *Heliyon,* 9(9), article number e19572. doi: 10.1016/j.heliyon.2023.e19572.

Технічна ефективність на декількох рівнях впровадження стандартних операційних процедур (СОП) для часнику у виробничому центрі в Індонезії

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Анотація. Актуальність цього дослідження полягає в подоланні перешкод для розвитку часнику в Індонезії, таких як низька продуктивність та обмежене використання технологій, що може стати на заваді самозабезпеченню та програмам скорочення імпорту. Метою цього дослідження було визначити технічну ефективність, детермінанти технічної неефективності та рівень технічної ефективності на різних рівнях впровадження стандартних операційних процедур вирощування часнику у виробничих центрах Індонезії. Дані перехресних досліджень були зібрані за допомогою інтерв'ю з 227 фермерами, відібраними за допомогою простого методу випадкового відбору. Виробнича функція Кобба-Дугласа та стохастичний граничний аналіз були використані для визначення факторів, що впливають на виробництво часнику, рівень технічної ефективності та детермінанти технічної неефективності. Для аналізу даних було використано метод максимальної правдоподібності. Рівень технічної ефективності на різних рівнях впровадження стандартних операційних процедур вимірювався за допомогою описового статистичного аналізу. Розмір господарства, насіння, сечовина та NPK добрива, гербіциди, жовті липкі пастки, сімейна праця, мульча та участь фермерів у програмах розвитку часнику суттєво впливали на виробництво часнику. Технічна ефективність варіювалася від 0,37 до 0,99, із середнім значенням 0,71. Досвід фермерів та впровадження стандартних операційних процедур значно знизили технічну неефективність. Загалом, рівень впровадження стандартних операційних процедур є помірним. У групі з високим рівнем впровадження стандартних операційних процедур середній показник технічної ефективності становить 0,77, тоді як у групі з помірним рівнем – 0,68. Результати дослідження можуть бути використані як модель для інших країн-імпортерів часнику для збільшення виробництва та зміцнення продовольчої безпеки

Ключові слова: неефективність; самозабезпеченість; стохастичний граничний аналіз; впровадження технологій

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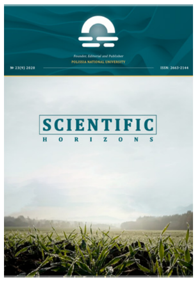

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Use of hop extract in the biotechnology of kefir beverage

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Abstract. The shelf life of fermented dairy products is only 3-5 days and is extended by the addition of preservatives to the production process, but the biological value of the kefir beverage is reduced. The purpose of this study was to determine the feasibility of using hop extract in the biotechnology of fermented milk beverage. Three samples of kefir beverage were produced: control (K) – using traditional technology based on dry starter "Kefir VIVO"; experimental (D1) – with the above type of starter in the amount of 0.05% by weight of milk and hop extract in the amount of 5% by weight of milk.

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The experimental sample (D2) was fermented using hop extract (10% by weight of milk). It was found that when using only hop extract for fermentation of the prototype kefir beverage, the duration of the technological process of its production is the same as when using dry starter and does not exceed 7-8 hours. The number of beneficial viable lactic acid microorganisms (*Lactococcus lactis ssp.*) in the fermented milk beverage made based on hop extract was $1.0 \cdot 10^7$ CFU/cm^3. These microorganisms have probiotic properties, which makes it possible to classify beverages enriched with hop extract as functional foods. In the experimental samples made using hop extract, yeast colonies were found in the amount of $3 \cdot 10^7$ and $8 \cdot 10^7$ CFU/cm^3, respectively. During the experimental storage period, the pH of all product samples was (4.71-4.46). Therewith, the acidity of the sample (D2) increased more slowly. Its organoleptic characteristics were improving. The shelf life has been extended to 10-15 days. The results of the study showed that milk can be fermented with hop extract, resulting in a new functional type of kefir beverage with high organoleptic characteristics, viability of beneficial microflora (lactic acid bacteria and yeast) and extended shelf life

Keywords: fermented milk beverage; shelf life; starter; lactic acid bacteria; yeast; fermentation; biotechnology

INTRODUCTION

Fermented milk products are made by fermenting milk. Therewith, its composition changes under the influence of microorganisms and the pH level decreases. The fermentation of lactose also leads to an increase in the bioavailability of nutrients and improves the quality of dairy products. At the same time, lactic acid microflora and its metabolic products inhibit the development of microorganisms that cause food spoilage and pathogens. The main products formed during the fermentation process in the production of fermented milk beverages are lactic acid, ethanol, and CO_2, which give them viscosity, sour taste, and lead to the accumulation of a low alcohol content. A prerequisite for fermented beverages is that the starter microorganisms are viable, active, and present in sufficient quantities in the product until the minimum shelf life. A considerable number of fermented dairy beverages are produced worldwide using mono- or complexes of starter cultures. Nevertheless, the issue of ensuring that such products have a longer shelf life is still relevant.

The principal function of fermented dairy starter cultures is to extend shelf life and increase safety due to the biopreservative function of metabolites produced during fermentation, as well as to improve the organoleptic, rheological, and nutritional properties of the finished product. Safety issues in fermented milk beverages arise from the presence of bacteriophages and antimicrobial agents that can inhibit the activity of bacterial starter cultures. This leads to a decrease in viscosity and a deterioration in the taste of the beverage. J. Tamang *et al.* (2020) found that the microbiota of fermentation starter products consists of selected and well-defined strains of lactic acid bacteria that are produced in concentrated and stable forms. Their wide availability, ease of use, and stable properties have made them widespread in many countries.

T. Bintsis and P. Papademas (2022) showed that the starter cultures used for milk fermentation include a variety of bacteria, dominated by *Lactobacillus species such as L. delbrueckii subsp. bulgaricus*, L. *helveticus*, L. *kefiranofaciens subsp. kefiranofaciens*, *L. kefiranofaciens subsp. kefirgranum* and *L. Acidophilus*, *Lactococcus spp.* such as *L. lactis subsp. lactis* and *L. lactis subsp. cremoris* and *Streptococcus thermophilus*. The microorganisms that make up the starter not only increase the acidity of the environment, but also affect the formation of texture, taste, and biochemical changes in the product.

Numerous studies by V. Braccini *et al.* (2021) have shown that kefir is produced using bacteria and yeast, which exist in symbiotic association in kefir fungi. It is a traditional example of the coexistence of bacteria and yeast, which produce compounds that are beneficial to health. As a rule, kefir fungi contain a relatively stable and specific microbiota enclosed in a matrix of polysaccharides and proteins. Microbial interactions in kefir are complex due to the composition of kefir fungi. Furthermore, certain populations of individual kefir grains shape the organoleptic characteristics of fermented beverages. Kefir is characterised by a distinctive taste typical of yeast and a noticeable fizzy effect.

Yeast and acetic acid bacteria practically do not ferment lactose, but they contribute to flavour formation by producing ethanol and CO_2. The properties of kefir yeast are less studied than those of bacteria. T. Srimahaeak *et al.* (2022) showed that *Kluyveromyces marxianus/Candida kefir*, *Kluyveromyces lactis var. lactis*, *Debaryomyces hansenii*, *Dekkera anomala* can ferment lactose. *Saccharomyces cerevisiae*, *Torulaspora delbrueckii*, *Pichia fermentans*, *Kazachstania unispora*, *Saccharomyces turicenysis*, *Issac* do not *ferment* lactose. Some authors have proposed alternative ways to produce kefir beverages using non-dairy substrates such as fruit and molasses (Farag *et al.*, 2020), agro-industrial waste (Aiello *et al.*, 2020), and plant extracts (Setiyoningrum *et al.*, 2019). However, only the organoleptic and some physicochemical properties of the product changed.

A potential source of antimicrobial activity is hops (*Humulus lupulus*), whose antibacterial effect is partly explained by the presence of humulone (alpha-acid), lupulone (beta-acid), and the polyphenol xanthohumol.

Hops are commonly used in baking and brewing. L. Nionelli *et al*. (2018) showed that hop starter inhibited the growth of fungi in bread for 14 days, characterised by a concentration of free amino acids, antioxidant and phytase activity higher than that of bread made with baker's yeast alone). Beer containing hops has also been found to be less perishable, indicating the antimicrobial potential of this plant (Blaxland *et al.*, 2022).

Furthermore, a considerable amount of "wild" yeast is concentrated on the surface of hop cones. D. Watanabe (2023) showed that during growth, yeast enriches the environment with a number of essential metabolic products, making it more suitable for the development of lactic acid bacteria. Thus, lactic acid bacteria, when co-cultured with yeast, use growth factors that are absent in milk but present in yeast autolysates. Furthermore, the alcohol produced (due to alcoholic fermentation caused by yeast) inhibits the rate of cell division of lactic acid microorganisms, thereby slowing down the aging of the population, as a result of which lactic acid bacteria stay active longer.

Considering the high antimicrobial effect of hops, their availability and distribution throughout Ukraine, they can be considered a promising raw material for use in the food industry, including in the production of fermented milk beverages. Therefore, the purpose of this study was to determine the feasibility of using hop extract in the biotechnology of fermented milk beverage.

MATERIALS AND METHODS

The study was conducted at the educational and scientific laboratory of craft technologies and gastronomic innovations of Sumy National Agrarian University in January 2023. Three samples of fermented milk beverages such as kefir were produced using the thermostatic method. The main raw material used was ultra-pasteurised cow's milk with a mass fraction (g/100 g) of 2.8 proteins, 2.5 fats, and 4.5 carbohydrates.

As a control (C), the kefir beverage (sample 1) was produced using direct application starter cultures for kefir "Kefir VIVO", which include kefir fungi microflora standardised with additional mesophilic and thermophilic microflora (0.1% by weight of milk, which is the amount recommended by the manufacturer). The prototype of product 2 (D1) was fermented with the direct application starter "Kefir VIVO" (0.05% by weight of milk) and hop extract (5% by weight of milk). Sample 3 (D2) was fermented with hop extract only (10% by weight of milk). This amount of extract had no negative effect on the organoleptic properties of the finished product (Fig. 1).

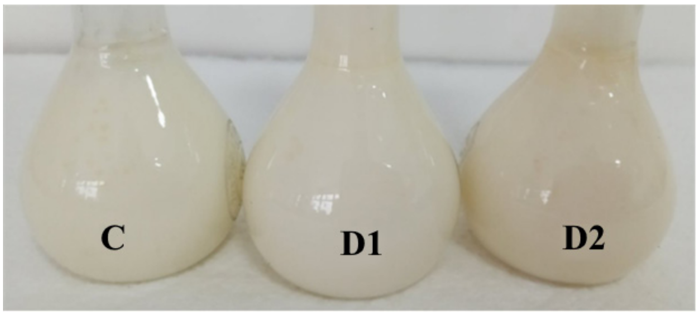


Figure 1. *Samples of fermented milk beverages*
Notes*: C – based on dry starter; D1 – based on a mixture of dry starter and hop extract; D2 – based on hop extract*
Source*: compiled by the authors of this study*

The amount of added extract was determined by the analysis of literature sources and a range of preliminary laboratory studies. When the amount of extract was increased to 15% and 20%, the product had a too liquid consistency and a noticeable bitter taste. When less than 5% hop extract was used for the fermentation, the fermentation time was around 16 hours. The hop extract was prepared by infusion. For this, the cones of wild-growing *Humulus* hop were mixed with hot distilled water (85°C) in a ratio of 10:1 and infused for 24 hours. The resulting extract was filtered and then added to milk heated to the fermentation temperature (25°C), and the starter was added. The mixture was mixed thoroughly and placed in the thermostat. The duration of fermentation of all kefir beverage samples was 7-8 hours.

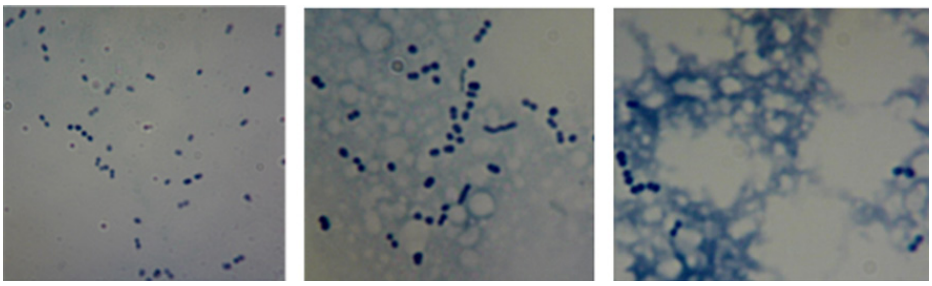
Study of microbiological parameters of kefir beverages. The number of lactic acid bacteria and yeasts was determined by plating serial dilutions on selective medium. Bacteria were counted according to DSTU 7999:2015 (2017), yeast – according to DSTU ISO 7954:2006 (2007). The active acidity was determined following DSTU 8550:2015 (2017), which is based on the determination of hydrogen ion activity using a potentiometric analyser, "pH-500" pH meter (Italy).

To determine the microbiological composition of the samples by morphological features, the samples were microscoped according to the generally accepted methodology "Instruction on microbiological control at dairy enterprises". The staining was carried out using a simple method. In this case, a few drops of methylene blue solution were poured onto a preserved smear for 3-5 minutes, then the paint was washed with water, and the smears were dried with filter paper. The samples were microscoped using a Konus Academy ×1000 immersion microscope system (Italy), and the samples were captured in the microscope field of view using a Delta Optical 2-megapixel camera (Poland). To determine the live lactic acid bacteria, on Day 3 of storage, using the cup method, plating was carried out on a special selective medium MPA (meat-peptone agar), followed by cultivation at 30±1°C for 72 hours. Plating for the detection of yeast and mould colonies was carried out on Sabouraud selective medium, followed by cultivation at 27±2°C for 72 hours.

Statistical analysis. Statistical data were calculated using the Fisher-Student method, considering statistical errors and the reliability of comparable analogous indicators. The values were considered significant at the level of more than 95% ($p<0.05$).

RESULTS AND DISCUSSION

Results of the microbiological study. Microscopy of the experimental samples was conducted after the fermentation process. Mesophilic lactic acid bacteria represented the microflora of the experimental samples (Fig. 2).



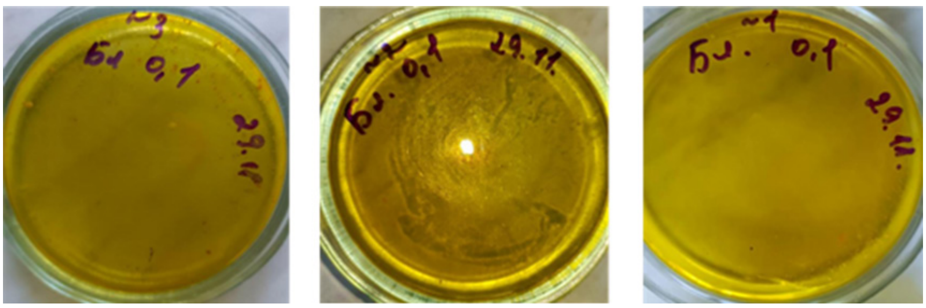
a b c

Figure 2. *Sample microscopy results*

Notes: *a – sample 1 (C); b – sample 2 (D1); c – sample 3 (D2)*

Source: *compiled by the authors of this study*

The dominant strains of microorganisms detected in the control sample (C) were *Lactococcus lactis ssp*. lactobacilli. The cells of *Lactococcus lactis ssp*. are spherical in shape, usually grouped into diplococci and short chains of 0.5-1.5 µm in length. The species composition of the microflora of samples D1 and D2 was comparable, but the number of lactobacilli in the field of view in sample D2 was lower. In the control sample (C) and sample 2 (D1), 50-80 cells were observed in the field of view. This may indicate a high initial concentration of lactic acid microorganisms in the product, which is also confirmed by the cup test. In sample 3 (D2), single cells and clusters were observed in the field of view, which can be explained by the use of only hop cone extract as a starter, i.e., a low initial concentration of *Lactococcus lactis ssp*. cells, but not their absence. Since ultra-pasteurised milk was used to prepare the test samples, no microbiological tests were carried out on it before fermentation. The results of determining the content of living microorganisms are presented in Figure 3.



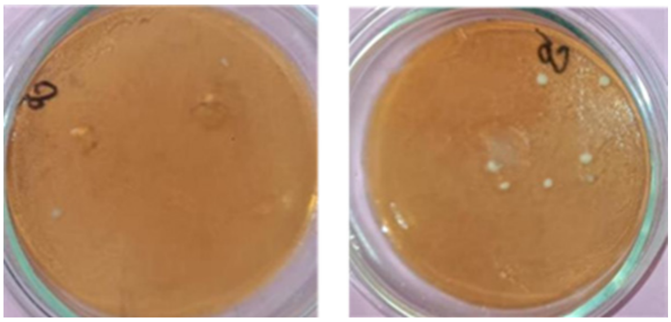
a b c

Figure 3. *Results of surface plating*

Notes: *a – sample 1 (C); b – sample 2 (D1); c – sample 3 (D2)*

Source: *compiled by the authors of this study*

According to the results of surface plating (Fig. 3), samples 1 (C) and 2 (D1) contain live lactic acid bacteria in the amount of $1.0 \cdot 10^8$ CFU/cm^3. Sample 3 (D2), made only from hop extract, contained $1.0 \cdot 10^7$ CFU/cm^3 of live lactic acid bacteria. In other words, all samples were within the limits set by the requirements (DSTU 4417:2005, 2006). The morphology of the colonies when cultivated on media and the morphology of the cells under microscopy was typical of kefir beverages. Plating for the detection of yeast and mould colonies was carried out on Sabouraud selective medium, followed by cultivation at 27±2°C for 72 hours. The results are presented in Figure 4.



b c

Figure 4. *Number of yeast colonies*

Notes*: b – sample 2 (D1); c – sample 3 (D2)*
Source*: compiled by the authors of this study*

No yeast growth was observed in the control sample (C). On Sabouraud selective medium, the strain *Kluyveromyces lactis var. lactis* grew with the formation of white matte convex colonies with smooth edges and a smooth shiny surface. This is a desirable phenotype for large-scale biosynthesis of biomass-related products, with a unique set of beneficial properties such as the fastest growth, heat tolerance, and a wide range of substrates (Bilal *et al.*, 2022).

As a result, it was found that all samples of kefir beverages did not contain mould. The yeast *Kluyveromyces lactis var. Lactis* was detected in the experimental samples of the kefir beverage. In the experimental product sample 2 (D1), their content was $3.0 \cdot 10^1$ CFU/cm^3, while in sample 3 (D2) – $8.0 \cdot 10^1$ CFU/cm^3. That is, the number of yeasts increased with the amount of hop extract added to the milk prepared for the fermentation process. This indicates that the hop extract contains yeast that can ferment lactose, as the fermentation time for all samples was the same, and in all cases a dense lactic acid curd, typical of fermented milk beverages, was formed. Hop extract can therefore be an alternative to bacterial leaven. The active acidity is an important indicator of the quality of fermented dairy products during storage. A decrease in pH indicates the formation of lactic acid. The results of the active acidity study are presented in Figure 5.

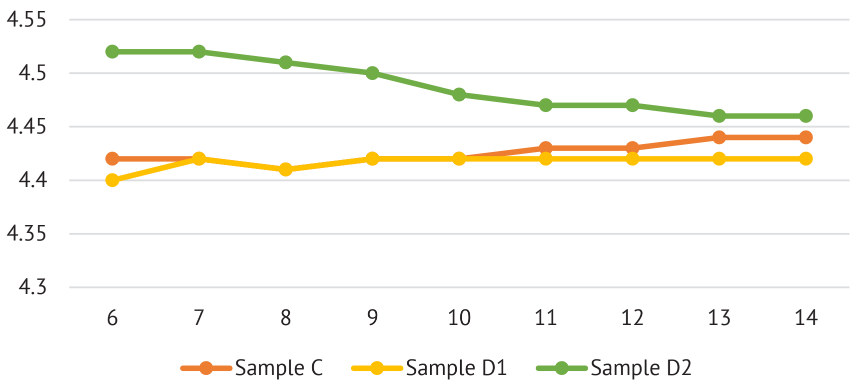


Figure 5*. Changes in pH during storage*

Source*: compiled by the authors of this study*

The study showed that after 8 hours of fermentation, all samples had sufficient acidity, which corresponds to the acidity of kefir beverages. However, already on Day 2 of storage, a rapid decrease in pH was observed in samples 1 (C) and 2 (D1), indicating a significant increase in the concentration of lactic acid. It is known that with an increase in the concentration of lactic acid, the development of lactic acid bacteria is inhibited, and their number begins to decline. This creates conditions for the development of pseudo-yeast and mould fungi.

In contrast to the control (C) and the experimental product sample (D1), the acidity of the sample 3 (D2) produced by fermenting the milk mixture with hop extract decreased more slowly. Even though the concentration of lactic acid in sample D2 was lower, there were no signs of spoilage. This is explained by the antimicrobial properties of hop extract

(Kumar Verma *et al.*, 2020; Kolenc *et al.*, 2022). Due to the biostabilisation of the fermented milk beverage with yeast, the product was suitable for longer storage for 14 days at 6±2°C.

The organoleptic characteristics of the experimental sample of fermented milk beverage – 3 (D2), enriched with hop extract, were the best. The consistency was homogeneous and viscous. The taste was sour-milk, tangy, with a pleasant, barely noticeable hop aroma. Moderate gas formation was observed. In samples 1 (C) and 2 (D1), a slight separation of serum was observed on Days 2-3 of storage. There was no gas formation in sample 1 (C). This led to the development of an industrial technology for a kefir beverage using hop extract. The scheme of production of kefir beverages based on hop extract is presented in Figure 6.

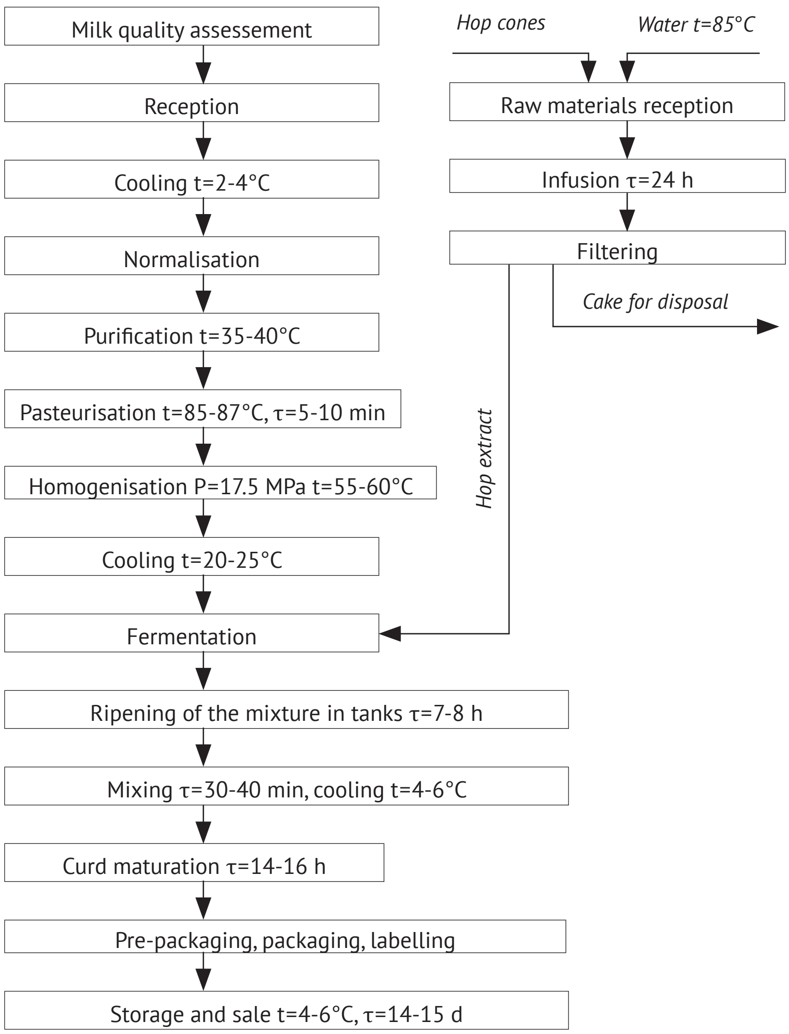


Figure 6. *Flow chart of production of fermented milk beverage with hop extract*
Source*: compiled by the authors of this study*

According to the proposed scheme, fermentation in industrial conditions is recommended to be carried out using the tank method, as this method is the most common in the production of kefir. The purified milk is cooled and normalised to a fat mass fraction of 2.5%. The normalised milk mixture is heated and homogenised to improve the structure of the finished product. The homogenised mixture is cooled to the fermentation temperature. It is recommended to add 10% hop extract at 25°C to the fermentation tank. After the hop extract has been added, the mixture is stirred thoroughly. The fermentation time is 7-8 hours. The resulting product is then thoroughly mixed to achieve a homogeneous consistency and cooled to the maturation temperature. After 14-16 hours of curd maturation, the kefir beverage is prepackaged and packaged. The recommended shelf life of the fermented milk beverage with hop extract is 14-15 days.

The results of the experiment showed that milk fermentation can be carried out using hop extracts. Since the ultra-pasteurised milk used for the study is free of lactic acid bacteria, the fermentation occurs due to the yeast present in the extracts made from wild hop cones. According to J. Varela *et al.* (2019), humans have been using yeast to make cheese and kefir for thousands of years, but the ability to ferment the milk sugar lactose has only been found in a few species of yeast, the first of which is *Kluyveromyces lactis*. Two genes, *LAC12* (lactose permease) and *LAC4* (lactase), are sufficient to take up lactose and hydrolyse it to glucose and galactose. The ability to grow on lactose as the sole carbon source is a defining feature of the nutritional yeasts *Kluyveromyces lactis* and *Kluyveromyces marxianus*. These are the strains that were detected on the experimental samples D1 and D2 (Fig. 4).

Microbiological testing showed that no pathogens were found in all samples, including those made with kefir starter. The predominant microflora of kefir beverages was *Lactococcus lactis ssp*. (Fig. 2). It is likely that the acidic pH prevents the growth of these microorganisms in this particular microenvironment. Other researchers have obtained analogous results. D. Kim *et al*. (2017), G. Aprea *et al*. (2023), investigating the tolerance of probiotic microorganisms to acidic pH, found that a decrease in acidity leads to the inhibition of pathogenic microflora.

It is known that the acidity of fermented foods is usually maintained or reduced during storage, which is related to microbial activity, which is a continuous fermentation process where lactic acid bacteria and yeast assimilate carbohydrates (Łopusiewicz *et al*., 2019; dos Santos *et al*., 2019). The study found that during the storage of fermented milk beverages made with hop extract, the pH decreased much more slowly than in samples C and D1 (Fig. 5). This means that the formation of lactic acid is slower, and the action of lactic acid bacteria is inhibited. The beverage did not spoil, and no moulds developed in it. It is likely that this effect was also caused by "wild" yeasts that developed on the surface of hop cones, which can inhibit the development of moulds. E. Sohlberg *et al*. (2022) showed that "wild" yeast can proliferate during the initial phases of fermentation, outnumbering other species of microorganisms, including lactic acid bacteria, which are producers of lactic acid. These results confirm the assumption made.

All kefir samples had a pH value of less than 4.7. This value is the maximum for microbial stability. Observations during the study indicate that during the storage of the product, the active acidity (pH) of the sample based on hop extract decreased gradually and did not exceed the permissible limits. Notably, the high organoleptic characteristics of the kefir beverage were maintained, and the consistency stayed homogeneous. No syneresis was observed. In contrast, the pH of the control sample 1 (C), made based on dry fungal starter, decreased sharply on the second day of storage. On Day 6 of the study, control sample 1 (C) showed the first signs of spoilage (curd structure was disturbed, sour taste and smell appeared). Such changes occurred in experimental sample 2 (D1) and 3 (D2) on Day 11 and Day 14 of storage, respectively. Analogous results of the antimicrobial activity of fermented milk beverages were obtained by other researchers (Ortiz-Merino *et al*., 2018; Al-Mohammadi *et al*., 2021) and were explained only by a decrease in the active acidity in the milk medium and the effect of the resulting lactic acid. However, the experiments conducted in this study indicate that the inhibitory activity of the experimental samples of fermented milk beverages against mould was also conditioned by substances present in hop extract, including an increased level of yeast in its composition, which cannot ferment lactose to lactic acid. During the storage of two kefir experimental samples 2 (D1) and 3 (D2), no accumulation of high concentrations of fermentation products – lactic acid – was observed.

No yeast was found in the control. This indicates their absence in the composition of dry kefir starter. Control sample 1 (C) was already unfit for consumption on Day 6 of storage. Yeasts have a higher resistance to lactic acid than other microorganisms, which allows them to grow dominantly (Sohlberg *et al*., 2022). As a result, the shelf life of fermented dairy products is extended. The number of yeast colonies in the freshly brewed test samples with different amounts of hop extract differed substantially. A positive effect of yeast on improving the quality of experimental samples 2 (D1) and 3 (D2) was observed. Thus, an increase in the amount of yeast under the influence of hop extract in the kefir beverage improved its organoleptic characteristics. The improvement of the organoleptic characteristics of kefir beverage made based on hop extract is probably conditioned by the presence of essential oils and hop resins in the composition of hop extracts. These biochemical compounds give the product a pleasant taste and aroma. According to the findings of A. Díaz *et al*. (2022), a considerable number of aromatically active compounds are related not only to the composition of hops, but also to specific fermentation conditions and to the concrete yeast strain used, which can produce interesting aromatic components such as higher alcohols or compound esters. Thus, by using certain types of hops in the production of fermented milk beverages, it is possible to give them unique organoleptic properties.

According to the findings of this study, it can be argued that hop extract, introduced into the process of manufacturing prototypes of the fermented milk beverage, has a bacteriostatic effect that can delay the development of negative microflora, which leads to product spoilage and has a positive effect on improving organoleptic characteristics and increasing its shelf life to 10-15 days.

CONCLUSIONS

The findings of this study showed that the use of hop extract for fermentation of milk mixture is appropriate and timely, since the partial or complete exclusion of starter cultures from the production of fermented milk beverages will improve the economic performance of Ukrainian dairy processing enterprises. A scheme for the production of a fermented milk beverage was developed, which is carried out according to the technological parameters that are usually used in industrial conditions. Therewith, the duration of milk fermentation in the production of the test samples of the beverage is practically the same as in the control.

The experimental product sample 3 (D2), made using hop extract, contains a sufficient amount of viable lactic acid microflora and has prominent organoleptic properties. This experimental sample contains yeast, probably a strain of *Kluyveromyces lactis var. Lactis*, which can ferment other milk carbohydrates, except lactose, the fermentation of which is accompanied by the formation of a high concentration of lactic acid. This causes product defects and reduces its shelf life. Given that yeast is a source of B vitamins, the presence of yeast in a fermented milk beverage will have a positive impact on consumer health.

The use of hop extract in the production of experimental samples of the fermented milk beverage contributed to a slow decrease in their active acidity, which was within the normal range. This allowed extending the shelf life of the above samples to 10-15 days. A technology for the production of fermented milk beverages based on hop extract for industrial use was developed, which will expand the range of fermented natural beverages with biologically active ingredients. The prospect of further research is to investigate the antioxidant properties of fermented milk beverages made based on hop extracts.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Aiello, F., Restuccia, D., Spizzirri, U.G., Carullo, G., Leporini, M., & Loizzo, M.R. (2020). Improving kefir bioactive properties by functional enrichment with plant and agro-food waste extracts. *Fermentation*, 6(3), article number 83. doi: 10.3390/fermentation6030083.

[2] Al-Mohammadi, A.R., Ibrahim, R.A., Moustafa, A.H., Ismaiel, A.A., Abou, Z.A., & Enan, G. (2021). Chemical constitution and antimicrobial activity of kefir fermented beverage. *Molecules*, 26(9), article number 2635. doi: 10.3390/molecules26092635.

[3] Aprea, G., Del Matto, I., Tucci, P., Marino, L., Scattolini, S., & Rossi, F. (2023). *In vivo* functional properties of dairy bacteria. *Microorganisms*, 11(7), article number 1787. doi: 10.3390/microorganisms11071787.

[4] Bilal, M., Ji, L., Xu, Y., Xu, S., Lin, Y., Iqbal, H.M.N., & Cheng, H. (2022). Bioprospecting Kluyveromyces marxianus as a robust host for industrial biotechnology. *Frontiers in Bioengineering and Biotechnology,* 10, article number 851768. doi: 10.3389/fbioe.2022.851768.

[5] Bintsis, T., & Papademas, P. (2022). The evolution of fermented milks, from artisanal to industrial products: A critical review. *Fermentation*, 8(12), article number 679. doi: 10.3390/fermentation8120679.

[6] Blaxland, J., Thomas, R., & Baillie, L. (2022). The antibacterial effect of *Humulus lupulus* (Hops) against *Mycobacterium bovis* BCG: A promising alternative in the fight against bovine tuberculosis? *Beverages*, 8(3), article number 43. doi: 10.3390/beverages8030043.

[7] Braccini, V.P., Arbello, D.D.R., Erhardt, M.M., Jiménez, M.S.E., Pedroso, M.A.P., & Richards, N.S.P.S. (2021). Fermented milk: Kefir. *Brazilian Journal of Development*, 7(3), 21121-21135. doi: 10.34117/bjdv7n3-021 .

[8] Díaz, A.B., Durán-Guerrero, E., Lasanta, C., & Castro, R. (2022). From the raw materials to the bottled product: Influence of the entire production process on the organoleptic profile of industrial beers. *Foods*, 11(20), article number 3215. doi: 10.3390/foods11203215.

[9] dos Santos, D.C., de Oliveira Filho, J.G., Santana, A.C.A., de Freitas, B.S.M., Silva, F.G., Takeuchi, K.P., & Egea, M.B. (2019). Optimization of soymilk fermentation with kefir and the addition of inulin: Physicochemical, sensory and technological characteristics. *LWT - Food Science and Technology*, 104, 30-37. doi: 10.1016/j.lwt.2019.01.030.

[10] DSTU 4417:2005. (2006). *Kefir. Specifications.* Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=84671.

[11] DSTU 7999:2015. (2017). *Food products. Methods of determination of the lactic acid bacteria.* Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=81078.

[12] DSTU 8550:2015. (2017). *Milk and dairy products. Measurement pH potentiomery a method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=71694.

[13] DSTU ISO 7954:2006. (2007). *Microbiology of food stuffs and sterns for animals. General guidance for enumeration of yeasts and moulds. Colony count technique at 25 °C.* Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=96955.

[14] Farag, M.A., Jomaa, S.A., El-Wahed, A.A., & El-Seedi, H.R. (2020). The many faces of kefir fermented dairy products. *Nutrients*, 12(2), article number 346. doi: 10.3390/nu12020346.

[15] Kim, D.H., Jeong, D., Oh, Y.T., Song, K.Y., Kim, H.S., Chon, J.W., Kim, H., & Seo, K.H. (2017). Stimulating the growth of kefir-isolated lactic acid bacteria using addition of crude flaxseed (*Linum usitatissimum* L.) extract. *Journal of Milk Science and Biotechnology*, 35(2), 93-97. doi: 10.22424/jmsb.2017.35.2.93.
[16] Kolenc, Z., Langerholc, T., Hostnik, G., Ocvirk. M., Štumpf, S., Pintari, M., Košir, I.J., Čerenak, A., Garmut, A., & Bren, U. (2022). Antimicrobial properties of different hop (*Humulus lupulus*) genotypes. *Plants (Basel)*, 12(1), article number 120. doi: 10.3390/plants12010120.
[17] Kumar Verma, S., Verma, R., Xu, F., Kumar Thakur, P., Girish, Y.R., & Rakesh, K.P. (2020). Antibacterial activities of sulfonyl or sulfonamide containing heterocyclic derivatives and its structure-activity relationships (SAR) studies: A critical review. *Bioorganic Chemistry*, 105, article number 104400. doi: 10.1016/j.bioorg.2020.104400.
[18] Łopusiewicz, Ł., Drozłowska, E., Siedlecka, P., Mężyńska, M., Bartkowiak, A., Sienkiewicz, M., Zielińska-Bliźniewska, H., & Kwiatkowski, P. (2019). Development, characterization, and bioactivity of non-dairy kefir-like fermented beverage based on flaxseed oil cake. *Foods*, 8(11), article number 544. doi: 10.3390/foods8110544.
[19] Nionelli, L., Pontonio, E., Gobbetti, M., & Rizzello, C.G. (2018). Use of hop extract as antifungal ingredient for bread making and selection of autochthonous resistant starters for sourdough fermentation. *International Journal of Food Microbiology*, 266, 173-182. doi: 10.1016/j.ijfoodmicro.2017.12.002.
[20] Ortiz-Merino, R.A., Varela, J.A., Coughlan, A.Y., Hoshida, H., da Silveira, W.B., Wilde, C., Kuijpers, N.G.A., Geertman, J.M., Wolfe, K.H., & Morrissey, J.P. (2018). Ploidy variation in *Kluyveromyces marxianus* separates dairy and non-dairy isolates. *Frontiers in Genetics,* 9, article number 94. doi: 10.3389/fgene.2018.00094.
[21] Setiyoningrum, F., Priadi, G.A.F., & Fifi, A. (2019). Supplementation of ginger and cinnamon extract into goat milk kefir. *Proceedings of the 5th International Symposium on Applied Chemistry 2019*, 2175(1), article number 020069. doi: 10.1063/1.5134633.
[22] Sohlberg, E., Sarlin, T., & Juvonen R. (2022). Fungal diversity on brewery filling hall surfaces and quality control samples. *Yeast*, 39(1-2), 141-155. doi: 10.1002/yea.3687.
[23] Srimahaeak, T, Petersen, M.A., Lillevang, S.K., Jespersen, L., & Larsen, N. (2022). Spoilage potential of contaminating yeast species *Kluyveromyces marxianus*, *Pichia kudriavzevii* and *Torulaspora delbrueckii* during cold storage of Skyr. *Foods*, 11(12), article number 1776. doi: 10.3390/foods11121776.
[24] Tamang, J.P., Cotter, P.D., Endo, A., Han, N.S., Kort, R., Liu, S.Q., Mayo, B., Westerik, N., & Hutkins, R. (2020). Fermented foods in a global age: East meets West. *Comprehensive Reviews in Food Science and Food Safety*, 19(1), 184-217. doi: 10.1111/1541-4337.12520.
[25] Varela, J.A., Puricelli, M., Ortiz-Merino, R.A., Giacomobono, R., Braun-Galleani, S., Wolfe, K.H., & Morrisse J.P. (2019). Origin of lactose fermentation in Kluyveromyces lactis by interspecies transfer of a neo-functionalized gene cluster during domestication. *Current Biolodgy*, 29(24), 4284-4290. doi: 10.1016/j.cub.2019.10.044.
[26] Watanabe, D. (2023). Sake yeast symbiosis with lactic acid bacteria and alcoholic fermentation. *Bioscience, Biotechnology, and Biochemistry*, 0, 1-5. doi: 10.1093/bbb/zbad167.

Використання хмелевого екстракту в біотехнології кефірного напою

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Анотація. Термін придатності до зберігання кисломолочних продуктів становить лише 3-5 діб і збільшується веденням в процес їх виробництва консервантів, проте, при цьому біологічна цінність кефірного напою знижується. Мета роботи – визначення доцільності використання хмелевого екстракту в біотехнології кисломолочного напою. Було виготовлено 3 зразки кефірного напою: контрольний (К) – за традиційною технологією на основі сухої закваски «Кефір VIVO»; дослідний (Д1) – із вище вказаним видом закваски в кількості 0,05 % до маси молока та екстрактом хмелю в кількості 5 % до маси молока. Ферментація дослідного зразка (Д2) проводилась із використанням хмелевого екстракту (10 % до маси молока). Встановлено, що при використанні лише хмелевого екстракту для заквашування дослідного зразка кефірного напою, тривалість технологічного процесу його виробництва є такою ж, як і при використанні сухої закваски та не перевищує 7-8 годин. Кількість корисних життєздатних молочнокислих мікроорганізмів (*Lactococcus lactis ssp.*) у кисломолочному напої, виготовленому на основі хмелевого екстракту, становила $1{,}0 \cdot 10^7$ КУО в 1 см^3. Ці мікроорганізми мають пробіотичні властивості, що дозволяє віднести напої, збагачені екстрактом хмелю до продуктів функціонального призначення. У дослідних зразках, виготовлених із використанням хмелевого екстракту, виявлено колонії дріжджів у кількості $3 \cdot 10^7$ та $8 \cdot 10^7$ КУО в 1 см^3 відповідно. Протягом дослідного періоду зберігання усіх зразків продукту рівень pH становив (4,71-4,46). При цьому кислотність зразка (Д2) наростала повільніше. Покращувалися його органолептичні показники. Термін придатності до зберігання збільшився до 10-15 діб. Результати дослідження показали, що молоко можна ферментувати хмелевим екстрактом, в результаті чого отримується новий функціональний тип кефірного напою з високими органолептичними показниками, життєздатністю корисної мікрофлори (молочнокислих бактерій та дріжджів) та подовженим терміном придатності

Ключові слова: кисломолочний напій; термін придатності; закваска; молочнокислі бактерії; дріжджі; ферментація; біотехнологія

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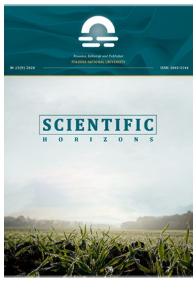

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Seed production system in Ukraine: Trends, challenges, and threats

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Abstract. The development of an effective seed production system in Ukraine is conditioned both by its key role in ensuring seed, food, and national security of the country and by the emergence of new challenges and threats that affect the functioning of the system and need to be countered to eliminate or mitigate their negative impact. The purpose of this study was to investigate the current trends in the functioning of the Ukrainian seed production system and to identify new challenges and threats to national interests. The methodological framework of this study included the dialectical

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method of scientific cognition, which was used to establish the relationship between the object of study, which is the seed production system of Ukraine, and events and phenomena occurring in nature and society that have a substantial impact on the object of the study. The methods of analysis and synthesis, systematic generalisation, and comparative analysis were also used. The study analysed the conditions of functioning of the breeding and seed production system in Ukraine and identified current trends that characterise its internal state. The study identified challenges and threats to the national seed production system that pose a threat to the seed, food, and national security of Ukraine. The study analysed destructive processes in the functioning of the national seed production system, which can lead to its degradation and destruction. Measures to overcome the consequences of the negative factors in the system of breeding and seed production in Ukraine were substantiated. The study scientifically substantiated the principal criteria for the development of an effective national seed production system. The study provided a reasoning for the need for long-term investment in breeding activities and identified priority areas of state support for the seed production system in Ukraine. The conclusions, proposals, and practical recommendations are of practical importance and can be used in the development of relevant programmes and measures aimed at supporting the development of seed production, specifically, breeding activities in Ukraine, and ensuring fair remuneration to breeders who are the authors of new productive crop varieties

Keywords: breeding; seeds and planting material; variety; seed security; sustainability; food security

INTRODUCTION

An effective seed production system is a crucial factor in increasing agricultural production and an additional source of income for farmers, as well as a prerequisite for food security. Considering the steady downward trend in the production of seeds of Ukrainian breeding of major crops caused by numerous problems that hinder the development of seed production in Ukraine, and in the context of global climate change and new challenges and threats associated with the consequences of the full-scale invasion of Russia, it is increasingly urgent to radically change the national seed production system, which should be not only effective, but also sustainable and dynamic.

L.H. Biliavska *et al*. (2020) point out that Ukrainian seed production has great reserves for further improving its efficiency. The researchers assume that the establishment of a seed production system in Ukraine will contribute to the growth of the national crop production potential and attract additional investments in the development of the breeding industry. An effective breeding and seed production system is a source of innovation. According to S.V. Mishchenko (2021), the development of a new paradigm for the development of the agro-industrial complex is possible only with the active and balanced introduction of innovations, including breeding and genetic ones.

K.V. Akulenko (2018) believes that the principal areas of breeding and genetic innovations in the agricultural sector of Ukraine may include new crop varieties with high potential productivity; renewable and environmentally friendly bioproducts; new crop varieties and hybrids with improved quality parameters; adaptation crops (development of varieties that are more adaptable to adverse weather conditions), etc. The seed production system involves the production of quality seeds and providing access to the results of breeding to agricultural producers. It should combine breeding activities, variety testing, zoning of new varieties and their mass reproduction, variety maintenance, control over varietal (testing) and sowing (seed control) qualities of seeds, as well as variety renewal and variety replacement. A seed production system functions effectively if it ensures seed security, i.e., if there is sufficient access to the required amount of quality seeds and planting material of the desired crop varieties at all times, in both good and bad harvest seasons (FAO, 2016).

O.T. Westengen *et al*. (2023) argue that to be effective, seed production systems must perform three principal functions: variety development and management, seed production, and seed distribution. N.P. Louwaars and G. Manicad (2022) emphasise that any seed production system, whether formal (official) or informal (farmer-led), must be sustainable. A sustainable seed production system contributes to the sustainability of seed supply and demand in a given context, and thus to seed security. The researchers interpret the resilience of a seed production system as its ability to anticipate, absorb, respond to, or transform the changes that result from change. These changes can be in the form of threats or opportunities created by markets, the environment, and technology.

A sustainable seed production system is an essential element in the sustainability of agricultural and food production. A sustainable seed production system requires ensuring crop diversity and its conservation. At the same time, a sustainable seed production system is a prerequisite for achieving seed and food security. L. Batten *et al*. (2021) emphasise that a fundamental component of a sustainable food production system is crop genetic diversity, not only because it allows the system to recover from agricultural challenges such as environmental hazards, pests, and diseases, but also because crop seeds also carry genetic information – an indispensable resource for breeders and farmers to develop new crop varieties. A prerequisite for the development of an effective seed production system is the search for criteria to ensure the efficiency of its functioning, as well as the identification of problems and opportunities for the development of the industry. J.L. Andrade-Piedra *et al.* (2020) believe that the effectiveness of the seed production system should be considered from the standpoint of the state, which is responsible for national food security and food price affordability; seed breeders and producers; farmers.

An efficiently functioning seed production system is a guarantee of the country's seed, food, and national security. It involves the fulfilment of the economic interests of all stakeholders, namely breeders, seed producers, and farmers. Ensuring fair remuneration for intellectual achievements of breeders, such as the creation of new high-yielding varieties, is a key condition for the development of breeding activities. That is why the purpose of this study was to assess the conditions for the functioning of the seed production system in Ukraine, identify problems that affect its development, and substantiate the development vectors for an effective seed production system, considering new challenges and threats.

MATERIALS AND METHODS

The theoretical framework for the investigation of the seed breeding and production system in Ukraine included the scientific studies of Ukrainian and foreign scientists. The sources of information are the data from the Register of certificates for sowing and commodity qualities of seeds of major crops in Ukraine for 2020-2023 (Register of certificates for sowing and commodity qualities of seeds, 2021-2023) provided by the Ministry of Agrarian Policy and Food of Ukraine and the results of the activities of research institutes of the National Academy of Agrarian Sciences (GMOs – good or harmful, 2021). The source of information on the legalisation of GMO crop varieties in Ukraine is the Law of Ukraine "On State Regulation of Genetic Engineering Activities and State Control over the Placement of Genetically Modified Organisms and Products on the Market" (2023). The study also employed information materials from the Seed Association of Ukraine (Seed Association of Ukraine, 2023), the Ukrainian Agrarian Council (UAC, 2023), as well as the results of research by the Centre for Food Safety (Centre for Food Safety, 2015) and the United Nations Food and Agriculture Organisation (FAO, 2016).

The study of the national system of breeding and seed production was based on the use of the dialectical method of cognition of reality to establish the cause-and-effect relationships of the elements of the system under study. The application of this method made it possible to carry out a systematic analysis of the processes and phenomena that directly affect the seed production system, considering their interdependencies and interrelationships. The literature cited in this study was reviewed using such theoretical research methods as observation, abstraction, analysis, comparison, and generalisation. Using the comparison method, comparable and differing approaches, opinions, and practical recommendations for the development of the seed breeding system in Ukraine and other countries were identified.

A comparative analysis of the performance of the Ukrainian seed production system in 2020-2023 was used to identify cause-and-effect relationships in the Ukrainian seed breeding and production system, which involved in-depth investigation and generalisation of relevant facts and phenomena, establishment of trends in the development of this system and identification of current challenges and dangers. The objective historical method, as well as the methods of induction and generalisation, were used to establish regularities in individual facts and to generalise them, which helped to predict possible scenarios of events. The deductive method was used to identify challenges and threats to the functioning and development of the seed breeding system in Ukraine as a result of building a logical chain of reasoning based on general information and individual facts.

By applying formal-logical methods of cognition, primarily analysis, synthesis, analogy, and comparison, the conclusions of this study were formed. Based on the analysis of theoretical and empirical findings of the investigation of the seed production system in Ukraine in 2020-2023 and using the methods of analogy, comparison, and synthesis, the study summarised and systematised its key provisions, which formed the basis for the conclusions. Practical recommendations on the development vectors for an effective seed production system in Ukraine were proposed using the heuristic method of generating ideas for solving the problem.

RESULTS AND DISCUSSION

Increasing the productivity of crops in modern conditions is possible mainly due to genetic advantages resulting from breeding activities. S.V. Mishchenko (2021) substantiates the need for breeding development by the fact that a variety cannot exist forever, it degenerates due to mutations, loses adaptation to environmental conditions due to climate change, the spread of new pests, and the emergence of new strains of pathogens, and loses demand due to changes in production requirements for crops; this is caused by the fact that new discoveries are being made in biology generally and in genetics specifically.

The current challenges and threats to agricultural development in Ukraine, such as global climate change, land degradation and dehydration, pose new challenges to the seed breeding and production industry. According to S.P. Ivanyuta *et al.* (2020), climate change, together with other negative anthropogenic factors, can lead to the expansion of risky farming and desertification in the southern regions of Ukraine. At the same time, the environmental situation in Ukraine is deteriorating due to Russia's military aggression. Large-scale soil contamination, erosion, and dehydration are exacerbating and accelerating climate change and negatively affecting agricultural production. The explosion of the Kakhovka Hydroelectric Power Plant was a global environmental disaster.

Under the current circumstances, it is critical to take measures to adapt to the changes that adversely affect Ukrainian agriculture. Among the priorities is the development of a productive and dynamic national system of breeding and seed production to produce crop varieties adapted to new growing conditions and provide them to agricultural producers. A modern seed production system must be sustainable and efficient, providing access to plant breeding results and a reliable supply of quality seeds. The availability of seeds and planting material of crop varieties desired by agricultural producers, adapted to local conditions and meeting their preferences, tastes, and expectations, in the required quantity and at any time, regardless of weather, anthropogenic, or any other negative factors, ensures seed security and is a vital condition for the development of the agri-food sector of Ukraine's economy.

Achieving such a state is possible not only with an efficiently functioning national seed production system. Therewith, the seed production system should meet the national interests of Ukraine, ensure food and national security, which implies protection from real and potential threats and dangers. The principal challenges and threats to Ukraine's seed production system today include the growing dependence of agricultural producers on foreign-bred seeds, which is not in Ukraine's interest and poses a threat to seed, food, and national security. Furthermore, the dominance of foreign breeding in Ukrainian agriculture can lead to the degradation and destruction of the national seed production system.

During the 1920s, the Ukrainian seed production system showed a steady trend towards an increase in the production of foreign-bred seeds and a corresponding decrease in Ukrainian seeds. Among the main groups of crops, the largest decline was in the production of seeds of Ukrainian grain breeding. Thus, in 2020, the production of winter wheat seeds of Ukrainian breeding totalled 93.6 thsd t, while in 2023 – 37.9 thsd t, i.e., the production volumes decreased by 59.5%. In 2023, the decrease in production of Ukrainian-bred spring and winter barley, maize, and winter rye seeds reached 80.3%, 76.2%, 50.6%, and 60%, respectively, compared to 2020 (Fig. 1).

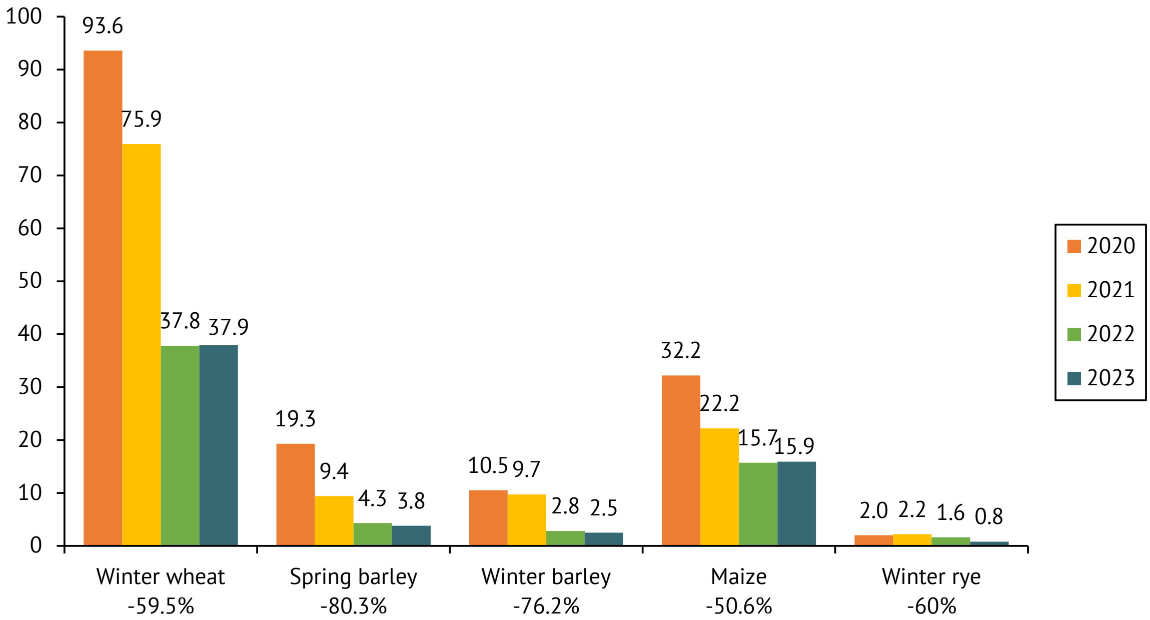

***Figure 1**. Seed production of Ukrainian grain breeding in 2020-2023, thsd t*

***Source**: developed by the authors of this study based on the Register of certificates for sowing and commodity qualities of seeds (2021-2023)*

In 2020-2023, not only did the production of seeds of Ukrainian grain breeding decrease, but so did the share of Ukrainian breeding in the production of conditioned seeds. In 2023, the share of seeds of Ukrainian winter wheat breeding decreased to 48.1%, compared to 66.2% in 2020, or by 18 points. A comparable trend was also observed for other grain crops. Thus, the share of spring barley seeds of Ukrainian breeding decreased from 57.8% in 2020 to 35.3% in 2023, or by 23 points, winter barley – from 49.3% to 20.2%, or by 29 points, maize – from 29% to 18.3%, or by 11 points, and winter rye – from 15.7% to 13.4%, or by 2 points (Fig. 2).

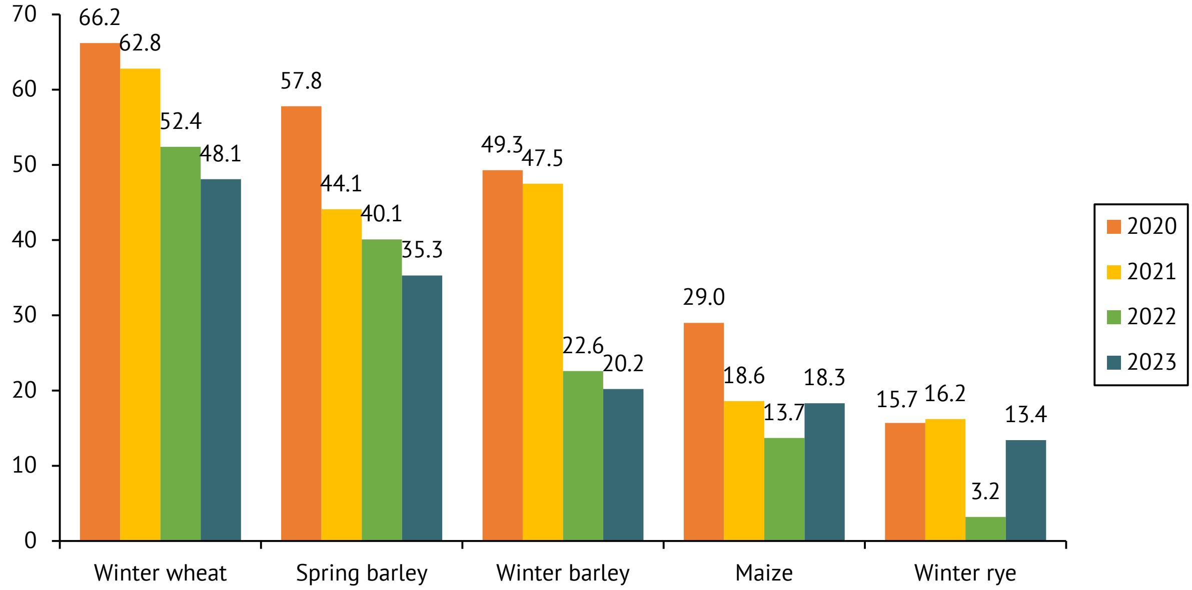

Figure 2. *Share of seeds of Ukrainian grain breeding in 2020-2023, %*
Source: *developed by the authors of this study based on the Register of certificates for sowing and commodity qualities of seeds (2021-2023)*

Apart from the steady upward trend in the share of foreign-bred seeds in the Ukrainian market of conditioned seeds, the growing monopoly of powerful multinationals is extremely dangerous for the national seed production system. Specifically, the share of Syngenta maize hybrids in the total production of foreign-bred maize seeds in 2023 was 31.6%, and Monsanto's share was 28.2%. Thus, these two companies together accounted for 59.8% of maize hybrids on the Ukrainian maize seed market. The vast majority of winter rye varieties in Ukraine are also foreign-bred. Moreover, the share of winter rye seeds of KWS Lokhov GmbH in 2023 was 94.7% of foreign-bred winter rye seeds, or 82% of all conditioned seeds of this crop in Ukraine.

A comparable trend is also observed in the market of conditioned oilseeds of Ukrainian breeding. In 2023, 1.4 thsd t of soybean seeds of Ukrainian breeding were produced, compared to 2.3 thsd t in 2020. Accordingly, the decline was 39.1%. The seed production of Ukrainian winter rapeseed also decreased from 1 thsd t in 2020 to 0.5 thsd t in 2023, or 47.4%, and for Ukrainian sunflower seeds – from 3.4 thsd t in 2020 to 2.7 thsd t in 2023, or 20.6% (Fig. 3).

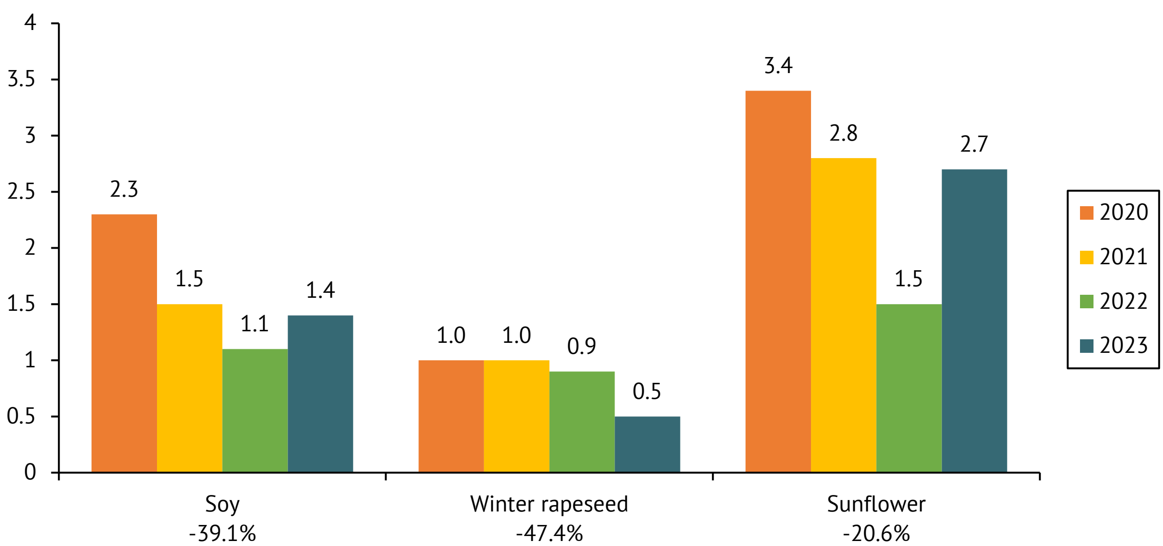

Figure 3: *Production of seeds of Ukrainian oilseed breeding in 2020-2023, thsd t*
Source: *developed by the authors of this study based on the Register of certificates for sowing and commodity qualities of seeds (2021-2023)*

In 2023, compared to 2020, the share of Ukrainian-bred seeds of soybean and winter rapeseed also decreased from 10.7% to 6.4% and from 10.2% to 8.9%, respectively. At the same time, the share of sunflower seeds of Ukrainian breeding slightly increased in 2023 and amounted to 9.1% compared to 7.4% in 2020 (Fig. 4).

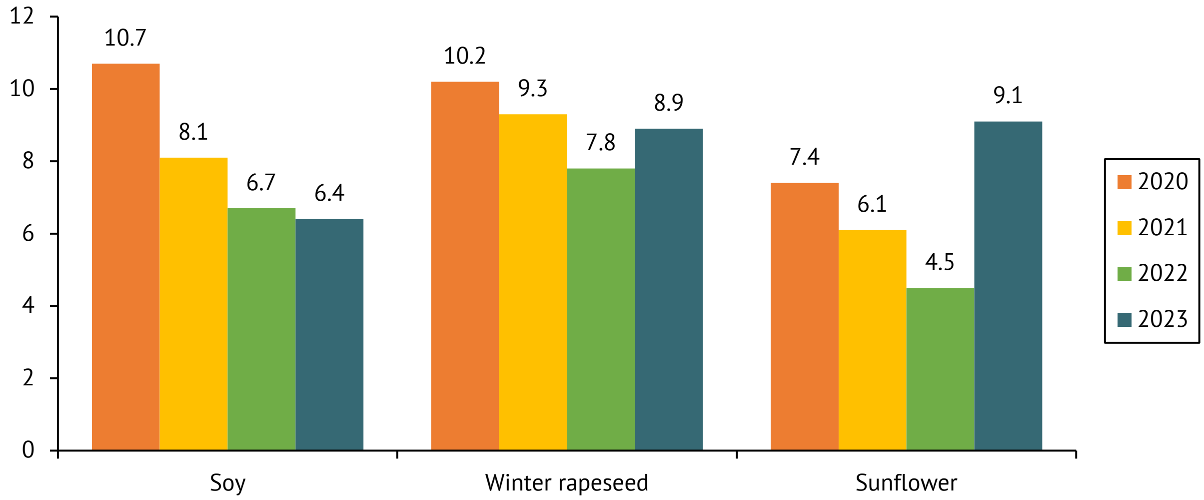

***Figure 4**. The share of seeds of Ukrainian oilseed breeding in 2020-2023, %*
***Source**: developed by the authors of this study based on the Register of certificates for sowing and commodity qualities of seeds (2021-2023)*

According to O.M. Mohylna *et al.* (2022), the main problems that hinder the development of seed production in Ukraine include lack of state control over the implementation and compliance with regulations; high competitive pressure from foreign firms and corporations, seed companies, which leads to further "shadowing" of the seed market; bankruptcy of state research farms subordinated to scientific institutions of the National Academy of Agrarian Sciences and licensing farms of various legal forms, which makes it impossible to produce certified seeds in full volumes of Ukrainian selection; violation of cultivation technologies, variety renewal, and variety replacement, which worsens the condition and sowing quality of seeds.

At the same time, the war with Russia exacerbates the existing problems of seed production in Ukraine. Disruptions in the logistics supply chain of conditioned foreign seeds necessitate fundamental changes in the current system of seed breeding and production in Ukraine. Replacing foreign-bred seeds with Ukrainian-bred seeds, which are more adapted to local growing conditions and meet modern requirements in terms of quality and yield, will help provide agricultural producers with quality seeds in the required quantity and within the required timeframe for sowing. However, such a strategy requires an increase in funding for national breeding centres, relevant research institutions and breeders, which are currently inadequately funded.

A major area for the development of an effective seed production system in Ukraine should be the support and preservation of local zoned crop varieties. L. Batten *et al.* (2021) note that the value of traditional varieties, which have historically evolved through the influence of the environment, including climatic conditions, pests, and diseases, making them well-adapted to the local environment, is conditioned by their ability to recover from environmental stresses. Furthermore, they are carriers of powerful genetic information that can be used for further seed breeding. To ensure the sustainability of Ukrainian agriculture, it is necessary to develop an effective, dynamic, and resilient national breeding and seed production system based on the preservation of local varieties and their use in breeding activities.

Allowing the cultivation of genetically modified plants could be extremely dangerous for Ukraine, its seed, food, economic, and national security. On 23 August 2023, the Verkhovna Rada of Ukraine adopted the Law of Ukraine "On State Regulation of Genetic Engineering Activities and State Control over Placing Genetically Modified Organisms and Products on the Market" (2023), which will enter into force on 16 September 2026. Considering the prominent level of import dependence of the Ukrainian seed market in Ukraine, the legalisation of genetically modified crop varieties poses a threat to the national system of plant breeding and seed production.

L.H. Biliavska *et al.* (2020) reported that the system of the National Academy of Agrarian Sciences of Ukraine includes 12 scientific institutions, including the Breeding and Genetic Institute – National Centre for Seed Science and Variety Studies, the Institute of Bioenergy Crops and Sugar Beet of NAAS, the V.Ya. Yuriev Institute of Plant Production of NAAS, the National Research Centre "V.E. Tairov Institute of Viticulture and Winemaking", which have biotechnology laboratories, relevant equipment and specialists, and can organise and support the creation, evaluation, and use of GMOs. However, following the current legislation and certain financial problems, research on GMOs is not carried out in the scientific institutions of the National Academy of Agrarian Sciences.

If the cultivation of genetically modified plants is legalised in Ukraine, it will open the market for genetically modified seeds to large corporations. The use of GMO plants will have a considerable negative impact on Ukraine's plant breeding and seed production system. B. Balasynovych and Yu. Yaroshevska (2010) warn that the massive use of GMOs reduces the varietal diversity of crops derived from a limited set of parental varieties, resulting in a narrowing of the genetic base of seed production. According to their estimates, the production and market of seeds in Ukraine may be monopolised by several multinational companies, including Monsanto, which owns 94% of the gene pool of all GM plants grown in the world and, together with several other multinational companies, controls 80% of the pesticide market, including 90% of the production and sale of the Roundup herbicide. There is a real threat that the gene pool of crops that determine the country's food potential may be concentrated in the hands of a few companies. R. Reich (2018) points out that Monsanto is using its political power in Washington to fight other countries' efforts to ban genetically modified seeds.

According to S. Grigorenko (2023), the approved circulation of GMOs in Ukraine will suspend investment in the seed business, leading to job losses, and will have an adverse impact on the organic market. Experts believe that the cessation of seed exports to the EU alone will result in an estimated loss of USD 100 million annually. The spread of GMO crop varieties causes genetic modifications in the food chain. Pollen or seeds from genetically modified crops contaminate conventional crops, often causing seed or product recalls and other problems for farmers and consumers. The regulatory mechanisms needed to prevent contamination are either absent or severely inadequate, putting export markets, farmers' livelihoods, and consumer confidence at risk (Center for Food Safety, 2015).

The spread of GMOs poses a threat to agrobiodiversity in Ukraine, including genetic diversity, and may cause genetic erosion. B. Balasynovych and Yu. Yaroshevska (2010) warn of a negative impact on biodiversity caused by the damage of non-target insects and soil microflora by toxic transgenic proteins with increased doses of pesticides and disruption of trophic chains. At the same time, GMO contamination due to cross-pollination of crops will cause problems when exporting products to the EU and China (Seed Association of Ukraine, 2023).

Therewith, Ukraine already has a problem of illegal cultivation of genetically modified plants that needs to be addressed. The All-Ukrainian Agrarian Council notes that the shadow segment of GMOs in the agricultural sector of Ukraine in terms of individual crops is significant, with the largest cultivation of genetically modified soybeans (UAC, 2023). According to market participants, as of 2021, approximately 50-65% of soybeans grown by Ukrainian producers are genetically modified, rapeseed crops account for up to 12%, and maize – approximately 1% (GMOs – good or harmful, 2021). Breeding activities require a significant amount of long-term investment in research and development by institutions and enterprises, as seed production is a more costly type of economic activity compared to crop production. According to the calculations of N.P. Louwaars and G. Manicad (2022), conditioned seeds should be 1.5-2 times more expensive than food grains of the same crop to break even. Furthermore, significant investments in research and breeding should be considered.

In Ukraine, breeding activities currently require substantial government support, including investment, as the level of use of foreign varieties in certain crops has reached a critically high level. At the same time, the rights and interests of breeders must be protected. Empirical research by C.R. Nhemachena *et al.* (2019) confirms that strengthening intellectual property rights for plant varieties creates incentives for plant breeding companies to invest more resources in plant breeding. M. Campi (2017) believes that strengthening plant intellectual property rights will lead to an increase in the production of improved crop varieties and technologies, which will positively contribute to agricultural productivity and economic growth. Ensuring intellectual property rights and providing fair remuneration to breeders who create new varieties and hybrids of crops will help to increase the productivity of intellectual labour and stimulate the development of breeding activities in Ukraine.

For the seed production system to function effectively, it is also important to ensure that innovative products are introduced into production and distributed. An advisory service could become a kind of chain between breeders/breeding centres and agricultural producers. However, agricultural advisory services in Ukraine have not yet been properly developed. FAO research (Huseynov, 2021) found that in Ukraine, large agricultural holdings and medium-sized agricultural enterprises with an area of more than 500 ha receive consulting services almost entirely from international and foreign companies; 33,164 family farms with an area of 20 ha to 500 ha have average access to advisory services, 90% of which are provided by raw material suppliers whose impartiality is questionable, and only 10% by professional independent advisers. Moreover, 4 million small farmers (2-20 ha) in Ukraine are poorly serviced by advisory services due to the lack of proper incentives from the state and information about the availability of such services.

The breeding and seed production system should be able to change in response to new challenges and threats, and the preservation and maintenance of

Ukrainian zoned varieties adapted to the local environment will contribute to the conservation of agrobiological and genetic diversity and increase the sustainability of agricultural production. Breeders' activities should be aimed at increasing the resilience of the seed production system, i.e., they should consider possible changes in crop growing conditions and consumer preferences in the future.

CONCLUSIONS

In Ukraine, in 2020-2023, there is a steady downward trend in the volume of production of seeds of Ukrainian breeding of major crops and the spread of foreign varieties. Specifically, the production of Ukrainian-bred winter wheat seeds in 2023 decreased by 59.5% compared to 2020, spring and winter barley – by 80.3% and 76.2%, respectively, maize – by 50.6%, and winter rye – by 60%. The production of seeds of Ukrainian oilseeds also declined. In 2023, compared to 2020, the decline in production of Ukrainian-bred winter rapeseed was 47.4%, while soybean and sunflower seeds were 39.1% and 20.6%, respectively. In 2020-2023, the share of seeds of Ukrainian breeding of major grains and oilseeds also declined. In 2023, the share of seeds of Ukrainian breeding of winter wheat was 48.1% compared to 66.2% in 2020, spring barley – 35.3% vs. 57.8%, winter barley – 20.2% vs. 49.3%, maize – 18.3% vs. 29%, winter rye – 13.4% vs. 15.7%, soybeans – 6.4% vs. 10.7%, and winter rapeseed – 8.9% vs. 10.2%.

The legalisation of genetically modified crop varieties is a threat to Ukraine's seed, food, and national security. Access to the Ukrainian seed market by powerful transnational corporations, which are already monopolists in certain segments of GMO crop varieties in other countries, is likely to be disruptive to the national seed breeding system. Furthermore, the spread of GMO crops threatens the loss of biodiversity and is dangerous for the sustainable development of Ukraine. Supporting Ukrainian zoned varieties adapted to the local environment will help to preserve agrobiological and genetic diversity and increase the sustainability of agricultural production. Global climate change, land degradation, and drought are some of the biggest current challenges and threats that will have a long-term impact on Ukrainian agriculture. At the same time, the war with Russia is exacerbating environmental problems. In this regard, the national breeding and seed production system needs to be fundamentally changed, as it must be able to ensure the development of new crop varieties adapted to new conditions on a continuous basis.

Building an effective, sustainable, and dynamic national seed production system requires long-term investment in breeding activities to ensure a continuous process of innovation and seed quality improvement. The protection of the rights and interests of breeders is a crucial factor in effective breeding activities. Breeding activities should be aimed at ensuring the sustainability of the seed production system. Breeders will consider possible changes in crop growing conditions and consumer preferences in the future to increase agricultural productivity and development. In the future, research on the functioning and development of the national system of breeding and seed production should be systematic. This will allow building an effective model of the national breeding and seed production system with set goals and development parameters.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Akulenko, K.V. (2018). Forming of model of modernization of domestic agricultural enterprises on the basis of innovation providing. *Social Economics*, 56, 9-17.

[2] Andrade-Piedra, J.L., *et al.* (2020). *User guide to the toolbox for working with root, tuber and banana seed systems*. Peru: CGIAR Research Program on Roots, Tubers and Bananas. doi: 10.4160/9789290605577.

[3] Balasynovych, B., & Yaroshevska, Yu. (2010). *GMOs: Current challenges and experience of legal regulation*. Kyiv: Institute for Economic Research and Policy Consulting.

[4] Batten, L., Plana Casado, M.J., & van Zeben, J. (2021). Decoding seed quality: A comparative analysis of seed marketing law in the EU and the United States. *Agronomy*, 11(10), article number 2038. doi: 10.3390/agronomy11102038.

[5] Biliavska, L.H., Biliavskyi, Y.V., Shapoval, O.S., & Panchenko, S.S. (2020). Current state and prospects of soybean seed breeding in the Forest-Steppe of Ukraine. *Bulletin of Poltava State Agrarian Academy*, 4, 45-52. doi: 10.31210/visnyk2020.04.05.

[6] Campi, M. (2017). The effect of intellectual property rights on agricultural productivity. *Agricultural Economics*, 48(3), 327-339. doi: 10.1111/agec.12337.

[7] Center for food safety. (2015). *U.S. Contamination Episodes Concerning Genetically Engineered Crops*. Retrieved from https://www.centerforfoodsafety.org/fact-sheets/3984/us-contamination-episodes-concerning-genetically-engineered-crops.

[8] FAO. (2016). Retrieved from https://www.fao.org/3/i5548e/i5548e.pdf.

[9] GMOs – good or harmful: Complete ban or regulation? (2021). Retrieved from http://naas.gov.ua/slide/gmo-korisn-chi-shk-dliv-povna-zaborona-chi-zakonodavche-regulyuvannya/.

[10] Grigorenko, S. (2023). *The draft law on GMOs endangers agricultural exports to the EU*. Retrieved from https://www.epravda.com.ua/columns/2023/02/8/696813/.
[11] Huseynov, F. (2021). *Good advice: How to return advisory services to the chain of agricultural production*. Retrieved from https://agravery.com/uk/posts/show/vdala-porada-ak-povernuti-doradci-sluzbi-u-lancug-agrovirobnictva.
[12] Ivanyuta, S.P. (Ed.). (2020). *Climate change: Consequences and adaptation measures: Analytical Report*. Kyiv: National Institute for Strategic Studies.
[13] Law of Ukraine No. 3339-IX "On State Regulation of Genetic Engineering Activities and State Control over Placement on the Market of Genetically Modified Organisms and Products". (2023, August). Retrieved from https://zakon.rada.gov.ua/laws/show/3339-20#Text.
[14] Louwaars, N.P., & Manicad, G. (2022). Seed systems resilience – an overview. *Seeds*, 1(4), 340-356. doi: 10.3390/seeds1040028.
[15] Mishchenko, S.V. (2021). Directions of breeding and genetic innovations in hemp growing, principles of their formation and implementation in agro-industrial activity. *The Formation of a New Paradigm for the Development of the Agro-Industrial Sector in the 21st Century*, 30-57. doi: 10.36059/978-966-397-240-4-2.
[16] Mohylna, O.M., Rud, V.P., Terokhina, L.A., Ilyinova, Y.M., Stovbir, O.P., Leus, L.L., & Sidora, V.V. (2022). Modern problems of seed production of vegetable crops and ways of their solution. *Vegetable and Melon Growing*, 71, 76-85. doi: 10.32717/0131-0062-2022-71-76-85.
[17] Nhemachena, C.R., Kirsten, J.F., & Muchara, B. (2019). The effects of plant breeders' rights on wheat productivity and varietal improvement in south African agriculture. *Sustainability*, 11(12), article number 3378. doi: 10.3390/su11123378.
[18] Register of certificates for sowing and commodity qualities of seeds. (2021-2023). Retrieved from https://data.gov.ua/dataset/f4f0bd0a-74ac-4f25-80cf-5add41f76df9/resource/233a03f8-6a76-4eac-ad38-4be363502b11.
[19] Reich, R. (2018). *Save capitalism*. New York: Vintage.
[20] Seed Association of Ukraine. (2023). Retrieved from https://ukrseeds.org.ua/blog/reforma-gmo-ryzyky-ta-perspektyvy.
[21] UAC (Ukrainian Agri Council). (2023). Retrieved from https://uacouncil.org/uk/post/var-vzala-ucast-u-roboti-profilnogo-komitetu-vru-sodo-obigu-gmo.
[22] Westengen, O.T., Dalle, S.P., & Mulesa, T.H. (2023). Navigating toward resilient and inclusive seed systems. *Proceedings of the National Academy of Sciences*, 120(14), article number e2218777120. doi: 10.1073/pnas.2218777120.

Система насінництва України: тенденції, виклики та загрози

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Анотація. Формування ефективної системи насінництва в Україні зумовлене як її ключовою роллю у забезпеченні насіннєвої, продовольчої й національної безпеки країни, так і появою нових викликів і загроз, які впливають на функціонування системи та яким необхідно протидіяти, щоб усунути або пом'якшити їхній негативний вплив. Метою статті було дослідження сучасних тенденцій функціонування системи насінництва України та виявлення нових викликів і загроз національним інтересам. Методологічним базисом проведеного дослідження є діалектичний метод наукового пізнання, який було застосовано для встановлення взаємозв'язків між об'єктом дослідження, в якості якого виступає система насінництва України, й подіями та явищами, що відбуваються у природі та суспільстві та які мають істотний вплив на об'єкт дослідження. Також було застосовано методи аналізу й синтезу, системного узагальнення та порівняльного аналізу. У статті було проведено аналіз умов функціонування системи селекції та насінництва в Україні та встановлено сучасні тренди, які характеризують її внутрішній стан. Встановлено виклики та загрози національній системі насінництва, які створюють небезпеку насіннєвій, продовольчій і національній безпеці України. Проаналізовано деструктивні процеси в системі функціонування національної системи насінництва, які можуть призвести до її деградації та руйнації. Обґрунтовано заходи щодо подолання наслідків дії негативних чинників в системі селекції та насінництва України. В дослідженні були науково обґрунтовані основні критерії формування ефективної національної системи насінництва. Здійснено аргументоване обґрунтування необхідності довгострокових інвестицій у селекційну діяльність та визначено пріоритетні напрями державної підтримки системи насінництва в Україні. Висновки, пропозиції та практичні рекомендації мають прикладне значення і можуть бути використані при розробці відповідних програм та заходів, спрямованих на підтримку розвитку насінництва, зокрема селекційної діяльності в Україні, та забезпечення справедливої винагороди селекціонерам, які є авторами нових продуктивних сортів сільськогосподарських культур

Ключові слова: селекційна діяльність; насіння та садивний матеріал; сорт; насіннєва безпека; стійкість; продовольча безпека

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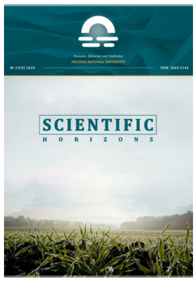

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Global trends in the development of a sustainable bioeconomy for rural growth in Ukraine

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Abstract. Growing global environmental problems are forcing humanity to think about transforming the basic principles of doing business, as the traditional economic order leads to an increase in the volume of pollutant and greenhouse gas emissions into the atmosphere, excessive depletion of the main types of fossil fuels, and considerable accumulation of industrial and household waste. In these circumstances, the alternative is to use low-carbon energy sources, which will minimise destructive environmental impacts. Therefore, the purpose of this study was to substantiate the theoretical and

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methodological foundations of bioeconomic activity and practical recommendations for the development of a sustainable bioeconomy in Ukraine. To fulfil this purpose, the study employed general scientific and special methods of theoretical and empirical research, specifically, at the theoretical level, the methods of theoretical generalisation, abstract-logical, hypothetical, historical, methods of ascent from the abstract to the concrete, etc. The empirical level includes comparative, descriptive, SWOT strategic analysis, graphs, and tables. Using the methods outlined in the historical retrospective study, the study monitored the volume of greenhouse gas and pollutant emissions into the atmosphere due to the considerable use of fossil fuels, which provokes an increase in global environmental problems in society. Under these conditions, sustainable economic activity is gaining popularity, allowing for the production of renewable energy from renewable resources, agricultural, forestry and fishery residues, as well as organic industrial and household waste. The study outlined foreign practices and Ukrainian initiatives to promote bioeconomic activity, considering the country's natural resource and intellectual potential, as well as financial national support for the bioindustry. Considering the findings of the study, the strengths and weaknesses of the sustainable bioeconomy were systematised using SWOT analysis, key threats to its formation in Ukraine were foreseen, and constructive opportunities for its development were identified. The practical value of this study lies in the scientific substantiation of proposals for promising strategic guidelines for the development of a sustainable bioeconomy with strengthening its capabilities and finding ways to minimise the destructive impact of key threats

Keywords: greenhouse gas emissions; fossil fuels; organic waste; bioeconomic activity

INTRODUCTION

The economic growth of modern society is associated with the need to rethink the principles of doing business, as the traditional economic order leads to a range of unresolved global environmental problems. Air pollution from exhaust gases from car engines poses a significant risk. According to statistics, 14.7 million tonnes of carbon monoxide are released into the atmosphere from exhaust gases from internal combustion engines (State Statistics Service of Ukraine, 2022). As a result of electricity generation at thermal power plants, millions of tonnes of hydrocarbons, nitrogen oxides, sulphur, phosphorus, iron, molybdenum, and other highly toxic substances are released into the environment. Thermal power plants emit carbon dioxide into the atmosphere, which causes a greenhouse effect and leads to an increase in the average temperature of the lower atmosphere. The accumulation of environmental problems is causing concern in society, forcing scientists to consolidate their efforts to find alternative ways to achieve sustainable development goals.

The issue of bioeconomy development became widespread at the end of the 20th century, due to the need to find effective tools for achieving sustainable goals. Thus, D. D'amato *et al*. (2021) consider the concepts of green economy, circular economy, and bioeconomy, which are popular in discussions of sustainable development at the macro level in politics, research, and business, to be promising ways to overcome global challenges. Each of these is based on renewable biodiverse and beneficial processes that provide tangible and intangible benefits that meet the economic and social needs of society. N. Szarka *et al*. (2023) proposed a detailed description of the development of a regional bioeconomic strategy, namely effective recommendations for establishing a flexible biodynamic platform that engages stakeholders from politics, science, industry, and society for a common regional goal. Yu. Maksimiv *et al*. (2021) and T. Shevchenko *et al*. (2022) consider an analogous approach, confirming that in practice, to avoid conflicts of interest, it is worth engaging citizens and stakeholders into the development of bioeconomic strategies, factoring in relevant global sustainable goals.

T. Gorokhova *et al*. (2020) consider the development of the bioeconomy in Ukraine as an element of the state strategy, proposing an algorithm for transforming Ukraine's economic systems into bioeconomic systems. H. Geletukha (2018), V. Yakubiv *et al*. (2020) considered the bioeconomic approach to bioenergy development, arguing that its implementation is possible only if both its founders, the state, and end users of biofuels are interested in the rational use of biomass resources. Therewith, N. Pryshliak *et al*. (2022) argue that the bioenergy potential of the agro-industrial sector of the economy requires research on its integration into the country's energy sector, and therefore the researchers have developed an indicative cluster model for organising the activities of biofuel enterprises and a coordinated development strategy, considering the energy, environmental, and socio-economic parameters of sustainable development of territories. J. Han Yeon and J. Seung-hwan (2023) confirm the fact that the implementation of a sustainable bioeconomy in practical reality requires considerable intellectual investment, proving the constructive impact of research and development, investment in human resources as a key development factor on the efficiency of bio-based businesses. The review of scientific opinions indicates the relevance of research on the bioeconomic aspect of farming in the context of increasing environmental challenges, which led to the investigation of this topic as the subject of this study.

The purpose of this study was to provide a theoretical substantiation for the feasibility of implementing bioeconomic principles of management in the context of accumulated global challenges and to develop practical provisions on the prospects for the development of a sustainable bioeconomy in Ukraine. In the context of this purpose, it is necessary to investigate the prerequisites for promoting economic activity on a sustainable basis; to outline foreign practices and Ukrainian initiatives to promote bioeconomic activity, considering natural resource and intellectual potential, as well as financial national support for the bioindustry; and, based on the findings of the study, to systematise the strengths and weaknesses of the sustainable bioeconomy, and to foresee key threats and constructive opportunities for development. The hypothesis of the study is that identifying the strengths and weaknesses of the sustainable bioeconomy will make it possible to provide preventive measures to minimise the destructive impact of threats in manifesting constructive opportunities for its development in Ukraine.

MATERIALS AND METHODS

The algorithm of the study is presented in Figure 1.

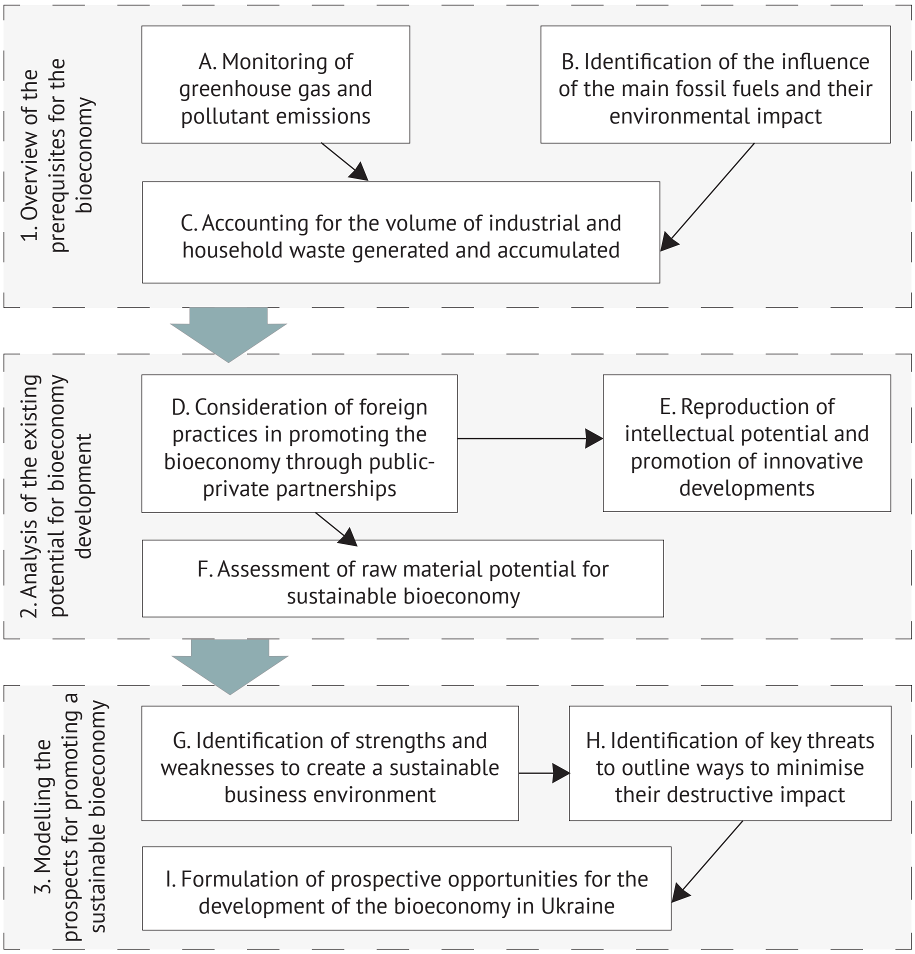

Figure 1. *Algorithm for researching trends in the development of a sustainable bioeconomy in Ukraine*
Source*: compiled by the authors of this study*

This study was based on a systematic approach, which enabled a comprehensive consideration of economic processes and phenomena for the development of a sustainable bioeconomy; a dialectical approach covered the investigation of the subject matter with a substantiation for the need to establish the impact of global environmental problems on its development; a synergistic approach involved considering the effective reproduction of natural resource, innovation, and intellectual potentials to enhance the effectiveness of promoting a sustainable bioeconomy in Ukraine, etc. During the staged study, general scientific and special methods of the theoretical and empirical level were used. At the theoretical level, the methods of theoretical generalisation were used to formulate conclusions on identifying promising opportunities for the development of a sustainable bioeconomy. The abstract-logical method helped to establish the impact of global processes on the state of the environment. The historical method reflected the dynamics of changes in economic phenomena in retrospect. Methods of ascending from the abstract to the concrete made it possible to move from global problems to their solutions at the local level. The hypothetical method played an important role in outlining the prospects for the development of the bioeconomy in Ukraine. The empirical level included a comparative method to find similarities and differences in the implementation of bioeconomic activities in selected developed countries, drafting graphs and tables to visualise the research material, a descriptive method involved their interpretation, and a strategic SWOT analysis method helped to investigate the current level of bioeconomy development to identify strengths and weaknesses, as well as threats and opportunities for its promotion in Ukraine.

The data visualisation based on the study results was presented with a different spatial and temporal interval depending on the availability of statistical information in the Global Networks (Our World in DATA, 2022). Some studies were conducted with a time limit of 2020 due to the lack of relevant information for 2021-2023 in official state statistical sources (State Statistics Service of Ukraine, 2022).

RESULTS AND DISCUSSION

The biggest driving force behind global climate change is greenhouse gas emissions, which pollute the air and cause an excessive greenhouse effect on the Earth. On a global scale, their volume in 2022 was 37.15 billion tonnes, compared to 22.75 billion tonnes in 1990. Greenhouse gas emissions from human activities and natural processes increased by 63% in 2022 compared to 1990. Their gradual growth over time is presented in Figure 2.

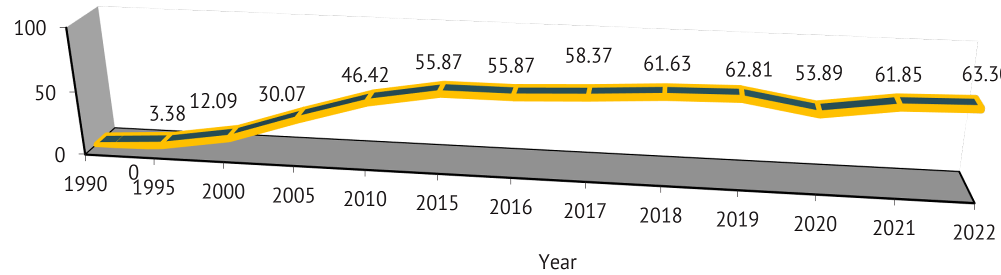

Figure 2. *Growth rate of greenhouse gas emissions in the world, %*
Source*: developed by the authors of this study based on data from Our World in DATA (2022)*

China is the world leader in greenhouse gas emissions (30.7%), as it emits almost a third of the total amount of all countries. The top three also include the United States, with a 13.6% share, and India, with a 7.6% share (Fig. 3).

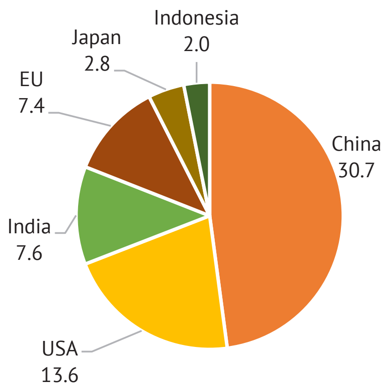

Figure 3. *Share of greenhouse gas emissions in the global ratio for 2022, %*
Source*: developed by the authors of this study based on data from Our World in DATA (2022)*

Japan and Indonesia accounted for 2.8% and 2.0%, respectively. In recent years, the EU countries have seen a decrease in greenhouse gas emissions, but their overall percentage is still high at 7.4%. As for Ukraine, the volume of greenhouse gases has decreased threefold over the past 30 years, but their share in the global ratio is still quite significant – 0.4%. Therewith, according to the Ministry of Economic Development and Trade of Ukraine (2017), the main sources of pollution are concentrated primarily in the energy sector, industrial activities, and agriculture and forestry. Starting from 2021, air emissions are regulated by the Law of Ukraine “On the Principles of Monitoring, Reporting, and Verification of Greenhouse Gas Emissions” (2019), which prescribes registration and subsequent annual monitoring of facilities that emit greenhouse gases to strengthen control over their volumes. At the same time, Ukraine pays a tax for entities that emit more than 500 tonnes of carbon dioxide per year, estimated at UAH 30 per tonne in 2022 compared to UAH 0.41 per tonne in 2018, which indicates a significant increase in the environmental tax.

The global increase in greenhouse gas emissions is primarily caused by the intensive use of fossil fuels. The increase in their production for energy generation occurred during the Industrial Revolution, which was characterised by in-depth research into the composition of oil, coal, and gas, and their introduction into mass production. It is known that until the beginning of the 20th century, a significant part of industrial products was produced on a biological basis using renewable raw materials. In the following decades, chemical technologies and oil field development contributed to its replacement by products based on petrochemical processing, which led to the development of new industries and provoked an increase in environmental problems. Over the past half century, fossil fuel consumption has increased approximately eightfold since 1950 and doubled since 1980. Over the past 30 years, there has been an increase in fossil fuel consumption by almost 40% (Fig. 4).

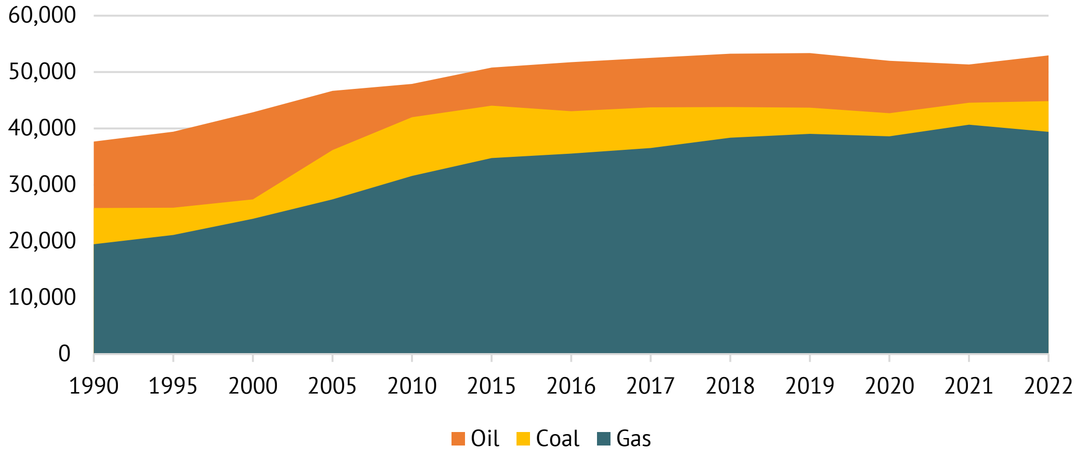

Figure 4. *Global fossil fuel consumption by major types, TWh*
Source*: developed by the authors of this study based on data from Our World in DATA (2022)*

The visualisation of fossil fuels broken down by coal, oil, and gas shows that coal production is currently partially declining in some parts of the world, but there is a significant increase in the use of oil and gas, which leads to adverse environmental impacts. Their excessive consumption leads to a shortage of raw materials (Fig. 5).

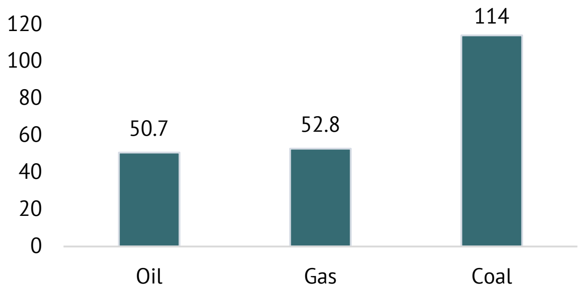

Figure 5. *World reserves of major fossil fuels, year*
Source*: developed by the authors of this study based on data from Our World in DATA (2022)*

According to published statistics, oil reserves for global consumption will last almost 60 years. Natural gas reserves are also limited. Humanity can live only 53 years with the existing gas reserves. The situation with coal reserves is much better, but their exhaustibility is undeniable, as the global average is 114 years. However, despite the considerable reserves of coal, which are much larger than those of gas and oil, its extraction and use in economic activities causes substantial environmental damage. Coal-fired power plants emit high levels of CO_2, and technologies to reduce emissions are too expensive to be used. Furthermore, coal mining has a substantial impact on the landscape and spatial infrastructure.

The exhaustion of global coal, oil, and gas reserves is driving up their prices, forcing developed countries to actively seek alternative solutions. In this environment, there is an increased focus on transforming the basic principles of business operations, with an emphasis on replacing fossil fuels with low-carbon energy sources, as the abandonment of fossil fuels will help minimise destructive global environmental impacts. Environmental problems can be overcome through the use of accumulated organic industrial and household waste in economic activities as an additional source of energy (Fig. 6).

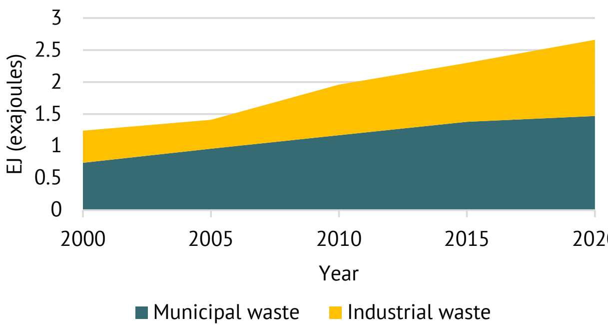

Figure 6. *Global accumulation of organic industrial and municipal waste*
Source*: developed by the authors of this study based on data from the World Bioenergy Association (2023)*

According to the World Bioenergy Association (2023), the energy supply from organic waste is 2.65 EJ, with municipal organic waste accounting for 55% of the total as of 2020, i.e., the majority, while industrial waste accounts for 45% of the total organic waste. Within 20 years, their volume doubled (by 98% and 138%, respectively). At the same time, the perception of household and business residues as raw materials for further consumption in production allows for additional savings, minimising the consumption of fossil fuels and reducing the destructive impact on the environment.

The understanding of the feasibility of promoting organic waste conversion initiatives and bioeconomic activities has led to the creation of international focal points for the exchange of knowledge and practices. Thus, the key programme to support the European bioeconomy is Horizon 2020 (H2020) and, specifically, its aspect related to overcoming global challenges "Food security, sustainable agriculture and forestry, marine and inland water research, and bioeconomy" with a budget of EUR 3.8 billion for 2014-2020. At the initiative of the European programme, a major joint technology initiative, the BBI JTI, referred to in EU regulation as the BBI Initiative (public-private partnership) worth EUR 3.7 billion between the EU and the Biotechnology Industry Consortium (BIC) was launched in 2014, with mobilised contributions in 2020 reaching almost EUR 1 billion during 2014-2015, leveraging an expected EUR 2.7 billion in private funding. Established in 2014, the BBI JU joint venture aims to support the development of renewable resource-based industries by providing grants for research and innovation projects until 2024. Alongside grants and other initiatives (e.g., InnovFin) under H2020, programmes such as the European Fund for Strategic Investments (EFSI) and the European Structural and Investment Funds (ESIF) are helping to promote the bioeconomy. European programmes are complemented by national funding and various instruments offered by regional and/or local development agencies (e.g., Tekes in Finland, Invitalia in Italy, Netherlands Enterprise Agency in the Netherlands, Innovate in the UK, etc.).

For a long time, the bioeconomic model of sustainable development of society was only abstract, without understanding of mass implementation in practice. The implementation of bioeconomic theory in the business environment took place only in the mid-20th century. Today, the bioeconomy is actively developing in the vast majority of developed countries. For instance, a company from Lower Saxony (Germany) uses milk that is not suitable for food consumption, colostrum from calving cows, or milk filtrate left over from cheese production to make protein and casein, and then forms it into fibres (the whey is dried, mixed with liquid and pressed through a fine sieve), which produces an antibacterial biopolymer that is easy to paint and has the advantage of saving water. Bioplastics are mainly used for vehicle interiors, including body parts and car seats. Car rubber tyres are made from dandelion and rubber tree. The advantage is natural rubber, which stays flexible even at low temperatures, and the disadvantage is the high price of natural rubber. The German company Biowert produces bioplastics and natural fertilisers from perennial grass plants. In the United States, a team of researchers from Yale University (2021) has developed and successfully introduced into production a sawdust-based bioplastic that can fully decompose within three months. The Netherlands is processing sugar beet waste into personal care products, detergents, paints, fibres, and biogas.

As the practices of foreign countries show, the key to the development of a sustainable bioeconomy is the availability of intellectual potential and the ability to implement scientific developments in practice. According to the World Intellectual Property Organisation (2022), Ukraine ranked 57th out of 132 countries in the Global Innovation Index, which has been calculated annually since 2007, in 2022, down 8 positions from 2021. This fact is associated with a weakening of human resources, a decline in the quality of education and science, and a deactivation of research and development (Fig. 7).

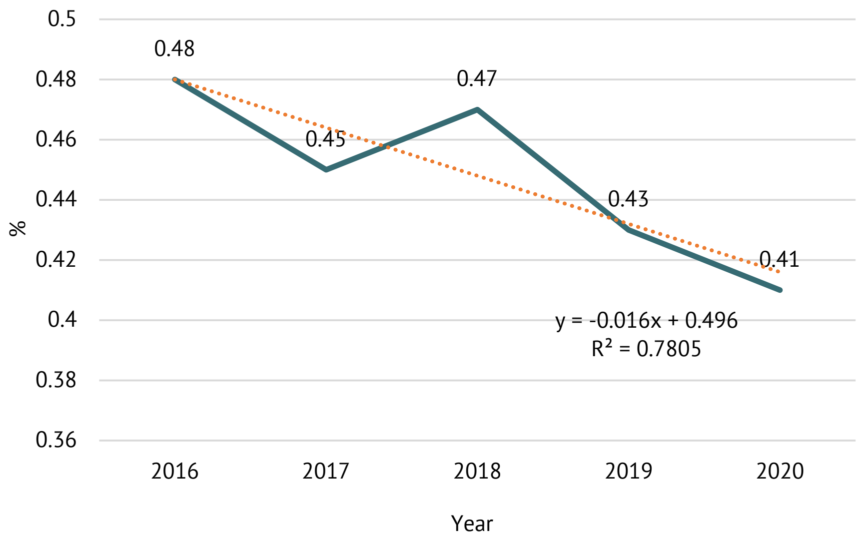

Figure 7. *Share of R&D expenditure in Ukraine's GDP*
Source*: calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2022)*

The educational and scientific component plays a leading role in shaping the bioeconomic environment. Thus, according to the State Statistics Service of Ukraine (2022), in 2020, there were 619 higher education institutions in Ukraine with 1.4 million students, including 22 institutions that train specialists in biotechnology and bioengineering. In 2020, as a result of the activities of scientific organisations, the Ukrainian National Office of Intellectual Property and Innovation (UKIPI) granted 29 patents for inventions to national applicants and 190 to foreign applicants among applications for the issuance of industrial property rights in technical areas, including bio- and ecotechnology, and registered 221 utility models, which is evidence of the growth of scientific personnel capable of developing innovative ideas in Ukraine.

The main industries in Ukraine where modern biotechnological production methods are actively used include agriculture, food, woodworking, textile, chemical industries, and the energy sector. The innovative business environment is represented by technologies for the production of tableware (plates, cups, cutlery) consisting of 80% corn starch and additional non-chemical ingredients. The project of Valentyn Frechko, who proposed to make paper from fallen leaves and initiated testing of his technologies at the Zhytomyr Cardboard Factory, is well-known internationally. A Ukrainian startup (Tolstykh, 2021) by the team of Daryna and Ilya Kichuk and Kostiantyn Shcherbyna signed a contract to produce Effa toothbrushes made of paper and corn starch that decompose in 2 months. The experimental experience of Yuriy Tostanovsky and Dmytro Bidyuk, who localised the Rekava business in Lviv to produce disposable tableware and flower pots from coffee grounds, is gaining popularity in Ukraine (Economic support of Eastern Ukraine, 2022). Tana company is known for its attempts to produce biodegradable tableware made from wheat, corn, and potatoes (Hnyp, 2021).

An example of sustainable management is the agro-industrial holding Myronivsky Khliboprodukt (MKhP), which produces biogas for internal use from plant biomass, including sunflower husks, as well as animal by-products and wastewater; it also produces fuel briquettes from grain waste, which reduces the load on the local landfill. The Poultry Complex branch of Vinnytsia Poultry Farm operates on a full closed cycle basis, with the by-products from poultry processing being sent to the animal by-products processing shop, where they are used to make feed ingredients for the farm's own animals. The holding's enterprises regularly conduct laboratory tests, which also helps to control the quality of production (MKhP, 2022). Therewith, due to the adoption of the Law "On Restricting the Circulation of Plastic Bags in Ukraine" (Law of Ukraine No. 1489-IX, 2021), the production of corn and potato starch bags has intensified, specifically, Novis company (Dnipro), Biosphere Corporation (Dnipro), GoGreen line of Freken Bok TM, Chystopes TM (Kyiv). An example of waste-free production on a biological basis is JSC Kokhavynska Paper Mill, which makes products from wastepaper exported to Ukraine from Moldova, Slovakia, Romania, Poland, etc.

This practice shows that the country's geographical location, favourable natural and climatic conditions for agriculture, the availability of fertile agricultural land and a considerable amount of forest and water bioresources contribute to the prospective development of bioeconomic activities in Ukraine. Over 40% of the territory is covered by high-quality soils, which makes it possible to develop agriculture and grow various crops. According to the State Statistics Service of Ukraine (2022), as of 1 January 2021, the total area of arable land in the country was 31.6 million hectares. The largest areas of arable land are in the Polissia, Forest-Steppe, and Steppe regions. The largest regions in terms of arable land are Chernihiv, Poltava, Kherson, Kharkiv, and Dnipro. Notably, between 2016 and 2020, the amount of arable land in Ukraine halved because of the ban on its sale and other transactions with it. According to the Ministry of Economy (2020), in 2020, only 0.1% of arable land was sold out of its total area. Ukraine's forest resources cover more than 15% of the country's territory, which makes it possible to meet the demand for timber and other forest resources. Thus, Ukraine has every opportunity to use its own biological renewable resources, i.e., plant and animal raw materials that are easily renewed to transform innovative ideas into new products, as well as to use accumulated residues of agricultural production, processing industry and household organic waste as a secondary raw material resource in economic activities.

Industrial and household waste in Ukraine is controlled by the State Environmental Inspectorate. At the regional level, waste management is coordinated by the local state administration, city and village councils, and public environmental inspectors. Activities to prevent and reduce the amount of waste generated are regulated following the Law of Ukraine "On Waste Management" No. 2320-IX dated 20 June 2022 (2023). The official waste coding system according to the current legislation is effective from 9 July 2023 (National Waste List and Waste Classification Procedure). Before the current list was adopted, Ukraine had the State Classifier of Waste (DK 005-96), which was approved by the Order of the Ministry of Ecology and Natural Resources No. 1201 "On Approval of the State Classifier of Waste" (2013). The State Classifier contains a hierarchical structure with 21 sections, 83 groups and more than 600 subsections describing different types of waste, including waste from industry, construction, medicine, household, and other areas of activity, etc. The structure of the generated waste is presented in Figure 8.

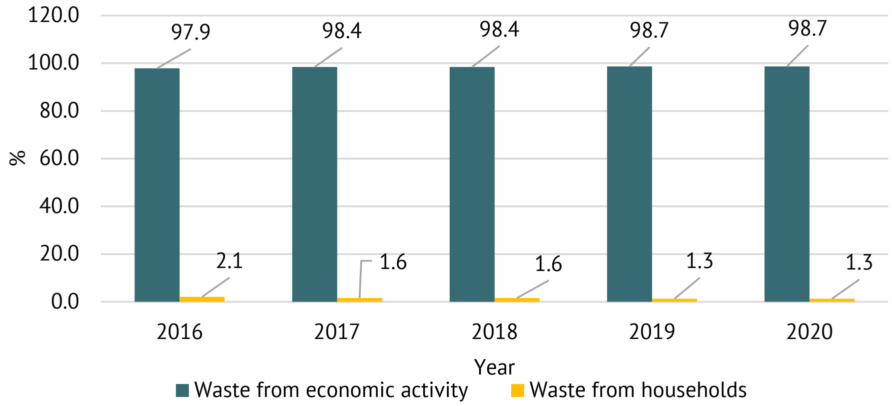

Figure 8. *Structuring of household waste and economic activity, %*
Source*: calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2022)*

The total amount of waste generated in 2020 increased by 56% compared to 2016. The focus is on waste from economic activity, as their share is 98.7% of the total waste generated. Considering that the volume of waste increased by 58% in 2016-2020, the need for efficient and conscious waste management is becoming increasingly urgent. Therewith, the share of waste used as a secondary material or energy resource increased by 18% in 2020 compared to 2016. At the same time, the volume of disposed waste is still a negative phenomenon, which increased by 64% in 2020 compared to 2016 (Fig. 9).

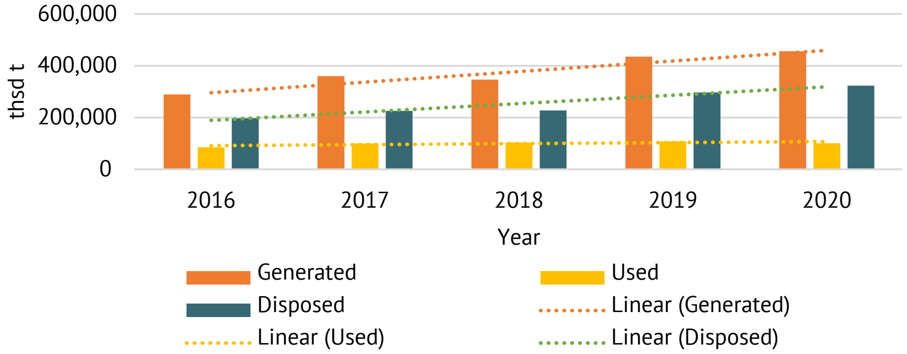

Figure 9. *Management of waste generated from economic activities*
Source*: calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2022)*

In the context of sustainable growth, there is a need to find ways to minimise the amount of waste removed in favour of further recycling. Specifically, the development of the bioeconomic sector involves considering the uniqueness of organic residues processing, which leads to their separation by material categories. Thus, agriculture, forestry, and fisheries (sector A according to NACE) account for a considerable share of waste generation, including 5,315.4 thousand tonnes in 2020 (Fig. 10).

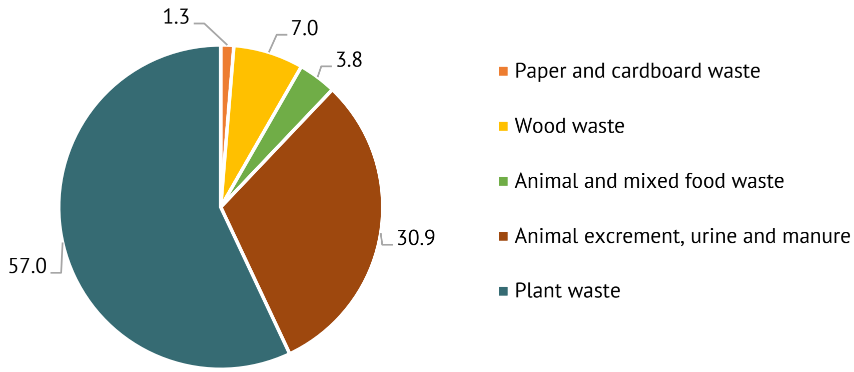

Figure 10. *Organic waste generated by material category (2020)*
Source*: calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2022)*

The organic waste presented is mainly of plant origin, which accounts for 57% of the total organic waste generation by material category. The specific features of organic waste management from economic sectors in 2020 are visualised in Figure 11.

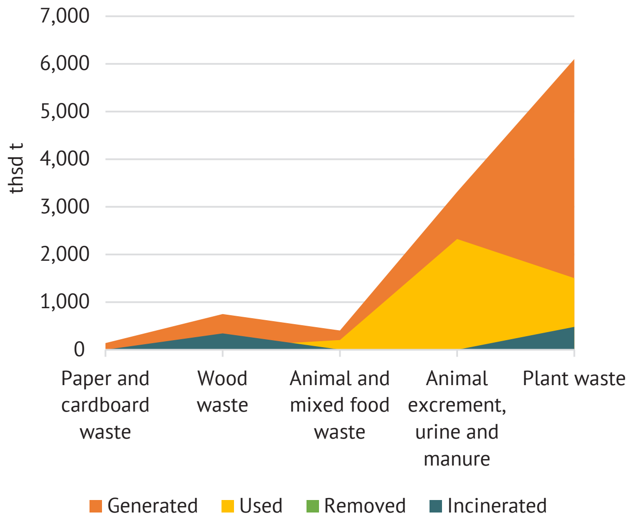

Figure 11. *Waste management by material category in 2020*

Source*: calculated by the authors of this study based on data from the State Statistics Service of Ukraine (2022)*

The study found that Ukraine has the potential to recycle vegetable waste, given the considerable share of its generation. Furthermore, food industry residues are actively exported to countries such as India, Italy, Turkey, Spain, etc. In 2020, the company exported waste worth USD 1,576,498 thsd, which is 3.2% of the total export structure, while commodity producers in other countries see such waste as raw materials for the production of goods, considering that residues such as sunflower oil cake, beet pulp, meat industry offal, and other waste have significant potential for further consumption in economic activities. This indicates the prospects of Ukraine in promoting sustainable bioeconomic activities, which will allow the development of the bioenergy sector to compensate for the shortage of natural gas in the production of heat and electricity, and the development of the bioindustrial sector will make it possible to consume waste as a raw material, while minimising production costs and reducing the area of land allocated for landfills, which is relevant in the context of expanded producer responsibility in the product life cycle. Considering the existing advantages in the development of a sustainable bioeconomy, it is important to outline promising areas for its development, which can be executed using the SWOT analysis method, as presented in Table 1.

Table 1. *Matrix of SWOT analysis of sustainable bioeconomy development*

STRENGTHS	WEAKNESSES
Favourable climatic conditions for agriculture	Lack of approved long-term goals and action plan for the development of a sustainable bioeconomy
Natural resource reserves provide high biomass potential	Weak effectiveness of state institutions and local governments in implementing regional waste management plans
High demand for alternative energy sources, including biofuels	Inferior quality of waste flow accounting and data analysis on the management of production residues
Globalised, fast-growing industry	Insufficient awareness of civil society of the separate collection system and the need to develop a culture of waste sorting
High intellectual potential, which allows involving educational institutions in the implementation of bioeconomic policy	The ineffective waste management system creates conditions for the expansion of landfills and the lack of monitoring of their environmental impact
Possible financing under government programmes	Weak ability of local governments to effectively cooperate and interact with scientific communities
Attracting external grant assistance under EU programmes (Norizon 2020, EU Life, EU4Business) and other available to Ukraine	Low level of innovation activity (Ukraine ranks 57th out of 143 countries according to the Global Innovation Index) due to weak opportunities for commercialisation of intellectual property
Specialisation in high-tech areas in education	Low level of awareness of opportunities to produce new products from organic waste and the benefits of treating or reusing it
Transition from globalism to national protectionism	Weak innovation ecosystems lead to the absence of a regional biomass market
OPPORTUNITIES	**THREATS**
Government support for innovative projects	Lack of a regional organisational and economic mechanism for industrial waste management
Positive institutional changes	Demographic crisis and low purchasing power of the population
Establishing cooperation (scientific, technological) with European bioeconomic platforms for academic transfer of ecobiotechnologies	Military escalation and high risks of political instability affecting the overall investment climate
Saving natural resources	Unattractive design of innovative bioproducts is possible

Table 1. Continued

OPPORTUNITIES	THREATS
Ability to quickly promote the development of sustainable business ecosystems	Imbalance in the economy – the country's transformation into a raw material appendage continues
Strengthening the competitiveness of the national economy (Ukraine ranks 85th out of 141 countries according to the Global Competitiveness Index)	Low consumer confidence in the quality of innovative bioproducts due to insufficient understanding of the principles of bioproduction and lack of awareness of sustainable consumption
Expediency of using agricultural land withdrawn from circulation	Low investment attractiveness of the biotechnology sector
Increasing the level of social responsibility through enhanced educational activities	Business distrust of government programmes is growing (due to the slow pace of reforms)
Streamlining the certification system for eco- and bioproducts	Outflow of qualified personnel abroad

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

The active use of own capabilities to transform innovative ideas by transforming renewable energy sources into food and industrial products requires the creation of a favourable investment climate to attract additional financial resources and introduce modern innovative technologies into production. As of 2020, the share of enterprises implementing innovations was 12-14% of the total number of operating enterprises, which is 3-4 times less than in the business communities of developed countries. Innovation processes in Ukraine are not popularised, as almost a third of the funds allocated for innovative developments are spent by producers on updating material and technical support, while less is spent on acquiring intellectual property rights. About half of the enterprises do not finance innovation activities at all, despite the existence of effective state support programmes that could be used for their own development (Table 2).

***Table 2.** Innovation support programmes in Ukraine*

Programme name	Subject	Areas
State Support Program "Affordable Loans 5-7-9%"	Entrepreneurship Development Fund	Development of entrepreneurship, including promotion of business entities, increase in production, exports, import substitution, high-tech production, energy efficiency, introduction of innovations, as well as promotion of creation of new jobs and enterprises, return of labour migrants to Ukraine
Programme "Ukraine: sustainable innovations in the bioenergy value chain"	The European Bank for Reconstruction and Development in cooperation with the Global Environment Facility (GEF)	Promotion of investment in innovative bioenergy technologies and practices related to the use of agricultural residues and waste by facilitating and developing sustainable bioenergy value chains
Pilot project to provide financial support to start-ups in Ukraine on a competitive basis	Innovation Development Fund	Financial support for start-ups in Ukraine, including in the field of information technology

***Source**: developed by the authors based on data from the Ministry of Economy of Ukraine (2023)*

Considering the realities of the national economy, it is necessary to consider the complementary nature of the interconnection of constraints to the development of a sustainable bioeconomy, as their chain reaction significantly hinders the effective establishment of circular production processes at the enterprise and the functioning of the entire bioeconomic sector. Overcoming the barriers to the development of bioeconomic activities requires consolidation of joint efforts of public authorities, economic entities, and the scientific community, as the ability to interact effectively will minimise the impact of destructive factors.

The production process of business entities may be disrupted by limited access to bioresources, namely, the low level of organisation of bioresource supply and problems with its procurement, which encourages producers to reorient and diversify their enterprises to achieve a closed cycle of their own production. This can be a challenging task for small producers, as it requires considerable capital investment. The resource dependence of suppliers and consumers of biomass can be reduced through the development of local competitive biomass markets and the launch of biomass auctioning in Ukraine.

The key barriers to the development of the circular bioeconomy at the national level are insufficient state support for business entities in the form of a taxation system and economic incentives for the development of the bioeconomic sector. The solution to this problem is to introduce additional economic methods of direct regulation, including additional targeted funding, targeted subsidies, setting state standards, regulatory requirements for quality and certification of products, which will create additional material incentives for the development of a sustainable bioeconomy. Indirect regulation methods include preferential taxation of bioproducts producers or differentiation of their taxes, provision of long-term and medium-term loan privileges, etc. All this will help create a favourable economic environment for the development of the bioeconomic sector.

The implementation of the bioeconomy goals is associated with the development of appropriate legislative and institutional frameworks that ensure sustainable growth and address a range of social, industrial, environmental, and demographic issues. The lack of regulatory framework for the bioeconomic system is a major obstacle that requires the transformation of existing environmental, civil, and administrative legislation in the field of waste management. Therewith, the system of extended liability of commodity producers and their capacity to reuse residues of economic activity is not sufficiently established, which substantially hinders the development of bioeconomic activity. The imperfect regulation of waste flow accounting and data analysis on the management of residues from economic activities underlies international disagreements in the formation of bioeconomic policy, which requires joint efforts and the search for ways to reach political consensus in this area.

CONCLUSIONS

Thus, the growing global environmental challenges necessitate the transformation of conventional business models with the reorientation of production to alternative energy sources that are low-carbon and low-cost. Therewith, considering the significant amount of organic industrial and household waste accumulated, the key to overcoming these problems is to operate on a biological basis, which minimises the destructive impact on the environment on the way towards sustainable growth. In Ukraine, the geographical location, favourable natural and climatic conditions for agriculture, the availability of fertile agricultural land, and a significant amount of forest and water bioresources contribute to the prospective development of a sustainable bioeconomy. The main industries in Ukraine where modern biotechnological production methods are actively used include agriculture, food, woodworking, textile, chemical industries, and the energy sector.

A detailed review of the current state of development of the sustainable bioeconomy in Ukraine is proposed to be carried out using the SWOT analysis matrix, which helped to identify promising opportunities for the development of the bioindustry, considering strengths and weaknesses, as well as key threats, to find ways to minimise their destructive impact. Therefore, it is necessary to intensify innovation activities, expand research and initiate the implementation of eco-projects through state support, attracting external grant assistance, and strengthening the role of state institutions and local governments in implementing national and regional plans for the development of a sustainable bioeconomy. At the same time, the introduction of waste-free technologies into practice is hampered by a lack of awareness of the possibilities of producing innovative bioproducts, as well as the benefits of processing or reuse, which requires increased promotion of the idea of closed-loop bioeconomy among business entities, as well as raising consumer awareness of the importance of implementing sustainable consumption principles and enhancing environmental awareness through intensified educational activities.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] D'amato, D., & Korhonen, J. (2021). Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework. *Ecological Economics*, 188, article number 107143. doi: 10.1016/j.ecolecon.2021.107143.

[2] Economic support of Eastern Ukraine. (2022). *Dishes made of coffee grounds and biodegradable candles with city aromas are made by entrepreneurs in Lviv*. Retrieved from https://era-ukraine.org.ua/posud-z-kavovoyi-hushchi-ta-biorozkladni-svichky-iz-aromatamy-mist-vyhotovlyayut-pidpryyemtsi-u-lvovi/.

[3] Geletukha, H.G. (2018). How to create a biofuel market in Ukraine? *Energy Balance in Ukraine*, 1(01), 7-22.

[4] Gorokhova, T., Mamatova, L., & Muterko, Kh. (2020). The development of the bioeconomy in Ukraine as an element of the transformational state strategy of sustainable development. *Management Theory and Research on the Development of Rural Business and Infrastructure*, 42(3), 279-288. doi: 10.15544/mts.2020.27.

[5] Han Yeon, J., & Seung-hwan, J. (2023). The relation between bio-industry performance and innovation capacity – focusing on the Korean bio-industry. *Sustainability*, 15(9), article number 7116. doi: 10.3390/su15097116.

[6] Hnyp, G. (2021). *"Tana" company plans to manufacture dishes from potatoes, wheat and corn*. Retrieved from https://agrotimes.ua/ovochi-sad/kompaniya-tana-planuye-vygotovlyaty-posud-z-kartopli-pshenyczi-ta-kukurudzy/

[7] Law of Ukraine No. 1489-IX "On Limiting the Circulation of Plastic Bags on the Territory of Ukraine". (2021, June). Retrieved from https://zakon.rada.gov.ua/laws/show/1489-20#Text.

[8] Law of Ukraine No. 2320-IX "About Waste Management". (2022, June). Retrieved from https://zakon.rada.gov.ua/laws/show/2320-20#Text.

[9] Law of Ukraine No. 377-IX "On the Principles of Monitoring, Reporting and Verification of Greenhouse Gas Emissions". (2019, December). Retrieved from https://zakon.rada.gov.ua/laws/show/377-20#Text.

[10] Maksimiv, Yu., Yakubov, V., Pylypiv, N., Hryhoruk, I., Pyatnychuk, I., & Popadynets, N. (2021). Strategic challenges for the sustainable management of the bioeconomy: Preventing conflict between the Central Banks. *Sustainable Economic Development,* 13(15), article number 8308. doi: 10.3390/su13158308.

[11] MHP. (2022). *Sustainability*. Retrieved from https://mhp.com.ua/uk/pro-kompaniiu/stalyy-rozvytok.

[12] Ministry of Economic Development and Trade of Ukraine. (2017). *Goals of sustainable development: Ukraine: National report*. Retrieved from https://www.kmu.gov.ua/storage/app/sites/1/natsionalna-dopovid-csr-Ukrainy.pdf.

[13] Ministry of Economy of Ukraine. (2023). *Programs to support innovative activities*. Retrieved from https://www.me.gov.ua/Documents/Detail?lang=uk-UA&id=becc6fc5-aa0a-4712-ae98-928855c59be5&title=ProgramiPidtrimkiInnovatsiinoiDiialnosti-.

[14] Ministry of Economy. (2020). *Sustainable development goals of Ukraine: Monitoring report*. Retrieved from https://me.gov.ua/Documents/List?lang=uk-UA&id=938d9df1-5e8d-48cc-a007-be5bc60123b8&tag=TSiliStalogoRozvitku.

[15] Our World in Data. (2022). *Energy consumption per person*. Retrieved from https://ourworldindata.org/energy

[16] Our World in Data. (2022). *Global consumption of fossil fuels*. Retrieved from https://ourworldindata.org/fossil-fuels.

[17] Our World in Data. (2022). *Review of data on CO_2 and greenhouse gas emissions*. Retrieved from https://ourworldindata.org/explorers/co2?stackMode=relative&facet=none&country=~OWID_WRL&Gas=All+GHGs+%28CO%E2%82%82eq%29&Accounting=Production-based&Fuel=Total&Count=Per+country.

[18] Pryshliak, N., Bondarenko, V., Sokoliuk, S., & Brovarets, O. (2022). The formation of a bioenergy cluster for the production of biofuels from agricultural crops and waste: The experience of Ukraine. *Polityka Energetyczna – Energy Policy Journal,* 25(4), 149-164. doi: 10.33223/epj/156210.

[19] Shevchenko, T., Ranjbari, M., Shams Esfandabadi, Z., Danko, Y., & Bliumska-Danko, K. (2022). Promising developments in bio-based products as alternatives to conventional plastics to enable circular economy in Ukraine. *Recycling,* 7(2), article number 20. doi: 10.3390/recycling7020020.

[20] State Statistics Service of Ukraine. (2022). *Environment of Ukraine 2021*. Retrieved from https://www.ukrstat.gov.ua/druk/publicat/kat_u/2022/zb/11/zb_dovkillia_2021.pdf.

[21] State Statistics Service of Ukraine. (2022). *Higher and professional pre-higher education in Ukraine in 2022*. Retrieved from https://www.ukrstat.gov.ua/.

[22] Szarka, N., García Laverde, L., Thrän, D., Kiyko, O., Ilkiv, M., Moravčíková, D., Cudlínová, E., Lapka, M., Hatvani, N., Koós, Á., Luks, A., & Jimenez, I.M. (2023). Stakeholder engagement in the co-design of regional bioeconomy strategies. *Sustainability,* 15(8), article number 6967. doi: 10.3390/su15086967.

[23] Tolstykh, M. (2021). *Ukrainian eco-brushes Effa have been put into production: When can they be purchased*. Retrieved from https://ecopolitic.com.ua/ua/news/ukrainski-eko-shhitki-effa-zapustili-u-virobnictvo-koli-mozhna-pridbati/.

[24] World Bioenergy Association. (2023). *Global bioenergy statistics*. Retrieved from https://www.worldbioenergy.org/uploads/231219%20GBS%20Report.pdf.

[25] World Intellectual Property Organization. (2022). *Global Innovation Index 2022*. Retrieved from https://www.wipo.int/edocs/pubdocs/en/wipo_pub_2000_2022/ua.pdf.

[26] Yakubiv, V., Panukhnyk, O., Shults, S., Maksymiv, Yu., Hryhoruk, I., Popadynets, N., Bilyk, R., Fedotova, Ya., & Bilyk, I. (2020). Application of economic and legal instruments at the stage of transition to bioeconomy. In *AHFE 2019: Advances in Artificial Intelligence, Software and Systems Engineering* (pp. 656-666). doi: 10.1007/978-3-030-20454-9_64.

[27] Yale School of the Environment. (2021). *Turning wood into plastic*. Retrieved from https://www.sciencedaily.com/releases/2021/03/210325190243.htm.

Глобальні тенденції розвитку сталої біоекономіки для сільського зростання в Україні

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Анотація. Нарощення глобальних екологічних проблем змушує людство замислитися над трансформацією базових засад ведення господарської діяльності, оскільки традиційний економічний порядок призводить до збільшення обсягу викидів забруднюючих речовин і парникових газів у атмосферне повітря, надмірного виснаження основних видів викопного палива, значного накопичення промислових та побутових відходів. В окреслених умовах альтернативою вбачається застосування джерел енергії з низьким вмістом вуглецю, що дасть можливість мінімізувати деструктивні впливи на довкілля. Тому метою дослідження було обґрунтування теоретико-методологічних засад ведення біоекономічної діяльності та практичних рекомендацій щодо розвитку сталої біоекономіки в Україні. Для реалізації поставленої мети застосовано загальнонаукові та спеціальні методи теоретико-емпіричного рівня дослідження, зокрема на теоретичному рівні використовуються методи теоретичного узагальнення, абстрактно-логічні, гіпотетичні, історичні, методи сходження від абстрактного до конкретного тощо. Емпіричний рівень охоплює порівняльний, описовий, метод стратегічного аналізу SWOT, складання графіків та таблиць. За допомогою окреслених методів у процесі дослідження історичної ретроспективи здійснено моніторинг обсягу викидів парникових газів та забруднюючих речовин у атмосферне повітря через значне використання викопних видів палива, що провокує нарощування глобальних екологічних проблем у суспільстві. У зазначених умовах набуває популяризації господарська діяльність на сталих засадах, яка дозволяє виробляти відновлювальну енергію з поновлювальних ресурсів, залишків сільського, лісового та рибного господарства, а також органічних промислових та побутових відходів. У дослідженні окреслено зарубіжний досвід та українські ініціативи просування біоекономічної діяльності з урахуванням природо-ресурсного та інтелектуального потенціалу країни, а також фінансової національної підтримки біоіндустрії. Беручи до уваги результати дослідження, за допомогою SWOT-аналізу, систематизовано сильні та слабкі сторони сталої біоекономіки, передбачено ключові загрози її формування в умовах України та визначено конструктивні можливості для її розвитку. Практична цінність дослідження полягає унауковому обґрунтуванні пропозицій щодо перспективних стратегічних орієнтирів розвитку сталої біоекономіки з посиленням її можливостей та пошуку шляхів мінімізації деструктивного впливу ключових загроз

Ключові слова: викиди парникових газів; викопні види палива; органічні відходи; біоекономічна діяльність

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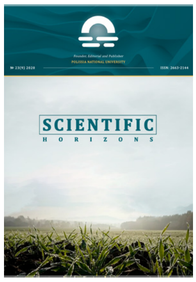

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War in Ukraine: Impact on global agri-food trade

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Abstract. The conditions and trends of the global agri-food market are elastic to crises and conflicts involving major market players, which threatens food security by blocking sustainable international trade opportunities due to the destruction of production capacity and value chains, as well as supply channels to consumer countries. The purpose of this study was to investigate the specific features and consequences of the impact of the Russian-Ukrainian armed conflict on world agricultural trade and food security at the national and global levels. The scientific conclusions are the result of

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the application of economic and statistical (time series, index, and factor analysis) and dialectical (induction and deduction, analysis, and synthesis) methods of scientific cognition. It was found that the universal features of wars include the ability to influence the global economy, create new geopolitical and economic uncertainty, rapidly increase prices for critical resources (energy), and ensure destabilisation of global value chains. As a result, the disruption of sustainable trade flows caused by military conflicts is an important source of changes in the global economy and the situation of individual countries and regions. It was proved that military operations on the territory of Ukraine led to restrictions in agriculture and forced adaptation of agribusiness to the factors of critical vulnerability. There are trends towards a reduction in production and the breakdown of conventional supply chains for agri-food products due to the destruction of the logistics infrastructure, which, together with a reduction in exports of agricultural products and fertilisers from Russia, has led to a rise in world food prices. As a result, the "price" of the Russian-Ukrainian war for the global economy is being formed, with growing hunger and poverty, as well as the environmental footprint of military operations. The practical significance of the findings of this study lies in the possibility of their application in strategic planning and substantiation of the areas of post-war reconstruction of the national economy in general and its agricultural sector specifically, as well as the restoration and strengthening of Ukraine's role in global food chains and combating hunger

Keywords: globalisation; international trade; world food market; food market conditions; food security

INTRODUCTION

Globalisation processes, which have been developing rapidly for several decades, despite their many benefits, pose existential risks to the global community. One of these risks is the growing interdependence of countries and the spread of negative trends and phenomena beyond national borders, becoming global. Military conflicts are becoming critical in the context of escalating international tensions in some regions of the world. Russia's armed aggression against Ukraine has become an indicator of the impact of local events on the stability of the global economic system. Uncertainty, as a primary consequence of the military conflict, provoked a rapid reaction of the global economic community in the context of globalisation, which was indicated by amplified fluctuations in the commodity and financial asset markets. The most vulnerable markets turned out to be energy and food.

The destruction of global food value chains, coupled with rising energy prices, has led to a crisis in the global agricultural market. The crisis was marked by a sharp rise in food prices and demand, temporary shortages of certain goods, intensified speculation, and the reformatting of agricultural value chains by actors and geographic location. The impact of the Russian-Ukrainian war on the global food trade is not only economic, but also socio-humanitarian in nature, with a critical consequence being the exacerbation of poverty, hunger, and global food security.

Despite the economic and social consequences caused by Russia's military aggression against Ukraine, the global economic system has been substantially affected by the reactions of both governments around the world aimed at mitigating real and potential risks to national economies and food consumers. Irrational demand due to inflationary expectations and consumer deficits, as well as an increased burden on the state budget due to increased spending to support Ukraine and refugees, have led to an increase in economic nationalism to support the population. Policy of some countries (restrictions on exports of agricultural products and fertilisers, limitation of food imports) has somewhat stabilised the situation at the national level, but has exacerbated the imbalance in global food trade, the price pressure from which is a critical factor for the food security of developing countries. Therewith, the crisis in international food trade is a potential source of new opportunities for some countries, such as expanding their niche in the global market. Their trade expansion policy allows redressing the imbalance of supply and demand, but it takes time and mutual agreement with other influential members of market relations. Considering the magnitude of the effects of global food trade volatility, the problem of identifying the factors of its development and developing mechanisms for mutual coordination of national food trade policies within a sustainable global food security system is becoming increasingly relevant.

The development of international trade is influenced by a multitude of interrelated hyper-, macro-, meso-, and micro-level factors, ranging from growing globalisation, cultural and linguistic differences, tariffs, trade barriers, and agreements to logistics solutions and competitive advantages. This list is subject to permanent additions and reductions because of changes in the global commodity markets and structural transformations in the global economy. Thus, J. Mehtiyev *et al*. (2021) develop the idea of causal links between the dynamics of international trade and indicators of the "financial health" of the global and national economies (inflation, devaluation, exchange rate, price volatility). Among the above factors affecting international trade, war occupies a special place. The principal idea of research on war and its impact on international trade from the perspective of the historical and evolutionary approach is the assertion that the widespread use of political power and military force leads to the creation of a specific form of the world trading system, which in a basic sense consists of two types of actors – industrial countries and exporters of goods (Krpec & Hodulak, 2019).

G. Zachmann *et al.* (2022) emphasise that modern wars are distinguished by the fact that they are accompanied by profound humanitarian consequences for the world, as they provoke a rise in prices not only for energy resources but also for food. D. Kleimann (2022) noted that fluctuations in global food prices and supply in times of war are largely conditioned by the decisive actions of governments trying to protect their populations. Along with investigating the impact of the war on the global agricultural market and food security, T. Sigaeva *et al.* (2023) addressed the complications of logistics for international trade. Military operations on the territory of Ukraine have led to the blocking of seaports, closure of airspace, instability of delivery costs, and vulnerability of logistics systems in the frontline regions, which necessitates the development of new logistics models and strategies. Developing this opinion, Yu. Kushnir *et al.* (2023) emphasise the micro-level context of this impact: difficulties with freight transportation prompted manufacturers and exporters to immediately transform and optimise business processes.

Despite the existence of many multidisciplinary studies of the system of international trade relations and its transformations under the influence of armed conflicts, the hybrid nature of the Russian-Ukrainian war and the complexity of its consequences for international trade in general and agri-food products specifically keep this issue relevant and motivate further developments in this area. Considering this, the purpose of this study was to identify the factors and consequences of the impact of the Russian-Ukrainian war on world agricultural trade and food security at the national and global levels. The working hypothesis of the study was the assumption that the volatility of global agricultural trade indicators is the result of the complex impact of changes in the markets for food, fertilisers, and energy resources as a result of the Russian-Ukrainian war, specifically, the destruction of Ukraine's agricultural, export and logistics potential caused by it, and the sanctions pressure on the Russian Federation and Belarus.

MATERIALS AND METHODS

The research methodology was formed according to the objectives and research hypothesis. The following methods were employed in this study: time series (to determine trends in the value of commodity exports from Ukraine in general and agricultural products specifically; to investigate fluctuations in the aggregate price index for food and certain types of agricultural products); index method (to compare changes in the value of agricultural exports from Ukraine and world exports in general); induction and deduction (to determine indicators of the elasticity of the world agricultural market to fluctuations in export supplies from Ukraine); analysis and synthesis, factor analysis (to identify the factors of volatility of world prices for agricultural products (specifically, grain); graphical and tabular methods (for visual presentation and systematisation of statistical and analytical data, research results). To establish the causal relationship between the processes in the chain "military actions in Ukraine – world food trade – global food security", the study used indicators that are tested by international organisations to monitor the world food market and food security at the national and global levels:

1) food price index – World Bank (2023) and Food Agriculture Organisation (2023) databases;

2) Global Hunger Index – Global Hunger Index (2023) database;

3) Global Food Security Index (Economist impact, 2022).

The reliability of scientific results is ensured by a step-by-step analysis of: 1) transformations of the production and export potential of the agricultural sector of Ukraine under the influence of military actions; 2) cause-and-effect relationships between the factors of influence and indicators of the development of world food trade with further identification of the key trends; 3) challenges to global food security under the influence of volatility in the world food trade. Consistent application of the methodological tools helped to fulfil the objectives of the study, namely: to assess the economic losses of the agricultural sector of Ukraine's economy and their impact on export potential; to identify manifestations, trends, and principal factors of volatility in world trade in agri-food products; to investigate the level of global food security as a critical result of the impact of the Russian-Ukrainian war on world food trade.

The information basis for the theoretical part of the study included the findings of Ukrainian and foreign economists, expert opinions of the World trade organisation (2024), International Food Policy Research Institute (2023), International monetary fund (2022; 2023), World economic forum (2022), Organisation for economic cooperation and development (Trade and environment working papers, 2017). The empirical study was based on the processing of analytical information from the State Statistics Service of Ukraine (2023) and expert studies of the Kyiv School of Economics (2023) (data on the destruction of agricultural infrastructure, losses of production and export potential of Ukraine), and other information resources from international databases Food Agriculture Organisation (2023), World Bank (2023), Trade map (2023), ResourceTrade.Earth (2023), Economist Intelligence Unit (2024) (data on the global agricultural market conditions, food security at the national and global levels).

RESULTS AND DISCUSSION

For a long time, Ukraine has been actively competing with the United States, Canada, and the EU in the global agricultural market. The annual growth of the agricultural sector was over 5%, while the share of agricultural production in GDP was over 10% and 16% together with processing (Cabinet of Ministers of Ukraine, 2022); the agricultural sector employed over 14% of the population. However, the full-scale armed aggression of the Russian Federation has caused significant civilian casualties, critical destruction, and damage to production facilities and infrastructure, and has also caused enormous economic and natural losses to the agricultural sector: risks of sowing and harvesting due to mined fields and shelling, logistical problems, labour shortages, etc.

According to the Kyiv School of Economics (2023), as of the beginning of the second quarter of 2023, direct losses to agriculture as a result of the war amounted to USD 8.7 billion. Agribusinesses suffered the largest losses due to the destruction of agricultural machinery, the destruction of grain storage facilities, theft, export outside Ukraine, or destruction of finished products. In total, as a result of Russia's armed aggression, over 110,000 units of agricultural machinery were destroyed, including the loss of major tillage equipment (tractors, seeders, harrows) worth more than USD 4.5 billion. Perennial plantations (fruit and berry crops – worth a total of USD 490 million), inputs and farm animals were also considerably damaged, and a significant loss of life was recorded.

Assessing the losses incurred by the agricultural sector in the field of animal husbandry (cattle, poultry, pig, aquaculture and fisheries, beekeeping, etc.), experts have found that the amount of such losses from the reduction in the number of cattle and pigs, bee colonies, etc., reaches USD 280 million. In the Kharkiv region, the cowsheds of the Agromol farm and the production facilities of the leading dairy producer Kharkiv Dairy Plant LLC were destroyed. Over 4 million chickens died at Europe's largest poultry farm in Chornobaivka, Kherson region (LATIFUNDIST, 2023a). In part of the temporarily occupied Zaporizhzhia region, the premises of a dairy farm and 4 buildings of the pig farm of PJSC Stepnoy Breeding Farm were destroyed, killing more than 6,000 pigs and about 1,000 heifers. Overall, during the war in Ukraine, the number of cattle decreased by 15.6%, or 2.4 million, including cows by 15%, or 1.3 million (LATIFUNDIST, 2023b).

The agricultural business suffered significant losses due to damage, theft, or destruction of goods and means of production. It is difficult to estimate the total number and amount of losses in this category, but the approximate amounts of losses have been established: fertilisers (over USD 68 million), fuel and plant protection products (about USD 28 million), and grain and sunflower seeds (about USD 2 billion) (Kyiv School of Economics, 2023). Most fertilisers for grain crops were used before the war, with high application rates to guarantee yields. However, in 2023, due to the high cost of imported logistics, the fertiliser application rate dropped substantially (15-20%).

The occupation of the southern regions of Ukraine and the mining of agricultural land also caused significant damage to agribusiness (Fig. 1). The area of mined agricultural land is about 471 thsd ha, which, apart from demining, also requires additional cultivation in the form of reclamation and levelling of the surface. To saturate the internal market with agricultural products and adjust prices, agricultural land for growing vegetables is being demined first, followed by grain and legumes, and land for other agricultural needs.

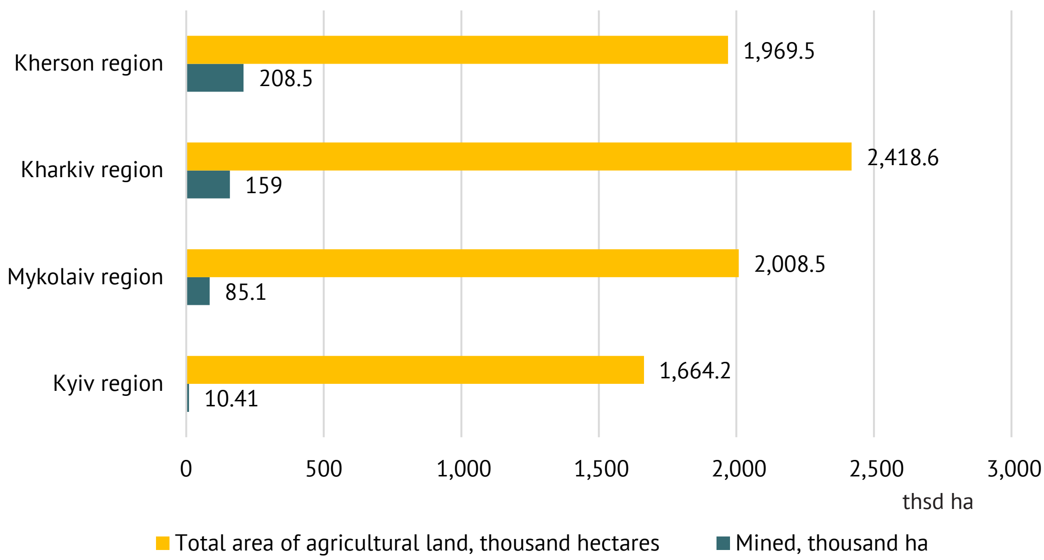

Figure 1. *Areas of agricultural land mined as a result of the war, 2023*
Source*: calculated by the authors of this study according to data from the State Statistics Service of Ukraine (2023)*

Apart from direct costs, Ukraine also suffered considerable indirect losses (over USD 30 billion) as a result of the war (Kyiv School of Economics, 2023), which include lower internal prices for export-oriented crops and disruption of export logistics corridors; losses due to reduced crop production; losses from reduced winter crop production; losses from higher prices for inputs and labour; losses from reduced livestock production.

The largest indirect losses – USD 14.3 billion – were recorded in the crop sector, with substantial damage caused by the inability to fully conduct the sowing season in the southern and eastern regions of Ukraine. Thus, the highest level of losses is accounted for by wheat (USD 2.9 billion), sunflower (USD 2.5 billion), and maize (USD 1.7 billion) (Kyiv School of Economics, 2023). As of the beginning of the second quarter of 2023, the livestock sector recorded losses of USD 1.7 billion due to a decrease in livestock, with production of milk and eggs, beeswax and honey, cattle and pig meat falling. Therewith, despite rising feed costs (produced in-house) and the rise in the price of premixes and other components of animal feed rations, producers benefited from low prices for their own grain products, which made livestock production profitable. The warehouse infrastructure has also suffered considerable losses, with facilities totalling 8 million tonnes of simultaneous storage capacity destroyed or damaged as a result of hostilities. Elevator complexes in 3 southern regions were the most affected (Elevatorist, 2023) (Fig. 2), with losses estimated at over USD 1.3 billion (Kyiv School of Economics, 2023).

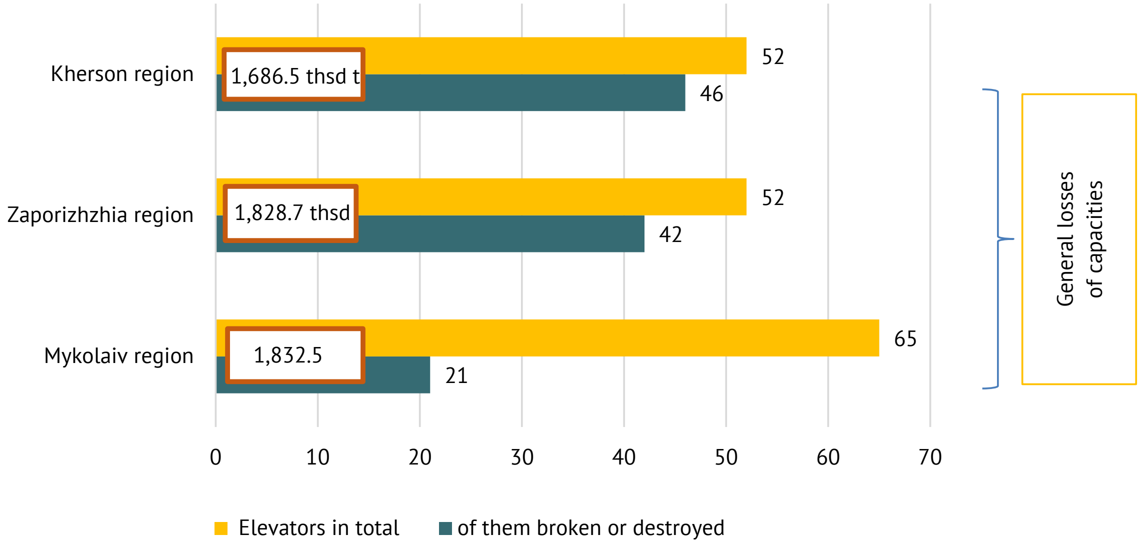

Figure 2. *Number of lost warehouse infrastructure (granaries) as a result of the war, 2023*
Source*: calculated by the authors of this study according to data from the State Statistics Service of Ukraine (2023)*

The following agricultural companies lost the most grain storage facilities as a result of the Russian military aggression and temporary occupation: OptimusAgro Trade (lost 50% of capacities, 16 out of 27 elevators are in operation), TESSLAGROUP(7 elevators are under occupation, 2 are de-occupied, of which 1 was destroyed by shelling), Bunge Ukraine (over 30% of capacities have been lost, 3 elevators are currently operating), NIBULON LLC (25% of capacities have been lost), State Food and Grain Corporation of Ukraine (control over 9 elevators has been lost) (Elevatorist, 2023).

Considering the overall losses in agriculture, economic and trade decline during the full-scale military invasion of Russia, Ukraine did not lose its foreign trade potential, and increased its export and import performance. This result was mainly achieved due to temporary trade liberalisation and a forced change in the institutional "rules of the game" in the market. To support agricultural producers as much as possible, the government temporarily suspended a range of import duties in the first months of the war, imposed restrictions on critical imports, simplified registration procedures for the import of agricultural machinery, and expanded credit support and grant programmes for agricultural producers. The export capacity of the state and international business activity of Ukrainian exporters were considerably strengthened by the EU's launch of logistics "solidarity routes", the development of customs infrastructure, and temporary measures to eliminate anti-dumping duties and tariff quotas for Ukrainian products and goods.

Over the past decade, Ukraine's economy has stabilised its growth rate as a result of systemic reforms and optimisation of its sectoral structure, as well as steadfast adherence to the course of integration into the European economic space. As a result of consolidated efforts by the state to promote economic interests in the international community and by private business to produce high-quality products, Ukraine has gradually increased its export potential, strengthening its position in the global market for goods and services. Agricultural products became the country's defining export item with a share of around 40%. Steady demand for food products ensured that the agricultural sector was able to maintain exports even during the crisis (in 2021, the value of exports exceeded the pre-crisis level after the COVID-19 pandemic by more than 25%). The Russian-Ukrainian war became a critical factor in preserving the country's agricultural export potential. The destruction of production facilities and the disruption of logistics routes for the sale of products and the supply of fertilisers and seeds led to a sharp decline in exports (Fig. 3).

Figure 3. *Dynamics of the value of Ukraine's exports, USD million*
Source*: calculated by the authors of this study according to data from the State Statistics Service of Ukraine (2023)*

In 2022, the value of merchandise exports in general and agricultural products specifically decreased by 35.2% and 15.6%, respectively. The key factor behind this trend was the closure of the principal sales channel through the Black Sea ports. At the same time, alternative routes through the land corridors of Poland, Romania, Slovakia, and Hungary were not institutionally agreed upon and insufficiently tested for large-scale exports.

The Russian-Ukrainian war has transcended national boundaries and become a critical factor for the global commodity market, specifically its agricultural and energy segments. The indicators of food market development turned out to be the most elastic, as both countries of the military conflict are significant food exporters (in 2020, Ukraine's share of the world market for maize was 13.1%, barley – 11.8%, wheat – 8.3%, and vegetable fats – 6.6%) (World Bank, 2022). The rise in food prices was a complementary result of national trends of declining production and the destruction of logistics infrastructure and chains in Ukraine, as well as a reduction in exports of agricultural products and fertilisers from Russia. Therewith, the volatility of world prices, rather than capacity, became a manifestation of the elasticity of the world food market to changes in export flows from Ukraine (Table 1).

Table 1. *Agricultural export value index, 2022*

Product type	Export value index, 2022 to 2021	
	Ukraine	World as a whole
Wheat	0.53	1.17
Barley	0.35	0.91
Maize	1.02	1.21
Sunflower oil	0.86	1.22

Source*: developed by the authors of this study based on data from Trade Map (2023)*

Specifically, the deficit in the wheat market was offset by the release and sale of stocks from India and China. In response to the threat to food security, Argentina, Brazil, and the United States have considerably increased their maize plantings. The problem of shortages of certain types of products was solved by countries with a prominent level of development by finding alternative sources of supply. At the same time, underdeveloped countries were more vulnerable due to the lack of their own reserves and alternative regional suppliers. The problem was most acute in the countries that were the primary importers of Ukrainian grain – Lebanon, Moldova, Qatar, Pakistan, Egypt, and Turkey. The principal indicator of the elasticity of the global agricultural market to fluctuations in exports from Ukraine was the price. The largest increase in food prices was recorded from February to June 2022, when it reached its maximum of 59% (Fig. 4). This was conditioned by the highest level of uncertainty about the duration and consequences of the Russian-Ukrainian war. A considerable number of contracts expired or were suspended due to force majeure.

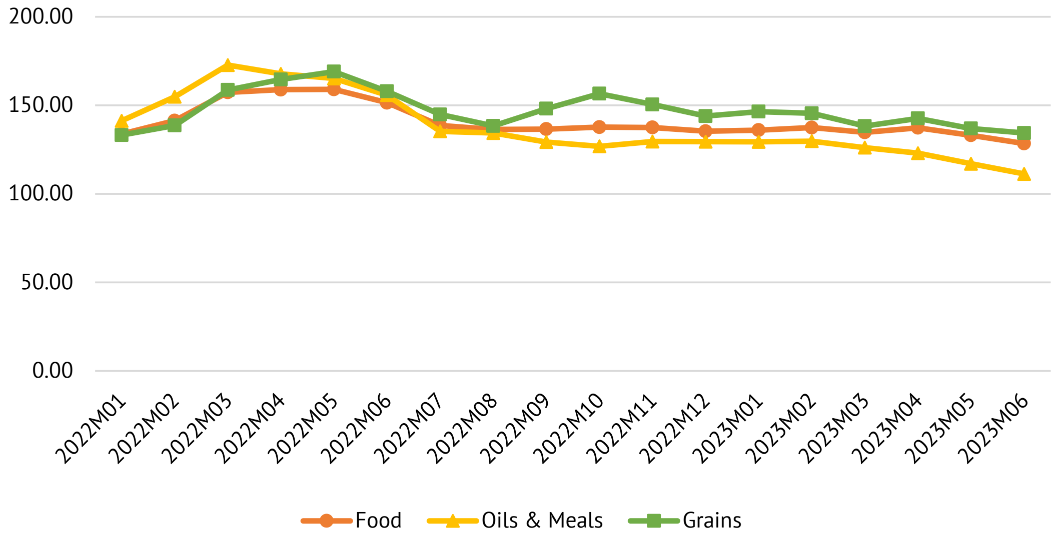

Figure 4. *World Bank Commodity Price Index*

Source*: developed by the authors of this study based on World Bank data (2023)*

According to analysts, this was the biggest jump in agricultural prices since 1974 and 2008. The high amplitude of price growth is conditioned by the volatility of the global agricultural market, which has not yet recovered from the 2019 crisis caused by the COVID-19 pandemic. For comparison, at the end of 2020, the aggregate food price index reached 107.3; in 2021, the index ranged within 115-127; in 2022, it was within 133-159 (World Bank, 2022). Prices rose for all commodities, with Ukraine and the Russian Federation playing a significant role in supplying them. However, prices for vegetable fats stabilised at a faster pace than grain. Specifically, in March 2022, the fat price index reached 172.8, with a downward trend since July 2022, when the index stopped at 111.3. At the same time, the aggregate grain price index did not fall below 133 in 2022-2023, reaching a peak of 169 in May 2022.

These trends are driven by the fact that the deficit in the global sunflower oil market was quickly compensated by other types of vegetable fats, such as palm, soybean, and other oils. At the same time, the high and steady demand for grain on the world market cannot be quickly met by other substitute commodities. The high volatility of global grain prices is the result of a range of factors:

1. Fertiliser shortages and rising prices. the Russian Federation and Belarus accounted for about 30% of global fertiliser exports. Although Russia's fertiliser exports are not subject to Western sanctions, supplies have been reduced due to disruptions in logistics, insurance, and banking. Carriers, insurers, and financial institutions have raised prices for their services due to reputational risks. Another factor was China's imposition of restrictions on fertiliser exports to stabilise prices in the internal market. Taken together, this led to sharp price fluctuations for minerals. The rise in mineral fertiliser prices started in mid-2021, peaking in April 2022 (the global price index was 293.7). Between October 2021 and November 2022, the price index did not fall below 200 (World Bank, 2022).

2. Decreased grain yields due to reduced use of fertilisers by farmers in the EU and deteriorating weather conditions in Argentina, Brazil, and the US.

3. Increased energy prices, which led to higher fertiliser production costs, and higher prices for all parts of the food value chain, including storage, processing, delivery, and sales.

4. Sharp increase in the number of forward and futures transactions in agricultural markets, which are inherently speculative. This was the result of prolonged and acute uncertainty about the outcome and duration of the Russian-Ukrainian war and stimulated a rise in agricultural commodity prices. In February 2022, grain futures prices on the Chicago Mercantile Exchange rose by 50%. The share of non-commercial traders (speculators) holding long positions in durum wheat and maize increased to 50% in early 2022 (United Nations conference on trade and development, 2022). In general, futures and forward contracts are classic exchange instruments that have a positive impact on commodity liquidity. However, excessive use of long-term instruments leads to distortions in the price situation. To minimise this effect, some countries, including the EU, introduced controls on financial speculation in commodity futures contracts after the 2008 financial crisis. However, such state regulation measures have not been practised since then.

To compensate for the food shortage and avoid sharp price fluctuations, in 2022, some EU countries began to impose restrictions on exports and imports of agricultural products and increase regional imports, which had a short-term effect on the national market but increased the impact on global price fluctuations. In these conditions, an effective method of diversifying price risks is for countries to build up stocks of agricultural raw materials and increase plantings of a wide range of crops, which will ensure long-term market stability.

Russia's aggressive intervention and armed actions on the territory of Ukraine, following the logic of the war's destructive impact, were not limited to the national economy, but also caused a shock to global food markets and updated the world's food price indices (Food Agriculture Organisation, 2023). The situation with food security in the world has also deteriorated considerably: according to international organisations, the number of people suffering from hunger during the war has increased to 349 million people (compared to ~200 million people recorded during the COVID-19 pandemic) (International Monetary Fund, 2023). The reason for this is not only the reduction in food exports from Ukraine, but also the entire range of factors that logically follow from the growing role of the Black Sea region in ensuring global food security, on the one hand, and changes in market rules under sanctions pressure, on the other hand (Glauber & Debucquet, 2023). This includes restrictions on the supply of not only Russian agri-food products, but also energy, fertilisers from Belarus, etc., which has a complex impact on food production and availability.

Even though Ukraine was among the leaders in the global grain market in the pre-war period (USD 10.9 billion with a 7.2% increase in the value of this export item in 2015-2020) and oilseeds (USD 9.3 billion in 2020, which is 9.1% more than in 2015 (ResourceTrade.Earth, 2023), the reduction in its export opportunities has affected the availability of a wider range of food products. It is noted that the cost of a food basket in East Africa increased by 55% in the first year of the war in Ukraine (World food programme, 2022a). The impact of the Russian-Ukrainian war has been most pronounced in food-insecure countries:

– against the backdrop of a general decline in the Global Hunger Index (GHI) (from 28.0 in 2000 to 18.2 in 2022), countries with moderate, severe, or alarming levels of hunger have higher GHI scores in 2022 than in 2014;

– 44 countries are once again in the group of countries with alarming levels of hunger;

– 46 countries will not be able to achieve low levels of hunger by 2030 (Global Hunger Index, 2023).

In general, Jordan, Israel, Lebanon, and Yemen are the most vulnerable to the effects of the war on their food security, having imported a key share of agri-food products from Ukraine (4.6%, 3.7%, 15.0%, and 5.2%, respectively) and Russia (5.3%, 1.5%, 5.2%, and 5.8%, respectively) in the pre-war period, including cereals from the two countries in total – 26.0%, 12.0%, 47%, and 24% each (ResourceTrade.Earth, 2023). In terms of changes in global food security indicators, the Russian-Ukrainian hybrid war has had a greater impact on local food availability than on the overall picture of food security in the world as a whole (Fig. 5).

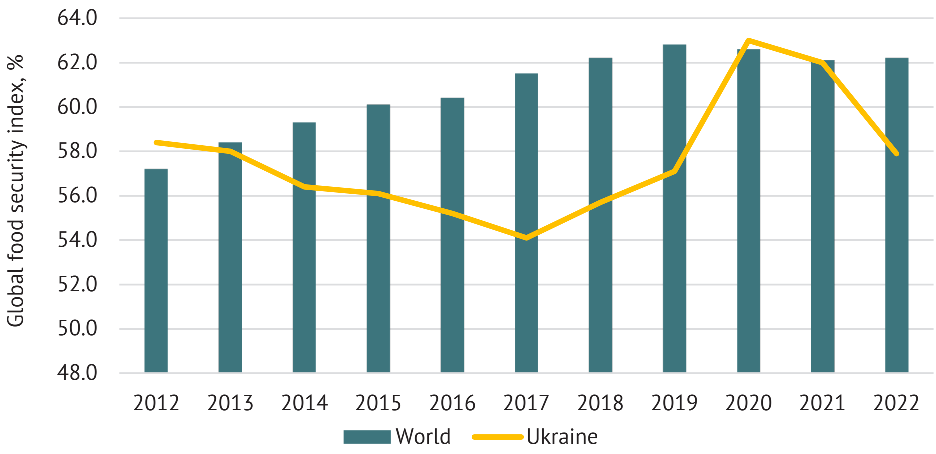

Figure 5. *Trends in food security: global and national profiles*
Source: *developed by the authors of this study based on Economist Impact data (2022)*

For Ukraine, in 2022, food security indicators plummeted to their lowest level since 2020, with the food security index falling to 58.4, which is only ¾ of the European average (74.8) (Economist impact, 2022). Despite the existing endogenous potential to produce enough food to meet the needs of 400 million people, about 45% of the population of Ukraine, according to the United Nations World Food Programme, is concerned about the problem of sufficient food, and every fifth resident is forced to reduce the frequency of meals or portion size, and to give up meat consumption in favour of children (World food programme, 2022c).

In the current context of geopolitical and security transformations in the architecture of the global economy, conflicts have been identified as a key driver of food insecurity due to their comprehensive impact on the food supply system – from agricultural production and processing, transportation, and supply of inputs, to marketing and consumption, financing, and supply chain infrastructure (Economist impact, 2022). At the same time, M. Chepeliev *et al*. (2023) shows the differential impact of war on different countries of the world. Thus, high-income countries (as a group) are much less negatively affected than most low- and middle-income countries. While direct shocks to agriculture have a negative impact on high-income economies, rising energy prices benefit energy-exporting countries in this group (the United States, Qatar, Saudi Arabia, Norway, Australia, Canada, Kuwait, and the United Arab Emirates), leading to an increase in purchasing power and calorie consumption by consumers.

The study of the impact of the war in Ukraine also shows changes in the positions of players in global markets. S. Jagtap *et al*. (2022) note that the international market demonstrates the significance of goods exported from Ukraine – wheat, maize, sunflower seeds, and oil. With the supply of these products shrinking and demand for them constantly rising, buyers in European countries are looking for alternative suppliers, which opens new opportunities for such important global producers of these products as Argentina, Australia, Brazil, Canada, China, India, Mexico, and the United States.

The war in Ukraine has triggered a so-called "three-dimensional" crisis – food, energy, and financial – that has a devastating impact on the most vulnerable people, economies, and countries (World Food Programme, 2022b). Exacerbated by the adverse effects of the COVID-19 pandemic, it has led to the largest increase in the number of people suffering from poverty and hunger since the Second World War (1.7 million people). Considering the high concentration of the global grain market, where Ukraine and Russia's share of wheat and barley exports together accounted for more than 30%, 36 countries – the most import-dependent and food-vulnerable ones – experienced problems with grain supplies. The overall impact of the Russian-Ukrainian war, including the destruction of the food supply system, has resulted in hunger and malnutrition for 222 million people in 53 countries (Lin *et al*., 2023). In contrast, EU countries with a high level of food self-sufficiency and, at the same time, dependence on imports of specific goods (e.g., sunflower oil, seafood, etc.) face the problem of their prompt substitution. Furthermore, as the war continues, the dependence of EU agri-food production on imports of key inputs such as energy, feed, and animal nutrition supplements, and fertilisers has become more pronounced (European Parliamentary Research Service, 2022).

The crisis of globalisation and the emergence of its post-industrial paradigm, combined with social centrism, have affected the understanding of the factors influencing international trade. These ideas have been echoed in studies that distinguish among other factors a category related to human well-being (Guo, 2023). In this context, the relationship between international trade and climate change has also been rethought – the traditional notion that the scale of international trade operations leads to an increase in the ecological footprint and an aggravation of the climate issue (Trade and environment working papers, 2017; Yamaguchi, 2021) has been replaced by arguments in favour of the opposite. Specifically, the impact of climate change on trade is substantiated both in a negative sense – through the destruction of infrastructure (due to extreme weather events such as tornadoes, tropical cyclones, convective storms, floods, etc, forest fires, etc.) and reduced factor productivity (due to impacts on labour productivity and biological effects such as insect infestations or the spread of viruses), and in a positive sense – through the opening of new supply chains (global warming may facilitate the opening of new routes for maritime transport) (Martínez-Martínez *et al*., 2023).

Recent research contributes to expanding the scope of factors influencing international trade, strengthening the geopolitical (specifically, the growing control of global supply chains by Asian countries) (Elion, 2022) and technological aspects of the impact on international trade (the continued growth of logistics costs). They also focus on global challenges (such as the pandemic, the war in Eastern Europe, etc.). Research is being actively conducted to investigate the interests and capabilities of international trade stakeholders as a separate driving force for its development. Specifically, some researchers argue that trade communities strengthen their power in international trade by stabilising resource flows (Huang *et al*., 2017) and improving their international position through cooperation with other countries (Dong *et al*., 2018). Despite the differences between individual wars in terms of their duration, scale, causes of outbreak, and methods of settlement, they all have a common feature – the ability to influence the global economy, creating new geopolitical and economic uncertainty, skyrocketing energy prices, and disrupting global value chains. Under these conditions, disruption of sustainable trade flows caused by military conflicts is an important source of changes in the global economy and the situation of individual countries and entire regions. These violations are understood as a side effect of achieving concrete political and military goals that are achieved militarily (Krpec & Hodulak, 2019).

Price shocks and supply fluctuations in the global food trade are exacerbated by active measures taken by governments (from guaranteed price ceilings for consumers to export restrictions) to protect their populations. Despite the emotional component and variability of such policies, their effect is the same – while protecting the interests of the population of some countries, they have a detrimental impact on all others, exacerbating agricultural trade deficits, and creating pressure for higher prices (Kleimann, 2022).

Considering Russia's unprecedented armed aggression against Ukraine, it has become an object of study for many researchers and is in the focus of attention of many international organisations and institutions. Thus, the World Bank has identified five of the most vulnerable areas of international trade and investment attraction for which the war in Ukraine has caused radical changes: the commodity market, logistics networks, supply chains, foreign direct investment, and other specific sectors (Ruta, 2023). The World Trade Organisation (WTO) notes that the conflict in Ukraine will affect global trade in commercial services, especially those related to the transport sector, such as container shipping and passenger air travel. Experts of the World Economic Forum primarily note that the war in Ukraine is causing food and fuel crises (World economic forum, 2022). In this context, some researchers note that the war and, as a result, the surge in prices for basic goods will make it difficult for policymakers in some countries to strike a delicate balance between curbing inflation and supporting the economy and its recovery from the pandemic (International Monetary Fund, 2022). In this regard, armed conflict, together with climate change and poverty, are factors that combine to create endemic and pervasive risks to global food security, a new reality with rising food prices and the expectation of problems with securing sufficient food.

CONCLUSIONS

The invasion of Russia provoked the largest civilian casualties in the history of Ukraine's independence, temporary occupation of territories and restrictions on agriculture, destruction of infrastructure, a decline in GDP and trade turnover (over 30%), which slowed economic development. The total losses of the agricultural sector of the economy amounted to USD 40 billion. Ukraine has suffered considerable losses due to the temporary occupation of territories and hostilities on agricultural land; over 2,600 agricultural businesses suffered critical losses during the military invasion of Russia, with sown areas decreasing by 1.9 million hectares. More than 500 thsd t of grain were exported from Ukraine to Russia, and over 20% of livestock and poultry were lost due to shelling.

Agribusinesses are forced to build an adaptive system of functioning that will help to mitigate the determinants of the critical level of vulnerability. These include the need to demine agricultural land; restore the destroyed warehouse infrastructure; establish import logistics for seeds, feed, and fertilisers, and veterinary products; increase agricultural export potential and provide food to the population of frontline areas and combat zones. The revitalisation of Ukraine's agricultural sector in the post-war period should be aimed at implementing a highly efficient export policy to support the trade balance and contribute to the country's macroeconomic stability.

The agricultural market has proven to be more resilient to fluctuations in external factors than other sectors of the global market. Its resilience is manifested in the ability to recover more quickly (in 2022, global exports of wheat, maize, and sunflower oil increased by an average of 20% compared to 2021). An indicator of elasticity is the price, the amplitude of which varies by commodity item and is higher for cereals (the aggregate price index for cereals in 2022-2023 did not fall below 133) compared to oilseeds (in 2022, the price index for vegetable fats was 111.3). Solving the problem of maintaining equilibrium in the agri-food market requires consolidation of efforts by the international community with the dominance of global social priorities, as countries' implementation of protectionist policies ensures short-term local effects at the national level but increases the impact on global price volatility.

Building a resilient global food security system in turbulent times is a key task for ensuring sustainable development, the anti-trends of which are growing hunger and poverty and the environmental footprint of military operations. The global hunger rate in 2023 did not change significantly (the index value was 18.1), but the proportion of undernourished people actually increased from 7.5% in 2017 to 9.2% in 2022, reaching approximately 735 million. The duration of Russia's aggression causes the world's reactions to its consequences and ways of resolving it to be chaotic. On the one hand, they are manifested in uncoordinated attempts to regulate exports through trade restrictions or speculative measures. On the other hand, countries that have experienced restrictions in access to food or resources for agricultural production are trying to mitigate potential risks or attract the world's attention to resolve the preconditions of the food crisis. The war's further impact on global food security may be exacerbated by the aggravation of the problem of hunger due to the reduction in production by the countries involved in the armed conflict and the effect of sanctions imposed on Russia, or by a surge in prices on the global food and input markets; and by an international response that may either exacerbate the crisis (through trade regulation instruments) or mitigate it (based on the experience of the previous global crisis).

The unpredictability of the timing and outcome of the end of the armed conflict in Ukraine makes it important to continue research in this area. Priority will be given to developments focused on assessing the loss of the country's economic (including export) potential and arguing for the possibility of restoring it, finding ways to restore positions in international commodity markets, and developing multidimensional and multilateral efforts to build a sustainable food system.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Cabinet of Ministers of Ukraine. (2022). *Draft Recovery Plan for Ukraine. Materials of the working group "New Agrarian Policy"*. Retrieved from https://www.kmu.gov.ua/storage/app/sites/1/recoveryrada/ua/new-agrarian-policy.pdf.

[2] Chepeliev, M., Maliszevska, M., & Pereira, M. (2023). The war in Ukraine, food security and the role for Europe. *EuroChoices,* 22(1), 4-13. doi: 10.1111/1746-692X.12389.

[3] Dong, D., Gao, X., Sun, X., & Liu, X. (2018). Factors affecting the formation of copper international trade community: Based on resource dependence and network theory. *Resources Policy,* 57, 167-185. doi: 10.1016/j.resourpol.2018.03.002.

[4] Economist impact. (2022*). Global Food Security Index 2022*. Retrieved from https://impact.economist.com/sustainability/project/food-security-index/.

[5] Economist Intelligence. (2024). Retrived from https://www.eiu.com/n/.

[6] Elevatorist. (2023). *Elevator companies most affected by the enemy's invasion*. Retrieved from https://elevatorist.com/spetsproekt/199-reyting-elevatornih-kompaniy-scho-naybilshe-postrajdali-vid-vtorgnennya-voroga.

[7] Elion. (2022). *Supply chain outlook: 4 factors affecting global trade*. Retrieved from https://elionpartners.com/news/supply-chain-outlook-4-factors-affecting-global-trade/.

[8] European parliamentary research service. (2022). *Russia's war on Ukraine: Impact on food security and EU response*. Retrieved from https://www.europarl.europa.eu/RegData/etudes/ATAG/2022/729367/EPRS_ATA(2022)729367_EN.pdf.

[9] Food Agriculture Organisation. (2023). *Food Price Index*. Retrieved from https://www.fao.org/worldfoodsituation/foodpricesindex/en/.

[10] Glauber, J.W., & Debucquet, D.L. (Eds.). (2023). *The Russia-Ukraine conflict and global food security*. Washington, DC: International Food Policy Research Institute (IFPRI). doi: 10.2499/9780896294394.

[11] Global Hunger Index. (2023). Retrieved from https://www.globalhungerindex.org/.

[12] Guo, H. (2023). The factors that affecting international trade. In *Proceedings of the 3rd international conference on economic development and business culture* (pp. 207-212). doi: 10.2991/978-94-6463-246-0_25.

[13] Huang, S., An, H., Viglia, S., Buonocore, E., Fang, W., & Ulgiati, S. (2017). Revisiting China-Africa trade from an environmental perspective. *Journal of Cleaner Production*, 167, 553-570. doi: 10.1016/j.jclepro.2017.08.171 .

[14] International Monetary Fund. (2022). *How war in Ukraine Is reverberating across world's regions*. Retrieved from https://www.imf.org/en/Blogs/Articles/2022/03/15/blog-how-war-in-ukraine-is-reverberating-across-worlds-regions-031522.

[15] International Monetary Fund. (2023). *Joint statement by the heads of the Food and Agriculture Organization, International Monetary Fund, World Bank Group, World Food Programme and World Trade Organization on the global food and nutrition security crisis*. Retrieved from https://www.imf.org/en/News/Articles/2023/02/08/pr2335-joint-statement-by-the-fad-imf-wbg-wfp-and-wto-on-food-and-nutrition-security-crisis.

[16] Jagtap, S., *et al.* (2022). The Russia-Ukraine conflict: Its implications for the global food supply chains. *Foods*, 11(14), article number 2098. doi: 10.3390/foods11142098.

[17] Kleimann, D. (2022). *Food security: The role and limits of international rules on export restrictions*. Retrieved from https://www.bruegel.org/blog-post/food-security-role-and-limits-international-rules-export-restrictions .

[18] Krpec, O., & Hodulak, V. (2019). War and international trade: Impact of trade disruption on international trade patterns and economic development. *Brazilian Journal of Political Economy*, 39(1), 152-172. doi: 10.1590/0101-35172019-2854 .

[19] Kushnir, Yu., Blaga, M., Pop, M., & Pop, Yu. (2023). Logistics and international trade of Ukraine in the conditions of war. Scientific Bulletin of Uzhhorod University. *Economy Series*, 1(61), 23-25. doi: 10.24144/2409-6857.2023.1(61).23-25.

[20] Kyiv school of economics. (2023). *Agricultural war damages, losses, and needs review*. Retrieved from https://kse.ua/wp-content/uploads/2023/05/RDNA2.pdf.

[21] Latifundist. (2023a). *A report from the Chornobaivska poultry farm*. Retrieved from https://latifundist.com/reportazhy/157-nas-vikinuli-z-mashini-strilyali-pid-nogi-ta-nad-golovoyu-a-potim-zaboronili-yizditi-za-kormami-reportazh-z-chornobayivskoyi-ptahofabriki.

[22] Latifundist. (2023b). *Times of losses. How much has Ukraine's agricultural sector lost from the war?* Retrieved from https://latifundist.com/spetsproekt/1032-chasi-vtrat-skilki-vzhe-vtrativ-agrosektor-ukrayini-vid-vijni.

[23] Lin, F., Li, X., Jia, N., Feng, F., Huang, H., Huang, J., Fan, Sh., Ciais, Ph., & Song, X.P. (2023). The impact of Russia-Ukraine conflict on global food security. *Global Food Security,* 36, article number 100661. doi: 10.1016/j.gfs.2022.100661.

[24] Martínez-Martínez, A., Esteve-Pérez, S., Gil-Pareja. S., & Llorca-Vivero, R. (2023). The impact of climate change on international trade: A gravity model estimation. *The World Economy,* 46(9), 2624-2653. doi: 10.1111/twec.13464.
[25] Mehtiyev, J., Magda, R., & Vasa, L. (2021). Exchange rate impacts on international trade. *Economic Annals-XXI*, 190(5-6(2)), 12-22. doi: 10.21003/ea.V190-02.
[26] ResourceTrade.Earth. (2023). Retrieved from https://resourcetrade.earth/.
[27] Ruta, M. (Ed.). (2023). *The impact of the war in Ukraine on global trade and investment*. Washington, D.C.: World Bank Group.
[28] Sigaeva, T., Misyukevich, V., & Timchenko, A. (2023). Logistics support of international trade: Necessity and status in modern conditions. *Economy and Society*, 54. doi: 10.32782/2524-0072/2023-54-13.
[29] State Statistics Service of Ukraine. (2023). Retrieved from https://www.ukrstat.gov.ua/.
[30] Trade and environment working papers. (2017). *Climate change and trade policy interaction: Implications of regionalism*. Retrieved from https://ideas.repec.org/p/oec/traaaa/2017-3-en.html.
[31] Trade map. (2023). Retrieved from https://www.trademap.org/.
[32] United nations conference on trade and development. (2022). *Development prospects in a fractured world: Global disorder and regional responses*. Retrieved from https://unctad.org/system/files/official-document/tdr2022_en.pdf.
[33] World bank. (2022). *Special focus. Impact of the war in Ukraine on commodity markets*. Retrieved from https://openknowledge.worldbank.org/server/api/core/bitstreams/c7f65ff2-9e31-5b2a-9ceb-ed37900e8223/content.
[34] World Bank. (2023). *Commodity markets*. Retrieved from https://www.worldbank.org/en/research/commodity-markets.
[35] World economic forum. (2022). *These 3 charts show the impact of war in Ukraine on global trade*. Retrieved from https://www.weforum.org/agenda/2022/04/ukraine-war-global-trade-risk/ .
[36] World food programme. (2022a). *Implications of the conflict in Ukraine on food access and availability in the East Africa region*. Retrieved from https://docs.wfp.org/api/documents/WFP-0000140223/download/ .
[37] World food programme. (2022b). *Global report on food crises. Global network against food crises and food security information network*. Retrieved from https://www.wfp.org/publications/global-report-food-crises-2022.
[38] World food programme. (2022c). *WFP reaches one million people with life-saving food support in conflict-stricken Ukraine*. Retrieved from https://www.wfp.org/news/wfp-reaches-one-million-people-life-saving-food-support-conflict-stricken-ukraine.
[39] World trade organization. (2024). *Documents and resources*. Retrieved from https://www.wto.org/english/res_e/res_e.htm.
[40] Yamaguchi, S. (2021). *International trade and circular economy – Policy alignment*. Paris: OECD Publishing.
[41] Zachmann, G., Weil, P., & Cramon-Taubadel, S. (2022). *A European policy mix to address food insecurity linked to Russia's war*. Retrieved from https://www.bruegel.org/policy-brief/european-policy-mix-address-food-insecurity-linked-russias-war.

Війна в Україні: вплив на світову торгівлю агропродовольчою продукцією

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Анотація. Кон'юнктура та тенденції розвитку світового ринку агропродовольчої продукції є еластичними до кризових та конфліктних ситуацій за участю основних ринкових гравців, що ставить під загрозу можливість забезпечення продовольчої безпеки завдяки блокуванню сталих можливостей міжнародної торгівлі внаслідок руйнування виробничого потенціалу та ланцюгів створення вартості, каналів постачання продукції до країн-споживачів. Метою статті було дослідженню особливостей та наслідків впливу російсько-українською збройного конфлікту на світову торгівлю аграрною продукцією та продовольчу безпеку на національному й світовому рівнях. Отримані наукові висновки є результатом застосування економіко-статистичного (ряди динаміки, індексний та факторний аналіз) та діалектичного (прийоми індукції та дедукції, аналізу та синтезу) методів наукового пізнання. Встановлено, що універсальними ознаками війн є спроможність впливати на світову економіку, формувати нову геополітичну та економічну невизначеність, стрімке зростання цін на критичні ресурси (енергоносії) та забезпечувати дестабілізацію глобальних ланцюгів створення вартості. Як наслідок, порушення сталих торгових потоків, зумовлене військовими конфліктами, є важливим джерелом змін у світовій економіці та становищі окремих країн і регіонів. Доведено, що військові дії на території України призвели до обмежень у веденні сільського господарства та вимушеної адаптації агробізнесу до факторів критичного рівня вразливості. Фіксуються тенденції до скорочення виробництва та злам традиційних ланцюгів постачання агропродовольчої продукції внаслідок руйнування логістичної інфраструктури, що разом зі скороченням експортних поставок агропродукції та добрив з росії обумовило зростання світових цін на продовольство. В результаті цього формується «ціна» російсько-української війни для світової економіки, елементами якої є зростаючі голод та бідність, а також екологічний слід військових операцій. Практичне значення результатів дослідження полягає у можливості їх застосування в процесі стратегічного планування та обґрунтування напрямів повоєнної відбудови національної економіки в цілому та її аграрного сектора зокрема, а також відновлення й посилення ролі України у глобальних продовольчих ланцюгах та протидії голоду

Ключові слова: глобалізація; міжнародна торгівля; світовий ринок продовольства; кон'юнктура ринку продовольства; продовольча безпека

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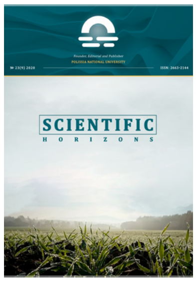

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Agricultural enterprise economic security systems modelling

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Abstract. The research relevance was determined by the current conditions of economic instability and the growing influence of external factors on the economic activities of enterprises, understanding and effective management of economic security issues is becoming extremely important for ensuring the sustainability of agricultural enterprises. The study aimed to provide a comprehensive analysis of the economic security of an agricultural enterprise, focusing on identifying key aspects and their impact on the sustainability and viability of the enterprise. The study employed an analytical method, statistical method, functional method, system analysis method, deduction method, synthesis method and comparison method. This study focuses on the economic security of agricultural enterprises, considering the complex aspects of efficiency, risk protection and the ability to adapt to changes in the economic environment. The study defines economic security as a systematic approach to risk management and sustainability. Particular attention is devoted to responding to changes in the external environment, such as price fluctuations, climate anomalies and global market trends. Theoretical models, such as the risk system model, effective resource management, innovative development, and global competitiveness, which determine various aspects of economic security, were considered. The study focuses on the financial condition of the agricultural company Kernel, which proved to be dynamic and ambiguous in 2020-2023. The analysis includes factors such as the impact of geopolitical events and economic instability due to the war. The company implements strategies for global competitiveness, demonstrating flexibility, innovation, and diversification to ensure sustainability. Strategies are proposed to expand production diversification, improve risk management, and use innovative

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technologies to adapt to climate change. The practical application of this study lies in the possibility of using the results and recommendations developed on their basis to improve the economic security systems of agricultural enterprises

Keywords: financial risks; resource optimisation; innovative strategies; market challenges; adaptation to changes

INTRODUCTION

In the modern world, the agricultural sector is a crucial component of the economic structure. The relevance of studying the economic security systems of agricultural enterprises is extremely important in the face of growing challenges caused by market instability and the impact of external factors. Agrarian enterprises, performing an economic function, are a key element of the global economy and are inextricably linked to food security and rural development. Despite these important roles, agricultural enterprises face numerous challenges and economic risks arising from unforeseen circumstances. Climate change, geopolitical turbulence and rapid technological change pose serious challenges to their successful operation. In Ukraine, the main challenge facing agricultural enterprises is the war. Studying and optimising the economic security systems of agricultural enterprises in wartime is a strategically important task. This is necessary to ensure their sustainability and development in a changing economic environment, which is determined not only by economic instability but also by geopolitical and climate change. Issues related to economic security in the agricultural sector are becoming increasingly urgent, as global competition and the growth of new challenges, such as urbanisation and changing consumer trends, require careful study and development of appropriate management strategies. This approach opens up prospects for improving effective management strategies of agricultural enterprises, contributing not only to their stability but also to restoring the balance in the global agricultural sector.

N. Volkova *et al.* (2023), analysing the key aspects of economic security of agricultural enterprises, systematically revealed the impact of factors that determine the sustainability of these enterprises in a changing market environment. Their research focuses on the mechanisms of adaptation of enterprises to economic fluctuations, considering effective resource and risk management strategies. Determining the importance of economic security research for the successful functioning of agricultural enterprises, V.S. Lesyuk (2021) focuses on the development of methods for effective risk management. His work proposes specific strategies and approaches to ensure financial stability and competitiveness in a volatile market. The study by O. Pravdyvets (2023), in turn, aims to study innovative approaches to modelling the economic security of enterprises. It provides sound modelling methods that consider current trends and challenges, such as climate change and technological progress. N.Y. Drabchuk (2023) determined optimisation strategies for the use of economic resources of agricultural enterprises by considering the issues of resource management. His research examines the practical aspects of balanced use of resources, which affects the overall sustainability and efficiency of management. The study by O. Kubai and O. Zastavniuk (2022) also examines the economic security of agricultural enterprises through the lens of global trends. Their work thoroughly analyses the impact of climate change and geopolitical factors on the sustainability and development of the agricultural sector, contributing to an understanding of how these larger trends may shape the future of the industry.

In general, the results of these studies form a comprehensive approach to understanding the economic security of agricultural enterprises, providing valuable scientific grounds for further research and implementation of effective management strategies in this sector. However, the development of specific strategies for improving the economic security of agricultural enterprises was not sufficiently presented. The study aims to provide a comprehensive analysis to improve the economic security systems of agricultural enterprises to ensure the sustainability and efficiency of the industry in the current economic environment.

MATERIALS AND METHODS

The study is based on a comprehensive analysis of several materials, including theoretical sources, financial reports of agricultural enterprises, documentation on yields, sown areas, operational indicators, and statistical reports. For a detailed review of the economic situation in the selected sector, the financial reports of the agricultural enterprise Kernel for the last 4 years (FY2023 Annual Report, 2023) were used. Thus, trends and key financial indicators of the industry were identified.

The analysis of documentation covering aspects of yields, sown areas and operational indicators provided an opportunity to understand production efficiency and factors affecting the profitability of agricultural enterprises (Kernel – The profitability..., 2023; Kernel – Everything about..., 2023). The active use of open data and statistical reports related to the agricultural sector helped to contextualise the results and determine the place of the industry in the economic environment. Consideration and analysis of academic articles and research in the field of agricultural economics and the security of agricultural enterprises play an important role in expanding the theoretical basis of the study.

The analytical method was primarily used to study the financial performance of agricultural enterprises in recent years. The statistical method used to study data on yields, revenues and other agricultural indicators was useful. This method was employed to identify trends that define agriculture and to establish correlations between different variables, which contributed to a deeper understanding of the factors that affect the efficiency of the industry and improved the understanding of the dynamics of the agricultural sector. The functional method was used to identify key aspects of resource and risk management in agricultural enterprises. This approach was employed to focus on the efficiency of business processes and identify opportunities for further improvements.

The study of the interrelationships of the agricultural system using the system analysis method provided a comprehensive view of the factors that determine economic security. This method was used to connect various elements, such as production, financial management and risk management, to create a holistic picture of the industry. The identification of general principles for managing the economic security of agricultural enterprises based on the deduction method involved the study of specific cases and facts. This approach was used to identify fundamental principles that can be applied in a broader context.

The synthesis method was used to create a holistic view of the economic security system of agricultural enterprises. This method was employed to overcome limitations and to consider the sector as a single complex. The comparative method was used to compare management strategies, risks, and resources of agricultural enterprises, which helps to select effective tools for applying the optimal approach. This method was employed to identify best practices that can be used for adaptation to improve the efficiency of the sector. As a result, these measures were used to assess the effectiveness of resource and risk management in agricultural enterprises and to consider the feasibility of implementing specific recommendations to improve the system.

RESULTS

Economic security is a key aspect of modern enterprise management, as it determines their sustainability, viability, and ability to adapt to changes in the economic environment. This concept encompasses a comprehensive set of factors that ensure the efficiency of economic activity and protect against the negative impact of external and internal threats. When defining the economic security of enterprises, it should be seen as a systematic approach to risk management and sustainability (Kahler, 2004). One of the key aspects of this concept is the ability to respond adequately to changes in the external environment, such as fluctuations in commodity prices, climate anomalies and global market trends. Effective economic security involves a deep understanding and management of the financial, production and market aspects of an enterprise.

The aspect of economic security covers the definition of the basic principles and models that define its essence. The systemic approach involves considering economic security as an integral part of strategic planning, where resource endowment, financial sustainability and risk management interact to ensure long-term stability. The internal and external environment is an important aspect of understanding economic security. Businesses should be prepared for the impact of various factors, identify them, and develop adaptation strategies. However, in addition to measures, it is also important to consider proactive approaches, such as innovation and the use of industry best practices.

Several key theoretical models define different aspects of economic security. The first of these is the risk system model, which recognises economic security as a complex system with a variety of risks. This approach provides an opportunity to identify and manage risks through reactive, proactive, and strategic strategies. Reactive strategies are aimed at solving problems after they arise, proactive strategies involve preventing risks, and strategic strategies integrate risk management into strategic management, creating a comprehensive system of protection. This approach allows businesses not only to respond to challenges and dangers but also to actively work on their prevention and strategic management, ensuring full protection in all aspects of their activities. The integration of risk management into strategic management makes the system more efficient and flexible, allowing businesses to adapt to changes in the environment and achieve sustainability in a dynamic market environment (Settembre-Blundo *et al*., 2021).

The second model, focusing on effective resource management, aims to optimise the use of finance, labour, and other assets to ensure the efficiency of the enterprise. It incorporates the rationalisation of production processes, efficient inventory management and optimisation of financial flows as key strategies to achieve this goal. The introduction of efficient production processes is aimed at increasing productivity and optimising the use of resources. Efficient inventory management helps to avoid storage overruns and ensures that the necessary materials are available for continuous production. Optimisation of financial flows includes rational allocation of funds, effective budget management, and minimisation of financial risks (Pandey *et al*., 2022).

The third model, focused on innovative development, focuses on the importance of innovation in ensuring competitiveness and adapting to changes in the economic environment. This approach is determined by the introduction of the latest technologies, stimulation of creativity and development of innovative thinking. The introduction of the latest technologies includes the use of advanced scientific and technical developments to optimise production processes and improve product quality. This may include the automation of production, the use of artificial intelligence and other innovative tools. Stimulating creativity involves activating the creative potential of the company's staff. This may include providing creative training, creating a favourable environment for ideas and innovation, and recognising and rewarding creative achievements (Xu, 2021).

Last but not least, the global competitiveness model analyses economic security in the context of global market conditions. This model involves a systematic review of international trends and the competitive situation, and research on global supply and demand, which allows businesses to adapt to international standards and requirements. The analysis of international trends and competition involves an assessment of economic processes and business strategies on a global scale. The study of global supply and demand is aimed at understanding how an enterprise can meet the needs of the international market and ensure an efficient supply chain system (Bakator *et al.*, 2019).

These theoretical models, using different approaches and strategies, identify the main directions for ensuring the economic security of agricultural enterprises. Given the complexity of the current economic environment, a combination of these models can be effective in achieving stability and successful adaptation to change. The role of economic security in the agricultural sector is to ensure sustainability, protect against financial difficulties and maintain the competitiveness of agricultural enterprises in changing market conditions. In the following, the economic security models will be considered in the context of the Ukrainian agricultural enterprise Kernel.

A review of the financial position of the agricultural enterprise Kernel can provide important insights into the efficiency and sustainability of the agricultural sector, as well as reflect the practical aspects of the role of economic security. The company specialises in the cultivation and processing of agricultural products holds a leading position in Ukraine and is known on the global market. Table 1 shows the financial position of the company.

***Table 1.** Financial position of Kernel company, USD million*

Indicator	2020	2021	2022	2023
Revenue	4,107	5,595	5,331	3,455
EBITDA	443	806	220	544
Net profit	123	506	-41	299
Assets	3,165	3,996	4,185	3,885
Main items	1,634	1,713	1,662	1,443
Current assets	1,531	2,284	2,523	2,442
Inventories	555	709	1,116	489
Available funds	369	574	448	1,077
Owned assets	1,494	1,948	1,686	1,744
Debt	966	1,085	1,696	1,474
Operating cash flow	269	461	-305	716
Financial cash flow	226	-48	476	-216
Investments cash flow	-203	-205	-294	10

***Source:** compiled by the authors based on FY2023 Annual Report (2023)*

Kernel's financial position proved to be dynamic and mixed during 2020-2023. During this period, the company saw an increase in revenue and net profit until 2021, which indicated its successful financial performance. However, in 2022, a decline was recorded in both revenue and net profit, and the latter even became negative. This is due to various factors, including the impact of geopolitical events and economic instability caused by the war. A further analysis of the financial indicators shows an increase in the company's debt and a loss in operating cash flow in 2022. This indicates increasing financial difficulties and the need for risk management. On the positive side, the company's cash flow is expected to increase in 2023, which could be a positive signal for overcoming financial difficulties in the future. Overall, the company may need to strategically manage risks and adapt to market changes to ensure sustainability and competitiveness in a challenging economic environment.

In the area of economic security, Kernel has a high level of research and analysis of potential risks that may affect its operations. The company identifies key factors such as fluctuations in agricultural commodity prices, changes in foreign exchange rates, political and regulatory changes, and uncertainty in production conditions. Market conditions in agriculture are highly vulnerable to external factors such as weather conditions and global production trends. In the context of the war in Ukraine, this risk is exacerbated by uncertainty and possible changes in the production and transportation of agricultural products. The volatile environment may result in unpredictable currency fluctuations, which has a direct impact on the company's financial liabilities and production costs. Agricultural business conditions, such as yields and technical aspects, may be significantly affected in the conflict zone, leading to uncertainty in production volumes and prices.

Kernel has implemented and actively uses a risk management model. This system includes the use of various financial instruments designed to protect against the negative impact of fluctuations in foreign exchange rates. For example, in the face of changes in exchange rates, the company may use derivatives or other instruments to minimise financial losses. The company employs advanced agricultural technologies and monitoring systems to respond to weather anomalies promptly and minimise crop losses, as inclement weather or extreme weather conditions can result in reduced production potential. Table 2 shows the company's acreage and yield data.

Table 2. *Kernel sown areas and yields*

Production	2020/2021	2021/2022	2022/2023
Corn			
Sown areas, ha	255,000	255,000	150,000
Yield, t/ha	8	9.3	8.5
Wheat			
Sown areas, ha	73,000	64,000	35,000
Yield, t/ha	4.9	6.1	4.5
Sunflower			
Sown areas, ha	149,000	154,000	130,600
Yield, t/ha	3	3	2.5
Overall land assets, ha	**510,000**	**500,000**	**363,000**

Source: *Kernel – The profitability of sunflower processing remains high (2023)*

These data show a decrease in the company's total land bank, as well as fluctuations in the yields of different crops during the period. The yields of corn, wheat and sunflower are lower in the 2022/2023 season compared to previous seasons. The decrease in the total land bank may indicate potential challenges related to resource constraints and land management. Fluctuations in the yields of different crops also have a direct impact on the financial performance of the enterprise, as yields determine the volume of production and, therefore, income. In the context of the economic security system, this information indicates the need to improve risk management strategies, adapt to changes in climate conditions and improve crop cultivation methods to ensure the stability and resilience of the enterprise in a changing environment.

Kernel is successfully implementing a global competitiveness model based on several key aspects: export page, flexibility and adaptability, innovations in production and marketing, quality system and consumer confidence, diversification, and vertical integration strategies. The company is actively expanding its export activities in Ukraine and internationally thanks to its high-quality products and innovative approaches. In the 2022/23 season, Ukraine's grain exports totalled approximately 49 million tonnes, up 1 million tonnes compared to the 2021/22 season. A significant portion of Ukrainian grain was shipped abroad via alternative routes, with only 55% exported through Ukrainian deepwater ports. This resulted in significant changes in the structure of exporters compared to previous years. Table 3 shows Kernel's operating performance.

Table 3. *Kernel's operational performance*

	2019	2020	2021	2022	2023
Sunflower processing, thousand tonnes	3,164	3,436	3,183	2,187	2,502
Sunflower oil sales, thousand tonnes	1,619	1,518	1,367	967	1,012
Grain exports, thousand tonnes	6,094	7,902	8,013	7,969	3,707

Source: *Kernel – Everything about the company, history, production, profits (2023)*

The indicators indicate fluctuations in the company's operations, which may be due to various factors, such as war, economic conditions, production circumstances and external factors. An important aspect is flexibility and adaptability, which allow Kernel to respond effectively to changes in market conditions and global challenges. A key element of global competitiveness is the innovations that the company implements both in agricultural production and in product marketing. Technologies for growing and processing agricultural products improve the quality and competitiveness of goods on the global market. The company devotes much effort to the production quality system, compliance with international standards (ISO) and building consumer confidence. Strict adherence to safety and quality standards creates the basis for success in the global market. In addition, the company successfully uses diversification and vertical integration strategies to ensure stability and competitiveness. A wide range of products, from grains to oilseeds, makes Kernel less dependent on fluctuations in individual market segments.

In summary, all these measures allow Kernel to compete successfully in the global market, maintaining high global competitiveness and ensuring resilience in the face of complex challenges, such as global changes in market conditions or geopolitical factors. The kernel takes a comprehensive approach to ensuring economic security, using models such as the risk system to identify and manage risks, the efficient resource management model to optimise the use of finance and resources, the innovation development model to maintain competitiveness, and the global competitiveness model to adapt to international standards. To constantly control and monitor the situation, Kernel uses systems for analysing financial statements, performance indicators and risk reports. This allows the company to respond to potential threats promptly and make informed decisions to ensure business stability and sustainability. To improve the economic security system of agricultural companies, a specific strategy can be proposed that covers various aspects of the enterprise. Figure 1 shows several steps that can contribute to improving the effectiveness of the economic security system.

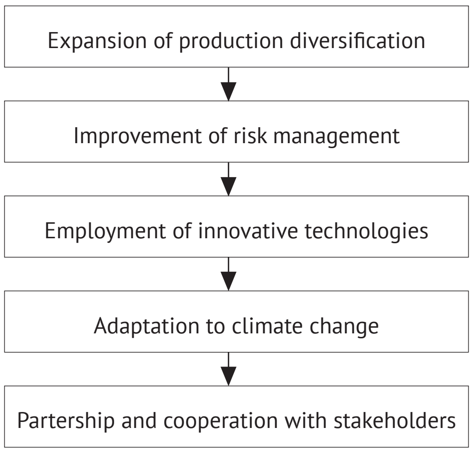

Figure 1. *Strategies for improving the economic security of agricultural enterprises*
Source: *compiled by the authors*

The strategy of expanding production diversification is key for companies. This includes developing organic production and expanding the range of crops grown. Organic products are becoming an important trend in agriculture, and companies can actively invest in this sector to ensure diversity and high demand for their products. For example, the development of organic production allows them to respond to the growing consumer demand for environmentally friendly products. In addition, expanding the range of crops grown reduces dependence on a particular type of agricultural product and allows for easier adaptation to changes in seasonal and market conditions. This strategy has a double effect: it not only broadens the company's market reach but also reduces its exposure to risks associated with changes in demand for specific agricultural products. The diversity of the product portfolio allows companies to manage risks more effectively and ensure stability in changing market conditions (Waha *et al*., 2018).

Risk management is the second key strategy for agricultural companies. In particular, they can use a variety of financial instruments, such as options or futures, to actively protect themselves from the negative impact of fluctuations in agricultural commodity prices. For example, the use of options and futures allows them to effectively minimise and control currency and price fluctuation risks. In the event of changes in exchange rates or agricultural commodity prices, companies can take timely action to protect their financial position. This makes them less vulnerable to unforeseen market conditions and ensures financial stability in changing economic circumstances. Employing innovative technologies to improve agricultural production is the third key strategy for companies. They can actively implement modern technologies, such as artificial intelligence systems, to accurately analyse climate conditions and predict risks in agriculture. For example, the use of artificial intelligence systems allows for detailed climate analysis and prediction of possible risks, such as adverse weather conditions or pests. This enables companies to respond to potential threats promptly and adapt their crop production strategies. The introduction of innovative technologies contributes not only to risk reduction but also to increasing the efficiency and productivity of agriculture, which is an important element in ensuring the economic security of enterprises in a rapidly changing market environment (Emerick *et al*., 2016).

Creating climate change adaptation strategies is the fourth important strategy for agricultural enterprises. As part of this strategy, companies can actively develop new plant varieties that are more resistant to extreme weather conditions. New varieties can be adapted to changing climatic conditions, which will help increase yields and reduce the impact of negative factors. In addition, innovative irrigation systems and other technologies can be introduced to ensure efficient crop production even in difficult climatic conditions. Ensuring high yields in extreme weather conditions is a key aspect of ensuring the economic security of companies, as it allows them to maintain production stability and respond to environmental challenges promptly. The last key strategy is to develop partnerships and stakeholder engagement. Businesses can actively cooperate with agricultural cooperatives, research institutions and other industry players to share resources, and experience and jointly develop new technologies. Cooperation with agricultural cooperatives can help improve production processes and optimise resource management. Scientific institutions can be valuable partners for the research and development of new technologies aimed at increasing the productivity and sustainability of crop production. In general, these strategies will help agricultural enterprises to ensure the sustainability and resilience of their economic condition in a changing business environment, increasing efficiency and reducing risks of their operations.

DISCUSSION

The results of the presented study of the economic security of agricultural enterprises reveal important aspects of the functioning of companies in the current economic environment. The main emphasis is placed on identifying and analysing the key aspects of economic security that determine the stability and viability of an enterprise. The research considers current trends and challenges in the economy and develops innovative methods for modelling economic security. This is an important aspect, as it allows us to adapt strategies to climate change, global market trends and technological progress in agriculture. Further analysis of key theoretical models, such as the risk system model, resource management, innovation development, and global competitiveness, reveals various aspects of economic security. The combination of these models creates a comprehensive approach to ensuring the sustainability of an agricultural enterprise in the face of change.

It is important to note the impact of the conflict in Ukraine on agriculture, in particular on harvests and production conditions. In addition, an important element is the active use of risk management by businesses, including the use of financial instruments to protect against the impact of exchange rate fluctuations and the use of advanced technologies to respond to weather anomalies and minimise crop losses. Strategies for improving the economic security system proposed for companies are identified as key components for ensuring sustainability and competitiveness. In particular, strategies to increase production diversification, improve risk management, use innovative technologies, and adapt to climate change are critical for the effective functioning of a company in a changing economic environment (Sahachko *et al.*, 2023).

B. Derevyanko *et al.* (2021) analysed the role of economic security in modern enterprise management, highlighting its key impact on the stability and viability of enterprises. The results of the analysis covered various aspects of economic security aimed at ensuring efficient operation and considering possible risks, such as fluctuations in product prices, the impact of climate change and global market trends. The authors' conclusions relate to the importance of systematic risk analysis and management to ensure the efficiency of an enterprise in a changing market environment. The study provides information that can serve as a basis for developing risk management strategies and improving the efficiency of the economic security of enterprises. The results of the authors, as well as the present study, focus on the role of risk management and the use of innovative technologies to ensure the sustainability of enterprises in a changing economic environment. All of the authors' approaches identify specific strategies aimed at improving the efficiency of management processes and ensuring the sustainability of enterprises, but a full analysis of their interactions and possible limitations is required.

M.K. Shad *et al.* (2019) highlighted a systematic approach to risk management and sustainability in enterprise management. The authors note an important aspect of the study, which is to consider changes in the global economic environment and the ability of an enterprise to effectively adapt to them. The coverage of such phenomena as price fluctuations and market trends indicates the need not only for a reactive response to changes but also for the introduction of systemic planning and strategic management to ensure the sustainability and successful adaptation of the enterprise to new conditions (Musayeva *et al.*, 2024). The results of the study emphasise the relevance of implementing an integrated management approach to ensure the effective operation of an enterprise in a changing economic environment. Compared to the present study, it is possible to note that the authors have effectively focused on risk management and the use of financial instruments to protect against negative impacts in the agricultural sector. However, the authors' study could be even more detailed, including specific examples and strategies for using advanced technologies to improve quality and productivity.

J. Clapp (2019) in his study examined in detail the basic principles and models of economic security, drawing attention to their importance in the context of strategic planning, in particular in the agricultural sector. He emphasised the importance of the interaction of three key components: resources, financial stability, and risk management to achieve long-term sustainability. The interaction of resources in the context of agricultural business may include optimising the use of land, labour and other assets. Financial stability is seen as a key element in ensuring the sustainability of an enterprise, while risk management is defined as a strategic approach to avoiding and mitigating potential threats (Cheremisina & Salo, 2023). The author's conclusions emphasise the importance of taking these components into account in strategic planning in the agricultural sector to achieve long-term sustainability, which makes his research relevant and useful for practical application in enterprise management. This approach was also considered in the present study, where the importance of these components in strategic planning was pointed out. However, innovative development and global competitiveness should also be considered, which can significantly affect the economic security of an enterprise.

D. Ciuriak and P. Goff (2021) analysed theoretical models of economic security and identified their key aspects and strategies. Focusing on theoretical aspects, they reveal the importance of innovative development, effective risk management, and global competitiveness. One of the key topics of the authors' research is innovative development. They view innovation as an important factor in ensuring economic security and competitiveness. The researchers show how innovations affect economic sustainability and how their implementation can reduce risks. Given the importance of concrete applications, especially in the current economic environment, it is important to combine theoretical models with concrete examples and analysis of real enterprises.

R. Vavrek *et al.* (2021) analysed the financial condition of agricultural enterprises in their study. The level of analysis and justification of potential risks that may affect the economic security of the enterprise under consideration is revealed. Key factors include fluctuations in agricultural commodity prices, changes in foreign exchange rates, political and regulatory developments, and uncertainty in the production environment. The volatility of the agricultural business, such as weather conditions and global production trends, can lead to unpredictable fluctuations in foreign exchange rates and commodity prices (Buka *et al.*, 2023). The authors should explore and consider aspects of risk management, identify specific financial instruments to protect against negative impacts and improve the consideration of advanced technologies to improve quality and productivity in the agricultural sector.

T.T. Duong *et al.* (2019) considered the practical experience of implementing a risk management system and using modern agricultural technologies to ensure economic security. The main focus of the study is practical examples of the use of financial instruments and monitoring systems to effectively respond to unforeseen circumstances. Financial instruments, such as financial derivatives, futures contracts, and monitoring of the company's financial position, can be used to effectively manage risks and ensure the economic security of agricultural enterprises (İsmayilov *et al.*, 2022). This approach allows for a better understanding of which tools and strategies can be applied in real agricultural business. The presentation of practical examples provides concreteness and helps to replicate successful risk management experiences to ensure economic resilience. However, it should be added that, in addition to identifying specific tools and strategies, an important aspect is to adapt these approaches to the specific conditions of each agricultural enterprise. Considering unique factors such as farm size, crop types, market conditions and regional peculiarities is crucial for the successful implementation of a risk management system (Oleksandrenko & Valchyshyna, 2023).

In general, the results indicate that effective economic security of agricultural enterprises requires a comprehensive approach that combines theoretical models, risk management strategies and practical experience in the use of modern technologies. Consideration of the changing market environment, as well as flexibility and innovation, are key factors for ensuring the sustainability and competitiveness of agricultural enterprises in the current economic landscape.

CONCLUSIONS

This study shows the key role of economic security in modern enterprise management, emphasising its impact on stability, viability, and adaptability to economic change. Several theoretical models defining economic security have been identified, each offering unique approaches and strategies. The risk system model considers economic security as a complex system that allows for the identification and management of risks through reactive, predictive, and strategic strategies. The resource management model optimises finances, labour, and assets, emphasising the rationalisation of production processes and efficient inventory management. Innovative development emphasises the importance of innovation for competitiveness, while global competitiveness considers economic security in the context of global market conditions.

Applying these models to agricultural enterprises, as in the case of Kernel, revealed a dynamic and mixed financial position during 2020-2023. External factors, including geopolitical events and economic instability due to the war, affected revenue and net profit. The study highlighted Kernel's proactive approach to risk management, using financial instruments and advanced agricultural technologies to respond to market and environmental uncertainties. Kernel's global competitiveness model demonstrated effective strategies such as export diversification, innovation, quality assurance and vertical integration. In general, the company takes a comprehensive approach to ensuring economic security, using models such as the risk system, the efficient resource management model, the innovative development model, and the global competitiveness model to ensure that the company can meet its objectives.

To improve the economic security of agricultural enterprises, a strategy has been proposed that includes expanding production diversification, improving risk management, introducing innovative technologies, developing climate change adaptation strategies, and developing partnerships. These strategies are aimed at increasing the company's resilience to market fluctuations, climate risks and geopolitical instability. Further research could focus on improving the risk assessment methodology and developing innovative adaptation strategies for agricultural enterprises in a changing economic environment.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Bakator, M., Đorđević, D., & Ćoćkalo, D. (2019). Developing a model for improving business and competitiveness of domestic enterprises. *Journal of Engineering Management and Competitiveness (JEMC)*, 9(2), 87-96. doi: 10.5937/jemc1902087B.

[2] Buka, S., Tkachuk, V., Kondratiuk, V., Tonkha, O., & Slobodyanyuk, N. (2023). Prospects for agribusiness in Ukraine over the next 5 years. *International Journal of Environmental Studies*, 80(2), 291-298. doi: 10.1080/00207233.2022.2157630.

[3] Cheremisina, S., & Salo, I. (2023). Monitoring of the aggregate level of economic efficiency of agricultural enterprises in Ukraine: Factors of influence and growth prospects. *Ekonomika APK*, 30(2), 24-37. doi: 10.32317/2221-1055.202302024.

[4] Ciuriak, D., & Goff, P. (2021). *Economical security and changing global economy*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3998169.

[5] Clapp, J. (2019). The rise of financial investment and common ownership in global agrifood firms. *Review of International Political Economy*, 26(4), 604-629. doi: 10.1080/09692290.2019.1597755.

[6] Derevyanko, B., Rozhenko, O., Khailova, T., Hrudnytskyi, V., & Podskrebko, O. (2021). *Strategic enterprise management is based on the modeling of its economic security*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3927356.

[7] Drabchuk, N.Y. (2023). Improvement of the economic mechanism of use of land resources in agricultural enterprises. *Scientific Innovations and Advanced Technologies*, 24(10), 421-429. doi: 10.52058/2786-5274-2023-10(24)-421-429.

[8] Duong, T.T., Brewer, T., Luck, J., & Zander, K. (2019). A global review of farmers' perceptions of agricultural risks and risk management strategies. *Agriculture*, 9(1), article number 10. doi: 10.3390/agriculture9010010.

[9] Emerick, K., De Janvry, A., Sadoulet, E., & Dar, M.H. (2016). Technological innovations, downside risk, and the modernization of agriculture. *American Economic Review*, 106(6), 1537-1561.

[10] FY2023 Annual Report. (2023). Retrieved from https://www.kernel.ua/investor-relations/financial-reports/

[11] İsmayilov, V., Shalbuzov, N., Karimova, V., Safarov, A., & Cabbarli, L. (2022). Government agencies in the field of sustainable agricultural development in various countries. *Rivista di Studi sulla Sostenibilita*, 2022(2), 165-183. doi: 10.3280/RISS2022-002011.

[12] Kahler, M. (2004). Economic security in an era of globalization: Definition and provision. *The Pacific Review*, 17(4), 485-502. doi: 10.1080/0951274042000326032.

[13] Kernel – Everything about the company, history, production, profits. (2023). Retrieved from http://shareuapotential.com/ru/Emitents/kernel_ua.html.

[14] Kernel – The profitability of sunflower processing remains high. (2023). Retrieved from http://shareuapotential.com/ru/News/Newsline/kernel-fin-rez-2023-09.html.

[15] Kubai, O., & Zastavniuk, O. (2022). Improvement of financial and economic security in the system of anti-crisis management of agricultural enterprise. *Agrosvit*, 4, 68-78.

[16] Lesyuk, V.S. (2021). Economic security as a factor of effective functioning of agricultural enterprises in a competitive environment. In *Proceedings of the X international scientific and practical conference information and analytical support of financial and economic security management of the state, region, business entities in the conditions of COVID-19* (pp. 151-153). Kharkiv: O.M. Beketov National University of Urban Economy.

[17] 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.

[18] Oleksandrenko, I., & Valchyshyna, V. (2023). Profitability management of agricultural enterprises in Ukraine. *Economic Forum*, 1(1), 138-145. doi: 10.36910/6775-2308-8559-2023-1-17.

[19] Pandey, A.K., Singh, R.K., Jayesh, G.S., Khare, N., & Gupta, S.K. (2022). Examining the role of enterprise resource planning (ERP) in improving business operations in companies. *ECS Transactions*, 107, article number 2681. doi: 10.1149/10701.2681ecst.

[20] Pravdyvets, O. (2023). Analysis of the domestic scientific research results in the direction of innovative development the enterprise's economic security system based on digital technologies. *Scientific Notes of the University "KROK"*, 69(1), 15-28. doi: 10.31732/2663-2209-2022-69-15-28.

[21] Sahachko, Yu., Smihunova, O., & Podolska, O. (2023). Prospects for the formation of investment support for the technological growth of the agricultural sector of the Ukrainian economy in the post-war period. *Ukrainian Black Sea Region Agrarian Science*, 27(3), 62-70. doi: 10.56407/bs.agrarian/3.2023.62.

[22] Settembre-Blundo, D., González-Sánchez, R., Medina-Salgado, S., & García-Muiña, F.E. (2021). Flexibility and resilience in corporate decision making: A new sustainability-based risk management system in uncertain times. *Global Journal of Flexible Systems Management*, 22(2), 107-132. doi: 10.1007/s40171-021-00277-7.

[23] Shad, M.K., Lai, F.W., Fatt, C.L., Klemeš, J.J., & Bokhari, A. (2019). Integrating sustainability reporting into enterprise risk management and its relationship with business performance: A conceptual framework. *Journal of Cleaner production*, 208, 415-425. doi: 10.1016/j.jclepro.2018.10.120.

[24] Vavrek, R., Kravčáková Vozárová, I., & Kotulič, R. (2021). Evaluating the financial health of agricultural enterprises in the conditions of the Slovak Republic using bankruptcy models. *Agriculture*, 11(3), article number 242. doi: 10.3390/agriculture11030242.

[25] Volkova, N., Mehtiev, R., & Popadin, Y. (2023). Key aspects of competitiveness and product quality of agricultural enterprises in the conditions of military aggression. *Economy and Society*, 54. doi: 10.32782/2524-0072/2023-54-10.

[26] Waha, K., van Wijk, M.T., Fritz, S., See, L., Thornton, P.K., Wichern, J., & Herrero, M. (2018). Agricultural diversification as an important strategy for achieving food security in Africa. *Global Change Biology*, 24(8), 3390-3400. doi: 10.1111/gcb.14158.

[27] Xu, T. (2021). Research on innovative development strategy of innovative enterprises based on the construction of modern economic system. *Lecture Notes in Economics, Management and Social Sciences*, 38, 98-102. doi: 10.23977/ICBEMI2021024.

Моделювання систем економічної безпеки аграрних підприємств

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Анотація. Актуальність проведення дослідження полягає в тому, що в сучасних умовах економічної нестабільності та зростаючого впливу зовнішніх факторів на господарську діяльність підприємств, розуміння та ефективне управління питаннями економічної безпеки стає надзвичайно важливим для забезпечення стійкості аграрних підприємств. Метою дослідження був комплексний аналіз економічної безпеки аграрного підприємства, зосереджений на виявленні ключових аспектів, їх впливу на стійкість та життєздатність підприємства. Серед використаних методів було застосовано аналітичний метод, статистичний метод, функціональний метод, метод системного аналізу, метод дедукції, метод синтезу та метод порівняння. Дане дослідження фокусувалося на економічній безпеці аграрних підприємств, розглядаючи комплексні аспекти ефективності, захисту від ризиків та здатності адаптуватися до змін у економічному середовищі. Робота визначає економічну безпеку як системний підхід до управління ризиками та забезпечення стійкості. Особливу увагу приділяється реагуванню на зміни зовнішнього середовища, такі як коливання цін, кліматичні аномалії та глобальні тенденції ринку. Були розглянуті теоретичні моделі, такі як модель системи ризиків, ефективного ресурсного управління, інноваційного розвитку, глобальної конкурентоспроможності, що визначають різні аспекти економічної безпеки. Дослідження стосується фінансового стану аграрної компанії Kernel, який виявився динамічним та неоднозначним у 2020-2023 роках. Аналіз включає фактори, такі як вплив геополітичних подій та економічної нестабільності внаслідок війни. Компанія реалізує стратегії глобальної конкурентоспроможності, демонструючи гнучкість, інновації та диверсифікацію для забезпечення стійкості. Пропонуються стратегії розширення диверсифікації виробництва, вдосконалення управління ризиками та використання інноваційних технологій для адаптації до змін клімату. Практичне застосування даного дослідження полягає у можливості застосування отриманих результатів та розроблених на їх основі рекомендацій для удосконалення систем економічної безпеки аграрних підприємств

Ключові слова: фінансові ризики; ресурсна оптимізація; інноваційні стратегії; ринкові виклики; адаптація до змін

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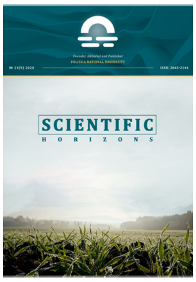

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Innovative approaches to improving the agricultural sector in the era of digitalization of the economy

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Abstract. Conducting a study on this topic is becoming relevant due to the rapid introduction of digital technologies in the agricultural sector, which requires urgent study to effectively address current challenges in agriculture. The purpose of this paper is to analyse innovative approaches to improving the efficiency of economic activity in the agri-food sector. The methods used include the analytical method, classification method, functional method, statistical method, synthesis method, and

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others. The study found that the use of innovative approaches has significantly improved the productivity and sustainability of the agricultural sector. The use of blockchain technologies has increased trust in the supply chain by providing verified and transparent information on product quality. The analysis of large volumes of data has made it possible to develop specialized solutions and strategies tailored to specific business conditions in different regions. The results show an increase in the resilience of the agricultural sector to changes in economic and climate conditions. The findings of the study highlight the potential of digital transformation as a strategic tool for innovative and sustainable development of the agricultural sector. The study identified key strategies for the future implementation of digital technologies, taking into account the needs of the agricultural sector. The conclusion emphasizes the importance of introducing digital technologies to increase efficiency, improve management and ensure the sustainability of the industry in today's digital economy. The practical significance of the paper is to analyse and highlight the factors that affect productivity and resource management in agriculture, which serves as a basis for further research and development of specific strategies and recommendations to improve the efficiency of the sector

Keywords: productivity improvement; implementation strategies; industry; resource management; efficiency

INTRODUCTION

In an era of rapidly developing digital transformation of the economy, the agricultural sector is recognized as one of the key industries that can benefit from innovative approaches and the introduction of digital technologies. This topic is important due to the need to increase productivity, adapt to climate change, ensure food security and competitiveness of the agricultural sector. Digital technologies will optimize production processes, make farms less vulnerable to extreme weather conditions, and contribute to sustainable development. In addition, they will allow farmers to be competitive on the global market and contribute to the development of new markets and jobs. The study is driven by existing and potential problems in the agricultural sector. These challenges include uneven adoption of digital technologies, data security and privacy issues, financial barriers to innovation on certain farms, the need to train qualified personnel, and ethical issues related to the use of digital technologies. Failure to study these aspects can lead to serious challenges for the development of the agricultural sector in the new digital economy.

In their work, V.V. Havrylyshyn *et al.* (2022) analyse the prospects and identify strategies for the digital transformation of cooperative entrepreneurship in Ukraine to promote sustainable economic recovery. As a result, the study uncovered and identified specific areas where digital transformation is most effective in promoting the development of cooperative entrepreneurship. However, it lacked an additional detailed overview of current digital technologies and their potential for application in the cooperative sector to allow for a more precise identification of specific opportunities and challenges. The aim of the study by B. Khakhula (2022) was to identify and analyse the economic factors that influence the development of innovation in agricultural enterprises in Ukraine, focusing on aspects of food resource use. As a result, a deep understanding of the economic problems that hinder innovation in Ukrainian agriculture, focusing on the use of food resources, was obtained. The recommendations and strategies developed on the basis of the results contributed to increasing the competitiveness and sustainability of the sector in a challenging economic environment. However, the author did not take into account the impact of the external environment, such as climate change, geopolitical factors, national and international economic policies on the development of innovations in agriculture.

M. Rudenko's (2020) study aims to reveal the impact of digitalization on the functioning of agricultural enterprises, in particular, to identify the benefits, challenges, and specific aspects of this process. The results serve as a basis for further research and strategic planning in the field of agricultural digitalization. However, there was a lack of analysis and recommendations on cybersecurity measures to protect agricultural systems in the context of digital transformation. In their work, L. Kononenko and D. Prykhodko (2023) analyse the process of forming strategies for agricultural enterprises in the context of digitalization, identify key aspects and define strategic directions that will contribute to sustainable development in the digital environment. As a result, the advantages provided by digital transformation for the development of competitive strategies were identified. However, the authors did not take into account global trends and challenges affecting the agricultural sector in the context of digitalization, such as international standards, market competition and international cooperation.

The paper by A. Shestakova *et al.* (2022) assesses the potential of digital technologies to support Ukraine's agricultural economy during the military conflict, identifies opportunities and develops strategies to increase resilience and productivity. As a result, strategies were created that contributed to increasing the resilience of the agricultural sector and reducing the impact of the conflict. However, the study lacked a detailed analysis of the military conflict and its possible impact on the agricultural sector, including supply disruptions, changes in operating conditions, and access to technical solutions. The aim of the research by A. Cherep and L. Sarbey (2023) was to study and identify key aspects of digital transformation as a means of rebuilding Ukraine's economy, to identify the benefits and ways to optimally use digital innovations. As a result, the paper focuses on the role of digitalization in rebuilding Ukraine's economy, in particular, on identifying ways to optimally use digital innovations for sustainable and effective economic development in the post-war period. However, it does not address the issues of inclusiveness and ensuring that the benefits of digitalization are enjoyed by all segments of society (Matsybora, 2023).

The purpose of the paper was to identify and analyse innovative approaches aimed at improving the efficiency of agriculture in the digital economy.

MATERIALS AND METHODS

This study was carried out using methods that reveal the theoretical and practical content of the object, providing a comprehensive view of innovative approaches to improving the agricultural sector in the context of the digital transformation of the economy. The analytical method helped to structure the economic and technological aspects of introducing digital innovations in agriculture, and identified effective strategies to improve productivity, efficiency, and competitiveness. This method identified how digital technologies affect domestic and foreign agricultural markets and the competitiveness of agricultural businesses.

The classification method allowed for the identification of groups of innovative approaches based on their impact on aspects of production, resource management, and market interaction, providing a more structured approach to formulating strategies for improving the agricultural sector in the digital age. It helped to identify different categories of innovations, their importance, and interrelationships, which opens up opportunities for accurate prioritization and improvement of strategies for implementing digital solutions in the agricultural sector. The functional method allowed considering in detail the interaction of various practical elements of the agricultural sector with digital technologies, identifying their interaction and determining the best strategies for achieving the goals of digital transformation in the economy. This method took into account the various functional aspects of the agricultural sector, systemizing them to better understand the impact of digital transformation on production and management processes, which contributes to the development of effective strategies to increase the productivity and competitiveness of the industry.

The statistical method allowed quantifying key indicators of the agricultural sector, identifying trends and relationships between digital transformation factors and business performance, contributing to an objective study of the impact of digital innovations on agriculture. The method also made it possible to identify structural changes and resource allocation in the agricultural sector, to establish correlations between the introduction of digital technologies and changes in productivity and profitability, which contributes to informed strategic decision-making in the context of the digital economy. The synthesis method in this study was used to comprehensively combine information from various sources, analyse the interaction of various aspects of the digital transformation of the agricultural sector, in order to develop a holistic view of innovative approaches and their consequences in the digital economy.

To evaluate the effectiveness and usability of innovative approaches, surveys were conducted for target groups, including agricultural professionals, technology experts, farmers, and other industry stakeholders. The surveys were conducted at agricultural enterprises and research centres that have modern infrastructure for implementing digital innovations. The survey involved 40 representatives of the agricultural sector, including farmers, technical staff and management, aged 36 to 57 years. They were asked to answer the following questions:

1. Do you perceive digital transformation as necessary to improve agricultural efficiency?
2. Have you noticed any improvement in productivity as a result of digital innovations?
3. Do you intend to expand the use of digital technologies in your business?
4. Do you use digital technologies in your agribusiness?

The research was conducted in accordance with the rules of the Declaration of Helsinki (2013).

RESULTS

Digital innovations in agriculture have proven to be a key factor in eliminating gaps and inconsistencies in production. The introduction of modern data monitoring and analysis systems allows producers to effectively interact with business processes and identify potential problems at an early stage (Pavlishyna & Kharin, 2023). One of the key aspects of digital transformation is the use of automated monitoring systems that continuously collect data on production parameters (Verbivska *et al.*, 2022).

This data includes information on soil quality, moisture, yield, and other parameters. This allows farmers and agronomists to have regular updates on the state of their farmland. Data analytics technologies are used to identify and predict potential problems, such as plant diseases or inefficient use of resources. Analytical tools allow for an in-depth analysis of the data and the development of optimal strategies for solving problems. In addition, digital technologies help to improve the management of resources such as water, fertilizer, and energy (Wrzecińska *et al.*, 2023). Thanks to precise control and automation, farmers are able to optimize the use of these resources, ensuring optimal conditions for plant growth and development.

The introduction of IoT devices in the agricultural sector is a promising area for effective monitoring and optimization of production processes (Umarov *et al.*, 2022). This innovative approach is important and powerful for ensuring a high level of efficiency in agriculture. The IoT system involves the interconnection and exchange of data between physical objects equipped with sensors, data collection tools, and other devices via the Internet. In the context of agriculture, this means the possibility of real-time monitoring of various parameters of production processes. One of the key aspects of implementing IoT in the agricultural sector is real-time monitoring of production processes. Sensors located on equipment, machinery, and infrastructure collect and transmit data on the operation of facilities. This data can relate to temperature, humidity, resource levels (such as water or fuel), and the condition of machinery and equipment. Thanks to the IoT system, farmers are able to monitor production processes in real time. This not only allows them to respond quickly to changes in the production environment, but also creates opportunities to optimize equipment performance and resource use.

The integration of artificial intelligence (AI) into agriculture has proven to be very effective as a tool for accurately predicting crop yields and adapting to changes in the environment (MacPherson *et al.*, 2022). The results of this innovative approach provide information on its significance and power in the context of optimal agricultural management. AI is used to process a large amount of data related to soil, weather conditions, plants, and other factors that affect crop production (Mondejar *et al.*, 2021). Analysing this data using artificial intelligence algorithms allows for accurate and reliable forecasts of expected yields. One of the key elements is the interaction with data from sensors located in different parts of the agricultural area. These sensors collect data on humidity, temperature, soil agrochemical composition, and other indicators that affect plant growth. The collected data is used to train AI models, which allows taking into account a variety of factors and their interrelationships. The introduction of AI allows accurately predicting yields based on the real conditions prevailing in a particular agricultural area. Such an accurate forecast allows farmers not only to ensure an optimal agricultural process, but also to respond quickly to any changes in the environment.

The introduction of blockchain technology in the agricultural sector has proved to be an effective means of ensuring the reliability of data in the supply chain. The results of this innovative approach reveal in detail the advantages and opportunities of using blockchain technology to ensure the reliability and integrity of information in agricultural production. The Blockchain is a technology that uses cryptographic methods to ensure the integrity and security of data (Gunay *et al.*, 2023). Each block in this data system has its own unique identifier, which is formed using a hash function. The hash includes information from the previous block, forming an insurmountable link between them. One of the key features of the blockchain is the formation of a chain of blocks, where each block is linked to the previous one. Each block contains its own data and the hash code of the previous block, making any attempt to change the information in the blocks extremely difficult. This approach ensures that if the data in one block is changed, it will change the hash code that includes that data, and therefore break the chain. Such a system provides a reliable and insurmountable structure for storing and transmitting data in a decentralized environment. This means that data about every stage of the supply chain (from growing plants to delivering products) is recorded and stored in blocks that cannot be manipulated or removed. The advantages of using blockchain to ensure data integrity include: irresistibility, reliability, decentralization, accuracy, and unity of data.

In a blockchain, data is validated by the entire network, making it extremely accountable and reliable. Every node in the network can check the history of the data stored in the blocks. The confirmation process ensures the reliability and inevitability of the information, as any attempt to change the data in a particular block will lead to incompatibility of the hash codes and trigger a warning to the entire network. The information in it is distributed and stored on different network nodes, which makes the system less vulnerable to attacks and unforeseen situations. This structure creates a robust system that can withstand explosions or data loss due to problems in specific parts of the network. In a blockchain, all network participants have equal access to data, which eliminates the possibility of information discrepancies and makes the data more accurate and unified. The use of drones and satellite sensing in agriculture has proven to be an effective tool for high-precision field monitoring, which helps to identify problems early and use resources efficiently (Taishykov *et al.*, 2024). They allow for regular monitoring of fields, detecting signs of disease, plant stress or other problems in real time. This approach allows agricultural producers to respond quickly and take measures to preserve their crops. Data collected from drones and satellites provides detailed information on plant health, soil moisture and other parameters. This helps to optimize the use of resources such as water, fertilizers and pesticides, reducing costs and minimizing environmental impact. Drones and satellites provide high accuracy and granularity of data, enabling differential application of inputs and accurate field mapping for production planning. Receiving regular and accurate data enables agricultural producers to make informed management decisions, leading to increased production efficiency and sustainable development.

Automation and robotisation of processes in the agricultural sector have brought about significant positive changes aimed at optimizing and improving production efficiency (Baierle *et al.*, 2022). The introduction of robots and automated systems has been a key factor in simplifying and accelerating various aspects of the agricultural process, leading to increased productivity (Abbasi *et al.*, 2022). One of the main benefits of automation is the increased efficiency of production processes. Robots and automated systems allow tasks to be performed faster and more accurately, which in turn reduces the time required for production cycles and contributes to an increase in overall farm productivity. In addition, automation ensures the stability and reliability of processes. Robots can work continuously and without losing productivity, which is especially important in the agricultural sector where time is a critical factor, especially during crop rotation and processing. An additional advantage is the reduced dependence on manual labour and the human factor. Robots can perform routine and time-consuming tasks, eliminating the possibility of human error. This increases the accuracy and consistency of tasks, reducing the likelihood of losses and improving product quality.

The use of 5G technologies in the agricultural sector opens up new perspectives and significant opportunities, especially in remote areas, where a stable Internet connection is identified as a key factor for the implementation of precision technologies (Tomble & Smuts, 2023). One of the key benefits of 5G is the provision of a stable and fast Internet connection anywhere, including remote agricultural areas, opening up access to a large amount of data and resources critical to the implementation of a number of precision technologies in agricultural production. The use of 5G technologies facilitates the implementation of precision agriculture. Fast and stable Internet connections enable the use of drones and sensors to collect data from fields in real time. These capabilities make it possible to analyse the condition of crops, identify problems and make prompt decisions to optimize production processes.

The introduction of 5G also helps to develop automation and IoT systems in the agricultural sector. A stable and high-speed connection allows for the connection of numerous devices and sensors, which enables monitoring and control of various aspects of agricultural activities. For example, automated irrigation systems or monitoring the condition of machinery. Additionally, 5G expands the possibilities for implementing artificial intelligence technologies in the agricultural sector. By providing high data transfer speeds, 5G creates the conditions for the implementation of advanced analytical systems, predictive models and other AI solutions that contribute to more accurate and efficient management of agricultural production. The use of precision farming systems, in particular the Global Positioning System (GPS) and related technologies, opens up great opportunities for optimizing the allocation and use of resources in the agricultural sector (Sridhar *et al.*, 2023). Technology has become a key tool for improving the efficiency and sustainability of agriculture.

The use of GPS allows accurately determining the geographical coordinates of each point on the field, which allows creating detailed mapping materials, including maps of soil and planted crops. This approach provides farmers with important information for making field management decisions. Precision farming systems allow adjusting the supply of resources, such as water, fertilizers and pesticides, depending on the actual needs of the plants. Optimizing the use of resources, reducing costs and increasing production efficiency. Using GPS, farmers can precisely control irrigation and spraying systems, directing them to where they are needed. This approach allows for efficient use of water and chemicals, providing an optimal environment for plant growth. GPS and precision farming systems allow for the creation of automated navigation systems for agricultural machinery. Tractors, combines and other machines can automatically control their movement on the field, ensuring precision and uniformity of work. Precision farming systems provide the ability to collect a large amount of field data in real time. This includes data on soil moisture, plant health, uniformity of resource distribution, and much more. This data is important for analysing and making detailed management decisions.

A survey was conducted among target groups to assess the usability of innovative approaches. Based on the results, a histogram was drawn up and the results of the survey are shown in Figure 1.

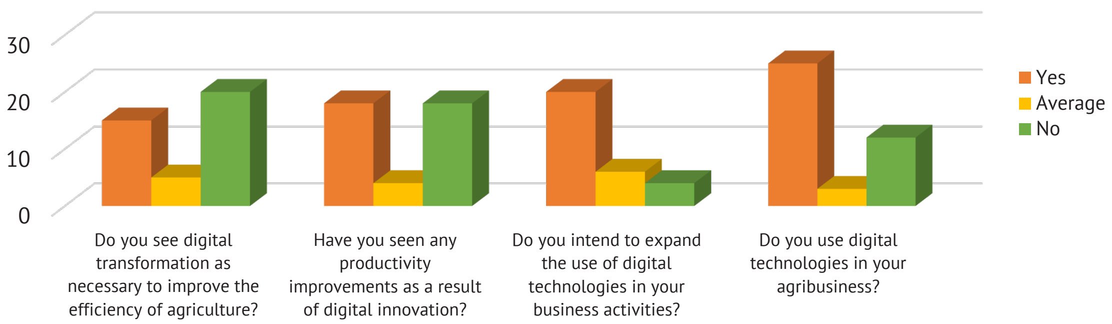

Figure 1. *The results of the survey on target groups*

Source: *compiled by the authors*

The results confirm that there is a diversity of views on digital transformation in the agricultural sector. While a large proportion of participants recognize the importance of digital innovations for improving farm efficiency, there are also those who are cautious or reticent to use digital technologies. In particular, almost half of the respondents confirmed that productivity improvements have been achieved through digital innovation. It is worth noting that most of them express their intention to expand the use of digital technologies in the future. However, there are also those who remain cautious and even reject digital solutions. These findings point to the need to develop flexible strategies for the introduction of digital technologies that take into account the diversity of approaches and readiness of different groups of rural entrepreneurs for digital transformation.

As a result, it was found that the introduction of digital innovations has significantly improved the efficiency and competitiveness of agriculture in the modern digital economy. In particular, automation, robotics, and the use of precision farming systems contribute to increased productivity and optimized resource use. This allows for efficient cultivation and processing of agricultural products, reducing costs and increasing yields.

DISCUSSION

This research work was focused on analysing and studying innovative approaches aimed at increasing the efficiency and improvement of agriculture in the digital economy. The study highlighted the importance of using digital tools to optimize business processes and its positive impact on the productivity and sustainability of agricultural enterprises. The analysis of the results showed that the introduction of modern technologies has the potential to solve a number of problems and improve the overall state of agricultural production in the digital economy.

One of the key advantages of this study is the in-depth consideration of innovative approaches to improving the agricultural sector. The study analyses in detail the impact of digital technologies such as artificial intelligence, data analytics, the Internet of Things, and others on all aspects of agriculture. The focus is on specific tools and methods, such as the use of AI for data analysis, the use of IoT and sensors to collect information, process automation in precision farming, and others. This allowed understanding how these technologies can be used by farmers to improve farm management, increase yields and reduce costs. In addition, the study took into account important aspects such as value chain interactions and environmental sustainability, which demonstrates a comprehensive approach to the topic. The inclusion of environmental aspects and the participation of all links in the value chain underlines the importance of sustainable development and interaction in the agricultural sector. The study also identified the challenges faced by agriculture in the process of digital transformation, which helped to identify possible limitations and ways to overcome them, making the work practically applicable to farmers whose solutions may include the integration of digital innovations to improve the efficiency and sustainability of their farms. The paper emphasizes its practical approach and relevance to the agricultural sector in the digital age.

In their study, Y.E.L. Doukas *et al.* (2022) identified the current level of digitalization in the EU agricultural sector, key trends, and identified European policy responses to these challenges. The results of this work serve as a basis for further discussions and the development of strategies to improve the digital transformation of agriculture in the European Union. They are also useful for decision-making at the European and national level. The study by these authors analysed specific technological and policy initiatives in the context of the EU and its members. The work on innovation approaches focused on the overall picture of innovation and technology in agriculture. Both studies are important for understanding and supporting digital transformation in the agricultural sector.

The study by A. Devaux *et al.* (2018) was aimed at examining the role of agricultural innovation in creating an inclusive value chain that takes into account the needs of all actors and promotes sustainable development. As a result, recommendations were formulated for governmental and non-profit organizations, agricultural enterprises and other stakeholders on further actions for inclusive agricultural value chain development. This paper aims to explore the relationship between agricultural innovation and inclusive value chain development, with a focus on the inclusion of all actors. This study focuses on a general approach to improving the agricultural sector in the digital economy, incorporating a wide range of digital technologies. Both studies reflect different aspects and approaches to the problem, but together they aim to contribute to the sustainable and inclusive development of the agricultural sector.

In their study, M.H. Ehlers *et al.* (2022) identified and analysed possible scenarios for the development of agricultural policy in Europe in the context of active digitalization, taking into account current trends, technological innovations and challenges facing agriculture. The study provides sound recommendations for shaping European agricultural policy in the digital economy, contributing to the sustainable development and competitiveness of the agricultural sector. As a result, the findings of the study identified optimal scenarios for the introduction of digital technologies in the European agricultural sector, which contributed to the further development and modernization of this industry in the digital age. This work was aimed at developing recommendations for the formation of agricultural policy in the context of digital transformation. The study focused on innovative approaches, with a focus on specific practical recommendations and strategies for the effective implementation of innovations in the sector. Both studies include a state-of-the-art review, technology study, identification of key challenges, scenario development, and performance evaluation. Both aim to provide evidence-based recommendations for improving the agricultural sector in the digital age.

The aim of the study by S. Abbate *et al.* (2023) was to unlock the potential of digital and sustainable transitions in the agri-food sector, as well as to identify the best strategies for their successful implementation. The study provided and identified insights on how digitalization has contributed to the achievement of sustainable development goals in the agri-food sector. The research findings are useful for developing strategies aimed at ensuring the sustainable development of the agri-food sector in the context of digital transformation and will contribute to the understanding and implementation of innovations in this area. Both studies make an important contribution to understanding the interaction between the agri-food sector and digital transformation. The Digital and Sustainable Transition additionally addresses sustainability issues, providing more comprehensive information on the transition to digital agriculture in the context of sustainable development, and additionally uses trend analysis, Strengths Weaknesses Opportunities Threats (SWOT) analysis and scenario modelling. This study focuses on general innovation approaches.

The study by V. Farace and A. Tarabella (2024) aims to study the role of digitalization as a driving force for the implementation of circular economy principles in the agri-food sector of small and medium-sized enterprises (SMEs). The study aimed to determine how these two trends can interact to promote sustainable development and optimize resources in the agricultural sector. The study found that digitalization and the circular economy can interact synergistically to provide agri-food SMEs with more efficient, resilient and sustainable production. Considering the interaction of these two approaches provides opportunities for further research and innovation in agriculture in the digital economy. This paper focuses on the interplay between digitalization and the circular economy to improve sustainability and efficiency in agri-food production. It emphasizes the opportunities and challenges of implementing digital and circular approaches at the level of agricultural SMEs. And this study presents specific tools and methods that can be used in practice by farmers. Both studies have made a valuable contribution to understanding how to improve the agricultural sector in the context of digital transformation.

An analysis of various studies on innovative approaches to improving the agricultural sector points to several key findings and trends. The use of innovative technologies, such as artificial intelligence and data analytics, is an important factor in improving the agricultural sector (Radchenko *et al.*, 2023). Intensive analysis of large amounts of data has allowed farmers to make more accurate and informed decisions to optimize production and resources. The use of precision farming technologies has made it possible to use land resources more efficiently and reduce environmental impact. Digital technologies allow for more efficient management of water, fertilizers, and other agricultural resources (Yatsiv *et al.*, 2022). Interaction in the value chain is also becoming important, where the introduction of digital technologies has facilitated cooperation between different participants. The importance of innovations in the agricultural sector is also underlined by their positive impact on the environmental sustainability of the industry. Digital innovations help reduce negative environmental impacts and promote sustainable production.

CONCLUSIONS

The study found that the introduction of digital technologies in the agricultural sector has great potential for transforming and optimizing production processes. One of the key trends was the active use of artificial intelligence and data analytics to process large amounts of information. This has enabled farmers to conduct detailed analysis, make informed decisions and optimize production. In particular, automated systems based on data analysis have enabled accurate decision-making in real time. This is important for the effective management of various aspects of agriculture, such as irrigation, fertilization, and machinery management.

The study also highlighted the importance of using IoT and sensors to collect real data from fields and livestock farms. This made it possible to monitor the condition of crops, track growing parameters and ensure optimal conditions for crop development. However, along with the benefits of digitalization, challenges have also been identified. Cybersecurity is becoming an increasingly important issue as the amount of digital data and its importance for agricultural production grows.

In summary, the study underlined that digital technologies have played a key role in increasing the efficiency, resilience, and competitiveness of the agricultural sector in the digital economy. The transition to digital production has become a strategic step for farmers and agricultural enterprises to achieve optimal results. The findings suggest that digital transformation in the agricultural sector has great potential to improve farm management, increase production efficiency, and create more resilient and sustainable agricultural production systems. Future research in the area of innovative approaches in agriculture could focus on the development of integrated digital platforms. These platforms could be designed to bring together different technologies to ensure efficient and coordinated use by farmers.

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CONFLICT OF INTEREST

None.

REFERENCES

[1] Abbasi, R., Martinez, P., & Ahmad, R. (2022). The digitization of agricultural industry – A systematic literature review on Agriculture 4.0. *Smart Agricultural Technology*, 2, article number 1000042. doi: 10.1016/j.atech.2022.100042.

[2] Abbate, S., Centobelli, P., & Cerchione, R. (2023). The digital and sustainable transition of the agri-food sector. *Technological Forecasting and Social Change*, 187, article number 122222. doi: 10.1016/j.techfore.2022.122222.

[3] Baierle, I.C., da Silva, F.T., de Faria Correa, R.G., Schaefer, J.L., Da Costa, M.B., Benitez, G.B., & Benitez Nara, E.O. (2022). Competitiveness of food industry in the era of digital transformation towards Agriculture 4.0. *Sustainability*, 14(18), article number 11779. doi: 10.3390/su141811779..

[4] Cherep, A., & Sarbey, L. (2023). Digitalisation as a tool for rebuilding the economy of Ukraine in the post-war period. *Young Scientist*, 12(124), 184-188. doi: 10.32839/2304-5809/2023-12-124-4.

[5] Devaux, A., Torero, M., Donovan, J., & Horton, D. (2018). Agricultural innovation and inclusive value-chain development: A review. *Journal of Agribusiness in Developing and Emerging Economies*, 8(1), 99-123. doi: 10.1108/JADEE-06-2017-0065.

[6] Doukas, Y.E.L., Maravegias, N., & Chrysomallidis, C. (2022). Digitalization in the EU agricultural sector: Seeking a European policy response. In *Food policy modelling: Responses to current issues* (pp. 83-98). Cham: Springer. doi: 10.1007/978-3-031-08317-4_6.

[7] Ehlers, M.-H., Finger, R., El Benni, N., Gocht, A., Sørensen, C.A., Gusset, M., Pfeifer, C., Poppe, K., Regan, Á., Rose, D.C., Wolfert, S., & Huber, R. (2022). Scenarios for European agricultural policymaking in the era of digitalisation. *Agricultural Systems*, 196, article number 103318. doi: 10.1016/j.agsy.2021.103318.

[8] Farace, B., & Tarabella, A. (2024). Exploring the role of digitalization as a driver for the adoption of circular economy principles in agrifood SMEs – An interpretive case study. *British Food Journal*, 126(1), 409-427. doi: 10.1108/BFJ-12-2022-1103.

[9] Gunay, S., Sraieb, M.M., Kaskaloglu, K., & Yıldız, M.E. (2023). Cryptocurrencies and global sustainability: Do blockchained sectors have distinctive effects? *Journal of Cleaner Production*, 425, article number 138943. doi: 10.1016/j.jclepro.2023.138943.

[10] Havrylyshyn, V.V., Oleksyn, I.I., & Tsolka, A.B. (2022). Directions of digitalization of cooperative entrepreneurship in the period of post-war reconstruction of Ukraine. *Herald of LUTE. Economic Sciences*, 68, 35-41. doi: 10.36477/2522-1205-2022-68-05.

[11] Khakhula, B. (2022). Economic problems of the development of innovative activity in agricultural enterprises of Ukraine. *Food Resources*, 10(19), 265-273. doi: 10.31073/foodresources2022-19-29.

[12] Kononenko, L., & Prykhodko, D. (2023). Formation of strategies of agricultural enterprises in the conditions of digitalisation. In *Proceedings of the all-Ukrainian scientific and practical conference "problems and prospects of economic development in the conditions of modernisation processes in Ukraine and the world"* (pp. 69-70). Kropyvnytskyi: Central Ukrainian National Technical University.

[13] MacPherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, I., & Helming, K. (2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review. *Agronomy for Sustainable Development*, 42, article number 70. doi: 10.1007/s13593-022-00792-6.

[14] Matsybora, T. (2023). Investment activity in Ukrainian agriculture during the war: New challenges and threats. *Ekonomika APK*, 30(5), 10-18. doi: 10.32317/2221-1055.202305010.

[15] Mondejar, M.E., Avtar, R., Baños Diaz, H.L., Dubey, R.K., Esteban, J., Gómez-Morales, A., Hallam, B., Mbungu, N.T., Okolo, C.C., Prasad, K.A., She, Q., & Garcia-Segura, S. (2021). Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet. *Science of the Total Environment*, 794, article number 148539. doi: 10.1016/j.scitotenv.2021.148539.

[16] Pavlishyna, N.M., & Kharin, A.V. (2023). Innovations in the era of digitalization. *Visnyk of Kherson National Technical University*, 1(84), 179-187. https://doi.org/10.35546/kntu2078-4481.2023.1.24.

[17] Radchenko, O., Tkach, L., & Dendebera, O. (2023). Financing innovations in the agricultural industry as a component of the digital development of Ukraine's economy. *Scientific Bulletin of Mukachevo State University. Series "Economics"*, 10(4), 54-65. doi: 10.52566/msu-econ4.2023.54.

[18] Rudenko, M. (2020). Features of the impact of digitalisation on the functioning of agricultural enterprises. *Herald of KhNAU. Economic Sciences*, 1, 202-212. doi: 10.31359/2312-3427-2019-1-202.

[19] Shestakova, A., Tkachuk, V., Melnyk, T., & Travin, V. (2022). Digital opportunities of the agrarian economy of Ukraine during the war period. *Economics, Management and Administration*, 3(101), 15-23. doi: 10.26642/ema-2022-3(101)-15-23.

[20] Sridhar, A., Ponnuchamy, M., Kumar, P.S., Kapoor, A., Nguyen Vo, D.-V., & Rangasamy, G. (2023). Digitalization of the agro-food sector for achieving sustainable development goals: A review. *Sustainable Food Technology*, 1(6), 783-802. doi: 10.1039/D3FB00124E.

[21] Taishykov, Z., Tolysbayeva, M., Zhumanazarov, K., Ibraimova, S., & Mizambekova, Z. (2024). Management of innovation processes in agriculture. *World Development Perspectives*, 33, article number 100566. doi: 10.1016/j.wdp.2024.100566.
[22] The Declaration of Helsinki. (2013). Retrieved from https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/.
[23] Tomble, R., & Smuts, H. (2023). Agricultural social networks: An agricultural value chain-based digitalization framework for an inclusive digital economy. *Applied Sciences*, 13(11), article number 6382. doi: 10.3390/app13116382.
[24] Umarov, I.M., Akhmetova, Z.B., Turlybekova, N.M., Tulebayeva, N.T., & Niyazbekova, Sh.U. (2022). Digitalization of agriculture – The path to the future of geoeconomics. In *Geo-economy of the future: Sustainable agriculture and alternative energy* (pp. 333-344). Cham: Springer. doi: 10.1007/978-3-030-92303-7_37.
[25] Verbivska, L., Zaichko, I., & Tymchenko, N. (2022). Management of investment and innovation resources of enterprises in the realities of digital economy. *Investments: Practice and Evidence*, 2, 67-73. doi: 10.32702/2306-6814.2022.2.67.
[26] Wrzecińska, M., Czerniawska-Piątkowska, E., Kowalewska, I., Kowalczyk, A., Mylostyvyi, R., & Stefaniak, W. (2023). Agriculture in the face of new digitization technologies. *Ukrainian Black Sea Region Agrarian Science*, 27(3), 9-17. doi: 10.56407/bs.agrarian/3.2023.09.
[27] Yatsiv, I., Yatsiv, S., & Smulka, O. (2022). Formation of production technological efficiency in the agricultural enterprises of Ukraine. *International Journal of Information Technology Project Management*, 13(2). doi: 10.4018/IJITPM.311843.

Інноваційні підходи до вдосконалення аграрного сектору в епоху цифровізації економіки

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Анотація. Проведення дослідження на цю тему стає актуальним через стрімке впровадження цифрових технологій в аграрний сектор, що вимагає термінового вивчення для ефективного розв'язання сучасних викликів у сфері сільського господарства. Мета даної роботи полягала в аналізі інноваційних підходів для вдосконалення ефективності господарської діяльності в агропродовольчому секторі. Серед використаних методів слід зазначити аналітичний метод, метод класифікації, функціональний метод, статистичний метод, метод синтезу та інші. У процесі дослідження виявлено, що робота із застосуванням інноваційних підходів значно покращила продуктивність та стійкість аграрного сектору. Використання блокчейн-технологій підвищило довіру в ланцюгу постачання, забезпечивши перевірену та прозору інформацію про якість продукції. Аналіз великих обсягів даних дав можливість розробити спеціалізовані рішення та стратегії, підлаштовані до конкретних умов господарювання в різних регіонах. Отримані результати свідчать про збільшення стійкості аграрного сектору до змін економічних та кліматичних умов. Висновки дослідження підкреслюють потенціал цифрової трансформації як стратегічного інструменту для інноваційного та сталого розвитку сільськогосподарського сектору. Робота визначила ключові стратегії для майбутнього впровадження цифрових технологій, враховуючи потреби аграрного сектору. Висновок акцентує на важливості впровадження цифрових технологій для підвищення ефективності, удосконалення управління та забезпечення стійкості галузі в умовах сучасної цифрової економіки. Практичне значення роботи полягає в аналізі та висвітленні факторів, що впливають на продуктивність та управління ресурсами в сільському господарстві, що служить основою для подальших досліджень та розробки конкретних стратегій та рекомендацій для підвищення ефективності галузі

Ключові слова: підвищення продуктивності; стратегії впровадження; галузь; управління ресурсами; ефективність

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