НАУКОВІ ГОРИЗОНТИ

Засновник, редакція, видавець:
Поліський національний університет

Рік заснування: 1998

Рекомендовано до друку та поширення через мережу Інтернет Вченою радою Поліського національного університету (протокол № 10 від 26 квітня 2023 року)

Свідоцтво про державну реєстрацію друкованого засобу масової інформації
серії КВ № 24997-14937 ПР

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

Журнал представлено у міжнародних наукометричних базах даних, репозитаріях та пошукових системах: Інституційний репозитарій Поліського національного університету, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index (OAJI), Scopus, Index Copernicus, Реєстр наукових видань України, Національна бібліотека України імені В. І. Вернадського, Crossref, Directory of Open Access Journals (DOAJ)

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SCIENTIFIC HORIZONS

Founder, Editorial and Publisher:
Polissia National University

Year of foundation: 1998

Recommended for printing and distribution
via the Internet by the Academic Council
of Polissia National University
(Minutes No. 10 of April 26, 2023)

Certificate of state registration
print mass media
Series KV No. 24997-14937 PR

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

The journal is presented international scientometric databases, repositories and scientific systems: Institutional Repository of Polissia National University, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index (OAJI), Scopus, Index Copernicus, Register of Scientific Publications of Ukraine, Vernadsky National Library of Ukraine, Crossref, Directory of Open Access Journals (DOAJ)

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НАУКОВІ ГОРИЗОНТИ

Том 26, № 3 2023

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

SCIENTIFIC HORIZONS

Vol. 26, No. 3 2023

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

ЗМІСТ

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SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 9-23

UDC 619:616-001.4-08:615.26/27:611.018.5:[636.7/.8+636.92]
DOI: 10.48077/scihor3.2023.09

Treatment of pets with the active substance dexpanthenol in wound processes

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Article's History:
Received: 27.01.2023
Revised: 27.03.2023
Accepted: 10.04.2023

Suggested Citation:
Paliy, A., Pavlichenko, O., Rodionova, K., Morozov, M., & Dankevych, N. (2023). Treatment of pets with the active substance dexpanthenol in wound processes. *Scientific Horizons*, 26(3), 9-23.

Abstract. Animal skin is a complex organ that directly perceives the influence of the external environment and performs a barrier-protective function, helps maintain the balance of the internal environment of the body. Disruption of each of the levels of the protective system leads to the development of inflammatory skin diseases. Treatment of wounds remains one of the most pressing scientific and practical problems of modern veterinary medicine. A number of researchers are searching for and developing new veterinary drugs for the treatment of wounds of various etiologies in small pets, but the use of drugs often causes adverse skin reactions. The purpose of this study was to evaluate the effectiveness of using a veterinary drug (ointment) in the treatment of wounds in

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domestic animals (dogs, cats, rabbits). The paper uses standard clinical, haematological, and biochemical research methods. The studies used a drug with the active substance dexpanthenol and excipients decamethoxine, Vaseline oil, emulsifier, glycerin, methylparaben, propylparaben, and purified water. The drug under study effectively reduced the wound surface area at all observation periods. It is proved that when using dexpanthenol-based ointment (10%), a complete wound-healing effect was observed in experimental animals on the 14th day of treatment: the area of wound surfaces decreased by 93.1±1.51%. The examined indicators were statistically substantially different from those in the group of untreated animals with skin wounds. The general clinical condition of domestic animals was examined, haematological and biochemical studies of animal blood were conducted under the conditions of applying an experimental drug to damaged skin areas. In animals with skin damage without treatment, the dynamic development of an acute inflammatory process in the body, the development of endogenous intoxication syndrome, signs of wound infection, pronounced exudation and slowing of contraction were observed. The developed veterinary drug with the active substance dexpanthenol simultaneously shows a pronounced anti-inflammatory and wound-healing effect and provides a rapid therapeutic effect in wound processes in small pets

Keywords: dogs, cats, rabbits, wounds, dexpanthenol, morpho-physiological parameters of blood, blood serum

INTRODUCTION

Every year, the number of small pets in the private homes of urban citizens is constantly growing. The most common pathology among animal diseases is mechanical damage to the skin – wounds that require urgent care. Veterinarians are provided with a large number of treatment tools, but the search and development of environmentally friendly and safe veterinary drugs for the treatment of skin pathologies in small pets remain an urgent issue.

All wounds, without exception, heal through inflammation, and in the absence of antiseptic treatment – through suppuration. Many aspects of wound healing in small animals have not yet been fully clarified: mechanisms of inhibition of granulation tissue growth and maturation, differentiation of connective tissue cells, and the relationship between inflammation, regeneration, and fibrosis in complicated wounds (Mauldin & Peters-Kennedy, 2016; Fernandes *et al.,* 2018; Somjorn *et al.,* 2021). Conservative means and methods of treating complicated wounds are often ineffective. There is a need to further search for new and improve registered drugs and treatment methods that stimulate reparative processes in wounds of various etiologies, and an in-depth investigation of their pharmacognosy.

Darwin & Tomic-Canic (2018) proved that the wound process is a dynamic self-regulating system, as each of its phases prepares and starts the next. The success of the wound process (Davidson, 2015; Gonzalez *et al.,* 2016; Cañedo-Dorantes & Cañedo-Ayala, 2019) depends on the type, size, location of the wound, granulation features, nature and amount of wound exudate, invasiveness and virulence of microorganisms, the immune status of the patient's body, the presence of concomitant diseases, and the rational choice of wound treatment tactics. The main condition for the normal course of the wound healing process is the synchronisation of the epithelialisation process, on the one hand, and the maturation of granulation tissue, on the other. Thus, in the dynamics of wound healing, three main periods are noted: cleaning of the wound defect from necrotic masses due to inflammation; proliferation of connective tissue elements with the formation of granulation tissue filling the wound; scar formation, its remodelling, and epithelialisation of tissues (Stettler *et al.,* 2017; Lux, 2022).

Basov *et al.* (2021) developed and tested the use in surgical practice of a device for visual monitoring of the wound during its treatment with pharmacological solutions (including antiseptic, antiseptic oxidizer, and osmotically active agent). This method accelerates the therapeutic effect by 43.8% compared to wound treatment with a 0.02% aqueous chlorhexidine solution and a local ointment with an antibiotic.

Negative Pressure Wound Therapy (NPWT) has been used in Europe and the United States for about 15 years. Studies by Nolff (2021) on cats have shown that the device effectively copes with infected wounds, increases granulation and neovascularisation, and promotes wound narrowing through active macrocontrtaction.

The group of researchers (Bekeschus *et al.,* 2021) tested gas plasma technology and recommended it for use in veterinary practice. Reactive oxygen and nitrogen forms have been shown to promote wound healing at various stages, have a negative effect on various types of microorganisms that complicate the inflammatory process, and lead to rapid hemostasis in the wounds of experimental animals (rodents and pigs). Enciso *et al.* (2020) recommend the use of allogeneic ASC therapy to improve the healing of acute and chronic wounds in dogs. They proved that treatment of wounds with fat mesenchymal stem cells from an adult animal already on the 90th day contributes to re-epithelialisation (more than 97%).

Alshehabat *et al.* (2020), based on experimental studies, suggest using the following methods for treating wounds in dogs: wet burn ointment (contains B-sitosterol, baicalin, and berberine as active ingredients based on beeswax and sesame oil). They note that this method

of treatment helps to accelerate epithelialisation, quickly reduces the wound area, and does not cause allergic reactions in animals with weakened immune systems.

In recent years, the attention of researchers has been attracted to therapeutic drugs for wound healing, especially with signs of bacterial infection, based on pantothenic acid. Researchers (Ebner *et al.,* 2002; Li-Mei *et al.,* 2016; Ogden *et al.,* 2019) prove that it is necessary for the normal function of the epithelium. It is a component of coenzyme A, which serves as a co-factor for various enzyme-catalysed reactions that are important in the metabolism of carbohydrates, fatty acids, proteins, gluconeogenesis, sterols, steroid hormones, and porphyrins. A stable alcoholic analogue of pantothenic acid is dexpanthenol, the local application of which is based on good penetration into the skin and rapid local concentration. During the treatment of superficial, postoperative wounds, and scars at the stage of formation, its effectiveness increases if dexpanthenol is introduced into the emulsion or ointments. It provides support for anti-inflammatory and antioxidant activity, which play an important role in cellular defence and recovery systems against oxidative stress and inflammatory response (Marquardt *et al.,* 2015; Nahirniy, 2022). Proksch *et al.* (2017) identified that the mode of action of dexpanthenol at the molecular level increases the mobility of molecular components of the stratum corneum of the skin, which are important for ensuring its barrier function, and modulates the expression of genes important for wound healing.

The purpose of this study was to determine the therapeutic effectiveness of dexpanthenol-based ointment in wound processes in small domestic animals.

MATERIALS AND METHODS

The study was conducted in 2020-2021 based on the laboratory of Veterinary Hygiene and Parasitology of the National scientific centre "Institute of Experimental and Clinical Veterinary Medicine", and in an animal shelter (Balakliya, Kharkiv region). The study programme was reviewed and approved in accordance with the current procedure by the bioethics commission of the National scientific centre "Institute of Experimental and Clinical Veterinary Medicine".

A drug with the active substance dexpanthenol was used to evaluate the effectiveness of the ointment in the treatment of wounds in domestic animals. Composition of the product (1 ml): dexpanthenol – 10 mg; excipients: decamethoxine, Vaseline oil, emulsifier, glycerin, methylparaben, propylparaben, purified water.

The following groups of animals were formed to conduct research:

Group I (intact animals) – clinically healthy animals. No clinical signs of skin damage were identified. The skin was smooth, elastic, moderately hydrated.

Group II (control pathology) – animals with skin damage, whose owners sought help within the first five days after the occurrence of wound damage. By origin, wounds are accidental, by the nature of the damage – stab and torn, by the depth of the damage – surface, by the degree of tissue destruction – with a large area of damage, by the degree of infection – contaminated. The animals were not treated with chemotherapeutic agents.

Group III (experiment) – animals with skin damage, whose owners sought help within the first four hours after the occurrence of wound damage (fresh wounds). By origin, wounds are accidental, by the nature of the damage – stab and torn, by the depth of the damage – surface, by the degree of tissue destruction – with a large area of damage, by the degree of infection – contaminated. The animals were treated with the drug under study.

In the first stage of the study, the wound-healing effectiveness of a veterinary drug was examined on mongrel cats of different ages and sexes. The following groups of animals were formed to conduct research:

Group I (intact control) – clinically healthy mongrel cats (n=15) aged 1 to 4 years with body weight from 2.1 to 3.9 kg. The animals were kept in a vivarium, but they did not have skin pathology, and the drug was not applied to them.

Group II (positive control, control pathology) – animals (n=9) with skin damage without treatment.

Group III (experiment) – animals (n=15) that were treated with the drug under study on damaged skin areas.

The animals were kept in aviaries on a standard balanced diet with free access to water, according to physiological needs. During the experiment, cats were examined, which included visual, palpation, thermometry, respiratory and heart rate examinations. Clinical examination of cats in the study groups included a detailed medical history and examination of the condition of the skin and mucous membranes (Stein, 1981; Vojtkovská *et al.,* 2020). Dynamic monitoring of animals was performed and changes in the wound surface area were determined 3, 7, and 14 days after the onset of the pathological process. In cats of the experimental groups, the affected skin areas were treated with preparations by applying a thin layer to the skin 3 times a day. Before applying the drug, hygienic treatment of the affected area was performed. Evaluation of the wound-healing effect of the drug was performed by analysing the activity of wound surface contraction in dynamics on the 3rd, 5th, 7th, 9th, and 14th days, determining the area of the wound surface in animals. The intensity of skin damage was established: slight erythema, clear erythema, clear erythema with compaction, erythema with hemorrhagic phenomena, and ulcers with severe infiltration (Elzayat *et al.*, 2018; Sofrona *et al.,* 2020). During the study period, blood samples were taken from cats for haematological and biochemical evaluation: before the drug was used, on the 3rd, 5th, 7th, and 14th days of the experiment.

In the second stage of experimental studies, the effectiveness of the veterinary drug was examined on

mongrel dogs of different ages and sexes. The following groups of animals were formed to conduct research:

Group I (intact animals) – clinically healthy mongrel dogs (n=17) aged from 1 to 9 years with body weight from 3.8 to 9.7 kg. No clinical signs of skin damage were identified.

Group II (control pathology) – dogs (n=10) with skin damage without correction and treatment.

Group III (experiment) – dogs (n=17) that were treated with the drug under study on damaged skin areas.

Animals of the control and experimental groups were kept in aviaries on a standard balanced diet with free access to water, according to physiological needs. Clinical examination of dogs of the experimental groups included a detailed medical history and evaluation of the coat condition, namely, the determination of thickness, elasticity, and dryness of the skin (Hardy, 1981). Dynamic monitoring of dogs was performed and changes in the wound surface area were determined 3, 5, 7, 9, and 14 days after the onset of the pathological process. In dogs of experimental groups, the affected skin areas were treated with the drug by applying a thin layer 3 times a day. Before applying the drug, hygienic treatment of the affected area was performed (Frees, 2018).

When assessing the influence of the adverse factor, substantial deviations in relation to the indicators of animals of the intact group and control pathology were determined ($p<0.05$). The criteria for the wound-healing effect of the drug under study were only substantially positive changes in the examined indicators in relation to the control pathology group.

During the study period, blood samples were taken from dogs for haematological and biochemical studies: before the drug was administered, on the 3rd, 7th, and 14th days of the experiment.

In the third stage of the experiment, the wound-healing effectiveness of the drug under study was examined on decorative rabbits. The following groups of animals were formed to conduct research:

Group I (intact animals) – clinically healthy decorative rabbits (n=5) without skin damage.

Group II (control pathology) – rabbits (n=5) with skin damage without correction and treatment.

Group III (experiment) – rabbits (n=5), that were treated with the drug under study on damaged skin areas.

Animals of the control and experimental groups were kept in cages on a standard diet with free access to water, according to physiological needs. Clinical examination of rabbits of the research groups included determining the condition of the coat. In rabbits of the experimental groups, the affected skin areas were treated with the drug by applying a thin layer 3 times a day. Before applying the drug, hygienic treatment of the affected area was performed.

Assessment of the wound-healing effect of the drug under study was conducted by determining the area of the wound surface in animals in dynamics on the 3rd, 5th, 7th, 9th, and 14th days. When assessing the influence of the adverse factor, substantial deviations in relation to the indicators of animals of the intact group and control pathology were determined ($p<0.05$).

The blood samples were kept in test tubes in a thermostat for 15 minutes to obtain serum from animals. A stainless metal stick was applied along the inner wall of the test tube to separate the serum from the clot. The samples were centrifuged at 3000 rpm for 15 minutes. Blood serum was taken using a pipette dispenser in sterile Eppendorf-type tubes.

Haematological examinations included: the determination of total haemoglobin (HGB), hematocrit (HCT), red blood cell count (RBC), and white blood cell count (WBC) (Bauer & Moritz, 2008; Becker *et al.,* 2008). The level of activity of the following enzymes was determined in the blood serum of animals: alanine aminotransferase (ALAT; EC 2.6.1.2) and aspartate aminotransferases (ASAT; EC 2.6.1.1) according to the Reitman-Frenkel method (Wilkinson *et al.,* 1972).

Examinations of the functional state of the liver of experimental animals included the determination of total protein by turbodimetric method, c-reactive protein (CRP), and urea – by the diacetylmonooxime method (Doumas *et al.,* 1981).

Statistical processing of the results was conducted using statistical methods (STATISTICA 10.0 for Windows) with the determination of the arithmetic mean (M), the statistical error of the arithmetic mean (m), the probability of difference (P) between the arithmetic mean of two variational series by the confidence coefficient for the difference of the averages (t). The difference between the two values was considered substantial at $*p\leqslant0.05$; $**p\leqslant0.01$; $***p\leqslant0.001$.

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

RESULTS AND DISCUSSION

In the first stage of the study, clinical examinations of mongrel cats were conducted to establish the effectiveness of the veterinary drug under study. The general clinical condition of cats was examined, haematological and biochemical examinations of cat blood were performed under the conditions of applying the drug to damaged areas of the skin. The clinical condition of cats in the control and experimental groups was determined daily throughout the entire study period.

Thermometry was performed, the condition of visible mucous membranes, skin and coat was examined.

According to the results of clinical observations at the beginning of the experiment, it was established that cats of Group I (intact animals) were clinically healthy, had visible mucous membranes of pale pink colour, moderately shiny, without damage, pigmented. The skin was smooth, medium thickness, elastic, without damage. The coat was thick, shiny, and close to the body. In cats of Group II (control pathology), a skin wound process of various etiologies was recorded: acute inflammation, skin compaction, scratches, rashes, pale skin, not elastic. Animals of this group were not treated with drugs. In cats of Group III (experiment), clinical signs of skin inflammation in the extremities and muzzle were noted: redness, peeling and itching, cracks, and bleeding. The animals were depressed and did not consume food willingly. On the damaged areas of the skin of cats, a thin layer of the drug under study was applied three times a day. Analysis of experiments on the wound-healing and anti-inflammatory properties of the experimental drug showed its high effectiveness (Table 1).

Table 1. *Dynamics of changes in the area of wound surfaces (M±m) in cats under conditions of skin damage*

Observation period, day	Wound surface area in observation groups, mm^2	
	Skin damage without correction	Application of the experimental drug
3	0.72±0.02	0.52±0.02*
5	0.59±0.02	0.28±0.01*
7	0.54±0.01	0.20±0.01*
9	0.37±0.03	0.12±0.02*
14	0.05±0.01	003±0.01*

Note: ** – this value differs statistically substantially (p<0.05) from the same value in the group of untreated animals with skin damage*
Source: *compiled by the authors*

The above indicates a tendency to heal wound processes when using the experimental drug. Cats with untreated skin damage showed signs of wound infection, severe exudation, and slowing contraction. Notably, in cats with skin damage, no wound infection was observed when using the ointment, and there was no exudation. The drug under study effectively reduced the wound surface area at all observation periods. The examined indicators were statistically substantially different from those in the group of untreated animals with skin wounds. Along with this, a number of morphological parameters of the blood of cats of the control and experimental groups were examined (Table 2).

Table 2. *Dynamics of morpho-physiological parameters of cat blood under the influence of the experimental drug (M±m)*

Experimental groups	Duration of the examination, days			
	before application	3rd day	7th day	14th day
	Haemoglobin (HGB), g/dm^3			
I	127.42±0.90	128.07±1.11	130.03±1.09	127.44±0.97
II	123.19±1.02*	123.17±1.32*	123.93±2.14*	128.15±1.58
III	119.75±1.15*	122.18±1.02*	124.17±1.2*	125.09±1.47
	Hematocrit (HCT), %			
I	36.34±1.23	37.15±1.42	38.16±1.12	37.35±1.12
II	37.13±1.12	37.08±0.25	37.24±1.15	38.19±1.83
III	45.33±1.03*	44.94±1.91*	36.22±1.26	37.12±1.54
	Red blood cells (RBC), $10^{12}/ dm^3$			
I	8.18±0.46	8.24±0.85	8.59±0.27	9.03±0.51
II	8.17±0.93	8.75±1.32	8.16±0.11	8.12±0.47

Table 2, Continued

Experimental groups	Duration of the examination, days			
	before application	3rd day	7th day	14th day
III	8.36±0.24	8.11±0.32	8.26±0.12	8.38±0.51
White blood cells (WBC), 10^9/dm^3				
I	9.51±0.43	9.57±0.26	9.87±0.24	9.54±0.15
II	13.25±0.41*	14.74±0.53*	13.74±0.43*	13.98±0.43*
III	12.85±0.63*	11.42±0.91*	10.99±1.14	9.67±0.54

Notes: ** – p<0.05; ** – p<0.01 according to the indicator in intact control*
Source: *compiled by the authors*

Analysing the obtained data (Table 2), the substantial changes in morpho-physiological parameters of the blood of cats were established, in particular, a reduced haemoglobin content in cats of groups II and III was recorded: before the start of the drug – by 3.32% and 6.02%, respectively; on Day 3 – by 3.83% and 4.60%, respectively; on Day 7 – 4.69% and 4.51%, respectively. A substantial increase in the hematocrit value was identified in cats of Group III before the start of the experiment – by 24.74%; on the 3rd day of the experiment – by 20.96%. The hematocrit values and the number of red blood cells in the cats of the experimental groups did not substantially differ from the indicators of the intact control. A substantial increase in white blood cells in groups II and III of cats with skin damage was identified before the experiment – by 39.33% and 35.12%, respectively; on Day 3 – by 54.02%, and 19.33%, respectively. On the 7th and 14th days of the experiment, leukocytosis was recorded in cats of Group II (39.21% and 46.54%, respectively). Such changes in the blood picture indicate the development of endogenous intoxication syndrome, which is caused by toxic products that are formed during the breakdown of tissues due to their destruction.

The examination of the dynamics of biochemical parameters in the blood serum of cats (Table 3) showed a substantial increase in the concentration of total protein in the blood serum of cats of groups II and III who had skin damage before use – by 7.63%, and 10.99%, respectively; on Day 3 – by 5.32% and 8.17%, respectively. On Day 7 of the experiment, total protein was higher than intact control in cats of Group III by 5.19%, and on Day 14 – by 2.08%. It was identified that the content of C-reactive protein (acute phase protein, an indicator of tissue damage during inflammation) in the blood serum of cats of groups II and III was substantially higher than the intact control: before the experiment, by 2.1 and 2.21 times; on Day 3 – by 2.04 and 2.15 times. On Day 7, the CRP content in the blood of Group III cats exceeded the control by 1.42 times. No substantial changes were recorded on Day 14.

Table 3. *Dynamics of biochemical parameters in the blood serum of cats under the influence of the experimental drug (M±m)*

Experimental groups	Duration of the examination, days			
	before application	3rd day	7th day	14th day
Total Protein, g/L				
I	77.33±0.21	78.57±0.16	77.13±1.11	78.68±1.34
II	83.23±1.12*	82.75±0.96*	80.11±1.14	79.21±1.02
III	85.83±1.32**	84.99±0.32**	81.13±1.23*	80.32±1.44*
C-reactive protein, mg/L				
I	4.23±0.08	4.25±0.08	4.59±0.24	4.65±0.31
II	8.96±0.11*	8.65±0.12*	5.52±0.36	5.12±0.36
III	9.23±0.21**	9.14±0.25**	6.54±2.54*	4.94±0.24
ALAT, IU/L				
I	12.57±0.63	12.92±0.35	12.19±0.46	13.15±0.38
II	12.46±1.24	12.73±0.17	12.88±1.13	12.56±0.43
III	12.58±1.17	11.99±0.65	12.61±0.24	12.44±1.82

Table 3, Continued

Experimental groups	Duration of the examination, days			
	before application	3rd day	7th day	14th day
		ASAT, IU/L		
I	28.17±0.96	28.14±0.46	27.84±0.54	29.14±0.36
II	28.51±1.02	28.31±1.13	28.23±0.42	27.17±1.06
III	28.33±0.42	27.97±0.41	29.11±1.24	28.31±0.94
		Urea, mmol/L		
I	5.25±0.17	5.31±0.24	5.77±0.23	5.81±0.14
II	7.36±0.75*	6.49±0.93*	5.99±0.46	5.67±0.26
III	7.14±0.17*	6.71±0.85*	6.14±0.87	5.39±0.43

Notes: ** – p<0.05; ** – p<0.01 according to the indicator in intact control*
Source: *compiled by the authors*

The activity of indicator enzymes (ALAT, ASAT) in the blood serum of cats during the experiment was within the physiological norm. The concentration of urea in the blood of cats of groups II and III exceeded the control: before the experiment – by 1.40, and 1.36 times; on Day 3 – by 1.22, and 1.26 times.

Clinical examinations were conducted on mongrel dogs to establish the effectiveness of the veterinary drug under study. The general clinical condition of dogs was examined; haematological and biochemical studies of dog blood were conducted under the conditions of applying an experimental drug to damaged skin areas. The clinical condition of the dogs of the control and experimental groups was determined daily throughout the experiment. Thermometry was performed, the condition of visible mucous membranes, skin and coat was examined. According to the results of clinical observations at the beginning of the experiment, it was established that dogs of Group I, intact animals, were clinically healthy, had visible mucous membranes of pale pink colour, moderately shiny, without damage, pigmented. The skin was smooth, medium thickness, elastic, without damage. The coat was thick, shiny, and close to the body. In dogs of Group II (control pathology), a skin wound process of various etiologies was recorded: acute inflammation, skin compaction, scratches, rashes. Dogs of this group were not treated with wound-healing drugs. In dogs of the III experimental group, clinical signs of skin inflammation in the extremities and muzzle were noted: redness, peeling and itching, cracks. The animals were depressed and did not consume food willingly. The drug under study was applied to the damaged areas of the skin of dogs in a thin layer three times a day. The results of the conducted planimetric studies are presented in Table 4.

Table 4. *Dynamics of changes in the area of wound surfaces (M±m) in dogs under conditions of skin damage*

Observation period, day	Wound surface area in observation groups, mm^2	
	Skin damage without correction	Application of the experimental drug
3	0.84±0.01	0.62±0.03*
5	0.78±0.02	0.32±0.02*
7	0.63±0.02	0.28±0.02*
9	0.45±0.03	0.19±0.01*
14	0.07±0.01	0.06±0.01*

Note: ** – this value differs statistically substantially (p<0.05) from the same value in the group of dogs with skin damage that were not treated*
Source: *compiled by the authors*

Dogs with skin damage that were not treated with a wound-healing ointment showed a slowdown in the wound-healing process. Notably, in dogs with skin damage, no wound infection was observed when using the ointment, and there was no exudation. The drug under study effectively reduced the wound surface area at all observation periods. The examined indicators were statistically substantially different from those in the group of dogs with skin wounds that were not treated. The results of the examination of a number of morphological parameters of the blood of dogs of control and experimental groups are given in Table 5.

Table 5. *Dynamics of morpho-physiological parameters of dog blood under the influence of the experimental drug (M±m)*

Experimental groups	Duration of the examination, days			
	Before application	3rd day	7th day	14th day
		Haemoglobin (HGB), g/dm^3		
I	126.44±1.08	127.52±1.17	126.47±1.25	127.84±1.25
II	124.51±1.12	125.218±1.11	125.96±1.12	126.11±1.21
III	123.15±1.47*	123.94±1.05*	124.11±1.45*	125.087±1.36
		Hematocrit (HCT), %		
I	36.99±1.24	37.16±1.12	37.87±1.15	37.28±1.16
II	37.54±1.19	38.11±0.15	37.18±1.19	36.83±1.11
III	41.23±1.55*	39.91±0.55*	37.84±1.23	36.28±1.09
		Red blood cells (RBC), 10^{12}/ dm^3		
I	8.21±0.24	8.54±0.16	8.54±0.83	9.18±0.65
II	8.32±0.78	9.01±0.32	8.37±0.12	8.15±0.32
III	8.53±0.63	9.13±0.47	8.28±0.19	8.37±0.96
		White blood cells (WBC), 10^9/dm^3		
I	9.87±0.32	9.56±0.34	9.57±0.37	9.67±0.95
II	12.47±0.92*	12.58±0.14*	10.85±0.89	9.99±0.57
III	14.26±0.53*	12.39±0.72*	11.81±1.17*	10.77±0.86

Notes: ** – p<0.05; ** – p<0.01 according to the indicator in intact control*
Source: *compiled by the authors*

The data provided in Table 5 shows that the haemoglobin concentration in dogs of Group III was substantially lower than the control: before the experiment – by 2.60%; on Day 3 – by 2.81%; on Day 7 – by 1.87%, respectively. In dogs of the III experimental group, a substantial (p<0.05) increase in the hematocrit value was established: before the start of the experiment – by 11.46%; on the 3rd day of the experiment – by 7.40%. The content of red blood cells in dogs of the experimental groups did not substantially differ from the indicators of the intact control group. Leukocytosis was established in dogs of groups II and III. Thus, before the start of the experiment, an increase in the number of white blood cells was recorded by 26.34% and 44.47%, respectively; on Day 3 – by 31.59% and 29.60%. On Day 7, an increased white blood cell count was established in dogs of Group III – by 23.41%. The results of the study of biochemical parameters in the blood serum of dogs are given in Table 6.

Table 6. *Dynamics of biochemical parameters in the blood serum of dogs under the influence of an experimental drug (M±m)*

Experimental groups	Duration of the examination, days			
	Before application	3rd day	7th day	14th day
		Total Protein, g/L		
I	78.22±0.32	77.67±0.52	77.23±1.16	79.58±1.53
II	82.69±1.24*	81.98±0.49*	79.46±0.55	78.54±1.11
III	83.64±0.51*	82.13±0.61*	81.35±0.82*	79.86±1.39
		C-reactive protein, mg/L		
I	3.98±0.67	4.23±0.16	4.46±0.21	4.51±0.25
II	4.79±0.24	5.09±0.32	4.97±0.37	4.36±0.51
III	5.42±0.36*	4.86±0.27	5.02±0.85	4.75±0.26
		ALAT, IU/L		
I	11.79±1.55	12.21±1.16	12.11±1.12	12.23±1.53

Table 6, Continued

Experimental groups	Duration of the examination, days			
	Before application	3rd day	7th day	14th day
II	11.46±1.81	11.93±1.37	12.19±1.71	11.17±1.26
III	12.03±1.25	11.05±1.52	11.51±1.32	12.04±1.45
ASAT, IU/L				
I	23.11±1.27	23.56±1.21	23.24±1.24	21.03±1.42
II	22.97±1.08	22.86±1.22	23.59±1.21	23.78±1.32
III	23.34±1.37	23.17±1.34	22.32±1.54	23.33±1.51
Urea, mmol/L				
I	5.53±0.56	5.86±0.42	5.94±0.22	5.67±0.26
II	6.87±0.81	6.19±0.51	5.63±0.21	5.48±0.26
III	7.73±0.17*	6.72±0.29*	6.59±0.43	6.58±0.15

Notes: ** – p<0.05; ** – p<0.01 according to the indicator in intact control*
Source: *compiled by the authors*

The results of the assessment presented in Table 6 indicate the dynamic development of an acute inflammatory process in the body of dogs that have had skin damage. Thus, the concentration of total protein in the blood serum of dogs was substantially higher than the control in dogs of groups II and III: before the experiment – by 5.71% and 6.93%, respectively; on Day 3 – by 5.54% and 5.74%; on Day 7 in dogs III – by 5.33%. The concentration of C-reactive protein in the blood was substantially higher (P<0.05) for intact control in dogs of Group III before the experiment – by 36.18%. The activity of the ALAT and ASAT enzymes in the blood of dogs of the experimental group did not substantially differ from the control.

A substantial increase in the urea content in the blood of dogs of Group III was established: before the experiment – by 39.78%; on Day 3 – by 14.68%. On Day 14 of the experiment, no substantial changes were recorded.

Clinical examinations were conducted on decorative rabbits to assess the effectiveness of the veterinary drug. The general clinical characteristics of rabbits were examined; haematological and biochemical examinations of rabbit blood were performed under the conditions of applying an experimental drug to damaged skin areas. The clinical condition of rabbits in the control and experimental groups was determined daily throughout the entire study period. Thermometry was performed, the condition of visible mucous membranes and skin was examined.

According to the results of clinical observations at the beginning of the experiment, it was identified that intact rabbits of Group I were clinically healthy, had visible mucous membranes of pale pink colour, moderately shiny, without damage, pigmented. The skin was smooth, thin, elastic, without damage. The coat was thick, shiny, and close to the body. In rabbits of Group II with control pathology, the wound process of the skin of various etiologies was recorded: acute inflammation, skin compaction, scratches, rashes. Rabbits of this group were not treated with wound-healing drugs. In rabbits of the III experimental group, clinical signs of skin inflammation in the muzzle and ears were noted: redness, peeling and itching, cracks. An experimental drug was applied to the damaged areas of the skin of rabbits in a thin layer three times a day. The results of the conducted planimetric studies are shown in Table 7.

Table 7. *Dynamics of changes in the area of wound surfaces (M±m) in decorative rabbits under conditions of skin damage*

Observation period, day	Wound surface area in observation groups, mm^2	
	Skin damage without correction	Application of the experimental drug
3	0.32±0.01	0.29±0.01*
5	0.29±0.01	0.21±0.01*
7	0.27±0.01	0.17±0.01*
9	0.15±0.02	0.12±0.005*
14	0.06±0.005	0.03±0.005*

Note: ** – this value differs statistically substantially (p<0.05) from the same value in the group of rabbits with skin damage that was not treated*
Source: *compiled by the authors*

On the 14th day of observation, the area of wound surfaces in rabbits that were treated with the drug under study decreased by 5.33 times. Decorative rabbits with skin damage that were not treated with the drug showed signs of wound infection. In rabbits with skin damage, no wound infection was observed when applying the ointment, and there was no exudation. The drug effectively reduced the area of the wound surface at all stages of the study. The indicators were statistically substantially different from those in the group of rabbits with skin wounds that were not treated. The results of the study of a number of morphological parameters of blood in rabbits of control and experimental groups are given in Table 8.

Table 8. *Dynamics of morpho-physiological parameters of rabbit blood under the influence of an experimental drug (M±m)*

Experimental groups	Duration of the examination, days			
	Before application	3rd day	7th day	14th day
		Haemoglobin (HGB), g/dm^3		
I	114.23±1.12	114.73±1.16	116.06±1.42	114.33±1.54
II	116.18±1.23	114.26±1.43	117.21±1.15	116.15±1.10
III	114.41±1.37	115.14±1.09	118.69±1.24	117.36±1.55
		Hematocrit (HCT), %		
I	35.18±1.11	35.23±1.32	34.59±1.22	35.12±1.11
II	36.42±1.06	34.99±1.29	35.11±1.36	34.99±1.08
III	35.76±1.43	36.05±1.44	34.57±1.20	35.45±1.33
		Red blood cells (RBC), 10^{12}/ dm^3		
I	7.16±0.98	7.97±0.67	7.62±0.93	7.27±0.68
II	7.52±0.63	7.83±0.55	7.35±0.38	7.66±0.85
III	7.97±0.46	8.12±0.74	7.68±0.54	7.16±0.63
		White blood cells (WBC), 10^9/dm^3		
I	7.38±0.84	7.64±0.51	7.82±1.43	7.21±1.53
II	8.35±0.60	8.17±0.43	7.94±0.31	7.72±0.96
III	9.17±0.54*	9.34±0.60*	8.76±1.12	8.22±0.90

Notes: ** – p<0.05; ** – p<0.01 according to the indicator in intact control*
Source: *compiled by the authors*

Analysis of the obtained data presented in Table 8 showed a substantial increase in the level of white blood cells in the blood of ornamental rabbits with a wound skin process (Group III). Thus, before the start of the experiment, the content of white blood cells exceeded the control by 1.24 times; on Day 3 – by 1.22 times. Notably, other morpho-physiological blood parameters in rabbits were within the physiological norm. The results of the examination of biochemical parameters in the blood serum of rabbits are given in Table 9.

Table 9. *Dynamics of biochemical parameters in the blood serum of rabbits under the influence of the experimental drug (M±m)*

Experimental groups	Duration of the examination, days			
	Before application	3rd day	7th day	14th day
		Total Protein, g/L		
I	64.62±1.48	65.78±1.97	65.23±1.13	66.63±1.58
II	72.54±1.21**	72.38±1.46**	71.42±0.93**	69.18±1.10
III	71.89±0.98**	71.73±1.32**	70.61±1.34**	69.36±1.17
		C-reactive protein, mg/L		
I	3.78±0.57	3.99±0.26	3.78±0.14	3.54±0.96
II	4.98±0.26*	5.12±0.21*	3.97±0.17	4.56±1.44

Table 9, Continued

Experimental groups	Duration of the examination, days			
	Before application	3rd day	7th day	14th day
III	5.34±0.38*	4.84±0.37*	4.23±0.56	4.16±1.20
		ALAT, IU/L		
I	32.21±1.56	31.74±1.85	30.59±1.15	31.15±1.21
II	31.51±1.24	30.27±1.12	31.75±1.32	30.52±1.14
III	32.96±1.68	31.89±1.36	32.51±1.10	32.87±1.04
		ASAT, IU/L		
I	43.14±1.55	44.52±1.44	42.24±1.69	43.26±1.38
II	42.46±1.48	43.85±1.26	43.22±1.27	42.32±1.85
III	43.14±1.37	44.26±1.48	42.97±1.51	43.17±1.37
		Urea, mmol/L		
I	3.11±0.21	3.26±0.15	3.14±0.15	3.47±0.19
II	4.52±0.26*	4.38±0.19*	4.20±0.18	4.11±0.21
III	4.78±0.16*	4.64±0.23*	4.55±0.16	3.99±0.15

Notes: ** – p<0.05; ** – p<0.01 according to the indicator in intact control*
Source: *compiled by the authors*

Analysis of the obtained data (Table 9) showed a statistically substantial increase in the total protein content (at the level of p<0.01) in the blood serum of rabbits of groups II and III: before the experiment – by 12.26%, and 11.25%, respectively; on Day 3 – by 10.03% and 9.04%, respectively; on Day 7 – by 9.49% and 8.25%, respectively. On the 14th day of the experiment, no substantial deviations were established.

A substantial (p<0.05) increase in the concentration of CRP in the blood of rabbits of groups II and III was established: before the start of the experiment – by 31.75% and 41.27%, respectively; on the 3rd day of the experiment – by 28.32% and 21.30%, respectively. The activity of the ALAR and ASAT enzymes in the blood of rabbits of the experimental group did not substantially differ from the control. The urea content in the blood serum of rabbits of groups II and III was substantially (p<0.05) higher than the control: before the experiment – by 45.34% and 53.69%; on Day 3 – by 48.16% and 42.33%, respectively. On days 7 and 14, deviations of this indicator were within the physiological norm.

As a result of the research on the effectiveness of the veterinary drug with the active substance dexpanthenol, an optimal pharmacological effect was achieved by the authors, namely, a pronounced anti-inflammatory and wound-healing effect of the drug: it promotes healing, activation of reparative processes (granulation and epithelialisation) of the skin and mucous membranes, and prevents bacterial complications. The drug effectively reduced the area of the wound surface at all stages of the study.

Saliy *et al.* (2022), based on a marketing analysis of the pharmaceutical market of Ukraine of medicines under pressure for veterinary practice, identified that the largest segment belongs to the D03 group "Products for the treatment of wounds and ulcerative lesions" – 13.79%, including 12.07% of dexpanthenol-based drugs.

Researchers (Motatabzadeh & Abtahi Froushani, 2020; Barrionuevo-Gonzalez *et al.,* 2021; Karahan *et al.,* 2021) agreed that dexpanthenol-based preparations, used to achieve an effective therapeutic effect on skin pathologies, in particular, wounds, deserve special attention. Being absorbed into the cells of the stratum corneum of the skin, dexpanthenol is rapidly converted to pantothenic acid, thereby contributing to the restoration and regeneration of damaged skin layers. Its effect is enhanced in combination with decamethoxin, which has a bactericidal effect. Rodin (2019), based on clinical studies, proved a high therapeutic effect of decamethoxin for skin wounds with bacterial complications. Bororova (2021) notes its antimicrobial effect against Gram-positive (*Staphylococci, Streptococci, Pneumococci*) and Gram-negative (meningococci, gonococci) cocci, *Corynebacteria, Enterobacteria, Pseudomonas*, protozoa, dermatophytes, yeast-like fungi of the *Candida* genus, chlamydia, and viruses.

The obtained data correlate with the data of other researchers. Boehm *et al.* (2021) prove that a local approach (the use of ointment) is the best treatment option for focal surface bacterial infections to prevent the development of acquired resistance to microbial strains. Ogden *et al.* (2021) proved the therapeutic effect of dexpanthenol on sciatic nerve compression injury in an experiment on Wistar albino rats. They noted that administration of 50 mg/kg dexpanthenol intraperitoneally in combination with 10 mg/kg thymoquinone intraperitoneally once a day for a week.

Data obtained by Sezgin *et al.* (2019) confirms the hypothesis that the use of dexpanthenol contributes to

the reduction of wound surface during treatment. In experiments on rats, the researchers proved that the local use containing a combination of dexpanthenol, silbiol, undecylenic acid, and lidocaine decreased the wound surface area on the 7th day of treatment from 5.07 to 1.42 mm^2 in the test group. As in this experiment, the full therapeutic effect was observed on the 14th day of treatment. The data obtained is also consistent with the results of the group of researchers (Küba *et al.,* 2021). During an experimental assessment of dexpanthenol (5% ointment) efficacy on rats, the greatest reduction in wound size in the late postoperative phase was noted: from day 10 to day 14. Ulger *et al.* (2014), comparing the effectiveness of 5% dexpanthenol ointment and 5% nebivolol ointment for wound healing, based on experimental modelling of the wound process in rats, concluded that no substantial changes in the healing process were recorded between the examined ointments. However, a therapeutic effect was observed only on the 21st day, which is 6 days longer compared to this experiment. This may be due to a 2-fold lower concentration of the active substance compared to the experimental sample of the ointment in this study.

Therewith, Gültekin *et al.* (2020) do not recognise the therapeutic effect of dexpanthenol. During the experiment on a monkey, they did not observe any changes in wound size and epithelialisation when using a 4-component ointment made from a mixture of dexpanthenol (5% ointment), nitrofurazone ointment (0.2%), zinc oxide (20%), and Centella asiatica (1%) twice a day for local treatment. However, unlike this experiment, the authors additionally used intramuscular administration of 5% diluted dexpanthenol (500 mg/2 ml ampoule) 1 time for 10 days. The lack of therapeutic effect may be due to the antagonistic effect of the simultaneous use of dexpanthenol and zinc oxide. Ultimately, the latter in the experimental 20% concentration shows an astringent effect, due to which the rate and level of dexpanthenol adsorption are disrupted.

CONCLUSIONS

Skin inflammations in small pets of various origins are characterised by intense itching of the skin and are complicated by bacterial microflora. In the absence of treatment with a wound-healing ointment, the wound-healing process slows down.

Changes in morpho-physiological parameters of blood (reduced haemoglobin content, increased hematocrit value, urea content, leukocytosis) in experimental animals with signs of a wound process before the start of the experiment indicate the development of endogenous intoxication syndrome. Analysing biochemical parameters in the blood serum of animals with skin damage, a substantial increase in the concentration of total and C-reactive protein was noted.

In experimental animals with skin damage, when using a dexpanthenol-based ointment (10 mg per 1 ml), no signs of infection of wounds with microflora and exudation were observed. The drug under study effectively reduced the wound surface area in experimental animals during the course of treatment: in cats – by 95.83%, in dogs – by 92.86%, and in decorative rabbits – by 90.63%.

On the 14th day of treatment, the number of white blood cells and C-reactive protein in experimental animals were within the physiological norm – in cats – (9.67±0.54) x $10^9/dm^3$ 4.94±0.24 mg/L, in dogs – (10.77±0.86) x $10^9/dm^3$ and 4.75±0.26 mg/L, in rabbits – (8.22±0.90) x $10^9/dm^3$ and 4.16±1.20 mg/L, respectively. There is no substantial difference between experimental and intact animals.

It was identified that the examined drug is well tolerated by sick animals, does not cause adverse reactions, does not have a negative effect on healthy tissues, and has a positive effect on the dynamics of haematological and biochemical parameters of the blood of experimental animals. The experimental drug can be recommended for use in clinical veterinary practice as an anti-inflammatory and wound-healing agent for small pets.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the staff of the laboratory of Veterinary Hygiene and Parasitology of the National scientific centre "Institute of Experimental and Clinical Veterinary Medicine", the multidisciplinary laboratory of the Odesa State Agrarian University for their assistance in conducting laboratory studies, and the head and veterinarians of the animal shelter (Balakliya, Kharkiv region) for organising and helping to conduct the experiment.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Лікування домашніх тварин препаратом з діючою речовиною декспантенол при ранових процесах

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Abstract. Шкіра тварин є комплексним органом, який безпосередньо сприймає вплив зовнішнього середовища і виконує бар'єрно-захисну функцію, а також допомагає підтримувати рівновагу внутрішнього середовища організму. Порушення кожного з рівнів захисної системи призводить до розвитку запальних захворювань шкіри. Лікування рани залишаються однією з найактуальніших наукових та практичних проблем сучасної ветеринарної медицини. Ряд науковців проводить пошук та розробку нових ветеринарних препаратів для лікування ран різної етіології у дрібних домашніх тварин, однак застосування лікарських засобів часто викликає побічні реакції з боку шкіри. Метою цієї роботи була оцінка ефективності застосування ветеринарного препарату (мазь) при лікуванні ран у домашніх тварин (собаки, коти, кролі). В роботі використано стандартні клінічні, гематологічні та біохімічні методи дослідження. У дослідженнях застосовували препарат з діючою речовиною декспантенол та допоміжними речовинами декаметоксин, масло вазелінове, емульгатор, гліцерин, метилпарабен, пропілпарабен, вода очищена. Досліджуваний препарат ефективно зменшував площу ранової поверхні на усіх термінах спостереження. Доведено, що за використання мазі на основі декспантенолу (10 %) повний ранозагоювальний ефект у дослідних тварин спостерігався на 14-ту добу лікування: площа ранових поверхонь зменшувалась на 93,1±1,51 %. Досліджувані показники статистично достовірно відрізнялися від аналогічних у групі нелікованих тварин із ранами шкіри. Вивчено загальний клінічний стан домашніх тварин, проведено гематологічні та біохімічні дослідження крові тварин за умов нанесення на пошкоджені ділянки шкіри дослідного препарату. У тварин із пошкодженням шкіри без лікування спостерігали динамічний розвиток гострого запального процесу в організмі, розвиток синдрому ендогенної інтоксикації, ознаки інфікування ран, виражену ексудацію та сповільнення контракції. Розроблений ветеринарний препарат з діючою речовиною декспантенол одночасно проявляє виражену протизапальну і ранозагоювальну дію та забезпечує швидкий лікувальний ефект при раньових процесах у дрібних домашніх тварин

Keywords: собаки; коти; кролі; рани; декспантенол; морфо-фізіологічні показники крові; сироватка крові

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 24-35

UDC 619:19:616:98:579.873.21:631.153.7
DOI: 10.48077/scihor3.2023.24

Immunological reactivity of animals with tuberculosis under the influence of ionising radiation

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Article's History:
Received: 1.02.2023
Revised: 15.03.2023
Accepted: 15.04.2023

Suggested Citation:
Kassich, V., Kasianenko, O., Klishchova, Zh., Kasianenko, S., & Mozghovyi, M. (2023). Immunological reactivity of animals with tuberculosis under the influence of ionising radiation *Scientific Horizons*, 26(3), 24-35.

Abstract. Effective control of animal tuberculosis is possible only with a comprehensive examination of the biology of the pathogen, epizootiology, pathogenesis, prevention methods, economic and environmental factors that affect the course of the disease. It is known that radiation exposure leads to autosensitisation of the body by the breakdown products of its tissues and the development of non-specific (false) immunological reactions. Therefore, the purpose of the study was to examine the immunological (serological) reactivity of tuberculosis patients exposed to gamma radiation in laboratory animals. Radiological, bacteriological, allergic, serological, and pathoanatomical research methods were used in the study. Guinea pigs were consistently irradiated with various doses of gamma rays, infected with Mycobacterium tuberculosis of various types, and, for 90 days, were

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examined by clinical, allergic, pathoanatomical, and serological methods in the complement fixation reaction (CFR) and passive hemagglutination reaction (PHGR) according to Boyden to detect antitubercular complement-binding antibodies and tissue autoantibodies. 45 and 90 days after infection with *M. bovis* and *M. tuberculosis* antitubercular complement-binding antibodies were recorded in serum samples of irradiated and non-irradiated animals in diagnostic titres (1:20-1:80), which indicates the active development of the infectious process. In irradiated and intact guinea pigs infected with *M. avium*, no anti-tuberculosis antibodies were detected in since guinea pigs are not susceptible to infection with the causative agent of avian tuberculosis. In serum samples from uninfected guinea pigs, both irradiated and intact, antitubercular complement-binding antibodies were not detected during the entire follow-up period (90 days). The high content of tissue autoantibodies in blood serum samples of animals irradiated with a dose of 200 R (0.0516 C/kg) is a manifestation of autosensitisation of the body by the breakdown products of its tissues due to radiation damage. The presence of tissue autoantibodies in blood serum samples of irradiated and Mycobacterium-infected animals did not affect serological indicators for the indication of anti-tuberculosis antibodies, which should be considered when conducting diagnostic studies by veterinary medicine laboratories

Keywords: tuberculosis; radiation; tuberculin; gamma radiation; mycobacteria; complement-binding antibodies; tissue antibodies

INTRODUCTION

Tuberculosis has a special place among infectious diseases of farm animals and poultry. The disease of livestock with tuberculosis causes substantial economic damage to animal husbandry and poses a danger to human health. The main method of life-long diagnosis of tuberculosis is clinical and allergic studies, and post-mortem – pathoanatomical and bacteriological. Auxiliary methods for diagnosing tuberculosis include simultaneous allergic, intravenous tuberculin, double intradermal tuberculin tests, ophthalmoprobe in cattle, histological, serological, immunological, and genetic studies. Nowadays, both technogenic accidents at nuclear power enterprises and the use of tactical nuclear weapons during military conflicts are a reality. Therefore, the investigation of radiation effects on biological objects, in particular, on the specificity of diagnostic reactions in the study of infectious diseases, becomes particularly relevant (Candeias, 2017; Cvetnić, 2021).

A number of authors (Akhtar, 2019; Kassich, 2022; Guo, 2021) note the appearance of positive reactions to tuberculin during allergic studies of livestock in the case of sensitisation of the body by atypical mycobacteria and when exposed to various adverse environmental factors, including ionising radiation.

Huang (2019), Wang (2019), Kassich (2019) prove that the reactions of the body to ionising radiation are heterogeneous in microorganisms and animals of different species, and they also differ in individuals of the same species. Researchers report that the biological action of ionising radiation is based on such phenomena as the absorption of radiation energy by the biosubstrate, the formation of active free radicals and ions (conversion of radiation energy into chemical), and the development of primary radiation and chemical reactions after irradiation.

According to Penn-Nicholson (2020), Lumniczky (2021), and Xi (2023) ionisation caused by ionising radiation consists in the formation of active radicals of water and organic substances HO_2+, H+, H_2+, etc. Under the influence of irradiation in the presence of oxygen, atomic hydrogen, hydroxyl, hydroperoxide radical, hydrogen peroxide, and atomic oxygen are formed in water. According to Katalin (2019), Atmakuri (2018), and Gaikwad (2018), the interaction of free radicals with organic and inorganic substances follows the type of redox reactions and constitutes an indirect effect. The mechanism of biological action of ionising radiation is not fully understood. However, it is known that the formed active radicals of water and organic substances actively injure the cells of the irradiated organism, which leads to autoimmune pathology, in particular, to the appearance of tissue autoantigens and anti-tissue autoantibodies (Saeed, 2016).

The first reports of the appearance of anti-tissue autoantibodies in the blood serum of dogs and rabbits after irradiation were made in 1934 by I.P. Mishchenko and M.M. Fomenko (Kassich, 2021). After radiation exposure, autosensitisation of the body occurs due to a violation of the antigenic specificity of proteins. The resulting autoantibodies have cytolytic activity. Sabiiti (2020), Scriba (2021), and Mtafya, (2019) argue that autoimmune reactions in the irradiated body proceed as auto-allergic processes. Some researchers (Basit, 2018; Naei, 2019; Roe, 2020) believe that tissue autoantibodies formed in the irradiated body are involved in increasing its radioresistance, and can also cause the development of non-specific (false) reactions to various antigens and allergens in the irradiated body, which can complicate allergic and serological studies and lead to diagnostic errors during the examination of irradiated animals.

In Ukraine, technogenic accidents at nuclear power enterprises are a reality, and the use of tactical nuclear weapons during a military conflict is also possible.

Therefore, the study of radiation exposure to biological objects, in particular, on the specificity of diagnostic reactions in the study of infectious diseases, becomes particularly relevant. In connection with the above the purpose of the study was the immunological reactivity of laboratory animals under the influence of sublethal doses of gamma radiation was examined.

MATERIALS AND METHODS

Guinea pigs were used in the amount of 200 heads, weighing 300-350 R, selected according to the principle of analogues to examine the regularities of the development of the infectious process in tuberculosis under the influence of ionising radiation. The animals were divided into 5 groups of 40 heads each. Guinea pigs were previously examined (30 days before irradiation) with a tuberculin test to exclude natural tuberculosis. No responders were identified. Four groups of animals were separately irradiated with gamma radiation at doses of 50, 100, 150, and 200 R (0.0129, 0.0258, 0.0387, and 0.0516 C/kg) with a dose rate of 2.65 g/sec on the IGUR gamma emitter (radiation source 137cz).

Irradiated and intact guinea pigs were divided into 2 equal groups of 100 heads each. Animals of the first group were examined one day after irradiation with a simultaneous allergic test with PPD-tuberculin for mammals and AAM. 7 days after irradiation, animals of this group (5-6 irradiated with doses of 50, 100, 150, and 200 R and intact) were infected with mycobacteria of bovine (strain Bovinus 8), human (strain M), and avian (strain Avium 780) types. Mycobacterium cultures were administered subcutaneously to each guinea pig in the groin area of 1 mg of raw bacterial mass suspended in 1 ml of a sterile isotonic NaCl solution. Animals of the second group (uninfected, irradiated and intact) were examined by a simultaneous allergic test 7 days after radiation exposure. 14 days after irradiation, 5 guinea pigs from each irradiated group and intact were infected with *M. bovis, M. tuberculosis* and *M. avium* of the same strains. An electronic photo of mycobacteria of the *M. bovis*production strain is shown in Figure 1.

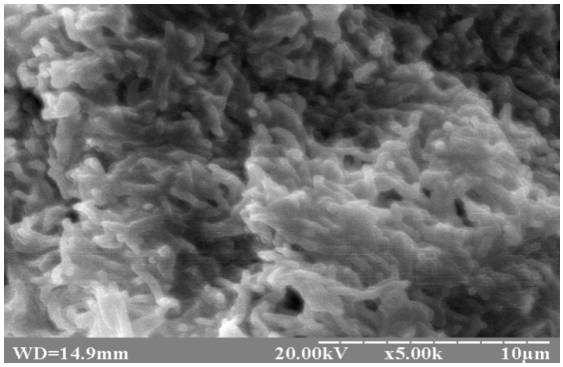

Figure 1. *Mycobacteria of the M. bovis production strain. Stick-shaped conglomerate*
Source: *microphoto by the authors*

14, 45, and 90 days after infection, the animals were examined with a simultaneous allergic test. Blood samples were taken from the heart during the same period for serological and haematological studies. Therewith, from the moment of irradiation to the end of the experiment, clinical observations were made on the state of animal health, the timing of death was considered, and pathoanatomical studies were conducted.

For the indication of antitubercular complement-binding antibodies in serum samples of experimental animals, the complement fixation reaction with the complex tuberculosis antigen UNDIEV was used, which was set up and recorded in accordance with the guidelines for the diagnosis of animal tuberculosis (Guideline for the Prevention and Control of Tuberculosis in Animals, 2009).

Serum samples of animals exposed to various doses of gamma rays were selectively examined (10 samples taken before and after infection) to detect tissue autoantibodies in the passive hemagglutination reaction (PHGR) according to Boyden with tissue antigens manufactured in this study according to the method of Ye.F. Chernushenko (Zazharskyi *et al.,* 2022).

Antigens (water-salt tissue extracts) for PHGR were prepared as follows. Testicular, adrenal, spleen, thymus, and pituitary tissues were thoroughly washed with running water and then with an isotonic NaCl solution. The tissues treated in this way were crushed and homogenised, and filled with a sterile isotonic NaCl solution at a rate of 1:4 for the extraction. The resulting emulsion was kept in a refrigerator at a temperature of 4°C for 18-24 hours, then centrifuged at a 1.5 thousand rpm rate for 20 minutes. The supernatant was used as an antigen. The protein concentration in the antigen was determined using a Lowry spectrophotometer. Information on the protein content of the manufactured antigens is shown in Table 1.

Table 1. *Protein content in tissue antigens*

Protein content (mg/mL) in antigens from:			
thymus	testicle	pituitary	adrenal
0.16	0.41	0.30	0.38

Source: *compiled by the authors*

When working with animals, the provisions of Article 26 of the Law of Ukraine No. 3447-VI of 16.10.2012 "On the Protection of Animals from Cruelty" (2012), "General ethical principles of animal experiments" approved at the first National Congress on Bioethics (Reznikov, 2003), requirements of the "European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes" (European convention, 1986), the "Universal Declaration on Animal Welfare" (Universal Declaration, 2007) were adhered.

RESULTS AND DISCUSSION

The results of examining the serological reactivity of marine animals irradiated and infected with tuberculosis pathogens are given below. Serum samples of experimental animals were tested in the complement fixation reaction with a complex tuberculosis antigen (CTA UNDIEV) developed by Yu.Ya. Kassich (1968) to indicate antitubercular complement-binding antibodies. The antibody titer of 1:20 ratio was considered diagnostic. During the examination of serum samples taken before infection, and 2 weeks after inoculation of irradiated and intact guinea pigs with infectious material, no antitubercular complement-binding antibodies were detected. The results of the serological examination of irradiated and intact animals 1.5 months after infection are shown in Table 2.

Table 2. *Results of the serological examination in the complement fixation reaction (CFR) with complex tuberculosis antigen (CTA) UNDIEV of blood serum samples from irradiated and intact guinea pigs 1.5 months (45 days) after infection*

No. of samples	Irradiation dose (R/C/ kg)	Type of tuberculosis pathogen	Results of RSC with CTA UNDIYEV in titers:			
			1:10	1:20	1:40	1:80
1	2	3	4	5	6	7
1	50/0.0129	*M. bovis*	+	-	-	-
2	50/0.0129	*M. bovis*	++++	++++	-	-
3	50/0.0129	*M. bovis*	++	+	-	-
4	50/0.0129	*M. bovis*	-	-	-	-
5	50/0.0129	*M. tuberculosis*	-	-	-	-
6	50/0.0129	*M. tuberculosis*	++++	++++	++	-
7	50/0.0129	*M. tuberculosis*	++++	++	-	-
8	50/0.0129	*M. tuberculosis*	++++	++++	-	-
9	50/0.0129	*M. avium*	++++	+	-	-
10	50/0.0129	*M. avium*	++++	+	-	-
11	50/0.0129	*M. avium*	++++	++	-	-
12	100/0.0258	*M. bovis*	++++	++++	++	+
13	100/0.0258	*M. bovis*	++++	++	-	-
14	100/0.0258	*M. bovis*	++	++	-	-
15	100/0.0258	*M. bovis*	++++	++++	++++	+
16	100/0.0258	*M. tuberculosis*	++++	++++	++	-
17	100/0.0258	*M. tuberculosis*	++++	++++	-	-
18	100/0.0258	*M. tuberculosis*	++++	++++	++++	+
19	100/0.0258	*M. tuberculosis*	++++	++++	+	-
20	100/0.0258	*M. avium*	++	++	-	-
21	100/0.0258	*M. avium*	-	-	-	-
22	100/0.0258	*M. avium*	-	-	-	-

Table 2, Continued

No. of samples	Irradiation dose (R/C/ kg)	Type of tuberculosis pathogen	Results of RSC with CTA UNDIYEV in titers:			
			1:10	1:20	1:40	1:80
23	150/0.0387	*M. bovis*	++++	++++	++	-
24	150/0.0387	*M. tuberculosis*	++++	++++	++	-
25	150/0.0387	*M. tuberculosis*	-	-	-	-
26	150/0.0387	*M. avium*	-	-	-	-
27	150/0.0387	*M. avium*	++	-	-	-
28	200/0.0516	*M. avium*	-	-	-	-
29	200/0.0516	*M. avium*	-	-	-	-
30	200/0.0516	not infected	-	-	-	-
31	200/0.0516	not infected	-	-	-	-
32	200/0.0516	not infected	-	-	-	-
33	200/0.0516	not infected	-	-	-	-
34	200/0.0516	not infected	-	-	-	-
35	not irradiated	*M. tuberculosis*	-	-	-	-
36	not irradiated	*M. tuberculosis*	++++	++++	++++	+
37	not irradiated	*M. tuberculosis*	++++	++++	++	+
38	not irradiated	*M. avium*	-	-	--	
39	not irradiated	*M. avium*	-	-	-	-
40	not irradiated	*M. avium*	-	-	-	-
41	not irradiated	not infected	-	-	-	-
42	not irradiated	not infected	-	-	-	-

Source: *compiled by the authors*

The materials in Table 2 demonstrate that 45 days after infection with *M. bovis* and *M. tuberculosis,* complement-binding antibodies were recorded in serum samples from irradiated and non-irradiated animals in diagnostic titers (1:20-1:40). Among those infected with *M. avium,* complement-binding antibodies in a titer of 1:10 (below the diagnostic one) were detected in one case in a group of guinea pigs irradiated with a dose of 50 R (0.0129 C/kg).

No complementary antibodies were detected in serum samples of non-infected animals, both irradiated and intact. The results of the serological examination of irradiated and non-irradiated guinea pigs 3 months after infection with mycobacteria are shown in Table 3.

Table 3. *Results of serological examination of blood serum samples from irradiated and intact guinea pigs in rzk with CTA UNDIEV 3 months (90 days) after infection*

No. of samples	Irradiation dose (R/C/ kg)	Type of tuberculosis pathogen	Results of CFR with CTA UNDIEV in the titers:			
			1:10	1:20	1:40	1:80
1	2	3	4	5	6	7
1	50/0.0129	*M. tuberculosis*	++++	++++	+	-
2	50/0.0129	*M. tuberculosis*	-	-	-	-
3	50/0.0129	*M. tuberculosis*	-	-	-	-
4	50/0.0129	*M. avium*	++++	++	-	-
5	50/0.0129	*M. avium*	-	-	-	-
6	50/0.0129	*M. avium*	++	+	-	-
7	100/0.0258	*M. tuberculosis*	++++	++++	++++	-
8	100/0.0258	*M. tuberculosis*	++	++	-	-
9	100/0.0258	*M. tuberculosis*	++++	++	-	-
10	100/0.0258	*M. avium*	+	-	-	-
11	100/0.0258	*M. avium*	-	-	-	-

Table 3, Continued

No. of samples	Irradiation dose (R/C/ kg)	Type of tuberculosis pathogen	Results of CFR with CTA UNDIEV in the titers:			
			1:10	1:20	1:40	1:80
12	100/0.0258	*M. avium*	-	-	-	-
13	150/0.0387	*M. tuberculosis*	++++	++++	++++	++
14	150/0.0387	*M. tuberculosis*	++++	++++	++	-
15	150/0.0387	*M. avium*	-	-	-	-
16	150/0.0387	*M. avium*	-	-	-	-
17	200/0.0516	*M. avium*	-	-	-	-
18	200/0.0516	*M. avium*	-	-	-	-
19	50/0.0129	not infected	-	-	-	-
20	50/0.0129	not infected	-	-	-	-
21	50/0.0129	not infected	-	-	-	-
22	100/0.0258	not infected	-	-	-	-
23	100/0.0258	not infected	-	-	-	-
24	100/0.0258	not infected	-	-	-	-
25	not irradiated	*M. tuberculosis*	++++	++++	_	_
26	not irradiated	*M. tuberculosis*	++++	++++	++++	++++
27	not irradiated	*M. tuberculosis*	++++	++++	++++	++++
28	not irradiated	*M. avium*	-	-	-	-
29	not irradiated	*M. avium*	++	-	-	-
30	not irradiated	*M. avium*	-	-	-	-
31	not irradiated	not infected	-	-	-	-
32	not irradiated	not infected	-	-	-	-
33	not irradiated	not infected	-	-	-	-

Source: *compiled by the authors*

The materials in Table 3 demonstrate that complement-binding antibodies in diagnostic titers (1:20, 1:40, and 1:80) on day 90 of the examination were recorded in irradiated and intact animals infected with *M. tuberculosis*. Therewith, positive results with a titer of 1:80 ratio were determined only in intact animals. In animals, irradiated at doses of 50-200 R (0.0129-0.0516 C/kg), complement-binding antibodies were recorded in titres of 1:10, 1:20, and 1:40. At the time of the study, all guinea pigs infected with the causative agent of bovine tuberculosis (*M. bovis)* died with a picture of generalised tuberculosis with a substantial increase in the spleen and liver, tubercles and foci of caseous necrosis in parenchymal organs (Fig. 2).

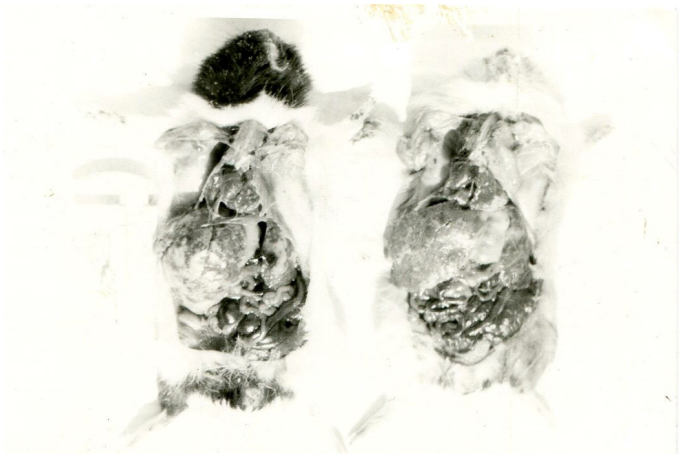

Figure 2. *Generalised tuberculosis of guinea pigs that died 25 days after being infected with M. bovis*
Note: *On the left – irradiated with a dose of 150 R (0.0387 C/kg). On the right – not irradiated*
Source: *photographed by the authors*

Antitubercular complement-binding antibodies were not identified in diagnostic titers exposed to gamma radiation and intact, Mycobacterium-infected guinea pigs with tuberculosis of avian type, which is natural, since guinea pigs are not susceptible to infection with *M. avium*. No complementary antibodies were detected in serum samples from uninfected guinea pigs, both irradiated and intact. Blood serum samples from animals irradiated with different doses of gamma radiation were selectively examined (10 sera selected before and after irradiation) in the passive hemagglutination reaction according to Boyden to identify tissue autoantibodies formed in the irradiated body in response to radiation damage to their tissues, which simultaneously become autoantigens and cause the development of immunological auto-allergic reactions (Zazharskyii *et al.,* 2022).

Table 4. *Results of indication of tissue autoantibodies in serum samples of infected, irradiated and intact guinea pigs 45 days after infection*

No. of samples	Irradiation dose (R/C/kg)	Type of tuberculosis pathogen	Results of PHGR (maximum titer of autoantibodies) with tissue antigens from:			
			thymus	testicles	pituitary	adrenal
1	2	3	4	5	6	7
1	50/0.0129	not infected	-	-	-	-
2	50/0.0129	not infected	-	-	-	-
3	50/0.0129	not infected	-	-	-	-
4	50/0.0129	not infected	-	1:2	-	-
5	50/0.0129	not infected	1:2	1:16	1:16	1:16
6	50/0.0129	*M. bovis*	-	-	-	-
7	50/0.0129	*M. tuberculosis*	-	-	1:2	-
8	50/0.0129	*M. avium*	-	1:2	-	-
9	50/0.0129	*M. bovis*	-	-	-	-
10	50/0.0129	*M. tuberculosis*	1:2	1:4	1:4	1:4
11	100/0.0258	not infected	-	-	-	-
12	100/0.0258	not infected	-	-	-	-
13	100/0.0258	not infected	-	-	-	-
14	100/0.0258	not infected	-	-	-	-
15	100/0.0258	not infected	-	-	-	-
16	100/0.0258	*M. bovis*	-	-	-	-
17	100/0.0258	*M. bovis*	-	-	-	-
18	100/0.0258	*M. tuberculosis*	-	-	-	-
19	100/0.0258	*M. tuberculosis*	-	-	-	-
20	100/0.0258	*M. avium*	-	-	-	-
21	150/0.0387	not infected	-	-	-	-
22	150/0.0387	not infected	-	-	-	-
23	150/0.03871	not infected	-	-	1:2	-
24	150/0.0387	not infected	-	-	-	-
25	150/0.0387	not infected	-	-	-	-
26	150/0.0387	*M. bovis*	-	-	-	-
27	150/0.0387	*M. bovis*	-	-	-	-
28	150/0.0387	*M. tuberculosis*	-	1:2	-	-
29	150/0.0387	*M. tuberculosis*	-	1:2	-	-
30	150/0.0387	*M. avium*	-	1:2	-	-
31	200/0.0516	not infected	1:128	1:128	1:4096	1:4096

Table 4, Continued

32	200/0.0516	not infected	1:512	1:512	1:4096	1:4096
33	200/0.0516	not infected	1:128	1:128	1:4096	1:4096
34	200/0.0516	not infected	1:512	1:512	1:4096	1:4096
35	200/0.0516	*M. bovis*	1:128	1:128	1:4096	1:4096
36	200/0.0516	*M. bovis*	1:128	1:128	1:4096	1:4096
37	200/0.0516	*M. tuberculosis*	1:512	1:1024	1:4096	1:4096
38	200/0.0516	*M. tuberculosis*	1:128	1:128	1:4096	1:4096
39	200/0.0516	*M. tuberculosis*	1:512	1:1024	1:4096	1:4096
40	200/0.0516	*M. tuberculosis*	1:512	1:1024	1:4096	1:4096
41	not irradiated	not infected	-	-	-	-
42	not irradiated	not infected	-	-	-	-
43	not irradiated	not infected	-	-	-	-
44	not irradiated	*M. bovis*	-	-	-	-
45	not irradiated	*M. tuberculosis*	-	-	-	-
46	not irradiated	*M.tuberculosis*	-	-	-	-
47	not irradiated	*M. avium*	-	-	-	-

Source: *compiled by the authors*

From the data shown in Table 4, it follows that tissue autoantibodies in high titers (1:128-1:4096) are detected in the blood serum of animals exposed to the gamma radiation at a dose of 200 R (0.0516 C/kg). In one case, autoantibodies in diagnostic titers of 1:16 were detected in a group of guinea pigs who were not infected with tuberculosis at a dose of 50 R (0.0129 C/kg).

The results of examining the immunological reactivity of animals irradiated and infected with tuberculosis pathogens are given in previous studies (Allen, 2018; Chaisson, 2019). It was determined that 14-60 days after infection with tuberculosis pathogens *M. bovis, M. tuberculosis,* and *M. avium* 90-100% of laboratory animals developed allergic reactions to PPD-tuberculin in mammals and poultry, mainly to a homologous allergen. Allergic reactivity persisted until 90 days into the study. After exposure to sublethal doses of gamma rays, guinea pigs developed non-specific reactions to tuberculin, malein, and brucelin. Non-specific reactions to mycobacterial allergens at a dose load of 200 R were observed in 16.6%; 150 R – 5.3% in the group, and after 27 days in irradiated doses of 50 R and 100 R in 25% and 33% of the examined animals. Reactions were manifested in the form of infiltrates at the site of allergen administration with necrosis in the centre and developed over time in the same time frame as specific tuberculin reactions. Isolated reactions to brucelin and malein occurred in animals infected with the causative agent of tuberculosis 60 days after irradiation at doses of 50 R, 100 R, and 150 R. The manifestation of non-specific allergies in irradiated animals depended on the radiation dose rate and radiosensitivity of the animals.

Few researchers have investigated the effect of ionising radiation on antibody formation after the infection of animals with the causative agent of tuberculosis. Thus, Oyarzabal (2019) showed a slight increase in hemagglutinin titers in guinea pigs infected with bovine Mycobacterium tuberculosis, irradiated with gamma radiation at doses of 100-150 R and intact in the hemagglutination reaction (HGR) with alttuberculin. Experiments were conducted on a small number of animals, so these results, according to the authors, can only be indicative.

(Burel, 2019; Belay, 2021; Donovan, 2020) observed the appearance of autoantibodies 15-30 days after irradiation when irradiating animals with tuberculosis. Data on the indication of antitubercular complement-binding antibodies in the blood of irradiated animals infected with the causative agent of tuberculosis was not identified in the available literature.

Some researchers (Torres, 2019; Gupta, 2020) believe that tissue autoantibodies formed in the irradiated body can cause the development of non-specific (false) reactions to various antigens and allergens, which makes it difficult to conduct allergic and serological studies and can lead to diagnostic errors during the examination of irradiated animals. In the experiments of this study, tissue autoantibodies to antigens from the thymus, testicles, adrenal, and pituitary glands in high titers (1:128-1:4096) were detected only in the blood serum of animals exposed to gamma radiation at a dose of 200 R (0.0516 C/kg). The high content of tissue autoantibodies in blood serum samples irradiated with a dose of 200 R (0.0516 C/kg) of animals is a manifestation of autosensitisation of the body by the products of decay of their own tissues due to radiation damage and the cause of the development of non-specific reactions to bacterial allergens, which were detected during

previous studies and described in literature sources. The results obtained in this paper coincide with the data of other researchers presented in the literature sources (Bhattacharya, 2016; Broderick, 2021).

Notably, the presence of tissue autoantibodies in blood serum samples of irradiated and Mycobacterium-infected animals does not affect serological parameters for indicating antitubercular complement-binding antibodies in CFR. Cross-reactivity and false reactions of tissue antibodies of the irradiated organism with complex tuberculosis antigen (CTA UNDIEV) were not observed. Evidently, tissue autoantibodies formed in the irradiated body do not have active centres complementary (affinity) to mycobacterial determinants present in CTA.

CONCLUSIONS

The immunological reactivity of animals with tuberculosis under the influence of ionising radiation was determined. In those infected with Mycobacterium bovine (*M. bovis*) and human (*M. tuberculosis*) types of tuberculosis, irradiated and intact guinea pigs with sublethal doses of gamma radiation develop serological reactions 45 and 90 days after infection, and antitubercular complement-binding antibodies are detected in diagnostic titers.

No antitubercular complement-binding antibodies were detected in diagnostic titers in guinea pigs exposed to gamma radiation and intact, infected with Mycobacterium tuberculosis of avian type. No complementary antibodies were detected in serum samples of non-infected animals, both irradiated and intact.

On day 90 of the study, complement-binding antibodies in diagnostic titers were recorded in irradiated and intact animals infected with *M. tuberculosis*. Therewith, positive results with a titer of 1:80 ratio were determined only in intact animals. In guinea pigs, irradiated at doses of 50-200 R (0.0129-0.0516 C/kg) infected with *M. tuberculosis*, complement-binding antibodies were recorded at titers of 1:10, 1:20, and 1:40.

In the blood serum of animals exposed to gamma radiation at a dose of 200 R (0.0516 C/kg), tissue autoantibodies in high titers are detected (1:128-1:4096). The presence of tissue autoantibodies in blood serum samples of irradiated and Mycobacterium-infected animals does not affect serological parameters for indicating antitubercular complement-binding antibodies in CFR. Cross-reactivity and false reactions of tissue antibodies of the irradiated organism with complex tuberculosis antigen (CTA UNDIEV) were not observed.

The prospect of further research is to examine the immunological reactivity of animals irradiated and infected with tuberculosis using special immunological methods: the reaction of delayed migration of lymphocytes, the reaction of blasttransformation of lymphocytes and the reaction of blood mononuclears, and molecular genetic methods.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Імунологічна реактивність хворих на туберкульоз тварин в умовах впливу іонізуючої радіації

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Анотація. Ефективна боротьба з туберкульозом тварин можлива лише при всебічному вивченні біології збудника, епізоотології, патогенезу, методів профілактики, економічних і екологічних факторів, які впливають на перебіг хвороби. Відомо, що радіаційне опромінення призводить до аутосенсибілізації організму продуктами розпаду власних тканин і розвитку неспецифічних (хибних) імунологічних реакцій. Тому метою дослідження було провести роботу з вивчення імунологічної (серологічної) реактивності хворих на туберкульоз опромінених гамма-радіацією лабораторних тварин. В роботі використовували радіологічні, бактеріологічні, алергічні, серологічні, патологоанатомічні методи досліджень. Мурчаків послідовно опромінювали різними дозами гамма-променів, заражали мікобактеріями туберкульозу різних видів і, впродовж 90 діб, досліджували клінічними, алергічними, патологоанатомічними та серологічними методами в реакції зв'язування комплементу (РЗК) та реакції пасивної гемаглютинації (РПГА) за Бойденом для виявлення протитуберкульозних комплементзв'язуючих антитіл та тканинних аутоантитіл. Через 45 та 90 діб після зараження *M. bovis* та *M. tuberculosis* в пробах сироватки крові опромінених та не опромінених тварин реєстрували протитуберкульозні комплементзв'язуючі антитіла в діагностичних титрах (1:20-1:80), що свідчить про активний розвиток інфекційного процесу. У опромінених та інтактних, інфікованих *M. avium* мурчаків протитуберкульозних антитіл не було виявлено, оскільки морські свинки не сприйнятливі до зараження збудником туберкульозу пташиного виду. У пробах сироваток крові від незаражених мурчаків, як опромінених, так і інтактних, протитуберкульозні комплементзв'язуючі антитіла не виявляли впродовж всього терміну спостереження (90 діб). Високий вміст тканинних аутоантитіл в пробах сироватки крові опромінених дозою 200 Р (0,0516 Кл/кг) тварин є проявом аутосенсибілізації організму продуктами розпаду власних тканин внаслідок радіаційного ураження. Наявність в пробах сироватки крові опромінених та заражених мікобактеріями тварин тканинних аутоантитіл не впливало на серологічні показники з індикації протитуберкульозних антитіл, що треба враховувати під час проведення діагностичних досліджень лабораторіями ветеринарної медицини

Ключові слова: туберкульоз; радіація; туберкулін; гамма-опромінення; мікобактерії; комплементзв'язуючі антитіла; тканинні антитіла

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 36-47

UDC 630*4
DOI: 10.48077/scihor3.2023.36

Harmfulness of the viburnum leaf beetle (*Pyrrhalta viburni Payk.*) on plants of the *Viburnum* L. genus and elements of its control technology for strategies in breeding work in the system of fruit and decorative gardening

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Article's History:
Received: 19.01.2023
Revised: 19.03.2023
Accepted: 7.04.2023

Suggested Citation:
Moskalets, T., Moskalets, V., Marchenko, A., Pelekhatyi, V., & Yakovenko, R. (2023). Harmfulness of the viburnum leaf beetle (*Pyrrhalta viburni Payk.*) on plants of the *Viburnum* L. genus and elements of its control technology for strategies in breeding work in the system of fruit and decorative gardening. *Scientific Horizons*, 26(3), 36-47.

Abstract. The studies were conducted in various ecological points of Ukraine (western and northern part of the Forest-Steppe, Southern Polissia) to examine the bioecological features of *Pyrrhalta viburni* Paykull and develop measures to reduce its harmfulness in the system of fruit and decorative gardening. The purpose of the study was to examine the bioecological features of the viburnum leaf beetle on plants of the *Viburnum* L. genus and elements of its control technology (selection of species, varietal composition, seasonal pruning, mechanised trunk, or inter-bush loosening of the soil, application of mineral fertilisers, use of paraffin oil and Actofit biological product) for strategies in breeding work. The study was based on the use of the method of conducting a qualification examination, visual methods (route and detailed), the method of accounting and describing pests, determining the degree and score of infestation, and the percentage of damaged plants. As a result, species

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of the *Viburnum* L. genus are differentiated by susceptibility to viburnum leaf beetle into: susceptible – *V. opulus*, *V. sargentii*, moderately or poorly receptive – *V. lantana*, and immune or resistant – *V. sieboldii*, and in the garden conditions on moderately or poorly susceptible – *V. opulus*and *V. sargentii* and resistant – *V. sieboldii* and *V. lantana*. The most effective measure of mechanical control of the viburnum leaf eater, in particular, in the collection, hybrid, breeding, and queen nurseries, is pruning individual branches with pest eggs laid on them during November-March. It is identified that the appropriate measure is the formation of biological barriers in the breeding nurseries of Viburnum, represented by other viburnum species (Siebold's viburnum, Viburnum lantana), which are less susceptible to the viburnum leaf beetle than the plants of Viburnum opulus or Viburnum sargentii, which will allow preserving valuable genotypes of the above-mentioned viburnum species from damage by the pest at an early stage and prevent the use of environmentally dangerous chemical pesticides. The results of the study expand information about the *Pyrrhalta viburni* Payk. species and can be used in the ecology of insect pests, the developed measures will allow controlling the populations of viburnum leaf beetle in the system of fruit and decorative gardening at an early stage

Keywords: viburnum leaf beetle; bioecological features; plant species of the *Viburnum* L. genus; pest infestation and damage to plants; control measures

INTRODUCTION

Pests-parasites of higher plants, developing on the surface or inside living tissues, use nutrients for their growth and development and often lead to serious changes in the host or their partial or complete death. Therefore, it is necessary to consider the bioecological features of pests to further control them. Among the plants that are not widely distributed in the culture, many species of the *Viburnum L.* genus are gaining popularity in both fruit and decorative gardening. The list of these species includes Viburnum opulus, Viburnum lantana, Viburnum sargentii, Viburnum prunifolium, Viburnum dentatum, Viburnum Roseum, Viburnum rhytidophyllum, etc. (Moskalets *et al*, 2019; Moskalets *et al.*, 2020).

One of the most dangerous insect pests of the above-mentioned genus is the viburnum leaf eater (*Pyrrhalta viburni* Paykull). Klimassewski *et al.* (2020) in their study note that autochthonous populations of the viburnum leaf beetle are common in Eurasia, including Ukraine, allochton infestations were observed in North America (Canada, USA). Both larvae and imagoes often destroy a substantial part of the leaf apparatus of viburnum, which negatively affects the condition of plants. The pest does not immediately destroy the host plants, but in case of repeated defoliation, death is noted in the second or subsequent years.

The Harmfulness of the viburnum leaf eater (*Pyrrhaltaviburni* Paykull) was investigated by American researchers (Weston & Desurmont, 2020), who note that this pest parasitises plants of many species *V. trilobum* Marshall, *V. opulus* L., *V. sargentii* Koehne, *V. rafinesquianum* Schultes, *V. recognitum* Fernald and *V. dentatum* L.

As noted by (Liesch, 2021), substantial damage to viburnum plants (leaves, fruits) can cause them to weaken or even die. New populations of *Pyrrhalta viburni* have a negative impact on both plants in nurseries and wild forms of viburnum and their associated fauna, which forms close biocenotic relationships with plants.

Based on the monitoring, it is possible to determine to a certain extent the locations of the viburnum leaf beetle, as noted by (Robinson & Simisky, 2022), who are specialists of the Centre for Agriculture, Food and the Environment (USA) and provide advice for production, as the employees of the University of New Hampshire hotline do (Ask UNH Extension, 2019). According to monitoring studies by experts from the Department of Entomology at Michigan State University (Donne & Smitley, 2020), the appearance or disappearance of the viburnum leaf beetle is dynamic, which often weakens the vigilance of gardeners. This is also noted by (Brewer, 2018) of Cornell University's Department of Horticulture and (Williamson, 2021) Clemson University's HGIC horticultural extension agent (USA).

A delay in the identification of the pest, as noted by (Connolly, 2021), contributes to its spread in both fruit and decorative viburnum plantings. As noted (Kraus *et al.,* 2022), in 48 US states, the viburnum leaf beetle can damage viburnum plants, although until recently the pest was localised only in two states near Canada. In Europe, there are a number of facts of concern for researchers about the growth of harmful viburnum leafhoppers. In France, researchers (MNHN & OFB, 2023) have been conducting thorough studies related to the vital activity of the viburnum leaf beetle since 2003.

Members of the British Royal Horticultural Society (Royal Society, 2023) reported that regular studies allow forming the dynamics of the pest over the years, in particular, in 2010, the viburnum leaf beetle was a type of garden pest in the leading positions. German researchers (Rheinheimer & Hassler, 2018) note that although the viburnum leaf beetle is absent in the Balkan Peninsula, this is not a reason to stop monitoring its detection.

The horticultural expert (Crossley, 2023) notes that the earlier the pest is detected, the easier it is to eliminate it, so it is important to monitor the damage and the pests themselves, in particular, to expand information about its biological features due to global climate change. Holly Crossley reports that a retrospective analysis of long-term data on the viburnum leaf beetle

shows that beetles and larvae of this species feed only on viburnum. This makes it easier to monitor its populations. It was recently identified that the above-mentioned pest in the shade is less parasitic on viburnum plants.

Weather and climatic factors play an important role in fluctuations in the number of viburnum leaf beetles. As noted by (Bradley, 2020), an employee of CBC News, elevated air temperatures in winter contribute to better wintering of the viburnum leaf beetle, and, consequently, an increase in the manifestations of parasitism of insect pests in gardens. According to the researcher (Maier, 2019), the expansion of the range of the viburnum leaf beetle is inevitable. Therefore, systematic monitoring of the manifestation of any unfavourable biotic factors in the future reduces problems and provides ways to solve them.

An increase in the area under viburnum plants, in the absence of timely control measures, can lead to an expansion of the range of viburnum leaf beetle not only in Ukraine but also abroad, in particular, as a harmful invasive species, which is often stated in scientific publications by entomologists in North America (Omand, 2016). In connection with the above, the study of bioecological features of the viburnum leaf beetle and the development of measures for its control in the system of fruit and decorative gardening is relevant.

The purpose of the study was to examine the bioecological features of the viburnum leaf beetle on plants of the *Viburnum L.* genus and develop measures to reduce its harmfulness.

MATERIALS AND METHODS

Records for damage to viburnum plants by viburnum leaf beetle were conducted in breeding nurseries of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (northern Forest-Steppe, Fastovsky district of the Kyiv region) during 2018-2021 and separate strongholds for environmental testing of viburnum source material (Western Forest-Steppe, in particular, Zhovkivsky, Zolochivsky districts of the Lviv region and the southern part of Polissia, in particular, Nosivsky and Nizhinsky districts of the Chernihiv region) during 2020-2021. Varieties of Viburnum opulus were involved in the study of the degree of plant damage: Uliana, Ania, Velykoplidna, Yaroslavna, and sterile varieties Roseum, Viburnum sargentii – Onondaga, Viburnum sieboldii Seneca, and Viburnum lantana – Vidrodzhennia and Aureum. Observations and records were conducted during April-September, according to the methodology of qualification examination of varieties of forest plant species (Methodology of qualification examination..., 2016).

The study used visual methods based on direct examination and counting of the viburnum leaf beetle and the organs of viburnum plants damaged by them, examining 5 viburnum trees or bushes along the diagonal of the quarter. According to the technique of execution, they alternated with route or detailed ones, depending on the scale of damaged plants. Route surveys were mainly used to visually detect the population of plants with imagoes and pest larvae, while the area of surveys was not less than 10% of the total area of visual surveys. During detailed accounting, the number (density) of the pest and the degree of damage to plants by it, the feasibility and methods of certain protection measures were determined. The degree of colonisation (damage) of plants by viburnum leaf beetle was determined on a special scale according to the "Methodology of qualification examination"(2016) (Table 1).

Table 1. *Scale for assessing the degree and points of infestation (damage) of viburnum plants*

Populating the leaf surface, %	Degree of population	Population point
0	0	0
<5	very weak	1
5-25	weak	2-3
26-50	medium	4-5
51-75	strong	6-7
>75	very strong	8-9

Source: *(Methodology of qualification examination..., 2016)*

The population of plants with viburnum leaf beetle was determined by the formula:

$$P = 100 \times \frac{n}{N}, \quad (1)$$

where *P* –population of plants, %; *n* – number of inhabited plants or leaves, pcs.; *N* – total number of plants (leaves) registered, pcs.

The coefficient of plant damage was determined by the formula:

$$K = (\mathrm{A} \times \mathrm{B}) \div 100, \quad (2)$$

where *K* – plant damage coefficient; *A* – percentage of damaged plants; *B* – average damage score.

Detailed records were conducted with a frequency of 10 days. Additionally, the pest population was recorded

using glue traps (catching belts). Traps were examined and captured beetles and larvae were counted daily or once every 3-5 days, removing insects from the adhesive surface with tweezers. The intensity of larval damage to plants was determined on a four-point scale: 0 – plants were not damaged; 1 – slightly damaged, about 25% was lost; 2 – medium, 26-50%; 3 – strongly, 51-75% of the leaf surface was lost. The results of accounting during the growing season were recorded in the study log. Damage from viburnum leaf beetle larvae was determined from special literature sources (Puzrina, 2020).

Pruning was conducted to control the pest in breeding nurseries (in 2018-2019 forming + regulating, in 2019-2021 – regulating + rejuvenating + sanitary pruning) during February-March (main – cutting or thinning of branches and additional – shortening of branches) and August-September (less often October); three-time trunk and inter-bush tillage during the growing season (or tillage at the stem strip of soil, which was 1.5-2 times wider than the crown of viburnum plants); application of nitrogen and phosphorus-potassium fertilisers (on average 3-5 kg/m^2 on a specially prepared area in the forest belt, paraffin oil was applied (before the vegetative buds opened) and treated with a 0.4% solution of Actofit biologics three times (in the daytime during the growing season of viburnum at an air temperature not lower than +18°C and not higher than +28°C every 14 days, with a norm of 4 ml/L of water + 0.1-0.2 ml/L of liquid soap). Mathematical data processing was performed using Statistica-6.0 and Microsoft Excel computer programmes.

RESULTS

Viburnum leaf eater *Pyrrhalta viburni* Paykull, 1799, synonym – *Galeruca viburni* (Payk.) belongs to the genus Pyrrhalta, tribe Galerucini, subfamily Galerucini (*Galerucinae*), leaf-eating families (*Chrysomelidae*), a number of Coleoptera or beetles (*Coleoptera*) of the Insect class (*Insecta*). The range of the viburnum leaf eater is West-Palearctic, except for the extreme southern and northern territories. These are insects with complete metamorphosis that go through the egg, larva, pupa, and imago stages in their life cycle. Imagoes of the pest were often identified on the leaves of viburnum in late June, until the onset of autumn frosts. Notably, imagoes, in addition to leaves, damage the fruits of Viburnum plants during the filling phase. Fruits damaged in this way often change shape or rot and fall off. Larvae are able to strongly skeletonise leaves, even before they bloom, in particular, at the top of branches. The larvae have been identified to make irregular round or elliptical holes that sometimes cross the thin veins of the leaf. Initially, small larvae feed on the lower surface of the leaf blade between its veins, eating the soft parenchyma (Fig. 1).

Figure 1. *Damaged viburnum leaf by viburnum leaf beetle larvae*
Source: *photographed by the authors*

Larvae of the first instar are light yellow, the second – also yellowish with black spots (up to 0.7 cm), the third instar – darker and in the second decade of June reach about 1 cm in length (Fig. 2).

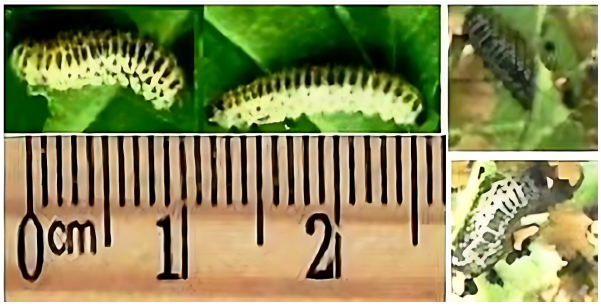

Figure 2. *Image of Pyrrhalta viburni Payk larvae*
Source: *photographed by the authors*

At the end of May or in the first or second decade of June, populations of viburnum leaf beetle larvae can be observed on viburnum plants. In particular, a high number of larvae was noted on fruit and decorative varieties of the viburnum plant (Moskalets *et al.*, 2023). Larvae develop for about four to five weeks. Further, their migration by stems to the soil surface can be observed, where the pupation stage takes place. The pupal stage usually lasts from two to three weeks and ends with the release of an adult beetle from the soil (Murray *et al.*, 2016).

In the first decade of July, there was an increase in the number of greyish-brown beetles, which was marked by the appearance of substantial mines on the leaves of viburnum. Imagoes of the above-mentioned pest, and larvae, gnaw holes in the leaves but have slower life activity than larvae (Fig. 3).

Figure 3. *Adult viburnum leaf eater*
Source: *photographed by the authors*

The second stage of the numerous appearance of the leaf-eating imagoes in the conditions of the Northern Forest-Steppe was noted in the third decade of June, the southern part of Polissia – in the first decade of July. The manifestation of imagoes' vital activity was noted by the end of the third decade of September (in certain years, 2018 and 2020, beetles of the above-mentioned pest were noted in the first decade of October). Both imagoes and larvae of the above-mentioned pest feed both singly and in groups, gnawing holes in the leaves of Viburnum creating a web (or skeletonised) pattern, causing substantial damage to viburnum trees (bushes) every spring. In late August-early September, female pests lay dirty-dark-yellow eggs in small groups (an average of 17 pcs.) on the apical branches of the current year. Then the eggs are covered with a cap of chewed bark and excrement, bonded with special cement, which they make. In autumn or winter, egg-laying sites can easily be identified on annual increments, along their lower side. According to Gyeltshen (Gyeltshen, 2022), the female viburnum leaf beetle lays about 100 eggs during its development cycle. It is noted that in some years (2018, 2021), drying of annual shoots was noted, where females of the viburnum leaf beetle gnawed out holes for laying eggs.

Thus, in the spring, larvae cause substantial damage to viburnum plants, and imagoes – in July-August. Damaged leaves often turn yellow, then half-eaten leaf particles near the vein turn brown with shrunken edges, while in wet weather, eaten leaves with pest excrement have an unpleasant smell. Frequent drying of the apical branches of Viburnum plants of the current year was also noted.

Strong colonisation of plants with viburnum leaf beetle leads to the loss of chlorophyll by the leaves and a decrease in the mass of a unit of surface. Plants of various types of Viburnum that were previously placed on a specially prepared plot in the forest belt during 2018-2021 were 5-9 times more populated by pest populations and suffered from it than in the conditions of a breeding garden, where viburnum plants had proper care (pruning, fertilising with mineral fertilisers, with stem or inter-bush loosening of the soil). Among the examined species of Viburnum in the forest belt, the most populated were *Viburnum opulus* L. (55-87%), *V. sargentii* Koeh. (75-90%), and *V. opulus* 'Roseum' (85-100%) plants. Notably, under the above conditions, the population (damage) of plants of the *V. lantana* L. species was at the level of 7-22%, and *V. sieboldii* Miq. – practically no viburnum leaf beetle. In the conditions of agrocenosis, the average annual population of plant *Viburnum opulus* L. and *V. sargentii* Koeh. species was at the level of 10% or lower. At the level of 35% was the population of plants *V. opulus* 'Roseum', in 2021 – at a level of more than 45%. The plants of the species *V. lantana* L. (with the exception of the collection nursery, where the population was 2-3%) and *V. sieboldii* Miq. on average, imagoes and pest larvae were practically not damaged (Fig. 4).

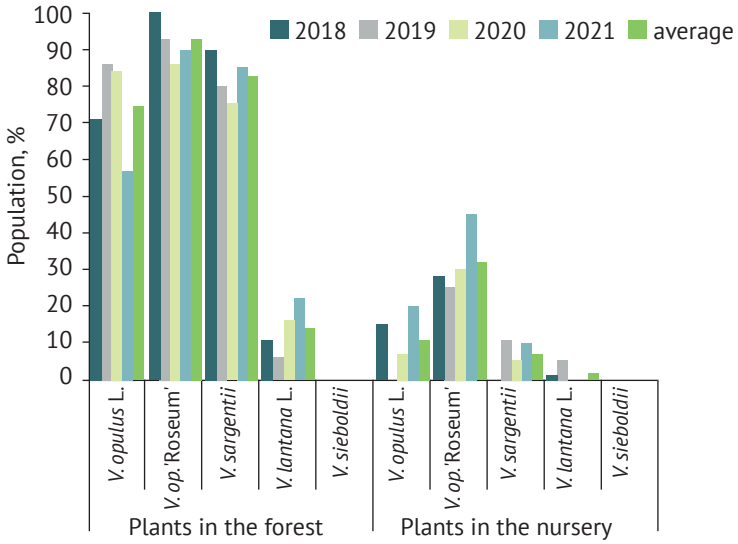

Figure 4. *Population of plants with viburnum leaf beetle depending on the place of cultivation of Viburnum plants by the year*
Source: *compiled by the authors*

The above gives grounds to popularise the above-mentioned types of Viburnum in the horticultural system, both for landscaping and for the formation of protective barriers against the viburnum leaf beetle. According to Figure 4, it can be stated that the stable population of Viburnum plants of individual species at the level of more than 60%, which is a cause for concern since the annual trend towards an increase in viburnum leaf beetle populations will pose a threat to plants in culture. Therefore, minimal damage to plants affects their condition, determines their resistance to drought and frost, suitability for reproduction by green or lignified seedlings, etc. Annual accounting of viburnum plants by pest population and assessment by damage score allowed for calculating the coefficient of damaged plants (Table 2).

Table 2. *Coefficient of damage to plants of the Viburnum L. genus by viburnum leaf eater (compiled by the authors)*

Place of plant growth	Species name	Year				Average by year
		2018	2019	2020	2021	
Plants in the forest belt	*V. opulus* L.	5	7.7	7.6	3.4	5.2
	V. opulus 'Roseum'	9	8.4	7.7	8.1	8.3
	V. sargentii Koehne	8.1	7.2	5.3	7.7	7.4
	V. lantana L.	0.3	0.1	0.5	0.7	0.4
	V. sieboldii Miq.	0	0	0	0	0
Plants in the collection nursery	*V. opulus* L.	0.5	0	0.1	0.6	0.3
	V. op. 'Roseum'	1.1	0.8	1.2	2.3	1.3
	V. sargentii Koehne	0	0.3	0.1	0.3	0.1
	V. lantana L.	0	0.1	0	0	0
	V. sieboldii Miq.	0	0	0	0	0

Source: *compiled by the authors*

According to Table 2, on average, the highest coefficient of plant damage in the forest belt was observed in the *V. opulus* 'Roseum' (8.3), *V. sargentii* Koeh. (7.4), and *V. opulus* L. (5.4) species. Under the conditions of culturocenoses, the indicators of the plant damage coefficient for almost all species did not exceed one. Based on the data in Table 2, it was possible to determine the average damage score and the degree of pest infestation (Table 3).

Table 3. *Average damage score of plants of the Viburnum L. genus viburnum leaf eater (compiled by the authors)*

Place of plant growth	Species name	Year				Average by year	Degree of population
		2018	2019	2020	2021		
Plants in the forest belt	*V. opulus* L.	7	9	9	6	7.8	very strong
	V. op. 'Roseum'	9	9	9	9	9.0	very strong
	V. sargentii Koehne	9	9	7	9	8.5	very strong
	V. lantana L.	3	2	3	3	2.8	weak
	V. sieboldii Miq.	0	0	0	0	0.0	0
Plants in the collection nursery	*V. opulus* L.	3	0	2	3	2.0	weak
	V. op. 'Roseum'	4	3	4	5	4.0	medium
	V. sargentii Koehne	0	3	2	3	2.0	weak
	V. lantana L.	1	2	0	0	0.8	very weak
	V. sieboldii Miq.	0	0	0	0	0.0	0

Source: *compiled by the authors*

According to Table 3, the average damage score for almost all the examined varieties of the *V. opulus* L. species (Uliana, Ania, Velykoplidna, Yaroslavna) was at the level of 7.8 and sterile Roseum and *V. sargentii* Koeh. species – 9 and 8.5, respectively, which indicates a very strong degree of pest infestation. In the conditions of garden breeding, the species *V. opulus* L. and *V. lantana* L. had an average damage score of 2 and 2.8, respectively,

i.e. a weak degree of infestation. Average damage score and degree of infestation of plants of the *V. sieboldii* Miq. species were zero, which could be checked when growing plants of this species at different ecological points (Fig. 5).

The above results allowed ranking species by susceptibility to viburnum leaf beetle depending on the growing conditions. Under conditions of non-interference with plant care (in a specially prepared place in a forest belt), various viburnum species were ranked as susceptible – *V. opulus*, *V. sargentii*, moderately or poorly receptive – *V. lantana*, and immune or resistant – *V. sieboldii*. Under the conditions of proper plant care, viburnum species were differentiated into moderately or poorly susceptible ones. – *V. opulus*and *V. sargentii*, and resistant – *V. sieboldii*and *V. lantana*.

Differentiation of viburnum species by susceptibility allows identifying and suggesting viburnum species that are not very susceptible or resistant to damage by the viburnum leaf beetle for the horticultural system as a measure to control its populations in culturocenoses. Due to the high degree of population and damage to plant species *V. opulus*, *V. sargentii*etc. in various ecological points in the early spring period (before budding), paraffin oil treatment was used, which does not have a phytotoxic effect on the plant and at the rate of consumption of a working solution of 200-250 l/ha and an oil concentration of 820 g/L forms a thin coating that effectively blocks the entry of air into the eggs and the hatching of leaf beetle larvae from them, which then suffocate. Therefore, the control of wintering stages of viburnum leaf beetle when using paraffin oil and during the growing season of plants by applying 0.4% solution of Actofit biological product (dose 4 ml/L + 0.1-0.2 ml/L of liquid soap) provided almost reliable control of viburnum leaf beetle populations both in the southern Polissia and in the Northern and Western Forest-Steppe of Ukraine (Fig. 5).

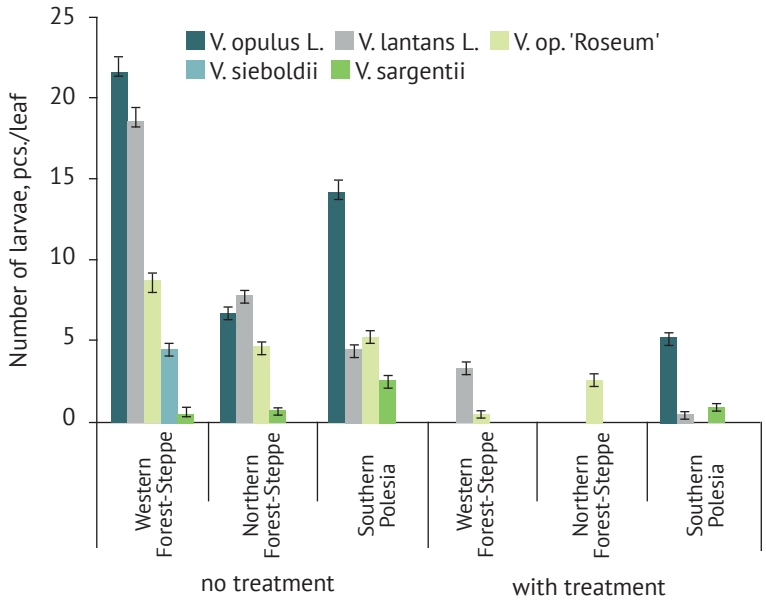

Figure 5. *The number of viburnum leaf beetle larvae, depending on physical and geographical conditions and the method of their control (treatment with paraffin oil and application of Actofit biological product), is average for 2020-2021 (compiled by the authors)*

Thus, the conducted studies allowed identifying the bioecological features of the viburnum leaf beetle regarding the choice of feed base from the list of different types of viburnum, the number depending on economic activity and growing conditions; ranking plant species by susceptibility to the pest and testing measures to reduce its harmfulness.

DISCUSSION

Leaf beetles are characterised by the attachment to forage plants and ecological niches, among which many biological forms that are visual objects for identifying the manifestations of parasitism are present (Gyeltshen, 2022). Until recently, this viburnum leaf beetle was widespread in Europe, since the late 1890s, individual specimens have been observed in North America, and already in 1924 entomologists recorded these beetles in Canada. Harmful infestations of the viburnum leaf beetle were recorded in North America in 1947, 1970, and 1994 (including the states of New York, Connecticut, New Hampshire, Massachusetts, Vermont, and Pennsylvania) and are occurring still (Smith & Hatch, 2017). As Chris Maier (Maier, 2019) notes, susceptible viburnum species were already at risk of substantial damage as of 2016, in particular, the territories of new locations for viburnum leaf beetles (Ohio, Michigan, Wisconsin, and Illinois).

Currently, the pest is widespread in the eastern part of the United States, in particular, in British Columbia

and parts of Washington, and is also localised, especially in western North America, according to Todd Murray (Murray*et et al.*, 2016) in recent years, the likelihood of pest coverage in the Pacific Northwest has increased. As noted above, the range of the viburnum leaf eater in Europe has been known for a long time, there are territories where the pest has been recorded for the first time in recent years (Mirza*et et al.*, 2021).

Entomologist Desurmont G. (Desurmont *et al.*, 2020; Weston & Desurmont, 2020) notes that the viburnum leaf beetle is one of the most dangerous pests of the viburnum garden. The researchers showed that in addition to Viburnum opulus, other species of the *Viburnum* L. genus were also susceptible to imagoes and larvae of the aforementioned pest (in particular, *Viburnum opulus* L., *V. lantana* L. etc.), which are very popular in the system of decorative gardening.

In the presented study, in addition to various species, preference for examining susceptibility was given to varieties of Viburnum opulus. (Desurmont *et al.*, 2019) report that regardless of viburnum varieties, the survival rate of viburnum leaf beetle eggs increases in association with ticks of the *Trichoribatestrimaculatu*s (Ceratosetidae) species as an example of commensalism.

As noted by (Liesch, 2021), in years of high abundance of viburnum leaf beetle, the use of *Viburnum zobata*, *Viburnum opulus*, and *Viburnum opulus* var. *americanum*) in gardening is not advisable since the plants of these species suffer from the above-mentioned phytophage, while *Viburnumplicatum* F. *tomentosum*, *Viburnum* x *juddii*, or *Viburnum carlesii* should be planted. Although, as evidenced by Desurmont & Weston (2014), stage 3 larvae from the optimal *Viburnum dentatum* host plant can migrate to suboptimal host plants (*V. lentago*, *V. carlesii,* and *V. sieboldii*).

Dr. Paul Weston (Weston, 2018), a woody plant entomologist at Cornell University, also investigated the susceptibility to damage of viburnum plants by the viburnum leaf beetle. As a result, different viburnum species were differentiated into susceptible (*V. dentatum*, *V. nudum*, *V. opulus*, *V. trilobum*, *V. propinquum*, *V. rafinesquianum*), moderately susceptible (*V. acerifolium*, *V. lantana*, *V. rufidulum*, *V. sargentii*, *V. wrightii*), and resistant (*V. bodnantense*, *V. carlesii*, *V. davidii*, *V.* x *juddii*, *V. plicatum*, *V. plicatum* var. *tomentosum*, *V. rhytidophyllum*, *V. setigerum*, *V. sieboldii*). From the data of the presented study, parallels can also be drawn, in particular, regarding the level of susceptibility to viburnum leaf beetle of plants of such species as *V. opulus*, *V. lantana*, *V. sargentii*, and *V. sieboldii*.

Weston (2018) also notes that to reduce the number of viburnum leaf beetle populations, pruning viburnum bushes or trees, in particular, removing egg-infested twigs is recommended, which in researcher's opinion is one of the most effective measures after growing resistant varieties and applying insecticidal soap or garden oil.

(Humphreys & Ruxton, 2019) note that leaf-eating pest larvae are more likely to fall from herbaceous plants than from woody plants before pupation or for protection from predatory insects. This is also evidenced by the data of (Konstantinov *et al.*, 2018). Therewith, according to (Matsubara & Sugiura, 2021) and (Shinohara & Takami, 2020), plant architectonics is important.

Many papers have been devoted to measures to control the viburnum leaf beetle, and as noted (Giesmann, 2017), all of them have their feasibility depending on the area of use of viburnum plants. The expediency of using fertilisers in the garden to improve the growth and development of plants and, ultimately, increase soil fertility is confirmed by (Wyckhuys *et al.*, 2017), which substantially affects the reduction of parasitism on the part of insect pests.

Imagoes and larvae of the viburnum leaf beetle are destroyed with contact insecticides (Actellic, Fundazol, etc.), if necessary, although beetles that are more mobile than larvae are more difficult to control. Therefore, to achieve the best results, insecticides are used when the larvae are in the first or second stage of development (Zverev*aet et al.*, 2017). Most garden crops are attacked by several insect pests. As broad-spectrum chemical control options become increasingly limited, there is a need to develop new control methods. Researchers consider it appropriate to use biological protective equipment in the control of leaf-eating pests (Liao *et al.*, 2021).

In particular, (Baroffio *et al.*, 2018) suggest using extracts from plants with phytoncidal properties in pest control (in particular, infusions of onions, garlic, chamomile leaves, tobacco, potato stalks, tomatoes, or bitter pepper fruits). An effective biological measure is the luring of certain species of ticks or birds, which will be able to reduce the population of leaf-eating pests. Thus, as noted by (Heimpel & Mills, 2017), biological control or reasonable selection and subsequent introduction of a specialised insect predator (in particular, spined soldier bug (*Podisus maculivenrtis*) against the pest, which effectively reduces their populations to less harmful levels.

As the researchers (Xiu*et et al.*, 2019) and (Wyckhuys *et al.*, 2018; 2019) state, predatory bugs can control the number of leaf-eating pests. Individual researchers (Silchuk*et et al.,* 2015) also suggest the use of bacterial preparations, in particular, Actofit, the effectiveness of which against viburnum leaf beetle larvae exceeds 80%. In particular, in the studies of the above-mentioned authors, the coefficient of damage to plants of the *Viburnum L.* genus from viburnum leaf beetle was 3 times smaller, and in this study for the individual species – more than 7-8 times.

Summarising the above, it can be concluded that problems with pests in the garden or field arise against the background of complete or partial failure to consider practical experience, which leads to a reduction

in certain plant species, an increase in the level of application of an intensive chemical protection system, or redevelopment of the production process, which generally entails negative consequences in both economic and environmental aspects. In this regard, in the system of fruit and decorative gardening with the expansion, introduction of new species, varieties of viburnum, elements of their cultivation technologies, etc., the priority is a comprehensive analysis of abiotic, biotic (including biocontrol of native and invasive pests), and anthropic environmental factors in combination with scientific-practical long-term experience.

CONCLUSIONS

Viburnum leaf beetle is the most dangerous pest for the plants of the *Viburnum* L. genus; studies have shown that it is very damaging to plants of Viburnum opulus, Viburnum Roseum, Viburnum sargentii, etc. Without proper care, viburnum plants sometimes suffer from mass populations of the viburnum leaf beetle. It is noted that imagoes of the viburnum leaf beetle were identified on the leaves of viburnum at the end of June, until the onset of autumn frosts. Therewith, beetles, in addition to leaves, damage the fruits of viburnum plants during the filling phase, which often change shape or rot and fall off. Larvae of the pest are able to strongly skeletonise the leaves, even before they bloom, in particular, at the top of the branches of viburnum plants.

Viburnum leaf beetle substantially damages the leaves of Viburnum opulus and Viburnum Roseum, which weakens the growth and development of plants, reduces decorative properties, and leads to the drying of annual branches. It is noted that damaged viburnum bushes or trees form a second leaf shoot after a short time, but their development is suspended by unsuitable conditions for growth in August-September.

Plants of the Viburnum opulus varieties have a low natural resistance to viburnum leaf beetle, but proper care of plantings (pruning, feeding with nitrogen and phosphorus-potassium mineral fertilisers, three-time trunk or inter-bush tillage, applying paraffin oil to the blooming of vegetative buds, and three-time use of Actofit biological product for vegetative plants) substantially reduces the number of its populations and reduces the susceptibility of plants to this pest.

For the system of fruit and decorative gardening, the following species of viburnum are recommended as a measure to control viburnum leaf beetles' populations in culturocenoses – *V. sieboldii, V. lantana* as they are poorly susceptible or resistant to damage by these pests.

A promising area of further research is the involvement of immune or low-susceptible species and varieties of the *Viburnum* L. genus in the breeding and production processes in the system of fruit and decorative gardening, which will correct the population characteristics or make it impossible for the viburnum leaf beetle to appear.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Шкодочинність калинового листоїду (*Pyrrhalta viburni Payk.*) на рослинах роду *Viburnum* L. та елементи технології його контролю для стратегій у селекційній роботі в системі плодового і декоративного садівництва

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Анотація. Представленні дослідження проведені врізних екологічних точках України (західна і північна частина Лісостепу, Південне Полісся) з вивчення біоекологічних особливостей *Pyrrhalta viburni* Paykull і розробки заходів щодо зменшення його шкодочинності в системі плодового і декоративного садівництва. Мета роботи передбачала вивчення біоекологічних особливостей калинового листоїду на рослинах роду *Viburnum* L. та елементи технології його контролю (підбір видового, сортового складу, сезонні обрізки, механізовані пристовбурові чи міжкущові рихлення ґрунту, внесення мінеральних добрив, застосування парафінової олії і біопрепарату Актофіт) для стратегій в селекційній роботі. Дослідження базувалися на використанні методики проведення кваліфікаційної експертизи, візуальних методів (маршрутного і детального), методу обліку і опису шкідників, визначення ступеня і балу заселення, відсотку пошкоджених рослин. У результаті досліджень види роду *Viburnum* L. диференційовано за сприйнятливістю до калинового листоїда на: сприйнятливі – *V. opulus*, *V. sargentii*, помірно або малосприйнятливі – *V. lantana* і несприйнятливі або стійкі – *V. sieboldii*,а в умовах саду на помірно або малосприйнятливі – *V. opulus* і *V. sargentii* та стійкі – *V. sieboldii* і *V. lantana*. Найефективнішим заходом механічного контролю калинового листоїда, зокрема в колекційному, гібридному, селекційному і маточному розсадниках, є обрізка окремих гілок з відкладеними на них яйцями шкідника упродовж листопада-березня. З'ясовано, що доцільним заходом є формування в селекційних розсадниках калини біологічних бар'єрів, представлених іншими видами калини (калина Зібольда, калина гордовина), які є менш сприятливими до калинового листоїда, ніж рослини калини звичайної чи калини Сержента, що дасть можливість на ранніх етапах зберегти від пошкодження шкідником цінних генотипів вищезазначених видів калини та запобігти застосуванню екологічно небезпечних хімічних пестицидів.Результати досліджень розширюють відомості про вид *Pyrrhalta viburni* Payk. і можуть бути використанні в екології комах-шкідників, а розроблені заходи дозволять на ранніх етапах контролювати популяції калинового листоїда в системі плодового і декоративного садівництва

Ключові слова: калиновий листоїд; біоекологічні особливості; види рослин роду *Viburnum* L.; заселення і пошкодження рослин шкідником; заходи контролю

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 48-57

UDC 631.581:631.51:631.432
DOI: 10.48077/scihor3.2023.48

Technology of protection of winter wheat from harmful biota in the Northern Forest-Steppe of Ukraine

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Article's History:
Received: 24.01.2023
Revised: 24.03.2023
Accepted: 11.04.2023

Suggested Citation:
Hrytsiuk, N., Bakalova, A., Ivaschenko, I., & Kotkova, T. (2023). Technology of protection of winter wheat from harmful biota in the Northern Forest-Steppe of Ukraine. *Scientific Horizons*, 26(3), 48-57.

Abstract. Winter wheat protection technology is aimed at preventing the mass spread of harmful biota and the possibility of its rapid restriction. Therewith, the main choice of pesticides and their timely use is precisely at the period when harmful organisms are in a sensitive stage to protective products, and plants are in the phase of forming and laying productivity elements. The purpose of the study is to examine the effectiveness of the proposed compositions of chemical preparations against harmful biota in improving the technology of winter wheat protection. When monitoring harmful organisms, generally accepted methods in phytopathology (Strakhov and Geschele scales), entomology (butterfly net, accounting site methods), and herbology (quantitative-weight) were used. The results of the study obtained during a production experiment to examine the effectiveness of product mixtures for a comprehensive system of protection of winter wheat crops are presented. Changes in the species and quantitative composition of winter wheat weed Synusia depending on the protection technology are established. The total number of weeds in the areas where the protection

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system was used decreased by 61.2 pcs./m^2 compared to the control option. Changes in the number of pests are presented (a decrease in the Hessian fly by 26 specimens/100 w.s. (wheat stem), Swedish fly – 31 specimens/100 w.s., grass aphids – 20 specimens per stem, Haplothrips tritici – 34 specimens/100 w.s., bread carabus – 6 beetles/m^2) when spraying winter wheat in the phases of exit into the tube and milk ripeness with insecticides Aktara 25 WG, 0.10 kg/ha + Karate seon 050 CS, 0.2 L/ha. The technical effectiveness of insecticides against pests was 73.8-89.5%, depending on the insect. It is proved that reliable protection against dominant diseases in the farm is achieved by using a combination of fungicides Alto Super 330 EC, 0.5 L/ha and Topsin M, WP, 1.0 kg/ha in the phase of entering the tube and Amistar extra 280 SC, 0.5 L/ha + Rex Duo, SC, 0.4 L/ha in the earing phase–beginning of flowering. The technical effectiveness of double spraying with recommended anti-disease products ranged from 77.1% to 86.8%. The proposed technology for protecting winter wheat from harmful organisms is effective, has passed production testing, and can be implemented in farms of all forms of ownership

Keywords: weeds; diseases; pests; herbicides; fungicides; insecticides; yield

INTRODUCTION

In Ukraine, one of the main tasks of agriculture is to obtain stable and high-quality grain yields. Increasing grain production and improving its quality belongs to winter wheat. Now in Ukraine, the export of wheat grain is one of the main economic instruments of the foreign policy of the country (Tsilurik *et al.,* 2017). According to its biological characteristics, winter wheat is one of the most productive agricultural crops. This is the most productive crop among the grain group of crops which makes the most use of photosynthetic active radiation. However, the potential yield of the crop is realised under certain conditions, such as normal overwintering of plants, the use of agricultural techniques that ensure good field preparation, accumulation of moisture, and the introduction of sufficient fertilisers and plant protection products from harmful organisms (Bakalova *et al.,* 2019; Lollato, 2019). Today, changes in climatic conditions and non-compliance with scientific cultivation technologies lead to a deterioration in the phytosanitary condition of the wheat field.

Planned management of agrocenosis is necessary to effectively prevent crop losses. The plant protection system is a rather complex technological process and is implemented by consistently conducting a set of agrotechnical measures aimed at increasing plant productivity, considering their impact on harmful organisms and special chemical means of protection from pests, diseases, and weeds. The tactics of chemical protection against harmful biota have their own characteristics, so the decision to use pesticides against them is made based on various criteria (Secun *et al.,* 2018; Markovska *et al*., 2018).

As noted by researchers Pisarenko *et al.* (2021), limiting the development of weeds, diseases, and pests through chemical protection products is an important agrotechnical measure, the effectiveness of which depends on the appropriate and correct choice of fungicides and insecticides from a wide range of drugs, compliance with regulations for their use to maximise the impact on harmful organisms without polluting the natural environment. According to V. Gamajunova *et al.* (2022), selecting products for the protection of field crops, including winter wheat, should be conducted according to the "List of pesticides and agrochemicals allowed for use in Ukraine" (2022) for current years.

Harmful biota causes great harm to plants. Various methods and means of protection are used to protect winter wheat crops. Therewith, it is important to ensure that individual measures are conducted in the determined time frame, considering the biological, morphological, and physiological characteristics of the development of pests, weeds, and pathogens. In this regard, there is a need to constantly monitor the harmful biota of the wheat field to control their abundance, spread, and harmfulness, which is the basis for improving the technology of plant protection against a complex of harmful organisms and adapting them to the modern agroecolological situation (Kosylovych *et al.,* 2017). Despite the constant updating of the range of pesticides and the technology of their application, in recent years the potential losses of the winter wheat crop have not changed radically (Liskovskyi *et al.,* 2020). Therefore, the need to use herbicides, fungicides, and insecticides in each specific case should be comprehensively justified. The criterion for such justification is to account for the number of harmful biota in each field and compare them with the economic thresholds of harmfulness (ETH) and the nature of the population of the field.

Thus, the purpose of the study is to examine the effectiveness of the proposed mixtures of pesticides in industrial winter wheat crops from a complex of harmful organisms in the conditions of the Northern Forest-Steppe of Ukraine. The following tasks were set to achieve this goal: identify the specific and quantitative composition of weeds, diseases, and pests; offer tank mixtures of fungicides and insecticides with the addition of microfertilisers for the effective destruction of a complex of diseases, pests, and various biological groups of weed vegetation without harming the growth and development of winter wheat and the environment; determine the technical effectiveness of joint use of pesticides and their tank mixtures.

LITERATURE REVIEW

T. Rozhkova *et al*. (2022) note that the use of non-certified seeds, reduced rotation of grain crops, violation of the terms of sowing, tillage, and fertiliser systems led to an increase in the development of fungal diseases, an increase in the number of phytophages, and substantial contamination of crops. Ukrainian researchers O. Derecha *et al*. (2018) claim that among the leaf diseases of winter wheat, septoriosis, brown leaf rust, and powdery mildew are the most harmful. Crop losses from leaf septoriosis can reach 30-40%, and losses from brown leaf rust with damage up to 40% are 0.3-0.4 t/ha, and more than 40% – exceed 1 t/ha. L. Kryuchkova and N. Hrytsyuk (2014) prove that root rot of various etiologies dominates among root diseases, crop shortages from them can reach 30%, symptoms of root rot damage can manifest themselves in all phases of plant growth and development, while the intensity of the disease varies substantially over the years depending on environmental and agrotechnical conditions.

In the research area, depending on the study area, all six types of root rot were identified – Pseudocercosporella, Rhizoctonia root rots, Fusarium, Gaeumannomyces, Bipolaris sorokiniana, Pythium root rot. I. Bakay *et al*. (2019) confirmed that Fusarium root rot is the most common. G. Slobodianyk *et al*. (2022) and O. Markovska *et al*. (2018) in their papers note that substantial reserves of pathogenic microflora and phytophage larvae accumulate in the soil, which, without proper sanitary treatment of seed material, lead to damage to seeds and seedlings of winter wheat. The most practical and cost-effective method of protecting against wheat diseases is pre-sowing seed treatment with approved pesticides. In addition, the positive effect of seed treatment is that much less effort is spent on wheat care during the growing season. It is also a preventive measure using a mixture of insecticidal and fungicidal mordants, which reduces the number of sprays of crops during the growing season, which, in turn, reduces the toxic load on agrocenoses.

V. Sakhnenko *et al*. (2018) reported that siphoning phytophages, especially cicadas, grass flies, and grass aphids, pose a substantial threat to winter wheat crops. The harmfulness of these pests is often underestimated due to unnoticeable damage. However, when sucking out nutrients, insects can introduce toxic compounds that disrupt metabolic processes, inhibit plant growth and development, and worsen winter hardiness and drought resistance. In addition, grass aphids and leaf beetles carry viral diseases of crops. A. Fedorenko *et al*. (2021) claim that grain is damaged by bread beetles – *Anisoplia agricola* P., *Anisoplia austriaca* H., *Anisoplia segetum* H., *Eurygaster integriceps* Put., *Zabrus tenebrioides* Goese.

Researchers O. Kurdyukova *et al*. (2019) and I. Storchous (2019) confirm that weeds compete with cultivated plants for light, water, and nutrients, reducing potential crop yields, and crop contamination can reduce yields by up to 60%, depending on its degree. In addition, failure to comply with the necessary isolation over time and substantial saturation of arable land with winter crops leads to the accumulation of a substantial number of specific cereal weeds in the fields, such as windgrass (*Apera spic aventi* L. Pal Beauv.), including wintering weeds species: cleavers (*Galium aparine* L.), tumbleweed mustard (*Sisymbrium loeseli* L.), flixweed *Deuscurainia Sophia* L. Webbex Prantl), horseweed (*Erigeron Canadensis* L.), drug fumitory (*Fumaria officinalis* L.)

MATERIALS AND METHODS

The technology of winter wheat protection was investigated based on previous studies of the authors, (Derecha *et al.,* 2018) and new ideas were implemented in the production experiment of the SE Experimental Farm Nova Peremoha of the Polissia National University of the National Academy of Agrarian Sciences of Ukraine in the Stara Chortoriia village, Zhytomyr district, Zhytomyr region during 2019-2021 according to such a scheme:

1. Without a protective system (control)
2. Security system (Table. 1)

Table 1. *Winter wheat protection system, 2019-2021*

Processing term and method	Preparation, a tank mixture	Consumption rate	Harmful organism
Seed treatment	Lamardor 400 FS + Gaucho Plus 466 FS	0.2 (1 L/t) 0.6 (1 L/t)	Loose, stinking, black smuts, seed mould, Cochliobolus sativus, Fusarium root rot. Grass flies, cicadas, ground beetle, thrips, fleas
Tillering phase (BBCH 21-29)	Granstar Pro 75, WG + Apiros 75 WG	20 g/ha + 15 g/ha	Annual and perennial dicotyledons, including weeds resistant to 2,4-D and cereals
Stem elongation phase (BBCH 30-39)	Alto Super 330 EC, + Topsin M, WP + Aktara 25 WG Orakul, s.	0.5 L/ha + 1.0 kg/ha + 1.0 kg/ha 1.0 L/t	Powdery mildew, brown leaf rust, leaf septoriosis, pyrenophorosis, cercosporellosis; cereal leaf beetle, grass aphids, thrips; increased disease resistance and yield
Booting-flowering phases (BBCH 41-69)	Amistar extra 280 SC+ Rex Duo, SC,	0.5 L/ha 0.4 L/ha	Ear diseases (Fusarium, septoriosis, alternariasis), powdery mildew, rusty diseases

Table 1, Continued

Processing term and method	Preparation, a tank mixture	Consumption rate	Harmful organism
Milk phase grain ripeness (BBCH 71–77)	Aktara 25 WG + Karate zeon 050 CS	0.1 kg/ha+ 0.2 L/ha	Spraying when the economic threshold of harmfulness is exceeded ETH: 2-3 larvae of the Eurygaster integriceps bug per 1 m^2 ; 40-50 specimens of Haplothrips tritici per ear, 20-30 specimens/w.s. of wheat aphid 3-5 specimens/m^2 of bread carabus

Source: *compiled by the authors*

The soils under the experimental plots are mainly chernozems and dark grey podzolic, which are characterised by the following indicators: the humus content ranged from 3.43 to 4.45%, hydrolytic acidity 2.3-3.0 mg-eq/100 g of soil and pH of salt extract 5.5-6.0, easily hydrolysed nitrogen compounds (75-124 mg/kg), increased mobile phosphorus content (185 mg/kg), average exchange potassium content (102 mg/kg).

Its predecessor is clover of the second year of use. The main tillage was conducted in the third decade of August – ploughing to the depth of the arable layer. Pre-sowing tillage was conducted to a depth of 6 cm with combined tillage units. Sowing was conducted on September 15-20 with an SZ-3,6 seed drill with treated Artemis seeds. They were sown in rows to a depth of 4-5 cm, with a seeding rate of 5.5 million germinating seeds per 1 hectare with row spacing of 15 cm. Mineral fertilisers in the main fertilising $N_{60}P_{60}K_{60}$ (ammonium nitrate, monokalium phosphate) were applied. Early spring root feeding was conducted with ammonium nitrate at a rate of 30 kg of the active substance. Repetition in the experiment is threefold, the area of the sown area is 190 m^2, accounting – 100 m^2 placement of options is systematic. The norm for working fluid consumption is 250-300 litres per 1 ha when spraying plants with protective products, in the control version, the plants were treated with an equivalent amount of water. Agricultural technology in the experiment was generally accepted for the Forest-Steppe zone.

In the course of the study, the following observations and records were conducted:

1. Phenological observations of wheat plant growth and development.

2. Accounting of winter wheat crops for leaf diseases was conducted at the first signs of diseases on the leaves, and subsequent ones – after 10-15 days, using Strakhov and Geschele scales. Root rot was recorded during the waxy ripeness phase according to the method of sampling sheaves. Sheaves were selected in four places from two adjacent rows with a length of 0.5 m. After selection, the plants were carefully examined and evaluated on a scale: 0 points – the plant is healthy; 1 point – up to 15% of the root system is affected; 2 points – 15-30% of the roots are affected; 3 points – 30-60% of the roots and base of the stem (Derecha *et al.,* 2018).

3. When considering the colonisation of wheat plants by dominant pests (grass flies, wheat thrips), the butterfly net method was used. The method of accounting for ground beetles was used. Accounting was conducted using a frame with a size of 0.25*0.25 m, which was applied to plants, after which they were examined, the number of pests was counted and recalculated for 1 m^2. When accounting for grass aphids, the method of plant tests was used (Trybel *et al.,* 2001; Omeliuta *et al.,* 1986).

4. Accounting for actual contamination was determined by the quantitative and weight method in two phases of crop development: tillering (BBCH 21-29), stem elongation (BBCH 30-39) (Hrytsaenko *et al.,* 2003). The species composition of weeds was determined in two repetitions of the experiment using atlases and reference books (Veselovskyi *et al.,* 1993).

5. The yield of winter wheat was determined by the method of threshing and weighing grain from each site.

RESULTS AND DISCUSSION

An integral part of optimising the main factors of growth and development of winter wheat plants is the protection technology, which includes integrated or comprehensive protection of plants from diseases, pests, and weeds.

The most harmful diseases of winter wheat in the region of research identified Fusarium (pathogens fungi from the genus *Fusarium*), helminthosporiosis (*Bipolaris sorokiniana*) root rot, brown rust (*Puccinia recondita* f. sp. tritici Rob. ex Desm), septoriosis (*septoriosis tritici* Rob. et Desm.), powdery mildew (*Erysiphe graminis* DC. f. *tritici*), Ustilago smut (*Ustilago tritici* Pers., Jens), which lead to substantial crop losses, and sometimes to complete plant death. An effective and universal method for these diseases is seed treatment, especially using complex drugs that destroy the infection or prevent its development in the soil, on the surface, and inside the seed. Preparations and mixtures of pesticides were selected considering the forecast of the development of diseases and pests using data from the phytosanitary examination of winter wheat crops on the farm.

The first stage in the proposed protection system is the treatment of winter wheat seeds with a two-component (protioconazole, 250 g/L + tebuconazole, 150 g/L) systemic preparation Lamardor 400 FS, with a norm of 0.2 L/t together with insecticidal mordant Gaucho Plus 466 FS at a rate of 0.6 L/t (imidacloprid, 233 g/L + clothianidine, 233 g/L), protection from cereal flies, cicadas, ground beetle, thrips, fleas.

The next step is to conduct protection from weeds. Ultimately, one of the main factors limiting the collection of high yields of agricultural crops, namely wheat, is substantial contamination of crops, which is determined by a supply of weed seeds and their vegetative organs in the soil. The weed control system includes compliance with agricultural techniques for growing crops and favourable conditions for plant growth and development. All methods of mechanical tillage should be conducted in the phase of weed germination. The experience of farming proves that it is not always possible to clear the fields of weeds only by agrotechnical measures. At the moment, weed control is most effective when combining agrotechnical and chemical measures. Notably, the trend of using tank mixtures of pesticides is currently one of the key ones, since such application can substantially reduce the cost of treatments and increase labour productivity.

Winter wheat crops were sprayed in the spring tillering phase (II-III decade of April) against annual and perennial dicotyledonous weeds with herbicides Granstar Pro 75, WG (tribenuron-methyl, 750 g/kg) with a norm of 20 g/ha in a tank mixture against cereal weeds with Apiros 75 WG (sulfosulfuron 78%) with a norm of 15 g/ha. The first symptoms of weed suppression appeared 7-10 days after spraying, and their complete death occurred in 3-4 weeks, depending on the type of weed. Treatment of crops with this combination of drugs led to a good cleaning of crops of annual monocotyledonous, dicotyledonous, and growth retardation of perennial weeds (Table 2).

Table 2. *Species composition of weeds of winter wheat agrocenosis, pcs./m² (average for 2019-2021)*

Type of weed	Economic threshold of harmfulness (spring tillering phase)	Without a protective system (control)	Protection system
Monocotyledons			
Common windgrass	8-10	20.5	6.2
Yellow bristle-grass	10-15	7.3	–
Couch grass	4-6	4.0	1.0
Dicotyledones			
Cornflower	3-6	10.4	1.6
Scentless mayweed	5-7	8.1	0.4
Field mustard	5-8	6.3	–
Wild pansy	10-12	9.5	1.2
Field bindweed	8-10	5.0	0.5
Total		72.1	10.9

Source: *compiled by the authors*

During the phytosanitary examination of the wheat field, the following weeds were identified on the farm. Among monocotyledons (cereals), the following varieties prevailed: common windgrass (*Apera spic-aventi* L.), yellow bristle-grass (*Setaria glauca* L.), couch grass (*Elytrigia repens* L.); dicotyledonous – cornflower (*Centaurea cyanus* L.), scentless mayweed (*Matricaria perforata* Merat.), field mustard (*Sinapis arvensis* L.), wild pansy (*Viola tricolor* L.), field bindweed (*Convolvulus arvensis* L.). Winter wheat crop losses with such contamination (72.1 pcs./m²) amounted to 26%. The total number of weeds in the areas where the protection system was used decreased by 61.2 pcs./m² compared to the control option. In addition, the flag leaf can retain the assimilation surface and stay green longer, which contributes to the overall health of plants and the formation of higher productivity.

In the stem elongation phase (BBCH 30-39), a tank mixture of fungicides Alto Super 330 EC, (ciproconazole 80 g/L + propiconazole 250 g/L) was used to protect crops from powdery mildew, brown leaf rust, leaf septoriosis, cercosporellosis at a normal rate of 0.5 L/ha and Topsin M, WP (thiophanate-methyl, 700 g/kg) at a normal rate 1.0 kg/ha. Since the number of pests exceeded the economic thresholds of harmfulness (ETH: cereal leaf beetle 15-20 specimens/m², grass aphids – 10 specimens/stem, thrips – 8-10 imagoes/stem) in this tank mixture, insecticide Aktara 25 WG (thiamethoxam, 250 g/kg) with a norm of 0.10 kg/ha was also added. For plant resistance to diseases and increased yield, microfertiliser Orakul, s., 1.0 L/t was added to the tank mixture.

The second fungicidal treatment was conducted in the earing phase – the beginning of wheat flowering BBCH 41-69 with a mixture of Amistar Extra 280 SC, 0.5 L/ha (ciproconazole 80 g/L + azoxystrobin 200 g/L) and Rex duo, SC, 0.4 L/ha (epoxiconazole 187 g/L + thiophanate-methyl 310 g/L) to protect crops from ear diseases (Fusarium, septoriosis, alternariasis) and powdery mildew, rusty diseases. The use of fungicidal treatments in the BBCH 30-39 and BBCH 41-69 phases substantially increased the resistance of winter wheat plants to diseases (Table 3).

Table 3. *Development of winter wheat diseases, % (2019-2021)*

Disease	Affected organ	Phase of manifestation of the disease	Without a protective system (control)		Protection system		Technical efficiency, %
			*P	*R	P	R	
Powdery mildew	Leaves Stems Ear	Shoots–waxy ripeness	45.8	31.0	15.4	7.1	77.1
Brown rust	leaves	Stem elongation	52.2	28.1	13.3	4.4	84.3
Septoriosis	Leaves Stems Ear	Stem elongation-milk ripeness	37	19	10	2.5	86.8
Loose smut	Ear	The beginning of waxy ripeness	0.4	0	0	0	–
Fusarium-helminthosporous root rot	Roots, base of the stem	Shoots-waxy ripeness	29.0	18.5	7.8	2.6	85.9

Note: **P – spread of the disease, *R – development of the disease*
Source: *compiled by the authors*

Thus, the spread and development of powdery mildew decreased by 30.3 and 23.9%, brown rust – by 38.9% and 23.7%, and septoriosis – by 27% and 16.5%, respectively, compared to the control variant. Ustilago smut was identified only in non-cultivated areas. The spread of Fusarium-helminthosporous root rot decreased to 7.8%, and its development – to 2.6%. Therewith, the technical effectiveness of double spraying with recommended anti-disease products ranged from 77.1% to 86.8%.

These products provided up to 90% protection of crops from diseases that prevailed on the farm, while in the control areas, the degree of disease damage was higher than the threshold of harmfulness. Spraying of crops is conducted in the phase of milk ripeness BBCH 71-77 with insecticides Aktara 25 WG, 0.10 kg/ha + Karate seon 050 CS, 0.2 L/ha (lambda-cyhalothrin 50 g/L) to prevent substantial crop losses from bread beetles (ETH – 5-6 beetles per 1 m^2), bread bugs (ETH – 1-2 larvae per 1 m^2 on crops of strong and valuable wheat, 4-6 specimens per 1 m^2 – on the rest of the wheat fields), bread carabus (ETH – 8 specimens per 1 m^2), grass aphids (10-20 specimens per stem), thrips (40-50 specimens per ear).

Notably, in recent years, due to substantial warming in May-June, there is a tendency to increase the number of pests on winter wheat crops (Table 4). During the survey of crops in the spring tillering phase, 35 specimens/100 w.s. of the Hessian fly and 42 specimens/100 w.s. were detected; in the stem elongation phase, 25 specimens/w.s. of wheat aphid, 38 specimens/100 w.s. of Haplothrips tritici; in the phase of milk ripeness – 7 specimens/m^2 of bread carabus.

Table 4. *Population of winter wheat agrocenosis with pests, specimens (2019-2021)*

Pest	Settlement organ	Damage phase	ETH	Without a protective system (control)	Protection system	Technical efficiency, %
Hessen fly	Internodes	Shoots-tillering	30-40 for 100 net swings	35	9	74.3
Swedish fly	Stem	Shoots-tillering	30-40 for 100 net swings	42	11	73.8
Grass aphids	Leaves, stems	Stem elongation-milk ripeness	10-20 specimens per stem	25	5	80
Wheat thrips	Ear, grain	Stem elongation-waxy ripeness	20-30 imagoes per 100 w.s.	38	4	89.5
Bread carabus	Ear, grain	Milk ripeness	3-5 beetles/m^2	7	1	85.7

Source: *compiled by the authors*

The results showed that the proposed insecticides reduced the number of phytophages: the Hessian fly – by 26 specimens/100 w.s., Swedish fly – 31 specimens/100 w.s., grass aphids – 20 specimens per stem, Haplothriw.s. tritici – 34 specimens/100 w.s., bread carabus – 6 beetles/m^2. The technical effectiveness of insecticides against pests

was 73.8-89.5%, depending on the insect. Competition from weeds, reducing the development of diseases, and the number of pests contributed to improving the growth and development of winter wheat (Table 5).

Table 5. *Winter wheat crop structure (2019-2021)*

Experiment scheme	Number of stems, pcs./m^2	Number of grains per ear, pcs.	Grain weight per ear, g	Weight of 1000 seeds, g	Yield, t/ha
1. Without a protective system (control)	380	23	1.1	34.8	3.1
2. Protection system	531	34	1.8	46.9	5.4
$HIP_{(0.05)}$ (t/ha)	2.8	0.7	0.04	1.0	0.2

Source: *compiled by the authors*

When using the protection technology, the number of stems increased by 151 pieces per 1 m^2, the number of grains in the ear – by 11 pieces; the weight of one grain from the ear – by 0.7 g, the weight of 1000 grains – by 12.1 g compared to the option where the protection system was not used. The increase in the yield structure had a positive effect on the yield of winter wheat, which was 5.4 t/ha, which is 2.3 t/ha higher than in the control version. The results of the studies are consistent with the experiments of a number of foreign and Ukrainian researchers.

Czech researchers A. Hanzalová & O. Zelba, (2022) report that brown leaf rust (*Puccinia triticina* Eriks) is quite common in the south-eastern part of the country in warm and dry years, so the authors recommend including a number of varieties with the gene of resistance to this disease Lr 37, Lr 24, Lr 28 in the winter wheat protection system. This is a very useful recommendation that should be considered in further studies.

Other researchers A.A. Bajwa *et al.* (2020) argue that climate change has affected the growth, virulence, reproduction, and spread of the most dangerous wheat pests. Canadian researchers R. Aboukhaddour *et al.* (2020) note that over the course of 100 years, due to changing climatic conditions, the pathogenic complex of winter wheat diseases has changed. Climate change has a direct negative impact on the effectiveness of existing pest and disease protection measures. Therefore, it is necessary to select new compositions of tank mixtures of protective products so that they are more effective against harmful organisms, do not cause resistance of pathogens and pests to pesticides, and also have a positive impact on the environment. This study considers all the above factors when selecting pesticide mixtures in winter wheat protection technology.

Researchers G. Kosylovych and Yu. Golyachuk (2017) recommend the autumn use of herbicides in the phase of 1-2 leaves of the crop (BBCH 11-12), using urea derivatives + dinitroanilines (a.s. isoproturon + pendimethanil), and in the phase of 3-5 leaves (BBCH 13-21) – sulfonylureas with metribuzin. In production experiments, herbicides were used once in a combination of Granstar Pro 75, WG 20 g/ha + Apiros 75 WG, 15 g/ha in the tillering phase (BBCH 21-29) because herbicides during spring application can negatively affect the development of the crop itself. Pisarenko *et al.* (2021) prove that the combination of fungicides Falcon (0.6 L/ha) and Titul Duo (0.2 L/ha) with herbicides Monitor (20 g/ha) improved the effectiveness of fungicides because fields without weeds have higher resistance to diseases due to better aeration of the stem. In contrast to these studies, a mixture of herbicides was used in production experiments without combining them with other drugs, which led to the destruction of annual and delayed growth of perennial weeds.

The obtained results of the conducted studies are generally consistent with the results of researchers O.V. Gurmanchuk *et al.* (2021), where the technical efficiency of a mixture of herbicides Granstar Pro 75 + Apiros 75, with norms of 0.025+0.013 kg/ha was 94.6%. The difference was observed in the species composition of weed vegetation, which is explained by different zones of experiment.

Jam (2019) demonstrates that the Zhytomyr region has a high level of colonisation of winter wheat grain by fungi of the *Fusarium* spp. genus, namely F. *graminearum, F. culmorum, F. poae, F. avenaceum*. In this regard, the author recommends using fungicides Follicur BT, EC (1.2 L/ha), Magnello 350 EC, (1.0 L/ha), a mixture of the fungicide Magnello 350 EC, (0.75 L/ha), and the biological product Gaupsin, s. (0.2 L/ha). In the proposed technology of protection against Fusarium infection, a mixture of Amistar Extra 280 SC, 0.5 L/ha + Rex Duo, SC, 0.4 L/ha is recommended.

In the technology of winter wheat protection against leaf diseases, tank mixtures of fungicides Alto Super 330 EC (0.5 L/ha) + Topsin M, WP (1.0 kg/ha) are proposed. In the papers by V.I. Martynenko, O.I. Logvenok (2018) the technical effectiveness of fungicides Soligor 425 EC, Falcon, EC, Vareon, EC, and Rex Duo, EC to powdery mildew was indicated in the range of 46.7-49.7%. V.P. Turenko (2018) proposed the fungicide Derozal SC (0.5 L/ha) against Septoriosis with a technical efficiency of 60.7%.

In general, the conducted studies are consistent with the papers of foreign and Ukrainian researchers,

but there are some differences with the results of other authors, which is explained by changes in the climatic factors of the research area.

CONCLUSIONS

Powdery mildew, brown rust, septoriosis, Ustilago smut, fusarion-helminthosporous root rot were detected during the monitoring of winter wheat production crops of the SE Experimental Farm Nova Peremoha of the Polissia National University of the National Academy of Agrarian Sciences of Ukraine over the years of research. Among the pests grass flies, namely Hessian and Swedish flies, grass aphids, Haplothrips tritici, and bread carabus were identified. All the above-mentioned diseases and pests exceeded the thresholds of economic harmfulness.

Seeds were treated with a mixture of preparations containing active fungicidal and insecticidal action substances to protect plant seedlings from diseases and pests. In the spring tillering phase (BBCH 21-29), considering the species and quantitative composition of the factual contamination, wheat crops were sprayed with a mixture of herbicides Granstar Pro 75, WG, 20 g/ha + Apyros 75 WG, 15 g/ha. Maximum effectiveness against diseases of winter wheat was provided by the use of tank compositions of fungicides Alto Super 330 EC, 0.5 L/ha + Topsin M, WP, 1.0 kg/ha in a mixture with microfertiliser Orakul, s., 1.0 L/ha and in the phase BBCH 41-69 a mixture of fungicides Amistar Extra 280 SC, 0.5 L/ha + Rex duo, KS, 0.4 L/ha. The technical effectiveness of these drug mixtures ranged from 77.1% to 86.8%, depending on the disease. Against pests, the insecticide Aktara 25 WG, 0.10 kg/ha was added to the mixture of fungicides in the phase of stem elongation, while the technical efficiency was 73.8-89.5%

The use of a comprehensive system of protection of winter wheat crops increases the productive indicators of the crop structure by 20-30%. Consequently, the yield increased by 2.3 t/ha compared to options without the protection system.

Further research should focus on a combination of agrotechnical and chemical measures to protect winter wheat from harmful biota. Namely, due to changes in the climatic conditions of the Forest-Steppe zone of Ukraine, the timing of wheat sowing should be considered more and a pattern between the timing of sowing and the development of harmful organisms should be established. Optimal wheat sowing times for the area under study should be established, thereby minimising the number of pesticide treatments.

ACKNOWLEDGEMENTS

The authors express their gratitude to the director of the SE Experimental Farm Nova Peremoha of the Polissia National University of the National Academy of Agrarian Sciences of Ukraine for the assistance and allocation of research sites for research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Технологія захисту пшениці озимої від шкідливої біоти у північному Лісостепу України

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Анотація. Технологія захисту пшениці озимої спрямована на запобігання масовому поширенню шкідливої біоти та можливість її швидкого обмеження. При цьому є головним вибір пестицидів та вчасне їх застосування саме у той період, коли шкідливі організми знаходяться у чутливій стадії до засобів захисту, а рослини – у фазі формування і закладання елементів продуктивності. Мета роботи передбачає вивчення ефективності запропонованих композицій хімічних препаратів від шкідливої біоти при удосконаленні технології захисту пшениці озимої. При моніторингу шкідливих організмів були використані загальноприйняті у фітопатології (шкали Страхова, Гешеле), ентомології (метод ентомологічного сачка, метод облікових ділянок), гербології (кількісно-ваговий) методи. Наведено, результати досліджень, отримані при проведені виробничого досліду з вивчення ефективності сумішей препаратів для комплексної системи захисту посівів пшениці озимої. Встановлено зміни у видовому та кількісному складі бур'янової синузії пшениці озимої залежно від технології захисту. Загальна кількість бур'янів на ділянках, де застосовували систему захисту, зменшилася на 61,2 шт. /м^2 порівняно з контрольним варіантом. Представлено зміни чисельності складу шкідників (зменшення гессенської мухи на 26 екз. /100 п.с., шведської мухи – 31 екз. /100 п.с., злакові попелиці – 20 особин на стебло, пшеничного трипса – 34 екз./100 п.с., хлібного туруна – 6 жуків/м^2) при обприскуванні пшениці озимої у фазах виходу у трубку та молочної стиглості інсектицидами Актара 25 WG, ВГ, 0,10 кг/га + Карате Зеон 050 CS,СК, 0,2 л/га. Технічна ефективність інсектицидів проти шкідників становила 73,8-89,5 % залежно від шкідливої комахи. Доведено що, надійного захисту від домінуючих хвороб у господарстві досягнуто застосуванням комбінацією фунгіцидів Альто супер 330 ЕС, к.е., 0,5 л/га та Топсін М, ЗП, 1,0 кг/га у фазі виходу у трубку та Амістар Екстра 280 SC, КС, 0,5 л/га + Рекс Дуо, КС, 0,4 л/га у фазі колосіння – початок цвітіння. Технічна ефективність подвійного обприскування рекомендованими препаратами проти хвороб становила від 77,1 % до 86,8 %. Запропонована технологія захисту пшениці озимої від шкідливих організмів є ефективною, пройшла виробничу перевірку та може бути впроваджена у господарствах всіх форм власності.

Ключові слова: бур'яни; хвороби; шкідники; гербіциди; фунгіциди; інсектициди; урожайність

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 58-69

UDC 635.34:631.564
DOI: 10.48077/scihor3.2023.58

Investigation of weight loss of napa cabbage depending on the type of packaging and head weight

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Article's History:
Received: 28.01.2023
Revised: 27.03.2023
Accepted: 8.04.2023

Suggested Citation:
Pusik, L., Pusik, V., Bondarenko, V., Sievidov V., & Semenenko, I. (2023). Investigation of weight loss of napa cabbage depending on the type of packaging and head weight. *Scientific Horizons*, 26(3), 58-69.

Abstract. The investigation of the issue of extending the period of consumption of fresh napa cabbage with different head weights due to the use of polymer films is relevant. The purpose of the study was to experimentally substantiate measures to extend the consumption of napa cabbage. The products were grown and stored on a farm. Studies with napa cabbage heads were conducted using the laboratory method and the method of mathematical statistics. It is established that napa cabbage loses up to 10% of its mass during storage for 20 days of storage. Individual packaging of heads in stretch film, in comparison with storage in open form, allowed for reducing the natural loss of their mass by half, increasing the storage period to 90 days. Among the hybrids examined, the best keeping properties were identified in a hybrid characterised by a high content of dry

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and dry soluble substances, vitamin C, and total sugar. When examining the shelf life of napa cabbage, depending on the weight of the head, it is identified that the stretch film extends the duration of storage of heads weighing 350-700 and 750-900 g to 70 days. Natural weight loss reaches 10.8%. Heads weighing more than 900 g with such packaging are stored for 90 days with natural losses of 8.8%. Inserts made of polyethylene film with a thickness of 40 microns extended the storage time of cabbage heads weighing 350-700 g to 80 days with a weight loss of 10.1%. Heads weighing 750-900 and more than 900 g were stored for 90 days with natural mass losses of 10 and 7.8%, respectively. Storage of a mixture of napa cabbage heads of different weights in the stretch film increased the storage period to 80 days, and in polyethylene film – to 90 days with a weight loss of about 10%. These results can be used by researchers in the trade industry to extend the storage period of fruits and vegetables

Keywords: fresh cabbage; head fractions; stretch filml; plastic film; shelf life

INTRODUCTION

Napa cabbage is an early-maturing crop that is suitable for growing in protected ground structures and long-term storage. Precocity, the rich chemical composition of the heads, and the ability to be stored for a long time make napa cabbage a valuable vegetable crop, which is successfully grown by Ukrainian producers in the open ground. Its presence in the diet contributes to the intake of fibre and essential minerals into the human body. The easiest and cheapest way to extend the storage period of fresh products is to pack them in polymer films. Therefore, investigation of the keeping properties of napa cabbage, depending on the type of packaging and the weight of the head, is relevant.

The modern assortment of this cabbage is represented by head hybrids of mainly foreign selection. Napa cabbage with elongated cylindrical heads is in demand among the population (Sun *et al.*, 2021). It has the aroma of fresh herbs, attractive colour, and a pleasant taste. Napa cabbage is high in sugar – 1.5-3.8%, contains up to 1 g of protein, 0.3 g of fat, 250 mg of potassium, 0.9-1.3 mg of iron, starch – up to 0.4, fibre – up to 0.7-1.2; calcium – 0.95, phosphorus – 1.16, potassium – 0.36, and sodium – 0.16%. The energy value of cabbage is low – 125 KJ/100 g (Zhou *et al.*, 2022).

Now consumers demand heads weighing 0.8-1.5 kg (Kovtuniuk *et al.,* 2020; Sadovska *et al.,* 2022; Dai *et al.,* 2019). Notably, the head of napa cabbage weighing from 350 g is considered standard (UNECE Standard FFV-44, 2017). The weight of the head depends on many factors: the characteristics of the hybrid, the cultivation technology, the weather conditions of the growing season, etc. Thus, napa cabbage of the Khibins'ka variety, in the studies of K.U. Holmamatovich (2021), due to various placement schemes, formed heads weighing from 0.62 to 1.24 kg. D. Paulus (2019) identified that with different soil moisture supply, weather conditions and hybrid characteristics, the weight of a napa cabbage head can vary by 5.5-27.5%. S. Teshome (2020) notes that a different fertiliser system leads to an increase in the head weight of this crop by 52.5%. In addition, during the period of mass maturation, a continuous harvest of napa cabbage is conducted and fluctuations in the mass of heads in the field can be substantial.

The high water content of napa cabbage heads creates the need for them to be stored in an environment with high relative humidity to prevent moisture evaporation. The presentation of vegetables depends on their loss of water during storage. It was identified that the maximum permissible water loss in white cabbage, potatoes, green peppers, and tomatoes is 7-8%; lettuce – 3-4%; strawberries, raspberries, currants, peas, and beans – 5-6%. Evaporation of water during storage depends on the characteristics of the variety, weather conditions of the growing season, and methods of harvesting and storage (Pusik *et al.,* 2019). Losses from water evaporation can account for 70-90% of natural losses (Ishaque *et al.,* 2019).

However, when storing napa cabbage, it is necessary to create a high relative humidity in the storage, which is not always possible. Practice shows that temperature fluctuations at high humidity in the storage area can lead to condensation on the surface of the product. Temperature fluctuations at high humidity in the storage area can lead to condensation on the surface of the product. Therefore, the evaporation of water during the storage of cabbage is inevitable. The choice of the method of storing napa cabbage with minimal loss of weight and quality remains relevant. Thus, conducting comprehensive research on factors that affect the natural weight loss of cabbage is relevant.

The main objective of the study was to compare the type of packaging and the weight of napa cabbage heads for weight loss during storage. Accordingly, the tasks were set to: establish the dynamics of natural mass losses, conduct a comparative assessment of the keeping properties of napa cabbage, depending on the type of packaging and head weight when using different hybrids.

MATERIALS AND METHODS

The study was conducted in 2019-2020 in the Agricultural Society "Mriya". It is located in the Lozivsky district of the Kharkiv region. Late-maturing napa cabbage hybrids Bazuko F_1, Bilko F_1, Suprin F_1 were examined Cabbage was grown according to generally accepted recommendations (Moiseichenko, 1992). Growing

method – seedling (seedlings with four-five real leaves were planted). Seedlings were planted in a permanent place in the third decade of July. The method of placing plants is the strip row with a placement scheme (40+100)x20 cm. The density of plant placement is 71.4 thousand units/ha. Repetition in the experiment is fourfold. The area of the sown area is 50 m^2, accounting – 21 m^2. Napa cabbage was grown by drip irrigation. Soil moisture was maintained at 80%, the norm of one vegetative irrigation was 70-150 m^3/ha. The placement of options in the experiment is systematic.

Bazuko F_1 (Bejo Zaden) is a high-yielding hybrid of napa cabbage. The growing season lasts 70 days. Head weight is 1.2-1.8 kg. It is characterised by high resistance to many keel races. Created for long-term storage. Does not lose its fresh green colour (Bazuko F_1, n.d.).

Bilko F_1 (Bejo Zaden) is characterised by excellent taste qualities. The growing season lasts 67 days. Head weight is 1.2-1.8 kg. Created for long-term storage. The hybrid is resistant to many keel races (Bilko F_1, n.d.).

Suprin F_1 (Syngenta) is a hybrid of napa cabbage created for long-term storage. The growing season is 60-65 days, the average head weight is 1.5-2 kg, has a light green colour. This colour remains after long-term storage (Suprin F_1. Syngenta vegetable seed catalogue).

Cabbage was harvested by hand in a continuous way, weighed, and divided into marketable and non-marketable products. Marketable products were divided into standard and non-standard according to the current standard (UNECE Standard FFV-44, 2017). In standard products, the content of certain components of the chemical composition was determined according to generally accepted methods:

- dry substances – by drying (DSTU ISO 751:2004, 2005);
- mass fraction of dry solutes – by refractometric method (DSTU ISO 2173:2007, 2009);
- ascorbic acid – titrimetric method using 2,6-dichlorophenolindophenolate sodium (Naichenko & Zamorska, 2010);
- total content of sugars and reducing sugars-photocolorimetric (ferricyanide) method (DSTU 4954:2008);
- sucrose content was determined as the difference between the total sugar content and reducing sugars multiplied by a factor of 0.95.

The cabbage was placed vertically (with the top of the head up) in plastic boxes. After assembly, the heads were cooled to a temperature of 1-2°C. Napa cabbage was stored in a refrigerator at a temperature of 0±1°C and relative humidity of 90-95%, for one day in trifold repetition. Standard heads were stored weighing not less than 350 g. The weight of the average sample is 10 kg. Storage was conducted in accordance with the guidelines for conducting studies on the storage of vegetables (Naichenko & Zamorska, 2010). Product monitoring was conducted every 10 days.

Observation of napa cabbage during storage was conducted within two experiments. In the first experiment, napa cabbage was stored in an open form (control); in boxes lined with a polyethylene film with a thickness of 40 microns (PF), and packed in a stretch polyvinylchloride film with a thickness of 8 microns (SF). Before packaging, the cabbage was cooled to storage temperature to prevent condensation on the film and heads. The experiment is three-factor: factor A – type of packaging, factor B – duration of storage, and factor C – features of the hybrid.

The second experiment involved examining the preservation of napa cabbage depending on the mass of the head. The examination was conducted with the Bilko F_1 hybrid. Standard products were sorted into fractions: 350-700 g, 750-900 g, 950 g and more. A mix of heads weighing more than 350 g was taken for control, according to the standard. Cabbage was stored in open boxes (OB); in boxes lined with 40 microns thick polyethylene film (PF), and packed in 8-microns-thick polyvinylchloride stretch film (SF). The experiment is three-factor: factor A – head weight, factor B – type of packaging, and factor C – storage duration.

During storage, the dynamics of natural mass losses were determined. Natural mass loss was determined as a percentage of the initial mass by the formula (1):

$$X = \frac{(A-B)*100}{A}; \quad (1)$$

where X – weight loss, %; *A* – weight of heads before storage, g; *B* – mass of heads after storage, g.

The sample was withdrawn from storage if the weight loss was more than 10%, and no more than 10% of the products were affected by diseases and physiological disorders.

RESULTS

The formation of components of the chemical composition of vegetables depends on the characteristics of the variety, hybrid, and growing conditions, that is, the biological value is genetically determined. Dry substances – insoluble and water-soluble are an energy source of respiration of plants. Insoluble substances make up the cell walls and determine the toughness of the skin and pulp to mechanical influences. The consistency and colour of vegetables depend on the presence of insoluble dry substances. Soluble substances include mineral salts, water-soluble vitamins, sugars (di- and monosaccharides), etc. Vitamin C, also known as L-ascorbic acid, is a water-soluble vitamin that is naturally present in fruits and vegetables. Ascorbic acid is considered a stimulator of the formation of dense, heavy inflorescences and fruits. In addition, it shows antioxidant properties, protects against the harmful oxidative effects of free radicals and other substances. Ascorbic acid helps plants cope with the stresses of drought and ultraviolet radiation (Deslous *et al.,* 2021). Sugars are the main energy material. When sugar molecules are broken down and oxidised, energy is released that

ensures the vital activity of the plant organism. Glucose is the main source of energy for cellular respiration (Eveland & Jackson, 2012).

Studies have established a substantially higher content of dry (LSD_{05}=0.1) and dry solutes (LSD_{05}=0.2), vitamin C (LSD_{05}=2.1), total sugar (LSD_{05}=0.2), and monosaccharides (LSD_{05}=0.3) in the hybrid heads Bilko F_1. The disaccharide content was 0.2-0.3% and there was no substantial difference between the hybrids (Table 1).

Table 1. *Content of some chemical components in napa cabbage heads (average for 2019-2020)*

Hybrid	Dry substances, %	Dry solutes, %	Vitamin C, mg/100 g	Total sugar, %	Monosaccharides, %	Disaccharides, %
Bazuko F_1	6.1	4.8	49.1	2.6	2.3	0.3
Bilko F_1	6.4	5.1	50.5	2.9	2.6	0.3
Suprin F_1	5.8	4.5	47.4	2.3	2.1	0.2
LSD_{05}	0.1	0.2	2.1	0.2	0.3	0.2

Source: *compiled by the authors based on their studies*

Notably, the accumulation of some components of the chemical composition, depending on the characteristics of the hybrid, ranged from 23 to 84%. The greatest dependence was observed between hybrid characteristics and dry substances (84%), total sugar (81%), and dry solutes (64%). Other factors and elements of the cultivation technology affect the content of chemical composition components within 1%. Correlation analysis showed that the weight loss of the heads during storage depends on the density of the heads and the components of the chemical composition (Table 2).

Table 2. *Correlation coefficient of weight loss of napa cabbage heads during storage from the density of heads and some components of chemical composition*

Indicators	*y*	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Y	1	–	–	–	–	–	–	–
x_1	0.97463	1	–	–	–	–	–	–
x_2	0.90784	0.978664	1	–	–	–	–	–
x_3	0.90784	0.978664	1	1	–	–	–	–
x_4	0.92982	0.988602	0.998443	0.998443	1	–	–	–
x_5	0.90784	0.978664	1	1	0.998443	1	–	–
x_6	0.85375	0.948636	0.993399	0.993399	0.985453	0.993399	1	
x_7	0.99587	0.950281	0.866025	0.866025	0.89257	0.866025	0.802955	1

Note: *y – weight loss, %; x_1 – head density, x_2 – dry substances, x_3 – dry solutes, %, x_4 – vitamin C, mg/100 g, x_5 – total sugar, %, x_6 – monosaccharides, %, x_7 – disaccharides, %*

Source: *compiled by the authors based on their studies*

V.A. Koltunov (2004) identified that the shelf life of cabbage depends on the density of the heads. The density of heads is determined by the number of leaves per unit length of the head, the angular interval of their alternation, and thickness. It was identified that stale varieties of white cabbage have a head density of more than 0.8, and non-stale – in the range of 0.60-0.76.

These studies have established that the density of napa cabbage heads ranges from 1.14 (Suprin F_1) to 1.36 (Bilko F_1). The head mass loss during storage is closely related to the head density (r=0.9746). The density of napa cabbage heads depends on the dry matter content (r=0.9786).

Regression analysis showed that daily weight loss depends on the content of dry solutes and on the density of heads: $y=10.2-30x_1+6x_2$. Where: Y – weight loss, %, x_1 – head density, x_2 – content of dry soluble substances. Thus, morphoanatomical and chemical indicators correlate with the shelf life of napa cabbage, so it can be concluded that the shelf life is determined by a complex of properties.

During the study of different types of packaging for the shelf life of napa cabbage, it was identified that

storage without packaging already on the tenth day led to weight loss at the level of 5.7-6.1%, depending on the hybrid (Fig. 1). By the twentieth day, natural weight loss increased to 10.6%. The heads of the Suprin F_1 hybrid lost mass more intensively, and Bilko F_1 – less. Substantial difference (LSD_{05}=0.3) in terms of mass loss, on the tenth day of the storage, was only between these two hybrids. On the twentieth day of storage, all three hybrids differed substantially in natural mass loss.

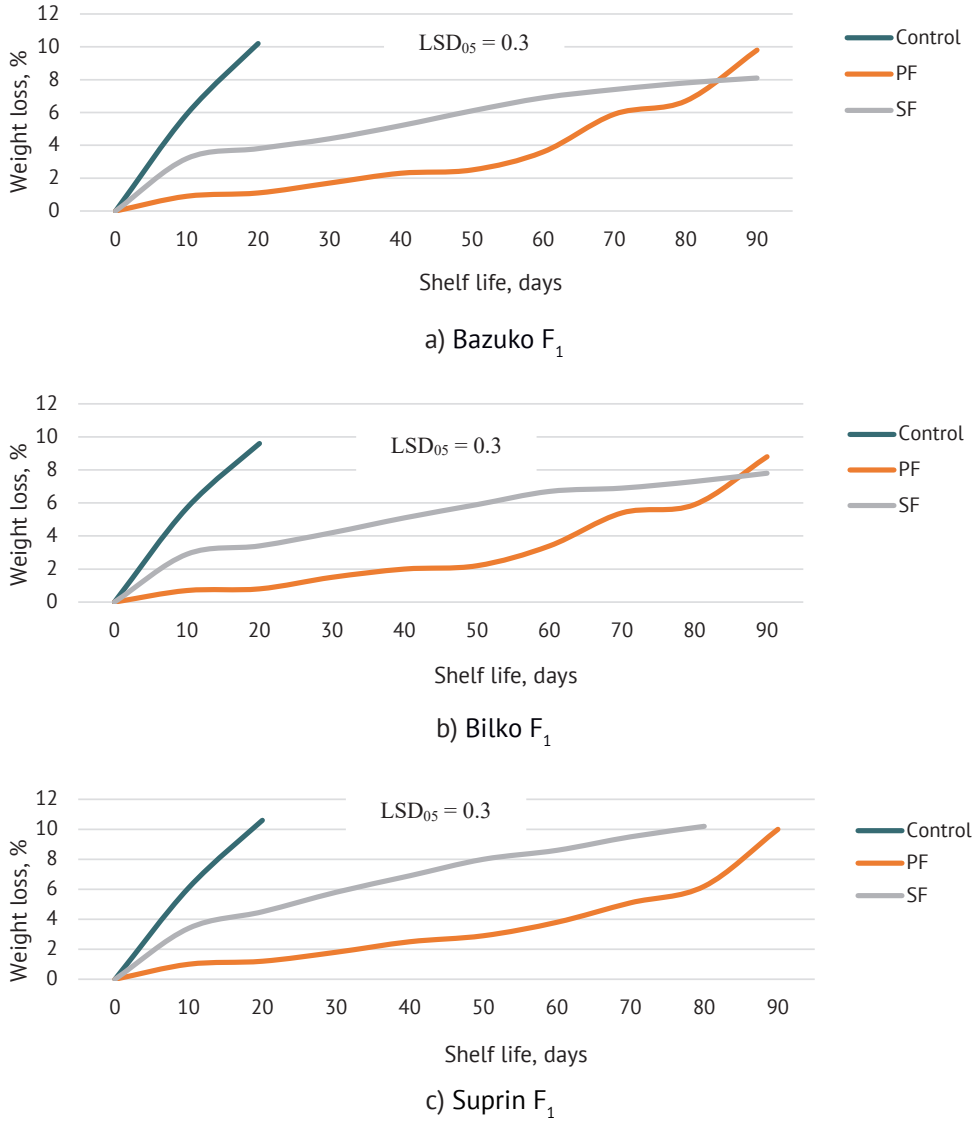


Figure 1. *Dynamics of weight loss of napa cabbage depending on the type of packaging, % (average for 2019-2020)*
Source: *compiled by the authors based on their studies*

The use of a 40-micron-thick polyethylene film on the tenth day of storage substantially reduced natural weight loss: it was almost six to eight times less than open storage. With further storage in a polyethylene film, natural losses gradually increased by 0.1 to almost 4% every 10 days. Notably, the Suprin F_1 hybrid lost more mass, and Bilko F_1 – less. Constant substantial weight losses were observed in experimental hybrids of napa cabbage from the 50th day of storage. On the 90th day of storage, natural weight loss reached 10% in the Suprin F_1 hybrid, slightly smaller it was in Bazuko F_1 – 9.8%, and substantially less (LSD_{05}=0.3) compared to the other hybrids – in Bilko F_1 – 8.8%. Notably, with this type of packaging, from the 80th to the 90th day of storage, there was a sharp increase in natural weight loss in all hybrids. Thus, if from the beginning of storage to the 80th day inclusive, natural weight loss every 10 days ranged from 0.1-2.3%, depending on the characteristics of the hybrid, then in the period from the 80th to the 90th day it amounted to 2.9-3.8%. This calls

into question the feasibility of storing napa cabbage heads with this type of packaging for such a long time.

Packaging of napa cabbage heads in a stretch film with a thickness of 8 microns also substantially reduced (LSD_{05}=0.3) the intensity of natural mass loss. However, compared to polyethylene film, the intensity of mass loss was higher. Thus, on the tenth day of storage, napa cabbage heads stored in stretch film lost 2.9-3.4% of their weight. This is almost half as much for open storage, but four times as much for plastic wrap storage. During the entire storage period, mass loss for hybrids every ten days was substantial. However, on the 90th day of storage, the natural mass loss of Bazuko F_1 and Bilko F_1 hybrids stored in polyethylene film was substantially less – by 1.7 and 1.0%, respectively. While the Suprin F_1 hybrid had a ten days less duration of storage of heads in the stretch film than other hybrids. The natural weight loss of this hybrid for 80 days of storage was 10.2%.

It was identified that the natural weight loss of cabbage heads depends by 30% on the type of packaging (factor A), by 10% on the duration of storage (factor B), and by 10% on the characteristics of the hybrid (factor C). In addition, the combined effect of the type of packaging and shelf life – 40% – had an impact on natural weight loss.

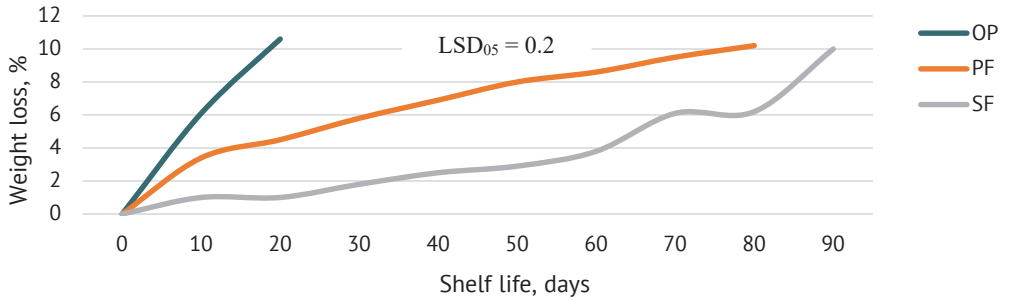
The correlation between weight loss, shelf life, and the packaging method of napa cabbage heads is determined. Under classical linear multiple regression, the coefficient (R) takes values from 0 to 1. It is assumed that the closer the coefficient is to 1, the better the model is. Therefore, it can be noted that there is a curved relationship between the weight loss of cabbage heads by the packaging method (Table 3). The coefficient of determination (R^2) is used as a model reliability marker.

Table 3. *Correlation of weight loss, shelf life, and packaging method for napa cabbage heads*

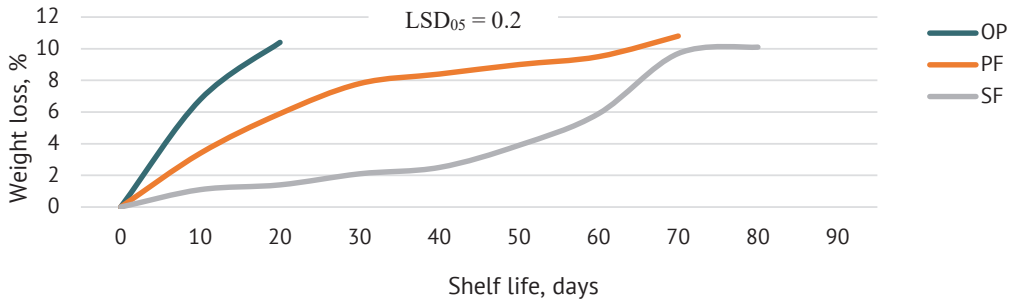
Option	Straight-line relation equation	R^2	Curvilinear relation equation	R^2
		Bazuko F_1		
1	Y=5.1x-4.833	0.99	$Y=0.8\ x^2+8.3\ x-7.5$	1.00
2	Y=0.959 x-1.827	0.88	$Y=0.121\ x^2-0.369\ x+0.832$	0.97
3	Y=0.797 x+0.907	0.92	$Y=0.075\ x^2+1.618\ x-0.735$	0.97
		Bilko F_1		
1	Y= 4.8 x-4.5	0.99	$Y=-0.9\ x^2+8.4\ x-7.5$	1.00
2	Y=0.873 x-1.733	0.89	$Y=0.1072\ x^2-0.306\ x+0.625$	0.97
3	Y=0.769 x+0.793	0.92	$Y=-0.075\ x^2+1.594\ x-0.857$	0.97
		Suprin F_1		
1	Y=5.3 x-5.03	0.99	$Y=-0.8\ x^2+8.5\ x-7.7$	1.00
2	Y=0.955 x-1.72	0.88	$Y=0.109\ x^2-0.249\ x+0.688$	0.96
3	Y=1.158 x + 0.531	0.94	$Y=-0.109\ x^2+2.257-1.483$	0.99

Note: *1 – open box (control); 2 – box + film 40 microns; 3 – stretch film 8 microns; x – duration of storage, days*
Source: *compiled by the authors based on their studies*

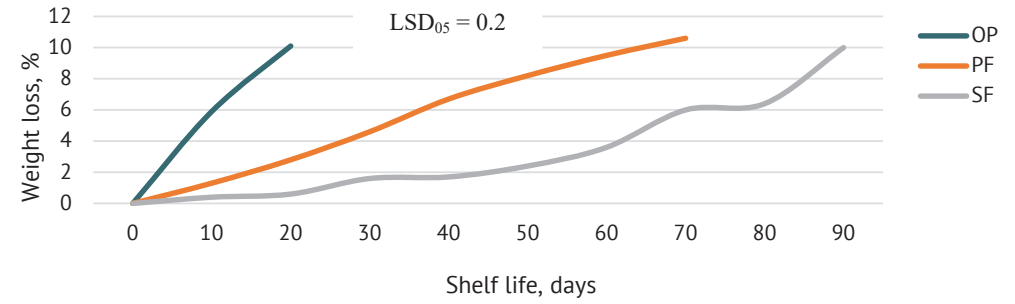
Thus, the use of packaging made of polyethylene film with a thickness of 40 microns and stretch film with a thickness of 8 microns helps to extend the shelf life and reduces the natural weight loss of napa cabbage heads. Natural mass loss is reduced by creating a passive modified gas medium (MGS) around the product. In MGS, the intensity of respiration of fresh fruits and vegetables slows down, and the enzymatic decomposition of respiratory substrates is delayed. In addition, MGS substantially suppresses the spoilage of products by microorganisms, since the increased content of CO_2 has an antimicrobial effect (Caleb *et al.*, 2013). When storing various fractions of napa cabbage heads, natural mass loss during storage in an open box was substantial (LSD_{05}=0.2) within 20 days (Fig. 2). On the 10th day of storage, natural weight loss was 5.7-6.8%, and on the 20th day, it reached 9.6-10.6%. The heads weighing more than 900 g were characterised by the lowest mass loss. As the head mass decreased, natural loss increased. A mix of napa cabbage heads of different weights lost 6.1% of the mass on the 10th day of storage, 0.2% more than heads weighing 750-900 g, and 0.7% less than heads weighing 350-700 g. On the 20th day of storage, the natural mass loss of the head mix in an open box was substantially higher compared to all the other storage options – 10.6%.



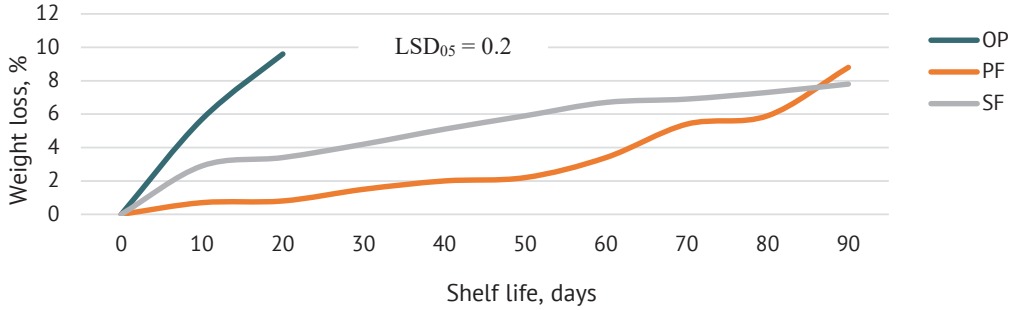
a) Mixture of heads weighing at least 350 g (control)



b) Heads weighing 350-700 g



c) Heads weighing 750-900 g



d) Heads weighing more than 900 g

Figure 2. *Dynamics of weight loss of napa cabbage depending on the head weight, % (average for 2019-2020)*
Source: *compiled by the authors based on their studies.*

Packaging of napa cabbage heads in stretch film contributed to a substantial (LSD_{05}=0.2) reduction of natural mass loss in all fractions. Thus, on the 10th day of storage in variants with a mix of heads and with heads weighing 350-700 g, the mass loss was two times less than for storage in an open box. In the version with a head mass of 750-900 g, loss decreased by 4.5 times, and in the version with a head mass of more than 900 g – by eight times. There is also a tendency to reduce natural weight loss due to an increase in the mass of cabbage heads. With further storage in stretch film, the shelf life of the head mix increased to 80 days and natural weight loss during this time amounted to 10.2%. Heads weighing 350-700 g and 750-900 g were

stored for 70 days and weight loss during this period was 10.8 and 10.6%, respectively. The difference in natural mass loss over the entire storage period, both between these two variants and within each of these variants, was substantial.

Heads weighing more than 900 g in the stretch film were stored for 90 days without loss of quality. Starting from the 20th day, the difference in weight loss for every 10 days of storage increased substantially and on the 90th day amounted to 8.8%. Storage of a mix of napa cabbage heads in a polyethylene film increased the shelf life, compared to packaging in a stretch film, by 10 days. During 90 days of storage, natural weight loss was substantially (LSD_{05}=0.2) lower and amounted to 10%.

Heads weighing 350-700 g in polyethylene film were also stored for 10 days longer with substantially lower loss than during storage in the stretch film – 10.1% for 80 days. The polyethylene film extended the shelf life of cabbage heads weighing 750-900 g by 20 days. Therewith, for 90 days of storage, natural mass loss in this variant was 0.6% less than for storage in stretch film for 70 days – 10%. Heads weighing more than 900 g in polyethylene film had the same storage duration as in the stretch film – 90 days. However, natural weight loss was 1% less – 7.8%.

DISCUSSION

The results of the experiment indicate a substantial influence of the mass of the napa cabbage head on the amount of natural mass loss and the duration of storage. Similar data were obtained by L.M. Pusik *et al.* (2022) when examining the influence of the mass of carrot root vegetables on the amount of natural loss during storage. The largest root crops were characterised by gradual, without sharp fluctuations, and the smallest natural mass loss during the entire storage period. The studies by L. Pusik *et al.* (2022) identified that the duration of storage of large carrot roots increases by 46 days and is 206 days. The yield of marketable products of small carrots is reduced by 9% (Pusik *et al.*, 2022). In the paper of I.K. Arah *et al.* (2016), it is noted that the preservation of vegetable products depends on post-harvest refinement: sorting by quality and calibration by the size of the food body. V.A. Koltunov & L.M. Pusik (2007) identified that at a daytime temperature of 26-30°C zucchini fruits with a diameter of more than 8 cm are stored for 7-16 days longer than those of 4.5-6.0 cm in diameter. At a temperature of 5±1°C, the shelf life is extended to 13-21 days. It was identified that the loss of fruit mass during storage at a temperature of 5±1°C is 42% dependent on their size. The yield of marketable products depends on the size of the fruit by 22%.

Similar studies were conducted on the storage of cucumbers of different lengths. It was identified that they are stored for almost two weeks with practically no loss at a temperature of 5±1°C in boxes with plastic wrap or in plastic bags with a capacity of 20 kg. The average daily loss of fruits, when stored in plastic bags, did not exceed 0.08-0.10% (Koltunov *et al.,* 2006).

Various means are used to extend the period of consumption of fruit and vegetable products, but the most affordable of them are synthetic films for packaging. The film creates a protective coating under which a modified gas environment is formed, which prevents the development of microorganisms on the surface of the product. Furthermore, W. Hu *et al.* (2007) identified that storing various types of cabbage in bags made of perforated film allows them to better preserve their appearance, taste, and ascorbic acid content. There is a lot of information about the successful use of an edible protective coating for the same purpose, but, for example, R.K. Dhall (2013) notes that the use of an edible protective coating to preserve fruits and vegetables is not always justified. Antimicrobial treatment and washing of products to clean and disinfect their surface also do not always justify themselves. Washing, both with ordinary water and with the addition of, for example, citric acid and ascorbic acid, chlorine, and treatment with ethanol, removed from the surface of the product parts of spores of pathogenic microorganisms and exudates that can be used as a nutrient medium for them. But this did not help to increase the shelf life of products that have delicate integumentary tissues, for example, microgreens. In addition, it leads to the development of microbes that are resistant to these substances. Turner *et al.* (2020) noted that the washing and drying technology is still imperfect. Therefore, the authors recommend using plastic packaging, which helps create a passive modified gas atmosphere, to extend the preservation of microgreens.

The morphological structure of napa cabbage heads makes the technology of washing and drying it impractical. Thus, the use of synthetic films is also a universal measure for preserving fruit and vegetable products. Thus, M. Choudhary & R.A. Devi (2021) note the positive effect of polymer films as the packaging on the preservation of colour, texture, and presentation of broccoli heads. When storing napa cabbage in a polypropylene film with different types of perforation at a temperature of 10°C within 10 days, B.M. Mampholo (2013) noted the preservation of the overall quality of the heads. A study of the storage of napa cabbage at temperatures of 4, 8, and 10°C was conducted by Shim *et al.* (2016). There are findings for storing napa cabbage at room temperature in a passive modified gas environment using multicomponent films: with a high transmission rate of water vapour and a film with a high transmission rate of oxygen (Yang *et al.,* 2018). Unfortunately, there are few studies on the complex influence of various factors on the preservation of napa cabbage, they are disparate and generalised.

E.F. Balan *et al.* (2007) identified that the rate of loss reduction during cabbage storage varies. During the transition to a state of rest, vital processes, especially

respiration, are inhibited. During the preparation for germination and in the process of germination of vegetable growth points (seeds, buds, eyes), the intensity of respiration increases. After that, there is a sharp decline in all vital processes. An increase in the intensity of respiration during the last storage period is associated with the formation of meristematic tissues with cells that have a larger number of mitochondria. Energy is needed for the biosynthesis of substances and the formation of new tissues, which explains the increase in the intensity of respiration at the end of storage.

A similar trend is observed during the storage of napa cabbage. Daily weight loss in the first 10 days ranged from 0.1% when storing heads in packaging to 0.61% in open form, in the middle of the storage period (50 days), daily loss increased to 0.5-1.6%, and at the end of storage 0.11-0.12%.

Based on the above, the research on the shelf life of napa cabbage, depending on the type of packaging and the size of the head, is relevant. Examining the dynamics of cabbage weight loss will allow for determining the duration of storage of heads with minimal weight loss and deterioration of quality. Weight loss of fruit and vegetable products is a function of many arguments. The definition of this indicator is of great scientific and practical importance. Knowing and regulating the factors that affect the weight loss of napa cabbage heads during storage can substantially decrease it.

CONCLUSIONS

Napa cabbage in boxes without packaging can be stored for 20 days, but with substantial natural weight loss of up to 10.6%. It was identified that the method of packaging napa cabbage heads affects the natural weight loss and shelf life. Individual packaging in a stretch film with a thickness of 8 microns reduces the natural weight loss of napa cabbage by almost two times, embedded in a container made of 40 microns plastic film, by six-eight times compared to storage without packaging. The use of polymer film packaging extends its storage period to 90 days.

The shelf life of napa cabbage depends on the mass of heads. Heads weighing 350-900 g were packed in stretch film and stored for 70 days with a natural weight loss of 10.8-10.6%. Polyethylene film extended the shelf life of heads weighing 350-700 g by 10 days – weight loss was 10.1%; heads weighing 750-900 g were stored for 20 days longer – weight loss was 10.0%. The mix of heads in the stretch film was stored for 80 days with a weight loss of 10.2%, and in those in polyethylene film – for 10 days longer with a loss of 10.0%.

Packing the head (more than 950 G) in a film provided a storage duration of up to 90 days. Natural mass loss in stretch film reached 8.8% and in polyethylene film with a thickness of 40 microns – 7.8%. Studies have shown that the density of napa cabbage heads ranges from 1.14 in Suprin F_1 hybrid up to 1.36 – in Bilko F_1. The head mass loss during storage is closely related to the head density (r=0.9746). The density of cabbage depends on the content of dry soluble substances (r=0.9786). Among the examined hybrids, Bilko F_1 has the best keeping properties, containing dry (6.4%) and dry solutes (5.1%), vitamin C (50.5 mg/100 g) and total sugar (2.9%).

Prospects for further research are possible with the improvement of elements of post-harvest refinement of cabbage. The possibilities of using edible films, coatings with antimicrobial properties have improved the concept of active packaging, they are designed to reduce, inhibit, or stop the growth of microorganisms on food surfaces. The results of the study can be used directly by manufacturers and representatives of the retail sector to extend the shelf life of fresh products.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Дослідження втрати маси капусти пекінської залежно від виду пакування та маси головки

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Анотація. Подовження періоду споживання свіжої капусти пекінської з різною масою головки за рахунок використання полімерних плівок є актуальним. Метою роботи було експериментальне обґрунтування заходів подовження строків споживання капусти пекінської. Продукцію вирощували і зберігали у фермерському господарстві. Дослідження з головками капусти пекінської проводили з використанням лабораторного методу і методу математичної статистики. Встановлено, що капуста пекінська під час зберігання втрачає до 10 % маси за 20 діб зберігання. Індивідуальне пакування головок у стретч-плівку, порівняно зі зберіганням у відкритому вигляді, дозволило зменшити природні втрати їх маси у два рази, збільшити період зберігання до 90 діб. Серед досліджуваних гібридів кращі лежкоздатні властивості були у гібрида, що характеризувався більшим вмістом сухих і сухих розчинних речовин, вітаміну С та загального цукру. При дослідженні лежкоздатності капусти пекінської залежно від маси головки встановлено, що стретч-плівка подовжує тривалість зберігання головок масою 350-700 і 750-900 г до 70 діб. Природні втрати маси при цьому сягають 10,8 %. Головки масою більше 900 г за такого пакування зберігаються 90 діб із природними втратами 8,8 %. Вкладні з поліетиленової плівки завтовшки 40 мкм подовжили тривалість зберігання головок капусти масою 350-700 г до 80 діб із втратами маси 10,1 %. Головки масою 750-900 і більше 900 г зберігалися 90 діб із природними втратами маси відповідно 10 і 7,8 %. Зберігання суміші різних за масою головок капусти пекінської у стретч-плівці збільшило період зберігання до 80 діб, а у поліетиленовій плівці – до 90 діб із втратами маси близько 10 %. Дані результати можуть бути використані науковцями в представниками торговельній галузі з метою подовження періоду зберігання плодів та овочів

Ключові слова: свіжа капуста; фракції головок; стретч-плівка; поліетиленова плівка; тривалість зберігання

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 70-80

UDC 630*4:632.4 (477.42)
DOI: 10.48077/scihor3.2023.70

The role of aphyllophoroid macromycetes as indicators of forest ecosystem disruption and reducers of biomass accumulation

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Article's History:
Received: 30.01.2023
Revised: 20.03.2023
Accepted: 10.04.2023

Suggested Citation:
Kulbanska, I., Boiko, H., Shvets, M., Vyshnevskyi, A., & Savchenko, Yu. (2023). The role of aphyllophoroid macromycetes as indicators of forest ecosystem disruption and reducers of biomass accumulation. *Scientific Horizons*, 26(3), 70-80.

Abstract. Aphyllophoroid macromycetes are a key link in natural and artificial biocenoses, in particular, forest ecosystems. Their peculiarity is due to the variety of morphological forms and the ability to colonise various substrates. The establishment of fundamental issues of the biotic organisation of this group of fungi, which considers both their specific features and integration into general ecological patterns, forms the necessary basis for their further research, protection, and practical use (in particular, when indicating and monitoring the state of forest biocenoses). The purpose of the study was to establish the species composition, taxonomic structure, and distribution (by mycohorizons) of aphyllophoroid macromycetes of forest stands in Zhytomyr Polissia. In the course of the study, classical phytopathological and forestry-inventory (biometric)

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analysis methods were used. Special methods of mycology, in particular, mycoindication, were also used in terms of identifying and examining aphyllophoroid macromycetes. Mycoflora of aphyllophoroid macromycetes of forest stands of Zhytomyr Polissia has 27 species belonging to 17 families, 8 orders of the *Agaricomycetes* class of the *Basidiomycota* division and is typical for the European temperate zone. The systematic component of the group under study is represented by the following orders: *Polyporales* (40.7% of their total number), *Hymenochaetales* (18.5%), *Agaricales* (14.8%), *Russulales* (11.2%), *Cantharellales*, *Thelephorales*, *Auriculariales*, and *Gomphales* (3.7% each). Analysis of the food structure of aphyllophoroid macromycetes shows that most of the mycoflora is represented by a complex of saproxilotrophic species, to a lesser extent parasite fungus (for example, *Inonotus hispidus, Phellinus robustus, Heterobasidion annosum*) and humus saprotrophs (*Thelephora terrestris*) are noted. The distribution of macromycetes by mycohorizons identifies that more than 70% of all finds were located in the subsurface mycohorizon, and the root mycohorizon is characterised by the smallest number of finds and species of macromycetes. There is a gradual decrease in the species diversity of aphyllophoroid macromycetes in the forest edge areas, which demonstrates fundamentally different stages of forest ecosystem degradation processes. The investigation of historical relationships between woody plant species and aphyllophoroid macromycetes, which act as biological indicators of the state of forest ecosystems, will further allow forming the of "maps of disruption of the integrity of forest biocenoses" for the analysis of sanitary risks, which should be implemented in the practice of forest protection

Keywords: wood-destroying fungi; mycohorizons; mycoflora; fruit bodies; edifying trees; Zhytomyr Polissia

INTRODUCTION

Forest biocenoses, as components of forest ecosystems, are a set of organisms consisting of various components – phytocenoses, zoocenoses, mycocenoses, and microbocenoses, which are closely interrelated in metabolism, energy, and information, which are manifested in competition for life resources, symbiosis, allelopathy, and consort relations. The use of these links as an indicator of anthropogenic disturbance of forest ecosystems is a relevant research area since the system "woody plant species – aphyllophoroid macromycetes" combines the processes of weakening and damage to trees, the accumulation of wood fall, and the rate of its decomposition by mycetes into a holistic process that clearly reflects the corresponding characteristics of the forest ecosystem.

One of the most numerous and insufficiently examined paraphyletic groups of fungi is aphyllophoroid macromycetes, from the standpoint of modern systematic structures, they are positioned as a set of life forms that unites representatives of the Basidiomycota division of multiple lines of phylogenetic order (Blinkova & Ivanenko, 2016; Holec *et al.,* 2020; Kunttu *et al.,* 2021). This group is a component of the heterotrophic complex of forest ecological systems. In particular, it is aphyllophoroid macromycetes that are the main reducers of dead trees. A large group of species is used in forestry practice as biological indicators of the condition, some species can destroy xenobiotics, while others – produce biologically active substances (Lavrov *et al.,* 2019; Kunca *et al.,* 2022; Rudawska *et al.*, 2022).

The fraction of aphyllophoroid macromycetes, in particular, xylotrophic species, in terms of qualitative and quantitative representation is the most numerous in the composition of mycobiota of forest cenoses (Shevchenko *et al.,* 2021). Therewith, the importance of xylotrophic fungi is absolutely ambiguous, since, on the one hand, they are pathogens of root and trunk wood rot, which negatively affects the overall phytosanitary state of the forest (Mihál *et al.,* 2021; Goychuk *et al.,* 2022). In contrast, saprotrophic species of xylotrophic fungi can destroy wood waste (i.e., dead organic matter, mortmass) (Ruszkiewicz-Michalska *et al.,* 2022); basidiomas and mycelium of aphyllophoroid fungi are the leading elements in the food chains of many species of stem pests, and some species of these macromycetes can also be used as biological indicators of untransformed anthropic forest coenoses (Rudolph *et al.,* 2018; Lavrov *et al.,* 2019; Alshammari *et al.,* 2021).

A targeted study of this group of aphyllophoroid macromycetes of forest stands has not yet been conducted. Currently, it is known about individual studies that describe the species composition and distribution of this group of fungi on the territory of a particular region (Christofides *et al.,* 2019; Kunttu *et al.,* 2020; Krynytska *et al.,* 2021). The authors also investigate the role and importance of aphyllophoroid macromycetes in the mycoindication of anthropogenic transformation of forest ecosystems (Lavrov *et al.,* 2019; Purahong *et al.,* 2022; Zou *et al.,* 2022). Thus, inventory and analysis of the species composition of mycoflora of aphyllophoroid macromycetes is a relevant research area and is of value for practitioners and researchers of the forest industry. The investigation and use of knowledge about aphyllophoroid macromycetes as biological indicators of anthropic forest disturbance is now a new and little-researched area.

In forest biocenoses, connections of higher woody plant species with fungi and fungi-like organisms are particularly common and developed (Yakhyaev *et al.,* 2019; Embacher *et al.,* 2023). Among the representatives of the group of wood-destroying, fungi or tinder

plants (xylomycobionts) are substantial in terms of the qualitative and quantitative composition of the mycological biota of forests. Therewith, parasitic aphyllophoroid and agaricoid fungi can have a negative impact on the overall sanitary condition of forest stands, in particular, as pathogens of root and stem rot processes (Kunttu *et al.,* 2018; Li *et al.,* 2022). In turn, saprotrophic fungi, conducting organic decomposition of plant raw materials, provide a cycle of energy and matter in the biogeocenosis (Krynytska *et al.,* 2019).

During the mycological diagnostics of the transformation of forest biocenoses, considering the species composition and distribution of aphyllophoroid macromycetes as bioindicators, it is necessary to consider the differences inherent in forest objects growing in different types of forest (Lavrov *et al.,* 2019). It is also known that the systematic, trophic, and species structures of aphyllophoroid macromycetes, the features of their functioning, and distribution may vary depending on changes occurring in the structure of the forest stand, the level of its anthropic load, the volume of forest litter, and tree fall (Blinkova & Ivanenko, 2016). There are separate studies concerning the species composition of the mycological complex in forests of natural and artificial origin that grow in various natural zones: Forest-Steppe – in field-protecting plantings and operational forests, Kyiv Polissia (Blinkova & Ivanenko, 2016), Transcarpathia (Krynytska *et al.,* 2021) etc. In particular, V.V. Lavrov *et al.* (2019) examined the features of the mycological diversity of forests located within the green zones of urbanised environments of Ukraine.

Identification of the species composition and features of the distribution of xylomycobionts in various natural zones of Ukrainian phytocenoses remain poorly examined today, despite the experience gained by researchers regarding the use of wood-destroying fungi and higher woody plants in the form of biological indicators of the sanitary state of forests (Haas *et al.,* 2019; Holec & Kučera, 2020).

The purpose of the study is a comprehensive examination of aphyllophoroid macromycetes of forest stands of Zhytomyr Polissia, in particular, identification, distribution, and taxonomic distribution, for the use of these indicators as mycoindication signs of disruption of the state of forest ecosystems.

MATERIALS AND METHODS

The research materials of the study were samples of aphyllophoroid macromycetes collected during the growing season of 2020-2022 within the forest stands of Zhytomyr Polissia. The collection of prototypes was conducted by the route-expedition method, and on temporary test areas in forest stands of the region under study. In the test areas, the studies were conducted at various degrees of organisation of biological systems, depending on the visible changes (transformations) of the ecosystem and the spread of aphyllophoroid macromycetes: the organ of a woody plant – roots, perianth part, trunk, crown, branch; woody plant species; species (population), tier (biogroup) of coenosis, phytocenosis.

Mycological samples were collected considering the individual characteristics of macromycetes. The aphyllophoroid macromycetes collected on different substrates of the same woody plant were considered to be from one species (this refers to different ecological niches). Therewith, different species of finds included macromycetes that grew (covered) one species of substrate but formed basidiomas of several species. Each find was recorded using a camera.

Under laboratory conditions, using light microscopy methods (MBI-3 microscope and MBS-9 binocular magnifier), species identification of the collected phytopathological material – fruit bodies of aphyllophoroid macromycetes was performed. The examination and analysis of macroscopic structures of the objects under study were conducted on temporary micro-preparations directly under a microscope at a magnification in the range from x8 to x100.

The distribution of aphyllophoroid macromycetes by spatial structure, i.e. by mycological horizons, was conducted. 5 types of mycohorizons were identified (crown, stem, lump, aboveground (including dead wood, fallen trees, dead branches), and ground), the number of aphyllophoroid macromycetes species, and the total number of finds were determined. Morphometrically, the following categories of dead substrates of the edifier of the macromycetes consortium were evaluated and distinguished: stumps of felled trees, large and small branches, dead wood, and fallen trunks.

Desk processing and identification of the collected mycological material was conducted based on the A.V. Tsyliuryk training laboratory of forest pathology of the National University of Life and Environmental Sciences of Ukraine according to generally accepted and special methods (phytopathology, mycology, general ecology, forestry and mensuration, and mycological indication) (Methodology of forestry research, n.d.; Lavrov *et al.,* 2018), using special determinants for individual taxa of aphyllophoroid macromycetes, the search engine of the "The world of mushrooms of Ukraine" (n.d.) website, and the application "Mushroom Identify" (the world of mushrooms, 2023). The taxonomic structure and prevalence of parasitic fungi were determined by the proportion of trees with characteristic fruit bodies from the total number of trees in the study areas (Sanitary rules, 2020). Modern Latin names of aphyllophoroid macromycetes are given in accordance with the nomenclature database (Index Fungorum, 2023). The analysis of the food specialisation of aphyllophoroid macromycetes was conducted considering the trophic adaptability of fungi to specific species of woody plants. Microsoft Excel was used in the process of creating standard charts to graphically display the results obtained.

RESULTS AND DISCUSSION

In the course of the conducted studies, it was identified that most of the species of aphyllophoroid macromycetes are characterised by different levels of food specialisation. In particular, 27 species were identified and identified in the forest stands of Zhytomyr Polissia on woody plant species. Most of the identified aphyllophoroid macromycetes are attributed to xylosaprotrophs, whose life cycle is limited to dead and fallen wood. The largest number of species was recorded on Scots pine, Scots oak, silver birch, white poplar, holly maple, and black alder (Fig. 1).

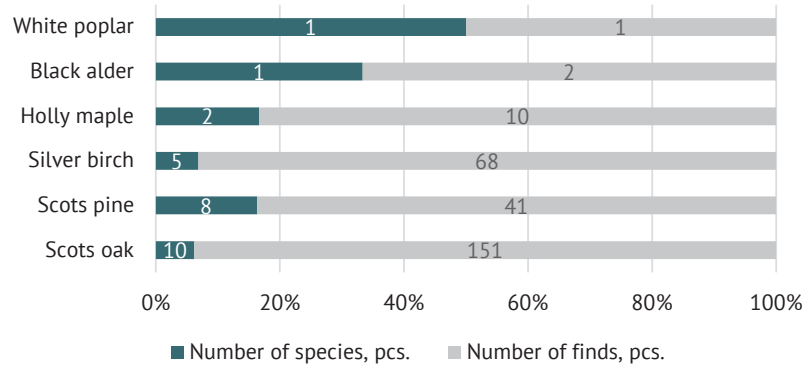

Figure 1. *Specialisation of aphyllophoroid macromycetes of forest stands of Zhytomyr Polissia based on substrate-forming woody plant species*

Thus, for aphyllophoroid macromycetes of forest stands of Zhytomyr Polissia, specialisation is typical for trees-edifiers of the consortium or substrate-forming plants. The largest number of species is recorded on Scots pine (*Pinus sylvestris* L.) (10 species, 37.0% of the total number of finds), Scots oak (*Quercus robur* L.) (8 species, 29.6%), holly maple (*Acer platanoides* L.) (2 species, 7.4%), silver birch (*Betula pendula* Roth.) (5 species, 18.6%), white poplar (*Populus tremula* L.) (1 species, 3.7%), and black alder (*Alnus glutinosa* (L.) Gaerth.) (1 species, 3.7%).

10 species of aphyllophoroid macromycetes were identified on Scots pine. Thus, on the roots, the lower part of the trunks, the stumps and the trunk of living trees, a perennial heterobizidion (*Heterobasidion annosum* (Fr.) develops, which causes variegated central rot of wood on the roots and is one of the most dangerous pathogens of mycotic diseases and mass dieback of coniferous forests. This macromycetes massively affects pine stands and leads to the loss of a substantial amount of wood and reduces the protective properties of forests. Over time, the affected stands are transformed into woodlands, due to the gradual weakening and dieback of woody plants. In infected trees, there is a disruption of the movement and pressure of oleoresin, which performs the function of physiological and mechanical protection against damage by phytophagous insects, the frequency and intensity of reproduction of which takes place at irregular intervals but is usually characteristic of weakened and dieback stands that are under stress, in particular, physiological (Hayova *et al.,* 2020).

On the soil and plant or tree remains, singly and in groups, the mycorrhizal fungus *Thelephora terrestris* Ehrh. was identified (Fig. 2a). Saprotroph on soil, symbiont. Despite the fact that the fungus is not a parasite, it can lead to the death of plants, enveloping seedlings of pine and other species. Such damage is called seedling suffocation. The distribution of red-belted conk (*Fomitopsis pinicola* (Sw.: Fr.)) was identified (Fig. 2b) – causes yellowish-brown in colour core-sapwood type prismatic rot, which leads to complete destruction of wood; shaggy bracket (*Inonotus hispidus* (Bull.)) – causes yellowish-white core trunk rot of a corrosive type; red ring rot (*Phellinus pini* (Brot.)) – causes variegated core stem rot of a corrosive type. On dead and fallen trunks, *Trichaptum fuscoviolaceum* (Ehren.), *Botryobasidium subcoronatum* (Höhn & Lits), *Chondrostereum purpureum* (Pers.) are common (Fig. 2b).

a) b) c)

Figure 2. *Thelephora terrestris Ehrh. (a), Fomitopsis pinicola (Sw.: Fr.) (b), and Chondrostereum purpureum (Pers.) (c)*
Source: *photographed by the authors*

Single fruit bodies of the scaly sawgill were identified on stumps and old fallen tree trunks (*Neolentinus lepideus* (Fr.)) (Fig. 3a). Groups of fruit bodies of strict-branch coral (*Ramaria stricta* (Pers.)) marked on rotten stumps and rotten wood submerged in the soil (Fig. 3b).

a) b) c)

Figure 3. *Neolentinus lepideus (Fr.) (a), Ramaria stricta (Pers.) (b) and Irpex lacteus (Fr.) (c)*
Source: *photographed by the authors*

8 species of aphyllophoroid macromycetes were identified on Scots Oak: crust fungus (*Irpex lacteus* (Fr.) (Fig. 3b), *Peniophora quercina* (Pers.), and *Radulomyces molaris* (Chaillet), which start recycling still-living wood and continue their development on the dead substrate. On the trunks and branches of living trees, *Phellinus robustus* (Karst.) is marked, which causes white and yellowish-white central wood rot, leading to tree death. On fallen trunks, dry branches and stumps of oak, *Hymenochaete rubiginosa* (Dicks.) Lév. is marked, which causes dry corrosion rot of wood. *Stereum hirsutum* (Willd.) and *Trametes versicolor* (L.) are also identified on the fallen trunks (Fig. 4a). In the litter on plant remains an unusual find was identified – the fruit bodies of *Cyathus striatus* (Huds.) (Fig. 4b).

a) b) c)

Figure 4. *Trametes versicolor (L.) (a), Cyathus striatus (Huds.) (b), Exidia glandulosa (Bull.) (c)*
Source: *photographed by the authors*

Aphyllophoroid macromycetes of holly maple consortia are represented by 2 species. Groups of maple tinder fruit bodies were identified on live trunks (*Oxyporus populinus* (Schumach.) Fr.), which is a wound parasite and causes intense yellow-brown stem rot. Basidiomas of the *Polyporus squamosus* (Huds.) Fr. are also noted on dry and fallen wood, causing white wound rot. *Mycoacia fuscoatra* (Fr.) was the only species of aphylophoric macromycetes identified on black alder. Fruit bodies were identified on fallen wood and fallen branches.

On growing trees, stumps, and fallen branches of silver birch, 5 species of aphyllophoroid macromycetes were recorded, the most numerous among them are 3 species: on growing trunks – *Piptoporus betulinus* (Bull.) – causes red-brown core-sapwood trunk rot of a destructive type; *Fomes fomentarius* (L.) – causes white marble-like core-sapwood trunk rot of a corrosive type. *Cerrena unicolor* (Bull.), which causes intense whitish rot of wood was noted on fallen trunks and stumps. Single fruit bodies of *Panus conchatus* (Bull.) were identified on stumps and fallen trunks. *Exidia glandulosa* (Bull.) (Fig. 4b) was observed in autumn from September to the beginning of frosts, usually on dieback, less often – standing, birch trunks, and on dry branches.

1 species of aphyllophoroid macromycetes was identified on the white poplar – *Schizophyllum amplum* (Lév.), trophic specialisation of which is adapted to fallen wood of varying degrees of destruction. It was identified that certain species of aphyllophoroid macromycetes begin the process of utilisation of dead

substrate or wood, directly still being in xerophilic conditions of the tree crown and form groups depending on the trophic and microclimatic needs of specific species belonging to their category.

Among the species composition of aphyllophoroid macromycetes, according to trophic preferences, there are parasitic fungi, saprotrophs, and species capable of forming facultative mycorrhiza. According to the obtained experimental data, in the examined mycoflora of forest stands of Zhytomyr Polissia, the fraction of fungi-saproxilotrophs, the life cycle of which is confined to dead and fallen wood, are most widely represented. A substantially smaller number of species is represented by a group of humus saprotrophs, among which 1 species is identified – *Thelephora terrestris*, which is a typical facultative mycorrhizal agent. A group of parasitic fungi was also noted, the most common among them in the forests of Zhytomyr Polissia were obligate parasites (*Phellinus robustus*, *Heterobasidion annosum*, and *Inonotus hispidus*).

Several species of macromycetes (*Fomes fomentarius*, *Oxyporus populinus*, and *Stereum hirsutum*) were facultative saprotrophs that begin their ontogenesis on living woody plants, and continue – on dead wood. Some species develop mainly on dead wood but are also able to colonise drying weakened woody plants, and that is why they are classified as facultative parasites (for example, *Fomitopsis pinicola*).

Analysis of the taxonomic structure of the identified aphyllophoroid macromycetes showed that these species belong to 27 genera, 17 families, and 8 orders of the *Agaricomycetes* class of the *Basidiomycota* division. Most of the examined species are formed by representatives of the *Polyporales* (11 species, 40.7% of their total number), *Hymenochaetales* (5 species, 18.5%), *Agaricales* (4 species, 14.8%), *Russulales* (3 species, 11.2%), *Cantharellales* (1 specie, 3.7%), and *Thelephorales* (1 species, 3.7%), Auriculariales (1 species, 3.7%), Gomphales (1 species, 3.7%) orders (Fig. 5).

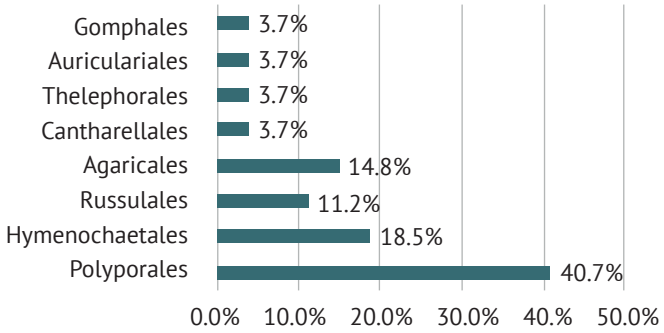

Figure 5. *Taxonomic structure of aphyllophoroid macromycetes of forest stands in Zhytomyr Polissia*

Leading families (*Polyporaceae*, *Hymenochaetaceae*, *Fomitopsidaceae*) cover more than 50% of the species composition of the examined mycoflora, which brings it closer to European forest mycological flora.

The general distribution of aphyllophoroid macromycetes of forest stands of Zhytomyr Polissia by mycohorizons was conducted (Table 1). The species diversity of aphyllophoroid macromycetes in forest stands of Zhytomyr Polissia is 27 species and 273 finds. Overall, 76.2% of all macromycete finds were identified in subsurface mycohorizon. The smallest number of finds and species of macromycetes from the total number is characterised by the root mycohorizon. There were no finds in the crown mycohorizon. A relatively small number of aphyllophoroid macromycetes were identified in trunk and butt wood mycohorizons.

Table 1. *Distribution of aphyllophoroid macromycetes of forest stands in Zhytomyr Polissia by mycohorizons*

No.	Variety of macromycete consort	Number of finds	Species of woody plant-edifier of the consortium	mycological horizons				
				1	2	3	4	5
1	*Heterobasidion annosum* (Fr.) Bref. 1888	39	*Pinus sylvestris* L.	+	+	-	-	-
2	*Fomitopsis pinicola* (Sw.) P. Karst. 1881	15		-	+	-	-	-
3	*Inonotus hispidus* (Bull.) P. Karst. 1879	3		-	-	-	+	-
4	*Thelephora terrestris* Ehrh. 1793	9		-	+	-	-	-
5	*Phellinus pini* (Brot.) Pilát 1941	44		-	-	+	-	-
6	*Trichaptum fuscoviolaceum* (Ehrenb.) Ryvarden 1972	2		-	+	-	-	-
7	*Botryobasidium subcoronatum* (Höhn. & Litsch.) Donk 1931	1		-	+	-	-	-

Table 1, Continued

No.	Variety of macromycete consort	Number of finds	Species of woody plant-edifier of the consortium	mycological horizons				
				1	2	3	4	5
8	*Neolentinus lepideus* (Fr.) Redhead & Ginns, 1985	6	*Pinus sylvestris* L.	-	+	+	-	-
9	*Chondrostereum purpureum* (Pers.) Pouzar, 1959	19		-	+	+	+	-
10	*Ramaria stricta* (Pers.) Quél., 1888	13		-	+	-	-	-
11	*Irpex lacteus* (Fr.) Fr. 1828	3	*Quercus robur* L.	-	+	-	-	-
12	*Peniophora quercina* (Pers.) Cooke 1879	1		-	-	-	+	-
13	*Radulomyces molaris* (Chaillet ex Fr.) M.P. Christ. 1960	1		-	-	-	+	-
14	*Phellinus robustus* (P. Karst.) Bourdot & Galzin 1928	12		-	+	+	-	-
15	*Stereum hirsutum* (Willd.) Pers. 1800	9		-	+	+	+	-
16	*Hymenochaete rubiginosa* (Dicks.) Lév. 1846	1		-	+	-	-	-
17	*Trametes versicolor* (L.) Lloyd, 1921	12		-	+	+	-	-
18	*Cyathus striatus* (Huds.) Willd., 1787	2		-	+	-	-	-
19	*Schizophyllum amplum* (Lév.) Nakasone 1996	1	*Populus tremula* L.	-	+	-	-	-
20	*Oxyporus populinus* (Schumach.) Donk 1933	4	*Acer platanoides* L.	-	-	-	+	-
21	*Polyporus squamosus* (Huds.) Fr. 1821	6		-	+	-	+	-
22	*Mycoacia fuscoatra* (Fr.) Donk 1931	2	*Alnus glutinosa* (L.) Gaerth.	-	+	-	-	-
23	*Piptoporus betulinus* (Bull.) P. Karst. 1881	22	*Betula pendula* Roth.	-	-	-	+	-
24	*Fomes fomentarius* (L.) Fr. 1849	29		-	-	-	+	-
25	*Cerrena unicolor* (Bull.) Murrill 1903	2		-	+	+	-	-
26	*Panus conchatus* (Bull.) Fr., 1838	1		-	+	-	-	-
27	*Exidia glandulosa* (Bull.) Fr., 1822	14		-	+	+	+	-

Source: *compiled by the authors*

Therewith, it was identified that the species diversity of the examined aphyllophoroid macromycetes gradually decreases in the areas of the forest edges, which is presumably caused by the rather unequal sanitary structure of the examined forests. This demonstrates the various phases of the degradation processes of forest stands and the transformation of their structure in the areas of dilution of the mother tent, its natural renewal and transformation of the dominant species of woody plants by synanthropic species, replacement of the stand with shrubs and shrubby thickets, etc. (Slesar & Kulbanska, 2022).

Summarising, it was noted that the aphyllophoroid macromycetes community unites virtually all ecological groups of fungi, including saprotrophs, mycotrophs, xylotrophs, coprotrophs, parasites of higher plants, and mycorrhizal agents, etc. It is aphyllophoroid macromycetes that are most widely used to indicate the general (including sanitary) state of forests. Among the representatives of this group of fungi, there are species represented in the Red lists of different countries of the world that now need protection and conservation.

Thus, the improvement of methods for assessing the anthropic impact on forest biocenoses, in particular, based on mycoindication methods, considering the species composition and distribution of aphyllorophoroid macromycetes, is promising, both in theoretical and practical terms, especially in conditions of complex influence of abiotic and biotic environmental factors, with mechanisms and methods of influence that differ among themselves.

The results obtained in the course of the study correlate with already known studies in this area. In particular, Polishchuk (2017) was able to identify 29 species of macromycetes, which are assigned to 28 genera, 18 families, and 6 orders of the Basidiomycota division (Agaricomycetes class) while investigating the distribution and structure of wood-destroying fungi of the Kyiv Polissia, on various categories of dead and living substrates. The largest number of species (8) and finds (35) of xylotrophic fungi were identified on *Betula pendula* L. and *Quercus robur* L. woody plants. It is noted that wood-destroying fungi are almost equally common on the trunk, the crown, and the butt wood. Accordingly, the studies on aphyllophoroid macromycetes of Zhytomyr Polissia allowed identifying 27 species of macromycetes belonging to 17 families, 8 orders of the Agaricomycetes class of the Basidiomycota division. The largest number

of species (10) and finds (151) of xylotrophic fungi were identified on *Pinus sylvestris* L. woody plants.

The findings were also mainly in the subsurface mycohorizon. Lavrov et al. (2019), investigating methods for diagnosing of recreagenic transformation of oak forests by the diversity of groups of xylotrophic fungi and phytobiota, identified that changes in the ecological state of oak forests of the urban plantings in the city of Bila Tserkva are caused by a complex of environmental factors leading to the degradation of middle-aged oak stands. It is confirmed that xylotrophic fungi quite informatively reflect the sanitary condition of plantings and perform a regulatory function in forests. The authors proposed the implementation of xylomycological indication of forest phytocenosis disorders in the forest monitoring system. A similar assumption was made based on this study. Therefore, it can be stated that the biota structure of aphyllophoroid macromycetes is a coded reflection of the structure of the forest stand and under any specific conditions depicts its indicators with high accuracy.

Blinkova & Ivanenko (2016), investigating the co-adaptive systems of woody vegetation of wood-destroying (xylotrophic) fungi in artificial phytocenoses, also touched upon the concept of "bioindication". The study analyses the role and functions of xylotrophs in the genesis of cultural phytocenoses and natural forests. Their study concerns exclusively forest stands. Christofides *et al.* (2019) investigated bacterial communities in wood that was colonised by wood-destroying fungi (*Vuilleminia comedens, Trametes versicolor*, and *Hypholoma fasciculare*). It was identified that all three species of fungi substantially delayed bacterial colonisation of wood. The conducted studies did not aim to establish a link between pathogens of bacterial diseases and aphyllophoroid macromycetes.

(Haas *et al.,* 2019) examined wood-destroying fungi in detail, in particular, *Serpula lacrymans*, and their impact on the construction qualities of wood. Notably, the conducted studies included aphyllophoroid macromycetes, whose vital activity is confined to both living and dead substrates. A study by Hayova *et al.* (2020) is dedicated to the Red Book species of wood-destroying fungi – *Fomitopsis officinalis* and its distribution within the Ivano-Frankivsk and Lviv regions. In the course of the conducted studies, not a single species of aphyllophoroid macromycetes was identified, which is classified in the Red Book of Ukraine. However, it was noted that the role of aphyllophoroid macromycetes in forests is quite diverse and therefore, this group of living organisms requires attention and research from the scientific community.

Species richness and composition of macromycetes (168 species identified) on the trunks of *Picea abies* are discussed in detail in the paper (Holec *et al.,* 2020). It is established that the number of wood-destroying fungal species on tree trunks correlated with an increase in tree cover, average decay stages, and a decrease in height. Among the dominant species of macromycetes, the following are highlighted: *Fomitopsis pinicola*, which was also a frequent find on the trunks of *Pinus sylvestris* during the conducted studies. Despite the fact that researchers have formed a large contribution to the study of wood-destroying fungi, none of the available studies has formed a comprehensive approach to the examination of the species composition and distribution of aphyllophoroid macromycetes of forest stands and the use of this knowledge for mycoindication of biocenoses transformed by anthropic factors. This will allow using them in mycoindication of disturbed (weakened, degraded) forest ecosystems in the form of biological indicators of the state, which in the future will allow forming the "maps of disruption of the integrity of forest biocenoses" for analysis of sanitary risks (phytosanitary forecasting).

CONCLUSIONS

Mycoflora of the identified aphyllophoroid macromycetes of forest stands of Zhytomyr Polissia has 27 species belonging to 17 families, 8 orders of the Agaricomycetes class of the Basidiomycota division.

The species diversity of the examined formation was quite characteristic of the European temperate zone. Analysis of the systematic structure of aphyllophoroid macromycetes shows that the largest number of species (11 species, 40.7% of their total number) is represented by the *Polyporales* order, and other orders are represented to a lesser extent. Thus, the *Hymenochaetales* order is represented by 5 species, which is 18.5% of the total number of identified macromycetes; the *Agaricales* order is represented by 4 species, which is 14.8%; the *Russulales* order is represented by 3 species, which is 11.2%. Other orders – *Cantharellales*, *Thelephorale*s, Auriculariales, and Gomphales are represented by 1 species, which is 3.7% of their total number.

Analysis of the food structure of aphyllophoroid macromycetes of forest stands in Zhytomyr Polissia shows that most of the mycoflora is represented by a complex of saproxilotrophic species, to a lesser extent – parasitic fungi and humus saprotrophs are noted.

A characteristic feature of aphyllophoroid macromycetes of forest stands is the specialisation of plants-edifiers of the consortium or substrate-forming species of forest woody plants. The largest number of macromycete species (10 species) was identified on the bodies of *Pinus sylvestris* L. On *Quercus robur* L., 8 species of aphyllophoroid macromycetes were identified. Aphyllophoroid macromycetes of the *Acer platanoides* L. consortia are represented by 2 species. The only species of aphilophoric macromycetes identified on the *Alnus glutinosa* (L.) Gaerth. was *Mycoacia fuscoatra*. 5 species of aphyllophoroid macromycetes were recorded on *Betula pendula* Roth. On *Populus tremula* L., 1 species of aphyllophoroid macromycetes was identified – *Schizophyllum amplum*.

It was established that the mycoflora of aphyllophoroid macromycetes of forest communities of the examined region form groups depending on the microclimatic and trophic species preferences that are directly included in their composition. A promising area for further research is the deepening of methodological approaches to the examination of aphyllophoroid macromycetes of forest stands, in particular, knowledge about the species composition, proximity to trees-edifiers of the consortium, distribution by mycohorizons, etc.

AKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Роль афілофороїдних макроміцетів як індикаторів порушення лісових екосистем та редуцентів накопичення біомаси

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Анотація. Афілофороїдні макроміцети виступають ключовою ланкою природних і штучних біоценозів, зокрема лісових екосистем. Їхня особливість обумовлена різноманіттям морфологічних форм і здатністю до колонізації різних субстратів. Встановлення принципових питань біотичної організації цієї групи грибів, що враховує як їх специфіку, так і інтегрованість у загальноекологічні закономірності, формує необхідну основу їхнього подальшого дослідження, охорони та практичного використання (зокрема при індикації та моніторингу стану лісових біоценозів). Мета роботи полягала у встановленні видового складу, таксономічної структури та поширення (за мікогоризонтами) афілофороїдних макроміцетів лісових насаджень Житомирського Полісся. В ході виконання дослідження використано класичні фітопатологічні та лісівничо-таксаційні методи аналізу. А також використано спеціальні методи мікології, зокрема мікоіндикації, в частині ідентифікації та дослідження афілофороїдних макроміцетів. Мікофлора афілофороїдних макроміцетів лісових насаджень Житомирського Полісся налічує 27 видів, які належать до 17 родин, 8 порядків класу *Agaricomycetes* відділу *Basidiomycota* і є типовою для європейської помірної зони. Систематична складова дослідженого угрупування представлена наступними порядками: *Polyporales* (40,7 % від їх загальної кількості), *Hymenochaetales* (18,5 %), *Agaricales* (14,8 %), *Russulales* (11,2 %), *Cantharellales*, *Thelephorales*, *Auriculariales* та *Gomphales* (по 3,7 % кожна). Аналіз харчової структури афілофороїдних макроміцетів засвідчує, що більша частина мікофлори представлена комплексом сапроксилотрофних видів, у меншій ступені відмічені гриби-паризити (наприклад, *Inonotus hispidus*, *Phellinus robustus*, *Heterobasidion annosum*) та гумусові сапротрофи (*Thelephora terrestris*). Розподіл макроміцетів за мікогоризонтами завсідчує, що понад 70 % усіх знахідок виявлено у надгрунтовому мікогоризонті, а найменшою чисельністю знахідок і видів макроміцетів характеризується кореневий мікогоризонт. Спостерігається поступове зменшення видового різноманіття афілофороїдних макроміцетів у напрямках узлісь, що, демонструє принципово різні етапи процесів деградації лісових екосистем. Дослідження зв'язків, що історично сформовані між деревними видами рослин і афілофороїдними макроміцетами, які виступають біологічними індикаторами стану лісових екосистем, у подальшому дозволить сформувати «карти порушення цілісності лісових біоценозів» для аналізів санітарних ризиків, які доцільно впроваджувати у практику лісозахисту

Ключові слова: дереворуйнівні гриби; мікогоризонти; мікофлора; плодові тіла; дерева-едифікатори; Житомирське Полісся

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 81-91

UDC 631.535:633.812.754
DOI: 10.48077/scihor3.2023.81

Features of growth and development of *Lavandula angustifolia* when grown under drip irrigation conditions in the Southern Steppe zone of Ukraine

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Article's History:
Received: 26.01.2023
Revised: 26.03.2023
Accepted: 11.04.2023

Suggested Citation:
Kachanova, T., Manushkina, T., & Kovalenko, O. (2023). Features of growth and development of *Lavandula angustifolia* when grown under drip irrigation conditions in the Southern Steppe zone of Ukraine. *Scientific Horizons*, 26(3), 81-91.

Abstract. In the context of climate change, agriculture must respond to new challenges – one of them is the search for and adaptation of new plant varieties in areas where they have not been grown on an industrial scale. The research aims to investigate the effect of biological treatment on the growth and development of *Lavandula angustifolia* under different irrigation methods to increase the efficiency of its use as an industrial crop in the Southern Steppe zone of Ukraine. The species *L. angustifolia* is primarily important as an essential oil crop and is used in the preparation of food and beverages, perfumery, medicine, pharmacy, cosmetics, industry, for air purification from particulate matter in urban plantations, as a honey plant and for decorative purposes. In the research. A randomized scheme of blocks with a 2x2 factorial arrangement was used with two bacterial preparations ("Azogran A" and "Biocomplex BTU") and two moisture levels (80-70-70% MHC and 90-80-70% MHC) in triple repetition. Plants in the 1st, 2nd, and 3rd year of vegetation were analysed following several factors, such as the beginning and end of the vegetative phase, the beginning of the budding phase, the flowering period, and the ratio of these indicators to the amount of heat received during the growing season. Phenotypic characteristics, green and dry mass yields, percentage of essential oils, and conditional yields were also evaluated under all the studied conditions. Overall, it was established, that the biggest stimulative effect on the growth of *L. angustifolia* was found when growing lavender under the irrigation

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regime of 90-80-70% MHC with double top dressing of plantings in the budding phase "Biocomplex BTU" – these plants were the most developed and had noticeably higher dry mass and theoretical yield. Therefore, the control of irrigation and treatment with biological products makes the prospect of industrial lavender cultivation in the Southern Steppe of Ukraine more accessible

Keywords: lavender; moisture level; bio-fertilizers; yield; essential oil content

INTRODUCTION

Climate change, as well as the plowing of virgin steppe and massive deforestation, complicated agriculture in South Ukraine. Annual precipitation in this region decreased by 71 mm compared to 2010, and air temperature increased by 2.0°C, which led to an additional increase in water evaporation from the soil (Vozhegova *et al.,* 2021). In these conditions, the problem of finding crops that can adapt to a lack of moisture has become apparent. One of the available options is essential oil crops, which are characterized by drought tolerance. In addition to the demand in the domestic market and the high cost of raw materials, another factor that favours the choice in favour of these crops is that many of them have already been widely distributed as industrial crops on the Crimean Peninsula. Some are still grown in Ukraine, albeit in much smaller volumes. The authors of the study on the assessment of varietal diversity of essential oil crops suitable for cultivation in the Southern Steppe zone identified varieties of the *L. angustifolia* species as the most promising in this area. The structuring and analysis were based on the official Register of Varieties of Ukraine (Vozhegova *et al*., 2021).

Currently, the volume of lavender cultivation allows to produce up to 1,500 tons of essential oils annually. However, the share of production of *L. angustifolia* varieties accounts for only about one-third of this amount (Zigene *et al.,* 2018; Crișan *et al.,* 2023). This species originates from the regions of France and Italy, and its oil is considered to be of the highest quality (Despinasse, 2020). In Italy, the cost of agronomic products of this species is about 5.8 thousand euros per hectare (Fichera *et al.,* 2013). Currently, the largest suppliers are Bulgaria, France, and China.

In Ukraine, as of 2018, lavender cultivation was estimated at 1 thousand hectares and 10-15 tons of essential oils per year (Giray, 2018; Kokovihin & Vozhegova, 2018). Until 2014, the first number was 3 thousand hectares, and the main plantations were located in Crimea, in areas with a climate close to the Mediterranean. Due to the loss of the peninsula, the production of raw materials for essential oil crops decreased and could not meet domestic needs. However, climate change trends determine the possibility of expanding the cultivation of *L. angustifolia* in the steppe zone of Ukraine. In 2014-2018, the Institute of Horticulture began breeding varieties adapted to the Ukrainian climate by order of the President. The resulting variety is currently undergoing certification and has not yet been approved for commercial use (Rudnik-Ivashchenko & Kremenchuk, 2019).

The experience of growing *L. angustifolia* in Tuscany confirms the possibility of using so-called marginal lands for cultivation of this species, i.e., lands unsuitable for growing other crops. However, the analysis of oil obtained from raw materials of 1-4 years old showed that its composition does not meet European quality requirements (Aprotosoaie *et al.,* 2017; Najar *et al.,* 2022). Prolonged drought can also negatively affect product quality. The oils of plants grown in comfortable conditions and with a moisture deficit of 25, 50, and 75%, respectively, had different pharmaceutical effects, the strength of which is directly proportional to the satisfaction of moisture needs (Hasibi *et al.,* 2022). In addition to the deterioration of essential oil quality, its quantity also decreases as several studies show, photosynthetic activity and growth are also significantly reduced with a lack of moisture (Szekely-Varga *et al.,* 2020, Radu *et al.,* 2020, García-Caparrós *et al.,* 2019). The systematization of materials by Ukrainian land reclamation scientists has shown that irrigation is one of the solutions to this problem.

Given that drought is estimated to account for 10% of all adverse abiotic factors, other ways to preserve yields have been identified. For example, applying certain elements, such as boron (Abdel & Manal, 2018) and iron nanoparticles (Adrees *et al.,* 2020; Paraskevopoulou *et al.,* 2020), or compounds such as chitosan (Behboudi *et al.,* 2019), under the root. Another option is spraying abscisic acid, which is also often called a stress hormone (Gorgini *et al.,* 2021). An approach based on the use of endosymbiotic bacteria is similar in the mechanism of action. Thus, bacteria living in plant tissues are not always parasites. Some of them help the plant to adapt to unfavourable conditions, in particular to a lack of moisture, using various molecular and genetic mechanisms. The most studied are the mechanisms of synthesis by the bacteria themselves or stimulation of the synthesis of phytohormones, including abscisic acid, by plant cells. They can also act as antagonists of parasitic bacteria or fungi. Bacteria that have a positive effect on plant growth and development are called growth-regulating bacteria (Yoshida *et al.,* 2019, White *et al.,* 2019; Ghaderi-Far *et al.,* 2021).

There is a lot of evidence that symbiotic bacteria improve the morphological and physiological characteristics of the host plant, making it more adaptable to environmental factors (Saberi *et al.,* 2021, de Vries *et al.,*

2020, Zia *et al.,* 2021). These and other bacteria that are useful for human economic activity can be included in biological products.

A biological product is a culture of one or more strains of microorganisms and auxiliary substances necessary for their growth, development, or involvement in certain metabolic processes. Such products are often used as biological fertilizers or for the prevention of plant diseases (Das, 2019; Abdelaal *et al.,* 2021). In the Mykolaiv region, there have already been attempts to use bacterial products in lavender cultivation. The treatment of different varieties of *L. angustifolia* with Radostim and Stimpo did not show any changes in the relative proportion of oil in the raw material, but the actual yield for all three varieties was higher when treated with Stimpo, which proves the effectiveness of such products (Manushkina, 2019).

The research aims to select the optimal moisture regime for the *Stepova* variety, to determine whether there is a correlation between the average daily temperature and growth stages, and to supplement data on the prospects for the use of biological products and their impact on plant growth and development.

MATERIALS AND METHODS

The experimental part of the study lasted from 2019 to 2021 in the Mykolaiv region. The soil of the experimental field is southern low-humus dusty-heavy loamy black soil on carbonate loess. As this region belongs to the Southern Steppe zone, it has a sharp continental climate. This means hot summers with frequent dry winds and rather warm winters. The temperature ranges from 3-5°C to 21-23°C. The sum of positive temperatures above 10°C reaches 3000-4100°C. The first frosts begin in the last third of October, and the last ones stop in early April or May at the latest.

Mykolaiv region is located in a zone of insufficient moisture, where the hydrothermal coefficient during the growing season is only 0.6-0.7, and the amount of precipitation during this time reaches 260-285 mm. This leads to the need for the irrigation of crops.

The object of research was a medium-ripened variety "Stepova", which had a light lilac colour of the Corolla. The experiment scheme included two factors: factor A (treatment of plants with Biopreparations): Control (without treatment), treatment of plants with "Biocomplex BTU", treatment of plants with "Azogran A". According to factor B (irrigation modes), two levels of crop moisture were studied: 80-70-70% MHC (main hydrophysical factor) and 90-80-70% MHC. Treatment with bacterial fertilizers "Biocomplex BTU" and "Azogran a" (2 l/ha) was performed twice with an interval of 14 days. The treatment was aimed at top dressing of plants, protecting them from diseases, and increasing their adaptive potential.

Bacterial fertilizer "Biocomplex BTU" contains cells of bacteria *Bacillus subtilis* (40±10%), *Azotobacter* (30±10%), *Paenibacillus polymyxa* (10±5%), *Enterococcus* (10±5%), *Lactobacillus* (10±5%), macro- and microelements, biologically active products of bacterial vital activity: nicotinic and pantothenic acids, pyridoxine biotin, heteroauxins, gibberellins, cytokinins, enzymes, fungicidal and bactericidal substances, etc. "Azogran A" is a nanocomposite complex bacterial preparation of highly active strains of nitrogen-fixing bacteria *Azotobacter vinelandii* IMV B7076 and phosphate-immobilizing bacteria *Bacillus subtilis* IMV B-7023 with bentonite nanoparticles.

Its predecessor was early potatoes. Lavender seedlings were planted manually in the autumn of 2017 according to the experiment scheme, the row spacing was 50 cm wide. The area of plant nutrition was 1x0.6 m. the total area of the experimental site was 1411 m^2. The planting area of the plot was 35 m^2. The area of the accounting plot was 25 m^2. The repetition was threefold, and the placement of sections was randomized. Mowing of the ground mass was carried out during the mass flowering phase and dried under shelter. Typical methods for crop production were used in the research. Statistical data processing was performed by the dispersive analysis method.

RESULTS

Climatic conditions during the study period were favourable for the vegetation of *L. angustifolia*. In particular, fears of tissue freezing or plant death in autumn and winter did not come true. In terms of moisture availability, the last years of observation were optimal, 2018 was dry, and 2019 was medium-dry. However, every year there was a drying of the upper soil layers, which began in the second half of April with an increase in temperature and a decrease in air humidity. To maintain favourable conditions for lavender, drip irrigation systems were launched in late April.

A lavender awakening occurred when the average daily air temperature remained at least 10…14°C for some time. Depending on the year, this was around March-April. The awakening of lavender in Ukraine occurs in March-April, when the average daily air temperature steadily passes through 10… 14°C. The full spring of 2019 year came very early, in the first days of March, periods of warm weather were often replaced by rain, but all this happened against the background of positive air temperatures. The resumption of lavender vegetation was observed on March 30. Spring 2020 also came early, but in the second half of March, frosts of varying intensity were noted: in the air they were from -0.4 down to -4.0°C; and at a height of 2 cm from the soil surface they were from -3 down to -8°C. Restoration of vegetation of lavender plants was recorded on April 10. Spring 2021 was characterized as late, cold, and prolonged, the awakening of lavender plants was recorded on April 17. The duration of the vegetative stage of development in 2- and 3-year-old plants was different and amounted to 64-66 days in 2020 and 55-57 days in 2021, respectively (Table 1).

Table 1. *Phenological features of Lavandula angustifolia plants depending on the experimental variants in the first, second and third years of vegetation*

Bio-fertilizer treatment	Date of phenophase onset					
	Restoration of vegetation	Complete regrowth	Budding	Beginning of flowering	Mass flowering	End of flowering
15.10.2018 – planting of seedlings						
2019						
Moisture level (B) – 80-70-70% MHC						
1. Control	30.III	1.VI	21.VI	30.VI	15.VII	27.VII
2. "Biocomplex BTU"	30.III	1.VI	21.VI	28.VI	12.VII	22.VII
3. "Azogran A"	30.III	1.VI	21.VI	28.VI	12.VII	22.VII
Moisture level (B) – 90-80-70% MHC						
1. Control	30.III	4.VI	23.VI	3.VII	18.VII	30.VII
2. "Biocomplex BTU"	30.III	4.VI	23.VI	1.VII	14.VII	27.VII
3. "Azogran A"	30.III	4.VI	23.VI	1.VII	14.VII	27.VII
2020						
Moisture level (B) – 80-70-70% MHC						
1. Control	10.IV	5.VI	14.VI	26.VI	4.VII	25.VII
2. "Biocomplex BTU"	10.IV	5.VI	14.VI	24.VI	1.VII	21.VII
3. "Azogran A"	10.IV	5.VI	14.VI	24.VI	1.VII	21.VII
Moisture level (B) – 90-80-70% MHC						
1. Control	10.IV	7.VI	16.VI	28.VI	6.VII	25.VII
2. "Biocomplex BTU"	10.IV	7.VI	16.VI	26.VI	4.VII	23.VII
3. "Azogran A"	10.IV	7.VI	16.VI	26.VI	4.VII	23.VII
2021						
Moisture level (B) – 80-70-70% MHC						
1. Control	17.IV	2.VI	10.VI	20.VI	8.VII	27.VII
2. "Biocomplex BTU"	17.IV	2.VI	10.VI	21.VI	5.VII	25.VII
3. "Azogran A"	17.IV	2.VI	10.VI	21.VI	5.VII	25.VII
Moisture level (B) – 90-80-70% MHC						
1. Control	17.IV	2.VI	12.VI	26.VI	10.VII	30.VII
2. "Biocomplex BTU"	17.IV	2.VI	12.VI	27.VI	7.VII	27.VII
3. "Azogran A"	17.IV	2.VI	12.VI	27.VI	7.VII	27.VII

Source: *compiled by the authors*

The beginning of the vegetation phase did not occur simultaneously in different years of vegetation. For the crops of the second and third years of life (2020-2021) it was noted in the middle of June (from 10.06 to 16.06). Plants of the first year (2019) entered this phase an average of 5-9 days later (for different options – from 21.06 to 23.06). A similar trend was observed for other phases of ontogeny, such as the beginning of flowering, mass flowering, and the end of flowering. Some lag observed in biennial plants was attributed to the physiological stress caused by their first wintering, as well as the lack of a developed adaptive mechanism in young plants.

All lavender plants had a long flowering period. For annual plants in 2019, it was 25-27 days, and for two-year ones it was 28-30 days, for three-year ones it was 30-37 days. It was determined that the duration of the life cycle (from the resumption of vegetation to the phase of mowing ripeness) of *Lavandula angustifolia* in the conditions of the Southern Steppe of Ukraine was

115-123 days in 2019, 103-107 days in 2020, and 98-103 days in 2021.

The research established that irrigation regimes somewhat affected the passage of phenophases by lavender plants: in areas with an irrigation regime of 80-70-70% MHC, plants began flowering 2-3 days earlier compared to the irrigation regime of 90-80-70% MHC. When plants were treated in the budding phase with bio-fertilizers, flowering was reduced by 2-5 days.

On average, for 2019-2021, the growing season of lavender plants under the irrigation regime of 80-70-70% MHC was 109 days, and under the irrigation regime of 90-80-70% MHC, the growing season of plants was reduced by four days (105 days). The shortest growing season was observed under the irrigation regime of 80-70-70% MHC with the treatment of plants with biofertilizers as it was 103 days.

Data analysis of Table 2 shows how significant the influence of weather conditions of a particular growing season is on the timing of the onset of the main phenophases of plant development. Complete regrowth of lavender is determined by the average sum of active positive temperatures above +10°C in the range from 779 up to 1080 degrees, for the onset of the budding phase, the required amount should approach the values of 966-1478. Mass flowering occurs when the sum of active temperatures exceeds 1400 degrees and approaches 2300°C.

Table 2. *The sum of positive active temperatures on an accrual basis (∑t>10), which is necessary for development of Lavandula angustifolia in the southern steppe of Ukraine, °C*

Years	Phase		
	Complete regrowth	Budding	Mass flowering
Moisture level (B) – 80-70-70% MHC			
2019	955	1428	1968
2020	779	966	1404
2021	1080	1219	2298
Moisture level (B) – 90-80-70% MHC			
2019	1020	1478	2020
2020	818	1010	1467
2021	1080	1257	2327
Mean value	955	1226	1914
V, %	13.7	17.1	20. 8

Source: *compiled by the authors*

Another factor that illustrates the biological features of Lavandula angustifolia plant development is the characteristic changes in its biometric characteristics. As the total results show, the influence of biological fertilizer and moisture levels is clearly traced (Table 3).

The use of bio-fertilizers accelerates biochemical processes, enhances the growth and development of plants. As such, observations of the dynamics of the height of lavender plants showed that starting from the budding phase, the positive effect of the studied fertilizers and drip irrigation can be traced. In 2019, in the first year, lavender developed slowly, plants reached 24.9-38.2 cm in height, depending on the treatment of the experiment. The second-year plants grew up to 36.2-45.4 cm, in the third year it increased to 44.4-57.3 cm. Average for irrigation regimes for 2019-2021 in the control, this indicator was 37.9 cm, when treated with "Biocomplex BTU" it was 43.8 cm, with "Azogran A" it was 41.2 cm, that is, the use of bacterial fertilizers increased the height of plants by 9-16% compared to the control. Optimization of the irrigation regime helped to increase the height of plants by 15-18% (Table 3).

Table 3. *Effect of bio-fertilizers on indices of some quantitative traits of lavender plants (2019-2021)*

Bio-fertilizers (A)	Plant height, cm	Bush diameter, cm	Number of side shoots, PCs.		Inflorescence length, cm
			in total	including with inflorescences	
Moisture level (B) – 80-70-70 % MHC					
1. Control	35.2	28.0	30.3	26.7	4.9
2. "Biocomplex BTU"	40.5	34.3	41.4	37.7	6.6

Table 3, Continued

Bio-fertilizers (A)	Plant height, cm	Bush diameter, cm	Number of side shoots, PCs.		Inflorescence length, cm
			in total	including with inflorescences	
3. "Azogran A"	37.7	33.6	37.7	34.7	5.6
Moisture level (B) – 90-80-70% MHC					
1. Control	40.5	32.1	34.1	31.0	5.9
2. "Biocomplex BTU"	47.0	40.1	47.8	40.3	7.3
3. "Azogran A"	44.6	36.9	38.5	35.7	6.5
Mean value	40.9	34.2	38.3	34.4	6.1
Range (max–min)	47.0-35.2	40.1-28.0	47.8-30.3	40.3-26.7	7.3-4.9
S	4. 6	4. 4	6. 0	6. 2	0. 9
V, %	11.5	13.0	15.7	16.8	13.8

Source: *compiled by the authors*

In the formation of the habit of a lavender bush, there is a direct relationship between its width and the number of stems. The wider the bush, the more branches it forms. So, in the third year of vegetation, when treating plants with bacterial fertilizers, the Stepova variety formed the habit of a bush with a width of more than 45 cm, which is by 22-26% higher than this indicator in the control. At the same time, the number of stems per plant ranged from 1.2-1.5 times higher than in the control.

On average, from 2019 to 2021, the diameter of the lavender bushes ranged from 28.0 to 40.1 cm, depending on the experimental variant, and the total number of branches per plant ranged from 26.7 to 43.3, 90% of these branches formed inflorescences. In terms of the range of variation, the latter indicator was less stable than the others as the coefficient of variation was 16.8%.

Due to the top dressing of plants with bio-fertilizers, the best development of lavender plants was observed, in particular, the total number of stems increased by 4-14 PCs per plant, including the number of flowering stems increased by 4.7-11.0 PCs per plant, inflorescence length increased by 0.5-1.7 cm, plant height increased by 2.5-6.5 cm, bush diameter increased by 4.8-8.0 cm in comparison with a control sample, which was not cultivated. This was most noticeable when the moisture level of lavender plantings was at 90-80-70% of MHC. In this variant, when treating plants with bio-fertilizer "Biocomplex BTU", there were 47.8 stems on one plant, including 40.3 PCs with flowers. The height of the plants was 47.0 cm, the diameter of the bush was 40.1 cm, the length of the inflorescence was 7.3 cm (average for 2019-2021 years).

The yield of dry flower raw materials *Lavandula angustifolia* in the first year of vegetation was low as 11.6-18.3 c/ha depending on the experimental variants, in 2020 the plants showed more intensive development and higher productivity, resulting in a yield increase of 1.6 to 1.8 times. In the third year of lavender cultivation, the yield of flowers was maximum as 43.7-57.1 c/ha, depending on the experimental variants, which was 3.1-3.8 times higher compared to the first year of vegetation.

On average, from 2019 to 2021, when growing *Lavandula angustifolia* at a moisture level of 80-70-70% MHC, the absolute dry mass weight was 28.2 c/ha, and if the regime of 90-80-70% MHC the yield was observed 31.3 c/ha (Table 4). So, comparing irrigation modes with each other, it should be noted that the irrigation mode of 90-80-70% MHC in the technology of growing lavender was more effective, although lavender belonged to plants that were unpretentious to moisture.

Table 4. *Influence of biopreparations and irrigation regimes on plant productivity Lavandula angustifolia Mill. (2019-2021)*

Bio-fertilizers (A)	Yield dry weight, c/ha	Essential oil content, %	Conditional oil yield, kg/ha	Deviation from control, ± kg/ha
Moisture level (B) – 80-70-70% MHC				
1. Control	25.4	1.52	38.56	-
2. "Biocomplex BTU"	30.3	1.68	50.95	+12.39
3. "Azogran A"	28.8	1.65	47.58	+9.02
Mean value	28.2	1.62	45.69	+10.71
Moisture level (B) – 90-80-70% MHC				
1. Control	26.8	1.41	37.83	-

Table 4, Continued

Bio-fertilizers (A)	Yield dry weight, c/ha	Essential oil content, %	Conditional oil yield, kg/ha	Deviation from control, ± kg/ha
2. "Biocomplex BTU"	34.3	1.60	54.83	+17.00
3. "Azogran A"	32.8	1.52	49.86	+12.03
Mean value	31.3	1.51	47.50	+14.52
LSD_{05} for yield on Factors: A –1.15; B – 0.95; AB – 1.64.				

Source: *compiled by the authors*

The period of intensive growth and, accordingly, accumulation of biomass occurs in Lavender in the month of June. Therefore, until then, it is necessary to create the most favourable conditions for the growth and development of plants, including planning such an agrotechnical event as top dressing. In our studies, positive results were obtained as a result of double foliar top dressing with "Azogran A" and "Biocomplex BTU" bio-fertilizers at a dose of 2 l/ha (with an interval of 14 days) in the branching and budding phase of plants. Spraying with bacterial fertilizers increased the yield of *Lavandula angustifolia* flower mass: the yield increase was 3.5-7.5 c/ha compared to the untreated control. The highest yield of 34.3 c/ha was obtained in the variant where the fertilizer "Biocomplex BTU" was applied while observing the irrigation regime of 90-80-70% MHC.

DISCUSSION

Complex research on the effect of drip irrigation and stimulation of *L. angustifolia* plants of Stepova variety under conditions of the Southern Steppe of Ukraine was conducted. The results showed that the most effective was the complex effect of irrigation and treatment, and in the variant where irrigation was more intensive.

The benefits of irrigation in the South of Ukraine have been described both in the context of steppe land exploitation during climate change (Vozhegova *et al.,* 2021) and in the results of studies on the increase in oilseed yields, where flax that was irrigated produced more than 1.7 times more oil than the control group. In contrast, in the absence of moisture, seeds cannot germinate, and plant growth, as well as photosynthesis, slows down, leading to the loss of part or even the entire crop (Szekely-Varga *et al.,* 2020, Zia *et al.,* 2021).

The effects of drought can be alleviated with the help of various substances: chemical elements, organic and inorganic compounds, biologically active substances, etc., but also to reduce plant stress, biological products containing endosymbiotic or rhizosphere bacteria or their metabolites are increasingly used. They penetrate plant tissues and adjust the plant's response from within so that it can function more efficiently and respond to environmental changes. Such products were used in this study (Vozhegova *et al.,* 2020).

According to the results of experimental studies, plants in all variants of the experiment, on average for three years of research, showed an absolutely expected result in terms of oil content: as the higher it was the productivity of plants, as the higher it was the yield of essential oil as a percentage. The control variant produced raw materials with an essential oil content of 1.47% without bio-fertilizer treatment, while the application of "Azogran A" increased the content to 1.59% (average for irrigation modes). Furthermore, the use of "Biocomplex BTU" improved the content by an additional 0.05-0.17%. The highest content of essential oil was found in *L. angustifolia* plants grown under irrigation following the 80-70-70% GHX method and with "Biocomplex BTU", where it was 1.68 % (Rennenberg, 2018).

The same trend continued for the release of essential oil from dry bio-raw materials. On average, for 2019-2021, plants in the control group had an average conditional essential oil yield of 38.19 kg/ha. This indicator in the variant with top dressing "Biocomplex BTU" was the highest for both irrigation modes. Thus, at a moisture level of 80-70-70% MHC, it was 50.95 kg/ha, and at 90-80-70% MHC it was 54.83 kg/ha. The conditional yield of essential oil from plants treated with "Azogran A" was higher than the control and reached 47.58 up to 49.86 kg/ha. Furthermore, heterogeneity of yield indicators depending on the year of vegetation was noted. The yield was about 1.5-2 times higher in the second year and 3-4 times higher in the third year, which is consistent with the cultivation of lavender in the Mediterranean region (Barut *et al.*, 2022). Other studies have also explored finding the optimal irrigation method.

One of the similar studies (Manushkina, 2019) also studied the effect of 2 biological products – Radostym and Stimpo – on the development of three varieties of *L. angustifolia* – Vdala, Syneva, and Stepova – for 3 years. Additional irrigation was not carried out. As a result, as in the present study, the relative mass fraction of essential oil after treatment did not change but varied depending on the variety, and the actual yield increased significantly compared to the control. In addition, the variety Stepnaya under the treatment with Stimpo gave a significantly higher average oil yield (137.36 kg/ha) than under the study of the effect of "Biocomplex BTU", which showed the best result in this study (54.83 kg/ha).

Among similar studies, the effect of inoculation with *Bacillus thuringiensiss* strain IAM 12077 of plants related to the species *L. dentata* studied in this work showed an increase in the absorption and assimilation of microelements by plants and an increase in green mass by more than 65.8%. A doubling in the activity of arbuscular mycorrhiza formation was also observed,

which increased the absorption area and, accordingly, the availability of water, which is one of the explanations for the reduction of drought stress in plants, which was also observed in the treatment with bacterial products in this study. At the same time, inoculation with *B. thuringiensiss* did not affect the composition of endophytic and rhizobial microorganism's characteristic of this lavender species in the study area (Armada *et al.,* 2018).

An interesting study was conducted to determine the effectiveness of using biological products based on fungi prone to the formation of arbuscular mycorrhiza (AMF) in the cultivation of lavender. Thus, *L. angustifolia* plants treated with biological products showed an increase in green mass of about 17-20% compared to the untreated control. An increase in leaf surface area and flowering intensity was also observed. Also, most fungi induced an increase in the synthesis of chlorophylls *a* and *b*, as well as some carotenoids. AMF-S and AMF-C showed the best results (Popescu & Popescu, 2022). Similar results have been obtained in other studies (Binet *et al.*, 2020, Pirsarandib *et al.,* 2022), in particular, a positive effect on the composition of essential oils during AMF treatment was found (Akachoud *et al.,* 2022). This indicates the feasibility of conducting research in this area to increase the efficiency of lavender cultivation in the Southern Steppe of Ukraine and reduce the impact of drought on plant growth and development and the quality content of essential oils.

Another interesting aspect was the issue of frost resistance of lavender. Depending on the variety, the proportion of surviving plants by the third year increased by 4-6% and ranged from 88% to 97%. This is another aspect that indicates the suitability of lavender for cultivation in these conditions (Manushkina, 2019).

The question remains whether the studied system of irrigation and application of products harms the production and composition of essential oils. After all, an important point that has not yet been studied much is the assessment of the quality of essential oils obtained from varieties grown in the Southern Steppes zone and their compliance with international standards.

A rather large-scale study conducted at the Rice Institute of the National Academy of Sciences of Ukraine was devoted to the analysis of the composition of essential oils of 13 varieties of *L. angustifolia,* conducted during 2016-2018. All the studied varieties were obtained as a result of selection in domestic institutes for cultivation in Ukraine, half of them is already grown for commercial purposes. The data obtained showed that none of the essential oils analysed during the three years of work met the quality criteria of the European Pharmacopoeia. At the same time, the essential oils of one of the varieties can be used in pharmacy, but only for purposes for which the α-terpinol content is not critical, 6 more are suitable for use in perfumery and related industries, and the authors recommend using the rest in landscaping and for decorative purposes. It is important to note that the "Stepova" variety was not considered in this study (Pokajewicz *et al.,* 2021). There is a study confirming a slight improvement in lavender essential oils under irrigation conditions, but the observed increases are rather minor (Sałata *et al.,* 2020).

That is, there are prerequisites for further research aimed not at studying the possibility of growing lavender in the Southern Steppe zone of Ukraine, but at determining the composition of essential oils obtained during cultivation with the involvement of various factors and the prospects for further improving their quality and compliance with internationally recognized standards.

CONCLUSIONS

Based on the conducted experimental studies, it was established that lavender plants of the third year of cultivation were characterized in the conditions of the Southern steppe of Ukraine by the duration of the growing season (from the resumption of vegetation to mowing ripeness) from 105 up to 111 days. The shortest growing season was observed under the irrigation regime of 80-70-70% MHC with the treatment of plants with bio-fertilizers as it was 103 days. The main factor determining the beginning of the development of lavender plants is the air temperature. Accelerated plant development begins at an average daily air temperature of +10°C and above. Mass flowering occurs when the sum of active temperatures passes through 1400°C and approaches 2300°C.

With the drip method of irrigation and top-dressing plants with bio-fertilizers, optimal conditions were created for the growth and development of *Lavandula angustifolia*. The most developed plants were recorded when growing plants with the maintenance of a moisture level of 90-80-70% MHC during the period of full regrowth-flowering with the treatment of crops in the budding phase "Biocomplex BTU". In this variant, the largest number of stems per plant was counted (47.8 PCs, including with flowers – 40.3 PCs), the height of the plants was 47.0 cm, the diameter of the bush was 40.1 cm, the length of the inflorescence was 7.3 cm (average for 2019-2021). This variant provided a dry raw material yield of 34.3 c/ha and an essential oil yield of 54.83 kg/ha.

Prospects for further research are to study the morphological and biological features, adaptive properties of lavender plants of new varieties during different years of cultivation and optimize the technology of growing crops in irrigated and non-irrigated conditions of the southern steppe zone of Ukraine.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Особливості росту і розвитку лаванди вузьколистої при вирощуванні в умовах краплинного зрошення в Південному Степу України

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Анотація. В умовах зміни клімату сільське господарство має реагувати на нові виклики - одним з них є пошук та адаптація нових сортів рослин у регіонах, де вони не вирощувалися в промислових масштабах. Мета роботи – дослідити вплив біологічного обробітку на ріст і розвиток *Lavandula angustifolia* за різних способів зрошення для підвищення ефективності її використання як промислової культури в зоні Південного Степу України. Вид *L. angustifolia* має перш за все значення як ефіроолійна культура і використовується в приготуванні продуктів харчування та напоїв, парфумерії, медицині, фармації, косметиці, промисловості, для очищення повітря від твердих частинок в міських насадженнях, як медонос і в декоративних цілях. У дослідженнях. Використовували рандомізовану схему блоків з факторним розміщенням 2х2 з двома бактеріальними препаратами («Азогран А» і «Біокомплекс БТУ») і двома рівнями вологості (80-70-70 % НВВ і 90-80-70 % НВВ) у триразовій повторності. Рослини 1-го, 2-го і 3-го року вегетації аналізували за кількома факторами, такими як початок і кінець вегетативної фази, початок фази бутонізації, період цвітіння, а також співвідношення цих показників з кількістю тепла, отриманого за вегетаційний період. Також оцінювали фенотипові ознаки, врожайність зеленої та сухої маси, відсоток ефірної олії та умовну врожайність за всіх досліджуваних умов. Загалом встановлено, що найбільший стимулюючий вплив на ріст *L. angustifolia* виявлено при вирощуванні лаванди за режимом зрошення 90-80-70 % НВВ з дворазовим підживленням рослин у фазу бутонізації «Біокомплексом БТУ» – ці рослини були найбільш розвиненими і мали помітно вищі показники сухої маси та теоретичної врожайності. Таким чином, контроль зрошення та обробка біопрепаратами робить перспективу промислового вирощування лаванди в умовах Південного Степу України більш доступною

Ключові слова: лаванда; рівень вологості; біодобрива; урожайність; вміст ефірної олії

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 92-100

UDC 633.2
DOI: 10.48077/scihor3.2023.92

Economic analysis of spring soft wheat seed production in North Kazakhstan region

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Article's History:
Received: 20.01.2023
Revised: 20.03.2023
Accepted: 13.04.2023

Suggested Citation:
Mukhametzhanov, A., & Zholaman, R. (2023). Economic analysis of spring soft wheat seed production in North Kazakhstan region. *Scientific Horizons*, 26(3), 92-100.

Abstract. In today's reality, the agriculture plays a very important role not only in achievement of sustainable economic development, but also in solving the global problem of hunger and ensuring the state independence from external food supplies. All above makes this industry an important factor for consideration in many countries. In this paper, the authors placed the emphasis on the economic analysis of individual crops in the industry, namely spring wheat in the North Kazakhstan region. Thus, the purpose of the work was to calculate the economic feasibility of growing this crop. The analysis was the main method during writing process. Besides, statistical research methods played an important role, as well as comparison, modelling, induction, and other methods. The article demonstrated that the cost of elite seed production is much higher than the cost of commercial grain crops per hectare. At the same time, the seed production helps to increase profitability per hectare; however, it can be observed the opposite trend in terms of efficiency per unit of capital invested, which was higher for producers of commercial grains than seeds. With that, the specifics of seed production impose higher requirements on agricultural producers in terms of energy efficiency, namely the provision of machine-tractor fleet and fleet of agricultural machinery, storage facilities, as well as equipment for cleaning grain. The paper draws conclusions about the decision for entrepreneurs to invest in the production of one or another type of product. The article brings new knowledge for understanding the peculiarities of economic development in Kazakhstan, especially in regional aspect and sector specifics

Keywords: Kazakhstan's economy; regional development; agriculture; entrepreneurship; investment

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INTRODUCTION

The relevance of this work is about the expert assessment formed on the profitability of several types of grain production in the North Kazakhstan region and making recommendations in the case of investment in this type of business. The agriculture plays an important role in the development of the state both economically and strategically (Zhang & Diao, 2020; Steinke *et al.,* 2019). There are several reasons for this. First, the agriculture in the vast majority of countries occupies a large part of the country's GDP (gross domestic product) (Schierhorn *et al.,* 2020; Meijerink & Roza, 2007); second, any state requires producing a certain amount of goods in this sector on its own in case of a crisis in the world economic system or other force major situations. In addition, the agriculture plays an important role for regional development because of its ability to provide jobs even in the poorest parts of the country, as well as to develop local infrastructure (Loizou *et al.,* 2019; Wang *et al.,* 2022).

In Kazakhstan, as a country that is essentially developing, the agriculture also plays a significant role (Petrick & Pomfret, 2016). However, given the high role of regional development in the country (Ursulenko, 2010), the authors decided to focus on only one region, namely North Kazakhstan. Since the main component of the products manufactured in the region is spring wheat seeds, the authors conducted an economic analysis of the feasibility of the manufacture of these products compared to another option for investing funds. According to the authors, such specialization will help to study certain features of the agricultural management in the region in more detail and to find ways to improve it.

A review of the literature has demonstrated that in recent years a number of papers have been published regarding the productivity and yield of wheat in the conditions of North Kazakhstan region. The number of papers regarding the economic analysis of the manufacturing process is limited not only in relation to North Kazakhstan region but also for the Republic of Kazakhstan as a whole. Nevertheless, it can be highlighted some of the works that came in handy during the study. First of all, the work of scientists who have studied agriculture in the Republic of Kazakhstan as a whole, such as F. Shulenbaeva *et al.* (2019), who examined the investment attractiveness of the industry and described possible scenarios for its future development. The works of importance featured the opinions of the scientists focused their attention on the development of the agriculture in the North Kazakhstan region. For example, the work of A.V. Shurr (2014) was helpful, which described in detail the state of the agriculture in the region and its individual areas. Another important observation was the article K. Abdullaev *et al.* (2020) who examined the possibility of changes in the agriculture in the North Kazakhstan region due to a more active use of some innovative technologies.

Therefore, the purpose of this article was to analyse the production of spring soft wheat seeds in the North Kazakhstan region and to assess the rationality of growing these products in the region. The object of the study was the costs and income for the production of this type of product, the process of its manufacture and the agricultural sector of Kazakhstan as a whole.

MATERIALS AND METHODS

As part of the work, the main objective was to explore the economic rationality of the production of the spring wheat seed in the North Kazakhstan region. However, examining the feasibility of any production process is quite difficult without being able to compare several options for investment. Therefore, in this work authors decided to compare the level of economic benefits from the production of commercial grain and elite spring wheat seeds, which helped to form quality conclusions about the feasibility of the manufacture of the studied products. In order to determine what type of production is the most profitable, authors chose two main indicators: profitability per unit area and the ratio of profit to cost. The first is calculation of the net profit (i.e., income minus all expenses) from the production of a certain type of wheat from one hectare of territory and the second is the ratio of net profit to the company's expenses.

The works of other scholars were important sources for compiling this paper. In addition, some components of the regulatory framework were used, in particular the Order of the Acting Minister of Agriculture of the Republic of Kazakhstan No. 4-2/266 "On approval of the Rules for certification of producers of original and elite seeds, seeds of the first, second and third reproductions, sellers of seeds" (2015). In addition, the work also uses statistical data sources, where worth mentioning is the Kazakh Scientific Research Institute for Economics of Agro-Industrial Complex and Rural Territories Development (2022), the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2022), local executive bodies of North Kazakhstan region, as well as data on the seed producers of North Kazakhstan region.

The main methods used in writing the paper were theoretical methods. Among the first was the analysis, which justified the amount of comparable and analysed data on the economic production of wheat in the North Kazakhstan region. In addition, authors used the comparison, with the help of which it was possible to better study the economic feasibility of seed production. The modelling played an important role in examining the economic benefits of seed and commercial grain production. In addition, the authors actively used the method of induction. Moreover, the work used statistical and economic analysis methods, including functional-value method, which evaluated the production of one

of the types of wheat in Kazakhstan. The entire research process can be divided into several stages. At the first stage, a general overview of agriculture was conducted, where the main goal was to investigate the economic feasibility of agriculture in the Republic of Kazakhstan and, in particular, in its individual regions, including the North Kazakhstan region for 2010-2021. In the second part, the authors conducted a direct analysis of the economic production of spring wheat in the North Kazakhstan region in terms of comparison between the manufacture of commercial grain and elite seeds and evaluation of the yield per unit area or invested funds.

RESULTS

In general, the agriculture is one of the most important sectors of Kazakhstan's economy: in the mid-10s of the XXI century, it was even the most profitable of other economic activities (Shurr, 2014). This is also confirmed by its significant share in the production of the country's GDP, as shown in Figure 1.

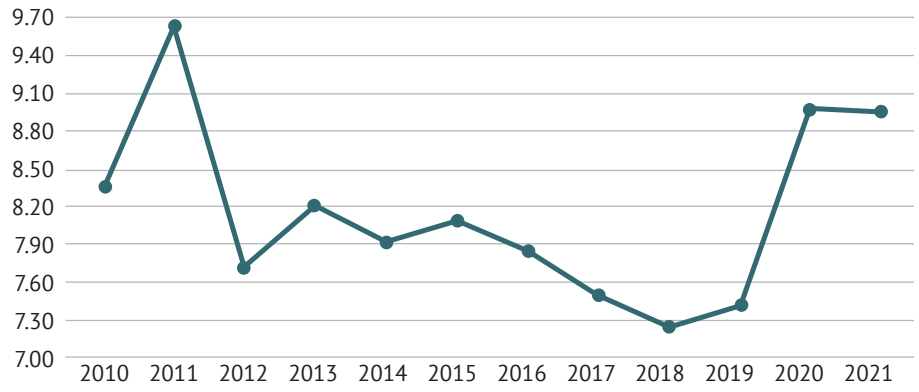

Figure 1. *Share of GDP produced in the agriculture in the total GDP of Kazakhstan in 2010-2021, %*
Source: *compiled by the authors based on data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2022)*

As can be seen in Figure 1, the share of the agriculture in Kazakhstan's GDP has remained at about the same level by 7-9% year after year. This part of the agricultural sector in the country's GDP is quite large by comparison with other countries: for example, the most highly developed countries the agricultural sector may have only 1-2% of GDP (Karatayev *et al.,* 2022). In order to examine the development of this industry in the country, authors constructed Figure 2, which describes the volume of production in the industry and the rate of its change.

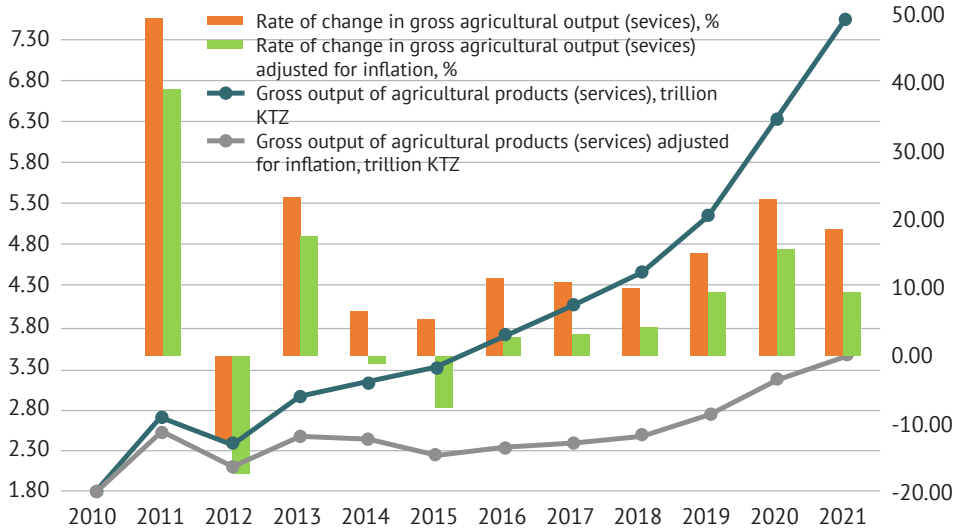

Figure 2. *Volume and rate of change in gross output (services) of the agriculture in Kazakhstan in 2010-2021 with and without inflation*
Source: *compiled by the authors based on data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2022); Inflation in Kazakhstan (2022)*

As can be seen in Figure 2, even taking into account inflation, the level of the agricultural development in the Republic of Kazakhstan has improved significantly, as evidenced by the significant growth rates of output of the industry: so, considering inflation this level has increased by about 90% over the past 11 years. In addition, fluctuations in the agricultural output are much lower than the country's total GDP. An assessment should also be made of the volume and the rate of change in gross output in the North Kazakhstan region, as this work evaluates the production of seeds notably from this region. This data is presented in Figure 3.

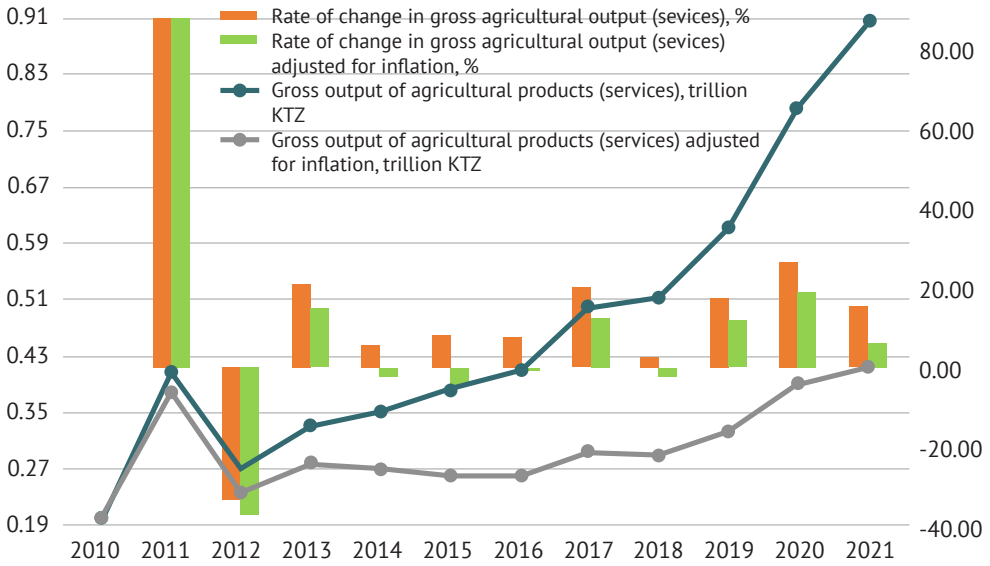

Figure 3. *Volume and rate of change in gross output (services) of the agriculture in Kazakhstan in 2010-2021 with and without inflation*

Source: *compiled by the authors based on data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2022); Inflation in Kazakhstan (2022)*

The territory of the North-Kazakhstan region also saw a significant increase in the agricultural output over the past 11 years. This was the reason to achieve a growth rate for this period of 109%, and also led to the fact that regional share in the total production by regions has reached a level of 12% (with 10% in 2010). Here it is worth noting that wheat is one of the main crops of the Republic of Kazakhstan (Petrick and Gotz, 2019; Feher and Fieldsend, 2019). The country produces about 12 million tons of wheat each year and exports more than 7 million tons; it is also one of the largest producers and exporters of soft wheat. The main regions of Kazakhstan where wheat is cultivated are the North Kazakhstan, Kostanay and Akmola regions. They account for 9.1 million hectares or 78% of the sown area and their share in the gross harvest of wheat is 76% at 10.1 million tons. North-Kazakhstan region shares with Turkestan region the second place among 14 regions by contribution to gross output of the agriculture in the republic. At the same moment, the share of crop production accounts for 75% of all agricultural production in the region. The dominant crop is wheat, which occupies half of the sown area or more than 2 million hectares annually.

In determining the economic return of the manufacture of one or another product, a comparative economic analysis is inevitable (Williamson, 1991; Moor, 1971). This paper compares the production of elite seed and commercial grain of spring soft wheat. The seeds make 10-15% of total variable expenses in the cost structure of wheat production. At the same time the seed quality, and namely their responsiveness to means of intensification, is a key factor that can significantly increase yields (Table 1). The expenses on commercial grain production are based on the direct costs per 1 hectare of sowing in 2020, calculated by the Kazakh Scientific Research Institute for Economics of Agro-Industrial Complex and Rural Territories Development (2022).

Table 1. *Structure of expenses for the production of elite seeds and commercial grain of soft wheat, KZT*

No.	Name of items	Grains	Seeds
1	Remuneration of labour	3366.0	26168
2	Seeds	12750	10263
3	Fertilizers and pesticides	18548	13558

Table 1, Continued

No.	Name of items	Grains	Seeds
4	Current repairs, spare parts	714	7463
5	Amortisation	1431	16172
6	Fuels and lubricants	5950	9715
7	Other major expenses	6070	16649
	Total expenses	48829	97990

Source: *compiled by the authors based on the data of Kazakh Scientific Research Institute for Economics of Agro-Industrial Complex and Rural Territories Development (2022)*

Table 1 shows that the production cost of elite seed demonstrate two-fold increase of similar costs per 1 hectare of commercial grain crops. It should be noted that such items as amortization, current repairs and expenses on the seeds exceeds the cost of commercial grain by more than 10 times, and on wages by almost 9 times. The agricultural producers spend more in the production of commercial grain only on two items, in particular on the cost of seeds and the purchase of fertilizers and plant protection products. However, this still does not mean that the production of grain is more profitable than seed, since the data in Table 1 do not take into account the income the companies receive from the sale of these products, which will also be analysed below. Possible reasons for such significant discrepancy in costs are as follows. Unlike ordinary producers of agricultural products, the elite seed farms have better energy efficiency due to the specifics of production, which includes the need in agricultural machinery, seed-cleaning equipment, specialized threshing floors and storage facilities necessary to ensure a set of works on the production of the planned volume of elite seeds (Order of the …, 2015).

On the other hand, the elite seed farms have lower seed expenses because they use crops from their own breeding facilities. Since the manufacturers use super elite seeds to produce elite seeds, their higher yields and resistance to plant diseases have positive impact on the cost of plant protection products. In addition, due to the greater energy efficiency compared to the average grain producers, the seed producers have more opportunities for using a full circle of necessary agro-technical measures. This increases costs for fuels and lubricants, payroll, and other expenses. In addition to information on expenditures, the survey of elite seed farms also provided data regarding the average yield of seed sown crops. The data show that the yield of seed producers significantly exceeds the regional average. Therefore, if in 2020 the yield of soft wheat in the North Kazakhstan region was 14.4 c/ha, it was at least 20.0 c/ha at the sown areas of elite seed farms.

Table 2 shows a comparative analysis of income and costs for the cultivation of 1 hectare of commercial grain and elite seeds of spring soft wheat.

Table 2. *Comparative analysis of income and costs for the cultivation of 1 hectare of commercial grain and elite seeds of spring soft wheat*

No.	Name of parameter	Calculation	Measurement unit	Producer of market grain	Elite seed growing farm
1	Yields	x	c/ha	14.4	20.0
2	Grain yield	x	c/ha	14.4	10.0
3	Seed yield	x	c/ha	0	10.0
4	Price per unit	x	KZT	8 000 (grain)	14000 (elite seeds)
5	Total revenue	((2*4.1) + (3*4.2))	KZT/ha	115200	220000
6	Total expense	(data from Table 1)	KZT/ha	48829	97990
7	Profit (income-expense)	(5-6)	KZT	66371	122010
8	Benefit-cost ratio	(7/6)		1.36	1.25

Note: *x – the cell is not filled*
Source: *compiled by the authors based on the data of Kazakh Scientific Research Institute for Economics of Agro-Industrial Complex and Rural Territories Development (2022)*

As can be seen from Table 2, the value of the profit indicator of the elite seed farm in relation to the producer of grain is higher by 84%, with a twofold increase in costs. At the same moment, it is necessary to note a number of specific features common for seed producers. Nevertheless, the benefit-cost ratio of commercial grain

production is higher by about 11% than that of seed: thus, a unit of capital invested by the entrepreneur in this type of production will bring a relatively large return.

First, as mentioned above, is the higher yield per one hectare of area in elite seed farms: 20.0 cwt/ha instead of 14.4 cwt/ha. At the same time, authors note that part of the resulting crop usually does not meet the requirements of the seed culture (moisture, purity, etc.) and is sold as commercial grain. This paper assumes that at least 50% of the crop is sold as commercial grain. At the same time, according to the requirements for elite seed farms, the share of seed production in the total sown area should be at least 25% and the share of elite seed production in the total volume of production should also be minimum of 25% (Order of the…, 2015). Second, the higher cost of 1 quintal of elite seeds compared with 1 quintal of commercial grain (14000 KZT vs. 8000 KZT). The authors note that the main volume of seeds can be sold not in the autumn at the end of the harvesting campaign, but rather in the spring of the following year in preparation for the sowing season. This fact implies the delayed nature of the calculated profit. Third, elite seed farms need to produce not just seeds that meet the characteristics of the elite culture, the seeds must also be in demand among agricultural producers of seed varieties, and this imposes high demands on the processes of variety renewal and variety change.

DISCUSSION

In the article, the authors assess the current state of agriculture in the Republic of Kazakhstan. As mentioned by Kühling *et al.* (2017), the main factors that affect the development of agriculture in the country are climatic conditions, financial support from the state, global pricing, and investment attractiveness of the industry. Thus, F. Shulenbaeva *et al.* (2019) in their paper wrote about the investment attractiveness of Kazakhstan and mentioned that it is quite high, especially given the likely subsequent increase in government support of the industry by various methods, which will further increase the influx of investment. By this, it can be also understanded certain prospects in terms of funding this industry at the country level. In terms of climate, as noted by A. Russell *et al.* (2018), the level of environmental friendliness in Kazakhstan varies greatly depending on the region: therefore, air and water quality can be worse in big cities than in rural areas. As for the situation in the world, COVID-19 crisis and other disasters also affect the agricultural companies: this was described in their paper by C. Elleby *et al.* (2020). They also noted that the pandemic was one of the causes of the price drop of many agricultural products. However, if you look at the price of the futures of many agricultural commodities, such as wheat, pork, and others, you can see that the existing price for the sector as of 2022 is more than favourable.

N.V. Vashukevich *et al.* (2021) conducted the estimation of land yields in Kazakhstan. In their opinion, despite the problems with yields and fertilizers, the potential of agricultural land in Kazakhstan remains high. However, scientists also mention that the country probably requires a new calibrated approach for development in the agricultural sector, as well as the creation of conditions for the processing of raw materials within the country and the involvement (development) of new agricultural technologies. Thus, in assessing the state of the above parameters of agricultural development in Kazakhstan, it can be noted that they are all at a high enough level, particularly given the governmental support for the industry. Despite the global crises driving up prices for many resources, including agricultural products, Kazakhstan's favourable climatic conditions make it a promising location for growing crops. Moreover, the country's increasing governmental support for the agricultural sector is likely to boost its investment appeal in the future. Although the level of environmental friendliness varies across regions, the areas suitable for cultivating crops are expected to have more favourable conditions.

Given that, the paper focused on the North Kazakhstan region, where it is important to assess how other scientists described the state of the agriculture in their works. Among these, authors mention A.V. Shurr (2014), who in his work described the development of the agro-industrial complex of North Kazakhstan region. As the author notes, the role of the agricultural sector in this area is due not only to high investments, but also to some social indicators: for example, a large part of the region's population (about 40%) lives in rural areas. In general, the scientist notes that high potential of the agricultural development in the region is not yet fully explored, especially in the context of grain culture growing. Probably, with deeper integration of Kazakhstan into international markets, the regional products could not only win their share, but also attract additional investments. In addition, A.V. Shurr (2014) examines the production of the agricultural sector of North Kazakhstan region in terms of districts and at a deeper level. For this purpose, several basic indicators were used, among them are the gross output of the agricultural sector, the sown area of all crops, the cost of output per quintal, the number of enterprises engaged in the agriculture and others. Thus, the scientist notes that the most profitable for the development of livestock are Kyzylzhar, Mamlutka, Magzhama Zhumabaeva districts, and for crop production, which has a clear preponderance both in levels of profitability and prevalence in the region, the districts are Kyzylzhar, Mamlyutka, Magzhama Zhumabaeva, Akkaiyn and Zhambyl. According to the author, another region worth mentioning is the Taiynsha region, where gross output in livestock and crop production are significant, as well as the Shal Akyn region, which has the lowest cost of

production per quintal. Besides, it would be important to estimate the share of grain crops in each of the districts, which, unfortunately, the author did not do.

E.Zh. Shorabaev (2009) in his work examines the opportunities for growing wheat in the North Kazakhstan region. The scientist notes that the most important problem for the development of the agriculture in the country, and particularly in this region, is the degradation of soils, caused by the use of outdated methods of cultivation and plowing land. This creates the need for a change in company policy on the environmental component of the agricultural sector. According to the scientist's opinion, one of the crops that could replace wheat in the future could be peas, given its adaptability to the conditions of particular region. Also interesting is the work of K. Abdullaev et al. (2020), which analysed the agriculture in the North Kazakhstan region in terms of innovative technologies, as well as the use of precision farming technology in the region. The scientists note that the introduction of innovative agricultural systems, especially precision farming technology, is very promising for the conditions of North Kazakhstan, because probably it could significantly increase the economic efficiency of the agricultural business in the region. Thus, the region does have significant potential for the agricultural development. However, the engagement of trained personnel will probably require governmental support and the introduction of innovative technologies should also be encouraged by the state (Gordon, 2019).

Thus, the analysis carried out in this paper demonstrates that the production of spring soft wheat seed compared with the manufacture of commercial grain in North Kazakhstan is much higher than the profitability of cultivation of 1 hectare of sown area. Besides, due to the specifics of the manufacturing process and sales of seed material, this task relies on capacity of the enterprises that have sufficient energy efficient machinery and fleet of agricultural machinery, storage tanks and seed-cleaning equipment, which also creates significant additional costs of doing business, especially in the short term. Therefore, this kind of production will become more relevant for manufacturers with large capitals and capabilities. Relying on the higher value of the benefit-cost ratio, small investors should probably invest in the production of commercial grain. However, another likely method of building production facilities under given conditions is to switch to the manufacture of commercial grain and seeds at the same time. By choosing this option (by diversifying personal business in this way), an investor will not only be able to generate a more predictable average level of income year after year, but also significantly reduce the risks in the event of unforeseen circumstances both in production and in the market for a specific product (in the event of a price change for it, for example). Nevertheless, in such a case it is also valuable for the entrepreneur to make a certain transition in order to achieve the required level of energy efficiency.

CONCLUSIONS

The paper analysed the state of the agricultural sector in Kazakhstan and in particular in North Kazakhstan region. Authors demonstrated that the agricultural sector is one of the fundamentals of the country's economic development, as indicated by its relatively high share in the total GDP. In turn, one of the most important regions in the country is North Kazakhstan, the reason for which is its high share in the production of the country's agricultural sector. In addition, the assessment of the development rates of the industry showed an increase of 90% in the country as a whole and 109% in North Kazakhstan. The industry has also shown a high level of sustainability in terms of productivity levels, compared to the overall GDP; it is a promising sector for investment and is likely to grow strongly in the coming years.

The paper describes the profitability of different options for wheat production (commercial grains and elite seeds), with a comparative study of the economic analysis of spring wheat seed production in North Kazakhstan region. Authors have demonstrated that seed production is more profitable per unit area (one ha), while production of commercial grains is more profitable per unit of capital invested. Thus, entrepreneurs with considerable amount of funds should invest in spring wheat seeds, while smaller entrepreneurs should invest in commercial grains. Another reason for such conclusions is the different initial investment required for this business, which is much higher for seed production than for commercial grains. However, it is also acceptable to switch to combined production, i.e., both grains and seeds at the same time, which would achieve a more predictable and average level of enterprise profitability and to carry out risk diversification, as well as reduce initial investments in production. A follow-up study of the agriculture in its other areas, in particular Turkestan and other provinces should look promising.

ACKNOWLEDGEMENTS

The article was prepared within the framework of the program-targets financing of the Ministry of Agriculture of the Republic of Kazakhstan IRN BR10865093 "Development and scientific substantiation of technical and technological parameters for the adaptation of space sensing and precision agriculture technologies to the actual production tasks of the AIC subjects and the formation of the necessary reference database".

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Економічний аналіз насінництва ярої м'якої пшениці в Північно-Казахстанській області

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Анотація. У сучасних реаліях сільське господарство відіграє дуже важливу роль не тільки в досягненні сталого економічного розвитку, а й у вирішенні глобальної проблеми голоду та забезпеченні незалежності держави від зовнішніх поставок продовольства. Все це робить дану галузь важливим фактором для розгляду в багатьох країнах. У даній роботі автори зробили акцент на економічному аналізі окремих культур галузі, а саме ярої пшениці в Північно-Казахстанському регіоні. Таким чином, метою роботи був розрахунок економічної доцільності вирощування даної культури. Основним методом при написанні роботи був аналіз. Крім того, важливу роль відіграли статистичні методи дослідження, а також методи порівняння, моделювання, індукції та інші. У статті показано, що витрати на виробництво елітного насіння значно перевищують витрати на вирощування товарних посівів зернових культур у розрахунку на гектар. При цьому насінництво сприяє підвищенню прибутковості з гектара, проте спостерігається протилежна тенденція щодо ефективності на одиницю вкладеного капіталу, яка була вищою у виробників товарного зерна, ніж у насінництва. При цьому специфіка насінництва висуває підвищені вимоги до сільськогосподарських товаровиробників з точки зору енергоефективності, а саме забезпеченості машинно-тракторним парком та парком сільськогосподарської техніки, елеваторними потужностями, а також обладнанням для очищення зерна. Зроблено висновки щодо прийняття рішення підприємцями про інвестування у виробництво того чи іншого виду продукції. Стаття привносить нові знання для розуміння особливостей економічного розвитку Казахстану, особливо в регіональному аспекті та галузевій специфіці

Ключові слова: економіка Казахстану; регіональний розвиток; сільське господарство; підприємництво; інвестиції

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 101-111

UDC 632
DOI: 10.48077/scihor3.2023.101

Main directions of plants integrated protection in the conditions of organic agriculture

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Article's History:
Received: 25.01.2023
Revised: 19.03.2023
Accepted: 15.04.2023

Suggested Citation:
Mero, G., Skenderasi, B., Shahini, E., Shahini Sh., & Shahini, E. (2023). Main directions of plants integrated protection in the conditions of organic agriculture. *Scientific Horizons*, 26(3), 101-111.

Abstract. The environmental situation in the world is only getting worse every year. This is caused by an increase in air pollution, wastewater pollution, wood burning, and others. Since 2013, ammonia emissions by European Union companies have increased significantly. This was facilitated, among other things, using synthetic pesticides. That is why the transition of agriculture to organic farming standards can be considered a good alternative. The aim of the study was to analyse the effectiveness of combining known organic pesticides in one biogeocenosis. A combined treatment of the vegetable crop *Brassica oleracea* with such biological pesticides as Bacillus thuringiensis and pyrethrin, combined with mass pest trapping, is proposed in the research. When combining these three approaches, the efficiency was 93%. The total crop yield was 27 tons/ha,

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while the area of the field where pheromone and yellow sticky traps were used had a yield of 34 tons/ha. These methods were effective against the following pests: *Ceutorhynchus rapae, Aleyrodes proletella*, and *Brevicoryne brassicae*. Leaf damage was reduced by 93% on average during the study period when using the combined approach. During the two-year research, it was possible to neutralize 1882 insects by mass trapping and find out that the largest number of *Ceutorhynchus rapae* affect the crop in May and August, but the use of pheromone traps is most effective in October. The combination of individual methods increased the effectiveness of each method due to the synchronized impact on different pests. Increasing vegetable yields in Albania in the future can also solve the problem of hunger in countries with unfavourable climatic conditions by increasing the export of these crops

Keywords: *Bacillus thuringiensis*; pyrethrum; *Brassica oleracea*; biological pesticides; a natural insecticide

INTRODUCTION

Following the European Environment Agency, the concentration of nitrogen dioxide and PM10 particles in the Balkans has significantly increased, resulting in more than 30,000 premature deaths. Such statistics harm the economic situation of countries, as they lead to increased healthcare costs and a decrease in the number of working-age people. Agricultural reforms can not only help improve its environmental safety but also meet the demand of discerning consumers who care about their health and demand better food quality (Shahini *et al.,* 2022).

One of the most important vegetable crops in high demand in Europe is *Brassica oleracea*, with global production of broccoli and cauliflower totalling 25,531,274 tons in 2020 (Siomos *et al.,* 2022). Most varieties of *Brassica oleracea* are rich in vitamin C, antioxidants, and other equally important nutrients. The main pests of *Brassica oleracea* are *Aleyrodes proletella, Brevicoryne brassicae, Murgantia histrionica, Ceutorhynchus rapae, Pieris rapae*, which cause considerable damage to the leaves of the crop, which also spoils its appearance.

When comparing conventional farming methods and organic farming systems, the sustainability of such systems is primarily determined, as well as how effective they are in the conditions of the studied agrocenosis (Kalajnxhiu *et al.,* 2012, Litterick & Watson, 2017). Important factors that influence the choice of methods for plant protection to ensure their self-regulatory mechanisms can be called both climatic conditions and risk factors inherent in a given area (Teqja *et al.,* 2017). For the changing climatic conditions of Albania, biochemical and microbial plant protection will be effective. This is dictated not only by climatic conditions but also by the presence of specific pests that damage crops in this region. Previous studies by the authors on this topic primarily focused on the environmental safety of the methods used (Seidenglanz *et al.,* 2021, Shahini *et al.,* 2021, Toshova *et al.,* 2009). Thus, in this region, Sh. Shahini *et al.* (2021) in recent works have demonstrated that combinations of different environmental pesticides significantly increase the overall effectiveness of such plant protection compared to the control sample and individual methods. Analysis of the protection of tomatoes from *Tuta absoluta* showed that when using *Bacillus thuringiensis*, fruit infection decreased by 29%, when treated with Indoxacarb pesticide, this figure reached 43%, and when mass trapping – 52% (Shahini *et al.,* 2021). For our study, we replaced Indoxacarb with pyrethrum and slightly modified the previously used technology.

The use of pyrethrum in different parts of the world has demonstrated its high effectiveness against aphids (Jansen *et al.,* 2010), bedbugs, worms, and other pests (Gokturk *et al.,* 2018). Based on the research work of Daniel Lybrand from Michigan, USA, the advantage of the insecticide is its harmful effect on the nervous system of insects, while being safe for warm-blooded animals and humans (Lybrand *et al.,* 2020). It also does not require additional disposal but decomposes under the influence of sunlight and changes in the pH of the environment (Sun *et al.,* 2020).

The data from the Balkan Reserve also indicate that *Ceutorhynchus rapae* is a serious threat to *Brassica oleracea*, against which the above methods of protection are not very effective (Toshova *et al.,* 2009). This can significantly affect the yield of *Brassica oleracea*. Pheromone and yellow sticky traps have shown good results in the control of *Ceutorhynchus rapae* (Seidenglanz *et al.,* 2022; Reddy *et al.,* 2018). The use of yellow sticky traps, although not popular in the Balkan Peninsula, has been used in the work of other scientists conducting research in similar climatic conditions. Elias Beckmann of the German Institute for Plant Protection has illustrated the effectiveness of such traps for monitoring whiteflies in recent publications, and similar work by authors from Mexico and Turkey has shown not only encouraging results but also indicated the commercial availability of this approach.

The use of traps in combination with other types of protection has broad prospects for implementation not only within organic farming but also for lands using conventional farming approaches. In general, as the literature review has shown, the number of works on similar topics in the Balkans is currently insufficient to present a complete picture of the problems that may arise at each stage of technology implementation but given the number of positive publications from other regions, further research may open up several new opportunities in this area. The research aims to combine known organic pesticides within one biogeocenosis and analyse the effectiveness of such a combination.

MATERIAL AND METHODS

The place for the research was the capital of Albania – the city of Tirana (41°19′48″N, 19°49′12″E), with a predominantly humid subtropical climate and an average annual rainfall of 1266 mm. The Broccoli Brassica oleracea Italica group was chosen as the crop under study (Table 1). The tests were carried out for 2 years (2021-2022) from August to October.

Table 1. *Characteristics of the researched plant culture*

Plant culture name	Brassica oleracea (Italica Group)
Height	from 45.7 to 76.2 cm
Width	from 30.5 to 61.0 cm
Lifetime	Two years
the pH of recommended soils	Neutral
Type of insemination	Hermaphroditic

Source: *compiled by the authors*

The *Brassica oleracea* Italica group was planted in rows at approximately 45-46 cm from each other, placed at an interval of 92 cm in the form of seedlings. The planting took place within a l-hectare plot of loamy soil, divided into two equal parts, in one of which crop protection was carried out using *Bacillus thuringiensis* and pyrethrum, and in the other, along with these methods, mass pest trapping was used. Pheromone traps were installed to prevent *Ceutorhynchus rapae*.

For the study, a solution of the pathogen pyrethrum from Syngenta was used in 8-ounce bottles with a concentration of 6-24 ml per gallon of water. *Bacillus thuringiensis* solution of the Dipel DF brand was also used. The concentration of the active ingredient was 300 g/l. A mechanical spray pump with a volume of 200 litters (flat-fan nozzle, pressure 5 atm, diameter 0.5 mm) was used to spray the pesticides.

The experiment was carried out using delta traps manufactured by Great Lakes IPM Inc. (Michigan, USA), which contained pheromone bait from ChemTica Internacional SA (Costa Rica) in the form of a grey rubber membrane impregnated with 4-methyl-3,5-heptandione. Each bait contained 10 mg of pheromone, which released 0.1 mg/day of the active ingredient.

The cup under each of the partitions was filled with 100 μL of pheromone solution in hexane, with a concentration of 0.1 mg/mL. After that, the hexane began to evaporate, simultaneously releasing the pheromone, which was in a special plastic bag. The bait was stored in aluminium bags at 4°C. Traps were placed in blocks at 8-10 m from each other. Every 2-3 days, insects were removed from the traps and their number was recorded. Yellow sticky traps (Ø 30 cm, 10 cm) were also installed, 1 trap per 0.1 ha.

To evaluate the effectiveness of the combined crop protection, the analysis of leaf damage was carried out by selecting 100 random leaves, for which the percentage of healthy and damaged leaves was calculated. The collected data were compared with the literature and data collected from the control plantation, where no pre-treatment of plants was carried out. The procedure was carried out weekly during the treatment of crops for two years. The values of adjusted efficiency were calculated based on Abbott's formula (Shahini *et al.*, 2021) (1):

$$(Ecorr)\% = [1 - (\frac{DL\ treatment}{DL\ control})] \times 100, \quad (1)$$

where DL is the average number of damaged leaves.

All data were analysed using IBM SPSS Statistics v.20 for Windows, where the average values were compared at the 0.05 probability level.

RESULTS

An important task when choosing pesticides was not only their safety for the environment but also their effectiveness against existing pests. The experiment was conducted in the field, which reduced the efficiency of pesticide spraying, but contributed to their decomposition under the influence of sunlight and prevented contamination of crops with residual solutions during harvesting.

The protection of broccoli *Brassica oleracea* was carried out by a combination of biological pesticides with different effects, considering the characteristics of pests that pose a major threat to cabbage plantations. However, it is worth noting that climate change can also affect the insect population, so the study of combining biological pesticides for plant protection in different climatic conditions is an important step to building a realistic picture of the effectiveness of this method. The treatment of the studied vegetable crop with *Bacillus thuringiensis* and pyrethrum reduced leaf damage by 57% compared to the control sample (Fig. 1).

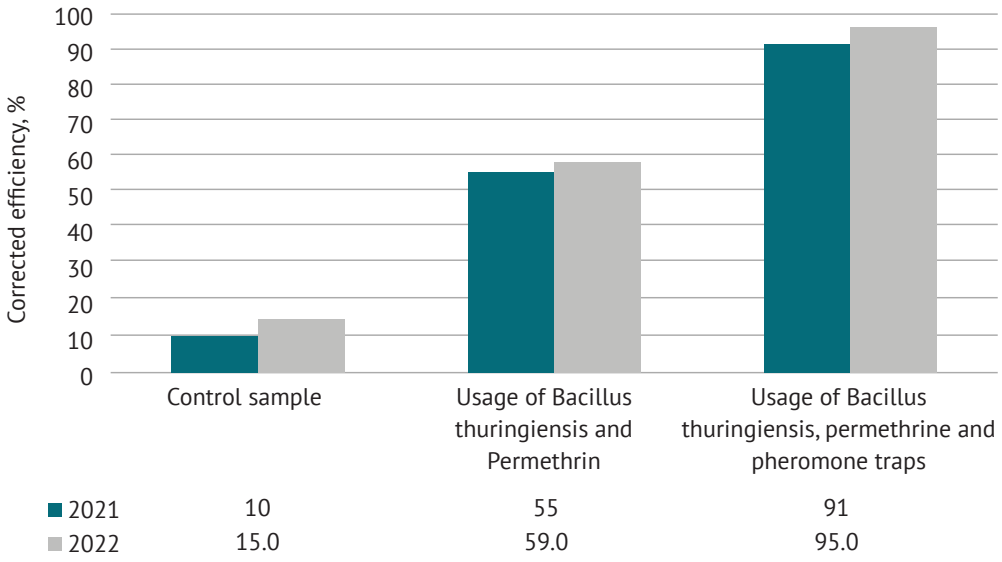

Figure 1. *Observed the effectiveness of plant protection in the period from 2021 to 2022*

Pyrethrum is a natural insecticide containing biologically active substances (Table 2) (Kawamoto *et al.,* 2020), usually obtained by drying the flowers of the chrysanthemum *Tanacetum cinerariifolium*, which does not involve the use of any synthetically produced compounds (Sun *et al.,* 2020). Its extraction is carried out through a series of sequential steps, namely: drying of flowers, dewaxing, saponification, evaporation, removal of fatty acids, and separation of pyrethric acid from chrysanthemic acid (Otienol *et al.,* 2020). The product is used in the form of a suspension in oil or water, sprays, and can also be sprayed in the air, covering large areas of land.

Table 2. *Biologically active compounds quantified from pyrethrin extraction*

Name	Abbreviation	Gross formula	Molecular mass
Pyrethrin I	Py I	$C_{21}H_{28}O_3$	328. 4
Pyrethrin II	Py II	$C_{22}H_{28}O_5$	372. 4
Serine I	C I	$C_{28}H_{28}O_3$	316. 4
Serine II	C II	$C_{21}H_{28}O_5$	360. 4
Jasmoline I	J I	$C_{21}H_{30}O_3$	330. 4
Yasmonlin II	J II	$C_{22}H_{30}O_5$	374. 4

Source: *compiled by the authors*

On the other hand, the use of *Bacillus thuringiensis* strains can reduce the level of insect nutrition, which leads to death from septicaemia. *Entomopathogenic fungi* produce endotoxins, which, when ingested by the insect stomach, destroy it from the inside (Schünemann *et al.,* 2014). The main producer of products based on various species of *Bacillus thuringiensis* in the United States, namely Valent Bioscience and Certis, while in Europe, biological pesticides are produced by Koppert Biological Systems, a company based in the Netherlands, and the Italian company Isagro.

The concentration of *Bacillus thuringiensis* was selected based on the analysis of previous studies (Shahini *et al.,* 2021). Following the experiments, the use of entomopathogenic fungi contributes to 58% to 98% of insect mortality (Biryol *et al.,* 2021), most often used to control aphids or whiteflies that can damage the stems and leaves of cabbage, which further affects the yield of the crop (Khun *et al.,* 2021). Additional treatment with a pyrethrin solution was supposed to increase the efficiency of *Bacillus thuringiensis*.

It is worth noting that insecticide spraying should be carried out with a certain frequency, since if the initial concentration of *Bacillus thuringiensis* can kill up to 97% of insects, then after 108 hours the product is only 1% effective against pests (Castro *et al.*, 2019).

Therefore, the optimal conditions were selected: treatment of plants every 24-36 hours with a concentration of 300 g/l of the active ingredient, which ensured a sufficient and controlled content of the pesticide in the crop and reduced the risk of re-infection.

To prevent the mortality of bees from pyrethrin, the spraying of the product took place at night. The use of pyrethrin as an independent insecticide, especially in the presence of many pests, is not advisable, because its effect is slow and insufficient, and at low concentrations, the nervous system of insects can even adapt to the product. On the other hand, its low toxicity and affordable cost demonstrate the advantages of pyrethrin in combination with other methods of protection, unlike synthetic pesticides that pollute groundwater.

A plot of land planted with broccoli *Brassica oleracea* Italica group treated with *Bacillus thuringiensis* and pyrethrum solution was carefully checked for damaged stems and the overall appearance of the plants was assessed. However, when the two methods were combined, *Brassica oleracea* was still affected by *Ceutorhynchus rapae*. The weevil larvae interfered with the transport of nutrients in the plant, distorting the stem tissue, which prevented its further growth.

In search of alternative solutions to increase crop yields, in addition to the above-mentioned methods, pheromone traps, and yellow sticky traps were placed on 0.5 hectares of the field. This approach allows the assessment of the impact of insect trapping on changes in the effectiveness of the combined plant protection method.

Pheromone traps were used, which can only attract weevils, while yellow sticky traps also captured whiteflies and aphids. However, in previous studies, yellow sticky traps were used only for population monitoring, and the treatment was carried out with the insecticide Proteus 110 OD, the active ingredient of which is thiacloprid (Grantiņa *et al.,* 2011). In addition to being toxic to bees, this active ingredient is also highly toxic to warm-blooded animals, with an LD50 of 40-840 mg/kg for rats and a Toxicity Category of 4 (EPPO, 2003). Therefore, this pesticide is not recommended for use, especially in the framework of compliance with organic farming standards.

During the two-year study, mass insect trapping helped neutralize 1882 pests, of which 606 were collected using pheromone traps. The pests were collected during the ripening period of the broccoli *Brassica oleracea* Italica group. The average air temperature in August was +33°C, in September – +29°C, and in October there was a decrease in the average daytime temperature to +22°C. Insects were caught using 50 traps. Following the results of the observation, many pests caught in pheromone traps were observed in October (Fig. 2).

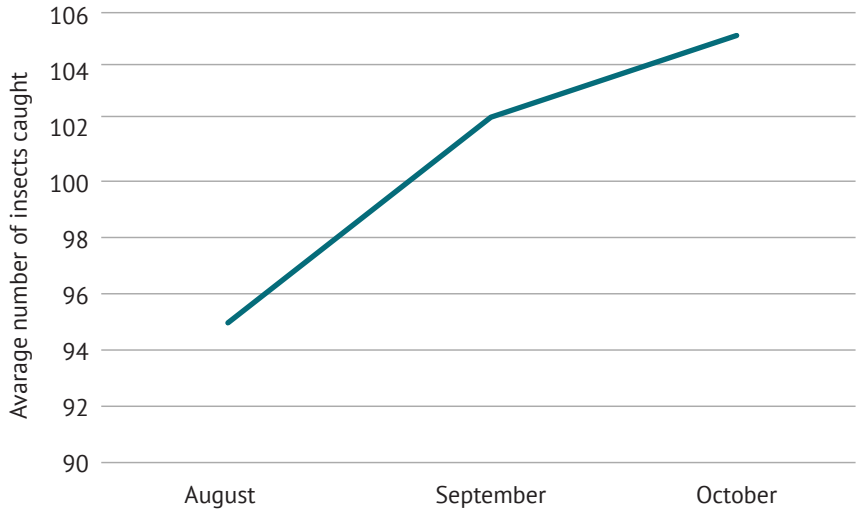

Figure 2. *The average number of Ceutorhynchus rapae captured by Great Lakes IPM Inc. traps in 2021-2022*

The results obtained (Fig. 3) also showed a significant fluctuation in the number of collected pests for each of the approaches over three months, but the average number of collected individuals per seizure in both 2021 and 2022 was 7 insects. This can be explained by both the variability of weather conditions, including precipitation and air temperature fluctuations and statistical error. In addition to the expected *Ceutorhynchus rapae*, other species of weevils, such as *C. obstrictus* and *C. pallidactylus*, were also caught in pheromone traps, but the majority of the pests caught, namely, 63%, were identified as *Ceutorhynchus rapae*. Different species of insects have specific olfactory receptors, which allow them to respond to certain types of chemical compounds. Olfactory receptor neurons contain specific proteins that are located on the palps and antennae of insects and determine their sensitivity to a certain type of molecule (Witzgall *et al.,* 2010).

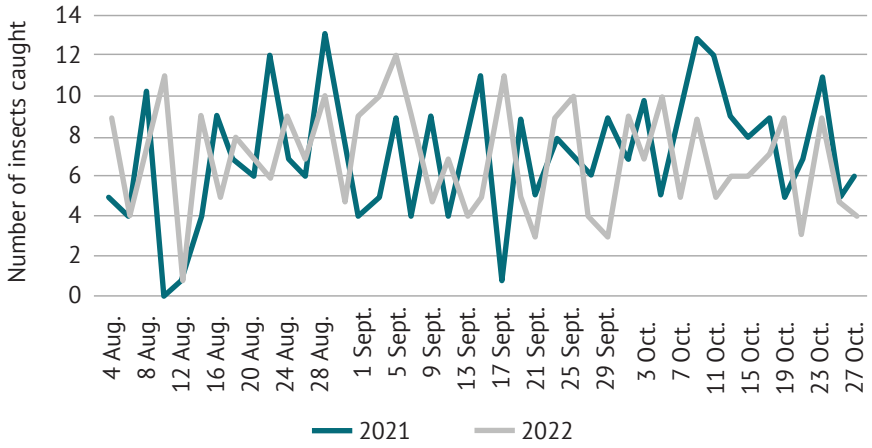

Figure 3. *The number of insects caught by Great Lakes IPM Inc. traps from August to October 2021 and 2012*

It is worth noting the influence of the average air temperature on the number of individuals caught. A decrease in temperature contributed to an increase in the number of insects collected during the month. It can be assumed that this pattern is due to the increased activity of weevils before hibernation, but this hypothesis requires further study. At the same time, the increase in humidity also partially reduces the effectiveness of the measures taken. Thus, in September, the number of rainy days was 14. Therefore, it should be assumed that the results of similar studies in greenhouse conditions will have significant differences from the field.

Previous studies have also indicated the significant effect of the yellow colour in attracting the attention of some pests, in particular weevils of various species (Cruz-Esteban *et al.,* 2021, Toshova *et al.,* 2009). Therefore, yellow traps were chosen as an additional type of protection for broccoli *Brassica oleracea*, which consisted of yellow plastic with a thin layer of glue. Although this type of trap has several disadvantages and should not be used for plantations with a high level of a plant infection, the feasibility of using such traps was proved by experimental values in this study. The yellow sticky traps were changed weekly for two years, and the number of insects and species was also recorded. The maximum number of caught pests was observed in May 2021, namely 103 insects (Fig. 4).

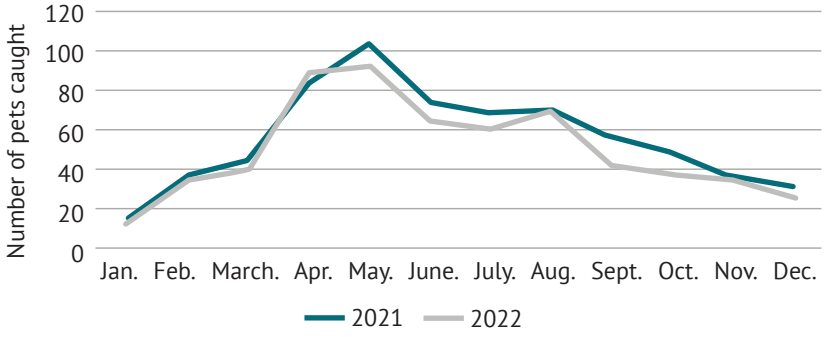

Figure 4. *Number of insects caught by yellow sticky traps from January 2021 to December 2022*

As expected, other insects were identified in addition to weevils (Table 3). That is, this method can be effective for crop protection in the combined type of plant protection. Its significant advantage is not only simplicity and commercial availability, but also safety compared to traditional plant protection products.

Table 3. *Species caught with yellow sticky traps during 2021-2022*

Types	Number of beetles caught, pcs	Number of beetles caught, %
Aleyrodes proletella	446	35.0
Brevicoryne brassicae	178	14.0
Ceutorhynchus rapae	548	43.0
Others	102	8.0

Source: *compiled by the authors*

Yellow sticky traps demonstrated high efficiency in catching whiteflies, which, in combination with the use of *Bacillus thuringiensis*, helped to prevent the impact of insects on the plant culture under research. The yield of cabbage was 27 tons/ha, with yields in the area where pheromone traps were installed significantly different from those where no traps were installed. The yield of the area where the combined approach was used was 67.8% of the total yield, which indicates a great potential for the introduction of mass pest trapping in combination with other methods of protection.

Damage to the leaves with the simultaneous use of three types of protection decreased by 91% in 2021 and by 95% in 2022 (Fig. 1). Visual evaluation of broccoli during the study helped to assess the prospects of using biological pesticides.

It is worth noting the influence of the average air temperature on the number of individuals caught. A decrease in temperature contributed to an increase in the number of insects collected during the month. It can be assumed that this pattern is due to the increased activity of weevils before hibernation, but this hypothesis requires further study. At the same time, the increase in humidity also partially reduces the effectiveness of the measures taken. Thus, in September, the number of rainy days was 14. Therefore, it should be assumed that the results of similar studies in greenhouse conditions will have significant differences from the field.

The results showed the feasibility of using a combined method of plant protection but also illustrated several issues that require further consideration. In particular, it concerns population control and selective trapping of *Ceutorhynchus rapae*. Although this study managed to reduce the number of pests on the plantation, this approach needs to improve the level of selectivity.

DISCUSSION

Indoxacarb is one of the most popular synthetic pesticides, but its toxicity, although not sufficiently studied, may pose a potential threat to humans and mammals along with other synthetic agents. Recent studies have demonstrated the advantages of *Bacillus thuringiensis* over Indoxacarb, which is a much safer analogy and can demonstrate good results in pest control (Nazarpour *et al.,* 2016). On the other hand, a study of *Tuta absoluta* control in tomato plantations showed the opposite results (Shahini *et al.,* 2021). Therefore, a good idea for further experiments would be to compare the effectiveness of combining these pesticides with safer ones and analyse the resulting efficiency.

An interesting approach to protecting rapeseed from *Brevicoryne brassicae* was discovered by scientists from Iran, who treated the crop with the proteobacterium *Pseudomonas putida* and acetylsalicylic acid. Their goal was to give the crop resistance to this type of pest to reduce the use of synthetic insecticides, but as the authors note, such an intervention can change the chemical composition of plants by increasing the content of some secondary metabolites (Khoshfarman-Borji *et al.,* 2020).

A study of the effect of directly colonized *Bacillus thuringiensis* on pak choi (*Brassica campestris var. chinensis*) leaves on whiteflies showed that the concentration of insecticide obtained in this way is insufficient to kill all individuals and leads to the mortality of only 35% of insects (Prabhakar and Bishop, 2009). On the other hand, the use of ready-made solutions is more effective, causing mortality of up to 80% of pests (Moxtarnejad *et al.*, 2014; Eski *et al.,* 2022).

A group of scientists from Karadeniz Technical University analysed the effect of *Bacillus thuringiensis* on individuals of the cicada family, namely *Orosanga japonica*, and managed to find an insecticide concentration that caused mortality of more than 97% of pests (Biryol *et al.,* 2021). However, in this study, such results were not achieved even when combining the treatment of crops with *Bacillus thuringiensis* and pyrethrum. This can be explained by the greater diversity of insects on the plantation.

It is also worth noting that the above experiments were conducted in greenhouse conditions, which allowed better research on the selective effect of individual pesticides and their combinations on plant crops, but in this study, the realistic conditions were attempted to be recreated to analyse the impact of additional factors that may affect the effectiveness of such methods in their practical implementation. In particular, for field conditions, due to constant weather changes and the lack of additional UV protection, the effectiveness of plant protection is significantly reduced.

Pyrethrin was also chosen as an additional environmentally friendly pest control agent. One of the research objectives was also to reveal new opportunities and prospects for this insecticide. Treatment of plants with pyrethrin can solve the problem of impact not only on the existing offspring of insects but can also reduce the number of larvae hatching from eggs. In previous studies, the number of hatched larvae after pyrethrin treatment decreased by 52% (Yang *et al.,* 2012). An interesting solution for further study could be the cultivation of pyrethrum directly near vegetable-keeled crops, as Albania's climatic conditions and soils are favourable for *Tanacetum cinerariifolium* (Sladonja *et al.,* 2014). To obtain a bioinsecticide concentrate, essential oils are separated by preparative high-performance liquid chromatography, and pyrethrins I and II, cinerin II, and jasmonin II, in addition to insecticidal properties, can affect the olfactory receptors of insects, thereby repelling them (Yan *et al.,* 2021). Pyrethrin also has the effect of reducing insect appetite, which helps to reduce the number of damaged leaves and stems (Takikawa *et al.*, 2022).

The literature review revealed a lack of studies comparing the impact of pesticides such as Indoxacarb

and pyrethrin on crop yields, their combination, and their toxic effects on the environment.

When combining different crop protection products, there is also a need to diagnose pest types and predict the adaptability of different insect species to each pesticide. For broccoli *Brassica oleracea* planted in subtropical climates, *Ceutorhynchus rapae* will pose a significant threat (Seidenglanz *et al.,* 2022). *Ceutorhynchus rapae* are common in areas with high humidity and feed on the leaves and stem of broccoli *Brassica oleracea*, so when growing this crop in a subtropical climate, the issue of controlling this pest has arisen. Among the known safe methods of plant protection against weevils, pheromone traps are highly effective. This approach not only helps save crops from the harmful effects of weevils but also allows for the analysis of the species diversity of insects in the study area. Pheromone traps have demonstrated good results in previous studies, but yellow sticky traps were more effective against the cabbage weevil (Toshova *et al.,* 2009). The addition of allyl isocyanates to the traps can further increase the weevil catch, but the goal of our work is to ensure minimal harm and maximum environmental friendliness of the methods, and these compounds, although not to a large extent, have toxicity for warm-blooded animals and humans.

In this research, the combination of the use of pheromone traps against *Ceutorhynchus rapae* with other methods of protection played an important role. The work of Samuel Cruz-Esteban *et al.* (2021) is also worthy of great attention, as they studied the effect of colour on the lure of *Drosophila suzukii* and *Zaprionus indianus*. In the field, on a blackberry plantation *Rubus ulmifolius*, the scientists found that yellow cards help to carry out high-quality monitoring and catching of insects. Such traps work due to the biological instincts of insects (Böckmann *et al.,* 2021, Takikawa *et al.,* 2022). And although, as noted, the effectiveness of this approach is somewhat inferior to that of synthetic pesticides, it is a good alternative solution to further increase crop yields. Using a similar technology in this study, it was possible to analyse the ratio of pests affecting *Brassica oleracea*. Thus, a clear understanding of the existing dangers will allow us to improve the methods of integrated broccoli protection in the future and demonstrate high exports of this vegetable crop for Albania. At the same time, an additional advantage of using simple traps is the availability of their implementation in conditions of a limited budget.

Combining different biological pesticides not only helps to increase the number of undamaged plants for further harvesting and sale but also has several other equally important benefits. Every year, farmers and other professionals working with synthetic pesticides put their health at risk, risking endocrine disruption due to chemical poisoning. That is why the integrated approach to crop protection discussed in this article will help to modify the approach to agriculture and pave the way for the introduction of new regulations aimed at simplifying, systematizing and, most importantly, protecting the environment from the harmful effects of toxic pesticides.

This method eliminates the use of synthetic pesticides, replacing them with biological pesticides, which significantly reduce environmental damage. However, for further study, it is important not only to select the right biological objects that will become safe analogues of popular insecticides but also to implement several measures that will ensure comprehensive plant protection against seasonal pests. The combination of biochemical and microbial protection is the most successful and cost-effective choice. Further research and implementation of new technologies for agricultural land in Albania will illustrate the possible disadvantages of these methods and help expand their scope of application globally.

In other words, this way it was possible to significantly reduce the level of toxic substances in the soil, increase crop yields, and this study illustrated the difficulties and benefits of implementing organic farming technologies on a specific example, ensuring the relationship between crops and organisms, as well as directing and controlling biosystems with minimal modification.

CONCLUSIONS

As a result of the research, the efficiency of the combined approach to plant protection against pests was obtained from the example of the broccoli *Brassica oleracea* Italica group. When using pyrethrin and *Bacillus thuringiensis*, the efficiency of the method was 57%, but the installation of pheromone and yellow sticky traps increased the efficiency to 93%. No synthetic pesticides and poisons were used in the process of crop treatment, and a combination of environmentally friendly and simple methods inherent in organic farming allowed for high yields without harming the environment. The massive trapping of insects, namely weevils, allowed not only influence the potential yield reduction but also to assess of the population of *Ceutorhynchus rapae* in the humid subtropical climate of Tirana. Of the 1882 insects recorded in the traps, 1276 were *Ceutorhynchus rapae*.

Further research into biological pesticides and the successful implementation of their use will both simplify and improve access to quality, safe food for a wide range of consumers. On the other hand, such an approach will increase the effectiveness of plant protection and find applications for less potent agents that, in combination with others, will show a high level of efficiency. It is also important to study the combination of these methods on the example of other crops to expand the scope of their application. At the same time, one of the methods can be replaced, because the pests of broccoli *Brassica oleracea* may be absent on other

crops but have their specific representatives that spoil the appearance of the plant or lead to its death.

When analysing all the possible hazards that can affect crop yields, massive insect trapping allows us to form a clear picture of the number of pests of each species. In addition, additional visual observation of the leaves, stem and general appearance of each plant helps to better select the means and ways to care for the plantation. In other words, the introduction of organic farming not only simplifies the process of plant protection but also increases crop yields with minimal additional resources.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Основні напрямки інтегрованого захисту рослин в умовах органічного землеробства

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Анотація. Екологічна ситуація у світі з кожним роком лише погіршується. Це спричинено збільшенням забруднення повітря, стічних вод, спалюванням деревини тощо. З 2013 року викиди аміаку компаніями Європейського Союзу значно зросли. Цьому сприяло, зокрема, використання синтетичних пестицидів. Саме тому перехід сільського господарства на стандарти органічного землеробства можна вважати хорошою альтернативою. Метою дослідження було проаналізувати ефективність поєднання відомих органічних пестицидів в одному біогеоценозі. У дослідженні запропоновано комбіновану обробку овочевої культури *Brassica oleracea* такими біологічними пестицидами, як *Bacillus thuringiensis* та піретрин, у поєднанні з масовим відловлюванням шкідників. При поєднанні цих трьох підходів ефективність склала 93 %. Загальна врожайність склала 27 т/га, тоді як на ділянці поля, де використовували феромонні та жовті клейкі пастки, врожайність становила 34 т/га. Ці методи були ефективними проти наступних шкідників: *Ceutorhynchus rapae*, *Aleyrodes proletella* та *Brevicoryne brassicae*. Пошкодження листя було зменшено в середньому на 93 % за період дослідження при використанні комбінованого підходу. За два роки досліджень вдалося знешкодити 1882 комахи шляхом масового відлову і з'ясувати, що найбільша кількість *Ceutorhynchus rapae* пошкоджує культуру в травні та серпні, а використання феромонних пасток є найбільш ефективним у жовтні. Поєднання окремих методів підвищило ефективність кожного з них завдяки синхронізованому впливу на різних шкідників. Підвищення врожайності овочевих культур в Албанії в майбутньому може також вирішити проблему голоду в країнах з несприятливими кліматичними умовами за рахунок збільшення експорту цих культур

Ключові слова: *Bacillus thuringiensis*; піретрум; *Brassica oleracea*; біологічні пестициди; природний інсектицид

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 112-123

UDC 631.173.2
DOI: 10.48077/scihor3.2023.112

Forecasting the technical condition of hydraulic transmissions of agricultural machines based on kinematic viscosity and pressure indicators of oil

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Article's History:
Received: 26.01.2023
Revised: 20.03.2023
Accepted: 9.04.2023

Suggested Citation:
Liashenko, D., & Meliantsov, P. (2023). Forecasting the technical condition of hydraulic transmissions of agricultural machines based on kinematic viscosity and pressure indicators of oil. *Scientific Horizons*, 26(3), 112-123.

Abstract. Maintenance of the technical condition of hydrostatic transmission of agricultural machines is not fully provided by the existing repair and maintenance system of Ukraine, which determines the search for available methods for early detection of hydraulic drive malfunctions. The purpose of the study was to synthesise a method for predicting the technical condition of the hydraulic transmission of modern agricultural machines by controlling the dynamics of changes in the values of the empirical dependence of pressure on the kinematic viscosity of oil in conditions of insufficient material and technical equipment of the production base. Generally accepted methods were applied to achieve this goal: analysis-synthesis, induction, observation, experiment, graphic method. As a result of the study, the author's hypothesis was confirmed, according to which the change in the kinematic viscosity of the working fluid relative to the initial value is determined by the current state of the hydraulic transmission, which is controlled by pressure measurement. Based on the identified shortcomings and problems of the current system of maintenance and repair, a methodology was proposed that provides for monitoring the operational indicators of agricultural machines and the kinematic viscosity of working fluid samples taken from their hydraulic transmissions. Kinematic viscosity values for constructing the predictive model were obtained by the capillary method and calculated using the Walter formula, and the dependence of viscosity on influencing factors was determined by bilinear interpolation. A regression model of pressure from kinematic viscosity was obtained by the least squares method, and the exponent was used as an approximating function. Based on the results of testing the models according to the Fischer criterion, their adequacy was confirmed, and the deviation of the theoretical values of the controlled parameters calculated using the most accurate

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model from the empirical ones was 0.34% for pressure and 1.3% for kinematic viscosity. The practical value of the study lies in the fact that the results allow reducing unproductive time costs associated with the downtime of equipment, due to emergency failures of hydraulic transmission units and contribute to the adaptation of the planned preventive maintenance system for agricultural machinery to the needs of the Ukrainian agro-industrial complex

Keywords: combine harvester; hydrostatic transmission; reliability; diagnostics; working fluid properties

INTRODUCTION

The innovative level of design features of hydrostatic gears, with which modern agricultural machines are equipped, causes increased requirements for monitoring their technical condition. Conducting diagnostic measures is usually reduced to identifying the causes of the loss of performance of the hydraulic transmission and the machine in general. This approach leads to unplanned downtime of equipment since resource diagnostics, which are regulated by the existing planned preventive system, do not provide for the possibility of predicting changes in the technical condition of the diagnostic object.

The main tasks of the planned preventive system (PPS) of technical maintenance and repair (TMR) of agricultural machinery, in accordance with the explanation of its essence in a study by Konovaliuk *et al.* (2013) is to maintain the components of the machine in good condition and increase their service life, the solution of which is regulated by the manufacturers of the equipment in the relevant regulatory-technical documentation. According to the studies by Zakharchuk (2019) and Petrov (2020), there is an increase in the number of processing areas per unit of equipment, and the trend of the permanent increase in imports of post-warranty equipment determines the problem of oversaturation of the Ukrainian machine and tractor fleet of the agro-industrial complex (AIC) with machines of the post-warranty period, which require special attention to monitoring their technical condition.

Considering the hydrostatic transmission of a modern agricultural machine as an object of PPS, in the conditions of the repair and maintenance base of Ukraine, the volume of work of which, according to Molodyk *et al.* (2009), has decreased by 5 times since the 90s of the 20th century and continues to decrease, which substantially increases the critical level of the problem of monitoring and restoring the operability of hydraulic machines, the official repair of which can only be conducted with the involvement of repair and maintenance bases of the manufacturer, the material-technical support of which today does not meet the needs for repair of the AIC of Ukraine.

Guo *et al.* (2017) estimated the durability of a modern hydraulic machine has a highly embedded resource, which, depending on the operating conditions and considering the seasonality of their load as part of an agricultural machine, can exceed 10 years of operation, but the average age of the machine and tractor fleet of most production enterprises eliminates this advantage.

Reducing the number of potential resource failures of hydrostatic transmission is possible due to the involvement of the forecasting component in the process of implementing regular maintenance regulations. Andrenko *et al.* (2018) define the concept of forecasting as a solution to the probabilistic problem of determining the behaviour of the system and its state in the future, depending on the factors of influence. Given the complexity of reproducing such studies, the paper presents three forecasting methods that are currently not relevant in practice and require their adaptation to the conditions of the repair and maintenance base of Ukraine: by constructing curves of reliability changes, Markov approximation, and the method of expert assessments. The presented methods of forecasting changes in the technical condition for their implementation in the context of modern hydrostatic transmission are not currently used due to the substantial influence of information uncertainty regarding the dynamics of changes in the resource of modern hydrostatic transmission units. According to studies by foreign researchers, the level of development of the subject on predicting the technical condition of hydraulic transmission units for agricultural machinery could not be estimated due to the complexity of access to relevant information.

Insufficient development of this subject in the conditions of the Ukrainian research complex is partly explained by the adaptability of hydraulic equipment under study only for outdated hydraulic machines GST-90, GST-112, the resource for the failure of which, according to the information provided by Voitov (2018), does not exceed 1000 operating hours and is not sufficient for conducting such studies. In turn, the construction of an available forecasting method is reduced to finding and extrapolating the empirical dependence of pressure on factors influencing it.

Since the indicator of the working fluid pressure in the system reflects the energy efficiency of the hydraulic machine, according to the studies by (Biluš *et al.*, 2021) and Koralewski (2011) is obtained by providing a balance between its mechanical and volumetric efficiency, which is largely determined by the kinematic viscosity of the working fluid. In a study, conducted by Zamiruddin *et al.* (2020), the dependence of the oil film thickness on the viscosity of the working fluid was

confirmed, the relationship between which is described by a positive correlation. In turn, a decrease in kinematic viscosity causes a deterioration in the lubricating properties of the oil, a change in the temperature regime due to an increase in the volume of throttling of the working fluid, a decrease in the productivity and service life of the axial piston hydraulic machine, etc.

Since during the circulation of the working fluid in the hydraulic system, it is prone to loss of its quality properties, the features of changing which are described in the textbook (Boichenko *et al.,* 2019), which lead to ageing of the working fluid and indicate a stochastic relationship between pressure and kinematic viscosity for further development of a method for predicting the state of the hydraulic drive.

Considering the fact that the degradation of the physico-chemical properties of the oil occurs during its operation, the catalyst for changes in the properties of the oil and its kinematic viscosity is the time and intensity of its operation, which is noted in a study by Majdan *et al.* (2019). In accordance with this, a working hypothesis was proposed according to which the loss of productivity of hydraulic machines can be tracked by the dynamics of changes in the pressure of hydraulic transmission, which is determined by the dependence of the kinematic viscosity of the working fluid on the intensity of operation and the technical condition of hydraulic transmission units.

Based on the above material, the purpose of the study was formulated: synthesis of a method for predicting the technical condition of hydraulic transmission of imported agricultural machines by controlling the dynamics of changes in the values of the empirical dependence of pressure on the kinematic viscosity of oil in conditions of insufficient material and technical equipment of the production base of the AIC of Ukraine.

MATERIALS AND METHODS

Measurements of the dynamics of pressure changes together with the established factors of influence on it were conducted during the performance of maintenance, which provides for the replacement of working fluid and filter elements on agricultural machines belonging to various agro-industrial enterprises of Ukraine, in accordance with the methodology developed in the laboratory of the Dnipro State Agrarian and Economic University (DSAEU). The developed methodology for predicting the operability of hydrostatic transmission included the selection of controlling factors and equipment for their monitoring, justification of the plan, and procedure for conducting studies.

The capillary method was chosen to determine kinematic viscosity v of the working fluid, the procedure for which is described in European Pharmacopoeia 10 (2019). This method is based on Poiseuille's law, the application of which is to determine the time of flow of a certain volume of liquid under the influence of gravity through a calibrated glass capillary viscometer at a constant temperature.

The choice of this method is determined by its availability and low complexity of implementation. An experimental setup based on the BPR-3 viscometer was developed to apply the method, d=0.92 mm, which additionally includes a water circulation and heating system (Fig. 1).

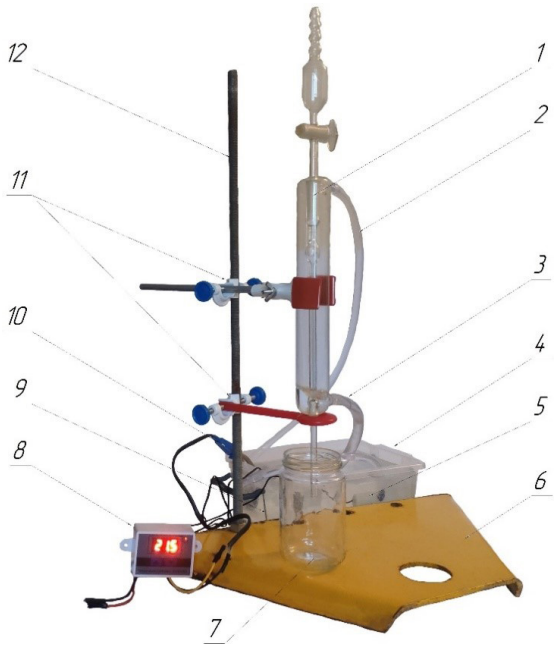

Figure 1. *Installation for determining the kinematic viscosity of the oil at a given temperature: 1 – viscometer, 2 – feed tube, 3 – drain tube, 4 – water tank, 5 – pump, 6 – stand, 7 – working fluid sample tank, 8 – thermostat, 9 – temperature sensor, 10 – electric heater, 11 – viscometer holders, 12 – rod*

The flow time of the working fluid sample is determined three times. Based on their arithmetic mean, kinematic viscosity is calculated using the formula:

$$\nu = \frac{g}{9.807} \cdot t \cdot k, \quad (1)$$

where g=9.80884 (m/s^2) – acceleration of gravity at the place where the kinematic viscosity of the liquid is measured; t – arithmetic mean of the liquid flow time (s); k=0.1716 (mm^2/s^2) – calibration constant of the viscometer.

Two constant temperature programmes were determined to reduce the influence of the human factor on the expression of the viscosity-temperature characteristics of the working fluid when setting the thermostat: T_1=40°C and T_2=60°C, and the calculation of the kinematic viscosity value at an arbitrary temperature is conducted according to the analytical Walter formula presented in the ASTM D341 (2020) standard:

$$log_{10}\big(log_{10}(\nu_T + 0.7)\big) = A - B \cdot log_{10}T, \quad (2)$$

where ν_t – kinematic viscosity of the liquid at temperature T (mm^2/s); T=t+273.15 – liquid temperature, (K); A, B – coefficients determined based on experimentally obtained kinematic viscosity values ν_1 and ν_2 at temperatures T_1 and T_2.

$$A = log_{10}\big(log_{10}(\nu_{T1} + 0.7)\big) + B \cdot log_{10}T1, \quad (3)$$

$$B = \frac{log_{10}(log_{10}(\nu_{T2}+0.7)) - log_{10}(log_{10}(\nu_{T1}+0.7))}{log_{10}\frac{T1}{T2}}. \quad (4)$$

Formula (2) was converted to the following to find the value of the kinematic viscosity from it:

$$\nu_t = 10^{10^{(A-B\cdot log_{10}T)}} - 0.7. \quad (5)$$

The working fluid pressure values were measured in compliance with the temperature requirements specified in the regulatory-technical documentation for the machine using an electronic diagnostic device (Fig. 2), which was developed and calibrated independently of the current study. The principle of its operation is based on reading pressure values using piezoresistive sensors, which are installed in the structurally provided technological holes of the volumetric hydraulic machine, and the temperature of the liquid in the hydraulic system through digital sensors, which are fixed to the couplings of high-pressure hoses at the point of their connection with the hydraulic pump.

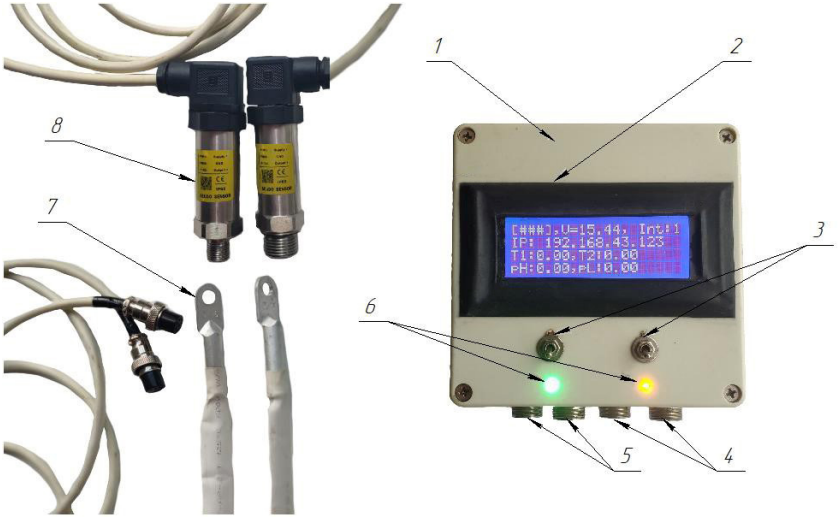

Figure 2. *Appearance of the device for measuring the pressure and temperature of the working fluid: 1 – computing unit, 2 – display, 3 – toggle switches, 4 – temperature sensor ports, 5 – pressure sensor ports, 6 – workflow indicators, 7 – temperature sensors, 8 – pressure sensors*

The operating time and fuel consumption of each technical system was recorded using the built-in computer, the main features of which are described in the TUCANO 500 configuration instructions (2018). The obtained data was grouped with the previously obtained diagnostic parameters of the machine and entered in the spreadsheet on the personal computer.

Notably, due to the unmanageability of the controlled parameters, which were selected as factors of the working fluid pressure response function, the construction of models was conducted based on the results of a passive experiment, which, accordingly, will mean a deterioration in the predictive properties of models, but according to Lapach (2020), the use of a passive experiment is allowed if it is impossible to conduct an active full factor experiment. In turn, due to the insufficient amount of information about the mechanism of the processes of changing the state of the working fluid and the operability of hydraulic system units (the dynamics of which is individual for each machine), it was decided to apply the cybernetic approach of the "black box", which is fully described in the study (Obod *et al.,* 2019).

As a result of the study of the relationship of controlled factors, the decomposition of an empirical dependence of pressure on the kinematic viscosity of the working fluid was conducted, according to which a four-level hierarchical structure of dependencies of controlled factors was formed, in which factors of the subsequent level are determined by factors of the previous level (Fig. 3), and the desired mathematical model will be a nested superposition of functions of the form:

$$p(\nu(i(t_c, V_c), t_з)), \quad (6)$$

where p – regression dependence of pressure on kinematic viscosity (MPa); ν – regression dependence of kinematic viscosity on the intensity of machine operation and total machine operating time t_s (mm^2/s); i – formula for the intensity of machine operation; t_s – car operating time per season (operational hours); V_s – fuel consumed per season (L).

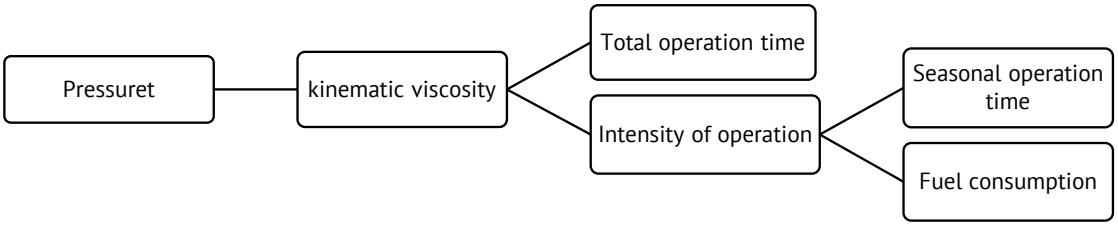

Figure 3. *Theoretical hierarchy of relationships between controlled parameters*

According to Formula (6), the solution to the problem involves consistently finding functional dependencies in descending order of their nesting level: operating intensity, kinematic viscosity, pressure. The formula for the intensity of operation of the machine (7) was determined in terms of the share of fuel consumption and operating time for the current season. This function was introduced to reduce the complexity of calculating the coefficients of the kinematic viscosity regression equation by reducing the number of predictors.

$$i(t_c, V_c) = \frac{V_c}{t_c}. \quad (7)$$

The kinematic viscosity formula $\nu(i, t_s)$ was decided to be calculated by the method of bilinear interpolation. However, its application requires compliance with certain conditions, namely, the presence of four points with coordinates corresponding to the predictors of the desired dependence, which form a rectangle whose sides are parallel in pairs to the abscissa or ordinate axes. Since the conditions for applying the method are violated due to the presence of an insufficient number of points, and the satisfaction of the condition for placing these points will be probabilistic, therefore, to ensure permanent compliance with the requirements of applying the method, an algorithm for converting the initial data in accordance with the requirements for applying bilinear interpolation for three arbitrary points was proposed, the procedure for which is presented below.

It is necessary to draw vertical perpendiculars to the abscissa axis through the existing three points, the abscissa value of which is minimum or maximum, and through the points, the ordinate value of which is minimum or maximum, draw horizontal perpendiculars to the ordinate axis to determine the vertices of a rectangle on the Cartesian plane, the coordinates of which will correspond to the values of the predictors of the function $\nu(i, t_s)$, and each such vertex will correspond to a single value of kinematic viscosity. As a result of the intersection of these lines, a rectangle with vertices at the points will be formed: $(i_{min}, t_{s.min})$, $(i_{min}, t_{s.max})$, $(i_{max}, t_{s.min})$, $(i_{max}, t_{s.max})$.

Finding the applicat for the formed points, the values of which correspond to the kinematic viscosity, is primarily reduced to finding the general equation of the plane in three-dimensional space:

$$A \cdot i + B \cdot t + C \cdot \nu + D = 0, \quad (8)$$

where A, B, C – coefficients of the equation.

According to the theoretical material on linear algebra and analytical geometry, which is systematised in the Osadcha manual (2020), it is possible to find the coefficients of equation (8) through a third-order determinant, the elements of which correspond to the differences of certain controlled parameters that are represented on one of the axes of a three-dimensional Cartesian coordinate system, the lower index of which corresponds to the maintenance number at which the diagnostic parameter was obtained:

$$\begin{vmatrix} i - i_1 & t - t_1 & \nu - \nu_1 \\ i_2 - i_1 & t_2 - t_1 & \nu_2 - \nu_1 \\ i_3 - i_1 & t_3 - t_1 & \nu_3 - \nu_1 \end{vmatrix} = 0. \quad (9)$$

Substituting the values of the controlled parameters obtained for the last three maintenances and identifying the determinant (9) on the left side of the expression, after reducing such terms, the desired general equation of the plane is obtained.

According to the geometric interpretation of kinematic viscosity, its value corresponds to the applicator of the intersection point of the perpendicular omitted to the XOY plane and plane (8). It is necessary to substitute

each of the four points formed at the beginning of the algorithm into equation (8) and solve it with respect to ν to find the desired applicates.

The model of the relationship between pressure and kinematic viscosity in accordance with the volume of observations of the dynamics of changes in controlled parameters at the initial stage was determined by the LaGrange polynomial of the 2nd degree, which in turn assumed the simplicity of its application and a low error of the formula, and minimising the influence of the Runge phenomenon in the current order of the polynomial, which Belanger (2017) conducted studies on to eliminate.

The results obtained using this algorithm provide sufficient conditions for applying the bilinear interpolation method to construct an empirical dependence of kinematic viscosity on the operating intensity and overall operating time of the machine. The calculation of the function-response values was conducted according to the approach described by Chapra and Raymond (2015):

$$F(i,t)=\frac{1}{(i_{max}-i_{min})(t_{3.\max}-t_{3.\min})}[i_{max}-i\ i-i_{min}]\begin{bmatrix}\nu_{11} & \nu_{12}\\ \nu_{21} & \nu_{22}\end{bmatrix}\begin{bmatrix}t_{3.max}-t\\ t-t_{3.min}\end{bmatrix}, \quad (10)$$

where $\nu_{11}=\nu(i_{\min}, t_{3.\min})$, $\nu_{12}=\nu(i_{\min}, t_{3.\max})$, $\nu_{21}=\nu(i_{\max}, t_{3.min})$, $\nu_{22}=\nu(i_{\max}, t_{3.max})$.

Checking the adequacy of forecasting using this formula showed unsatisfactory results of approximation accuracy, and therefore, using the least squares method (LSM), it was determined that the optimal function for describing models is an exponential function of the form (11), the coefficients of which are obtained from the system of linear equations (12).

$$f(x)=a_1\cdot e^{a_2\cdot x}, \quad (11)$$

where a_1, a_2 – undefined coefficients

$$\begin{cases}a_1\cdot n+a_2\cdot\sum_{i=1}^{n}x_i=\sum_{i=1}^{n}y_i\\ a_1\cdot\sum_{i=1}^{n}x_i+a_2\cdot\sum_{i=1}^{n}x_i^2=\sum_{i=1}^{n}x_i\cdot y_i\end{cases}. \quad (12)$$

Since function (11) is not linear with respect to its coefficients, it is necessary to reduce it to a linear form and perform substitutions, the substitution of which in the system (12) allows finding the coefficients a_1, a_2 and the LSM model.

$$\ln y=\ln a_1+a_2\cdot x \quad (13)$$

$$\begin{cases}a_1'=\ln a_1\\ y'=\ln y\end{cases}. \quad (14)$$

RESULTS AND DISCUSSION

Increased attention to monitoring the technical condition of hydraulic systems (HS) by the value of the working fluid pressure, in contrast to monitoring its supply, is explained by the structural adaptability of hydraulic machines provided by technological holes through which mechanical or electrical pressure monitoring sensors are connected, and the installation of a flow meter in the HS circuit is accompanied by a number of problems, including: the need for depressurisation of the system, which causes a higher labour intensity, the possibility of violating the integrity of connections in the places where the flow meter is installed, soil contamination with oil; high cost of implementation. Therefore, monitoring the technical condition by the working fluid pressure value is a priority, since it does not require substantial material and labour costs with a satisfactory level of its information content.

According to the user's instructions for the Comia C6/C8 combine harvester (2020), the regulations for conducting periodic maintenance of which are similar to most agricultural machines of the world market leaders, the procedures for maintaining the technical condition of the HS are limited to organoleptic inspection of tightness, oil level and surface contamination, and the preliminary assessment of the technical condition is reduced to monitoring such diagnostic parameters as pressure and flow of working fluid, the permissible deviation of which is not regulated by the documentation.

The DSTU 2193-93 (1994) standard established the permissible deviation of operability for the total efficiency and feed rate, which should not decrease by more than 15% and 7% relative to the initial values, respectively. However, the problem of establishing a correlation between the total efficiency and the working fluid pressure makes this technical requirement time-consuming and financially expensive to implement. In practice, the operation of the hydraulic transmission is stopped only if it is impossible for it to perform its functions in full, which, on the example of Lexion combine harvesters, corresponds to a pressure threshold of 40 MPa for the 90R130/100 hydraulic pump, the nominal pressure value of which, according to the official manufacturer's catalogue (2016), is 45 MPa.

Observations on the dynamics of changes in controlled parameters took place during four seasons of operation for each machine equipped with hydraulic transmission, except for the first one, the object of study of which failed due to an emergency failure due to an operational factor. A certain number of observations is established in accordance with the rules of forecasting, namely, the extrapolation period for the future should not exceed a third of the observation period described by Batsamut (2020). An additional fourth observation was performed to evaluate the accuracy of the obtained empirical dependencies.

Immediately before implementing regular maintenance, diagnostic parameters for monitoring the technical condition of hydrostatic gears and machine operation indicators, shown in Table 1, were recorded.

Table 1. *Indicators of controlled parameters of the study objects*

No. of object	Object experiment	Season	Total operating time, operating hours	Pressure, MPa	Temperature, °C	Fuel consumption, L
1	Tucano 480	1	4193.60	41.74	50.81	162177.00
		2	4638.40	41.68	49.01	179389.00
		3	-	-	-	-
		4	-	-	-	-
2	Tucano 570	1	4578.35	41.95	50.44	169444.00
		2	5144.50	41.62	49.15	190425.00
		3	5716.65	41.16	49.47	211600.00
		4	6250.80	40.98	47.03	231403.00
3	Lexion 560	1	6797.92	41.91	47.99	242727.00
		2	7351.52	41.74	47.77	262520.00
		3	7883.12	41.21	48.86	281531.00
		4	8446.72	41.13	49.71	301658.00
4	Lexion 560	1	6071.16	41.89	49.96	247292.00
		2	6674.80	41.77	51.33	271911.00
		3	7249.44	41.70	50.69	295357.00
		4	7813.08	41.62	51.19	318294.00
5	Lexion 580	1	4501.22	41.67	47.88	190383.00
		2	5060.24	41.52	46.30	214034.00
		3	5572.26	41.32	46.67	235738.00
		4	6129.28	41.29	46.17	259290.00
6	Lexion 580	1	4952.91	41.33	51.94	185246.00
		2	5443.9	41.09	51.09	203625.00
		3	5921.89	40.61	47.60	221529.00
		4	6405.88	40.42	46.20	239619.00

Source: *compiled by the authors*

The results of determining kinematic viscosity based on working fluid samples that were removed from hydraulic transmissions after scheduled maintenance work are presented in Table 2.

Table 2. *Kinematic viscosity indicators of working fluid samples*

No. of object	Season	Kinematic viscosity at 38°C, mm^2/s	Kinematic viscosity at 40°C, mm^2/s	Kinematic viscosity at 58°C mm^2/s
1	1	45.48	42.20	23.30
	2	43.76	40.60	22.14
	3	-	-	-
	4	-	-	-
2	1	42.90	39.60	20.90
	2	40.90	37.70	19.80
	3	40.20	37.20	20.00
	4	39.40	36.50	19.70
3	1	39.80	37.60	23.70
	2	39.40	37.20	23.30
	3	37.00	34.80	21.40
	4	36.10	34.00	21.10

Table 2, Continued

No. of object	Season	Kinematic viscosity at 38°C, mm²/s	Kinematic viscosity at 40°C, mm²/s	Kinematic viscosity at 58°C mm²/s
4	1	41.20	38.20	21.00
	2	38.70	36.00	20.30
	3	38.40	35.80	20.22
	4	38.40	35.80	20.22
5	1	44.30	40.80	21.40
	2	42.80	39.50	20.90
	3	40.90	37.70	19.70
	4	40.00	36.80	19.10
6	1	39.30	36.30	19.40
	2	37.70	34.90	18.80
	3	35.90	33.30	18.20
	4	35.70	33.10	18.20

Source: *compiled by the authors*

Table 3 shows the theoretical values of the desired controlled parameters calculated according to the research methodology, based on which an assumption is made about the technical condition of the research object at the time of performing the next maintenance.

Table 3. *Predicted values of controlled parameters of study objects*

No. of object	Intensity of operation, L/operating hours	Viscosity, mm²/s	Pressure, MPa
1	-	-	-
2	37.05193991	29.09	39.04
3	35.76750601	32.60	40.67
4	40.79360815	33.89	41.61
5	42.35878058	36.32	41.15
6	37.46030481	31.78	40.28

Source: *compiled by the authors*

From the graphical interpretation of the comparative characteristics of theoretical and practical values of viscosity and pressure of the working fluid (Fig. 4) it can be seen that the accuracy of the approximation is satisfactory and sufficient to confirm the working hypothesis. Moreover, the resulting calculation error is largely due to the poorly defined intensity of machine operation, and to a lesser extent, the influence of undetected factors.

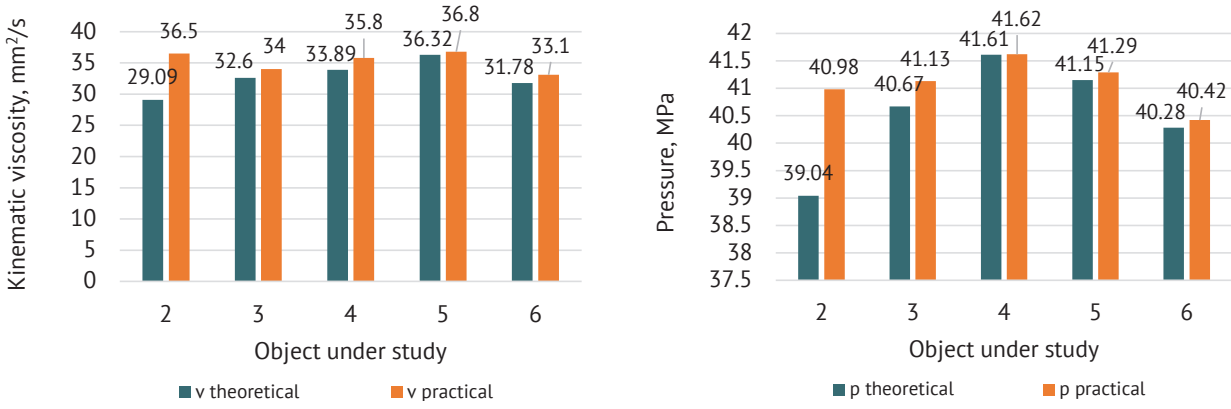

Figure 4. *Comparative characteristics of the values of theoretical and operational indicators: 1) kinematic viscosity; 2) pressure*

The mathematical statistics apparatus was used and the prediction results were compared with the control values obtained during the fourth maintenance to check the adequacy of the developed models. Statistical indicators of the substantiality of models are shown in Table 4.

Table 4. *Estimation of the substantiality of pressure regression dependences on kinematic viscosity*

No. of object	MAPE	η	R^2	SE	F-statistics	α– reliability
1	-	-	-	-	-	-
2	0.047%	0.912	0.832	0.005540	4.955	0.1
3	0.01%	0.995	0.990	0.001250	97.6067	0.1
4	0.00777%	0.956	0.914	0.000955	10.5812	0.1
5	0.000505%	0.990	0.990	0.000056	11372.4191	0.1
6	0.018%	0.988	0.977	0.001940	41.5973	0.1

Source: *compiled by the authors*

The values of the mean absolute percentage error (MAPE) do not exceed 0.047%, which indicates a successful choice of the exponent as a function for approximating the pressure dependence on kinematic viscosity. The value of the coefficient of determination R^2 is within [0.832; 0,99], this confirms the high compliance of the developed models with the original data.

Empirical correlation relationship η, which is used to measure the strength of the correlation dependence of kinematic viscosity and pressure, changes within the interval $0 \leqslant \eta \leqslant 1$, the smaller the deviation η from one, the stronger the response (pressure) depends on the feature factor (kinematic viscosity). The deviation of the calculated values of η for models does not exceed 0.088, which at the qualitative level on the Cheddock scale corresponds to a very high correlation strength.

The measure of variation in the factual data around the model is the standard regression error indicator (*SE*), which does not exceed 0.005, which theoretically causes high prediction accuracy. However, the influence of random operational processes on the values of response functions and their additional extrapolation minimises the substantiality of this statistical indicator. But comparisons of theoretical and practical values of the controlled parameters showed a deviation of 4.73% for pressure and 20.3% for kinematic viscosity of the least accurate model No. 2, a deviation of 0.34% for pressure and 1.3% for kinematic viscosity of the most accurate model No. 5.

The hypothesis of the substantiality of models was tested according to Fischer's F-criterion at the substantiality level α=0.1. Based on the results of this, the adequacy of models for objects No. 3, 5, and 6 was confirmed and refuted for objects No. 2, 4. Possible discrepancies in the accuracy of the models may be due to measurement error and the influence of random factors (which in the case of object No. 1 led to an emergency failure).

The obtained results of forecasting the technical condition of hydrostatic transmission according to the developed method confirmed the possibility of its practical application in the production conditions of agricultural enterprises. Notably, regardless of the accuracy of the forecast of the technical condition using this method, the possibility of an emergency failure of the hydraulic drive is not excluded, which can be caused by subjective and difficult-to-predict factors.

In accordance with the complexity of the search for papers relevant to the current study, an analogy was drawn with models for predicting the state of hydraulic machines for other diagnostic features at the qualitative level and it was established that the scientific and practical substantiality of the current study for improving the planned preventive system of maintenance and repair of agricultural machines is substantial, which is explained by the use of available equipment and the low labour intensity of its implementation.

Andrenko *et al.* (2018) provide a list of methods: based on reliability change curves, Markov approximation, and expert assessment method, which can theoretically be used to predict the technical condition of hydraulic drives. Forecasting based on reliability curves is based on an assessment of the maximum reliability of hydraulic drives and the probability of failure-free operation. This method provides for an analytical description of the probability of failure-free operation of the hydraulic drive and requires a substantial amount of bench studies, the results of which will not correspond to the actual operating conditions of the machine. Since the production of hydraulic equipment by different manufacturers may differ in resource to failure and their operation as part of agricultural machinery does not provide for a uniform load, this method can only be effective when operating in conditions that are close to bench conditions. Forecasting the characteristics of the hydraulic drive according to the Markov approximation is conducted on a similar principle, but the function of the probability of failure-free operation is determined by the equation of the Markov process, the

determination of the coefficients of which is accompanied by substantial difficulties, since the dynamics of their change is described based on long-term observations of the quantitative change in the connection of structural and diagnostic features of the hydraulic machine, which means the need for periodic depressurisation of the HS and dismantling of the study object to perform direct diagnostics. The method of expert assessments based on the results of a survey of experts in the relevant industry is also accompanied by problems with its implementation: the optimal number of experts to reproduce the method is 5-10 and its application allows determining the weight of factors on the state of the hydraulic drive only at a qualitative level. According to the above disadvantages, the information content of this heuristic method when predicting the technical condition of hydrostatic transmission units is low, and its applicability is difficult in the Ukrainian repair and maintenance base conditions.

Based on the GO methodology and grey systems theory, the integrated HS prediction approach described by Liu (2018) is a solution for predicting systems with a small data sample and information uncertainty. The essence of the method is to determine the input and output signals that reflect the state of the hydraulic system, represent the units in the form of a GO model, and collect statistical information according to which the accuracy of the model is adjusted. Narrowing down the object of the study by this method to a hydraulic drive, the method is reduced to determining the factors of influence and their substantiality on the reliability of a hydraulic machine, which is a typical forecasting problem that is not solved by this method.

Methods described in the papers by Guo *et al*. (2020) and Li *et al*. (2021), based on forecasting by vibration oscillations and on the method of machine learning k-nearest neighbours, respectively, reflect current trends in the development of forecasting hydraulic machines in laboratory conditions, the implementation of which is accompanied by increased requirements for diagnostic equipment and the need to dismantle hydraulic drives. An attempt to integrate the first method into an agricultural machine equipped with a hydrostatic transmission will lead to a substantial loss of its information content due to the presence of other sources that affect the amplitude of vibrations. Integration of the second method will not lead to a loss of its efficiency, but the cost of operating equipment will substantially increase due to the need for expensive equipment, the installation of which occurs when the HS circuit is depressurised, which in turn will increase the labour intensity of the maintenance and the requirements for the qualification of equipment operators. Therefore, research on the development of available methods for predicting the technical condition of hydraulic drives of agricultural machines based on the pressure dependence on the working fluid parameters is the basis for improving the area of optimisation of the TOR system of hydraulic equipment.

CONCLUSIONS

The analysis of the features of ensuring the technical condition of hydraulic transmission drives of agricultural machines showed that the existing system of support and restoration of the working condition of hydraulic transmissions substantially depends on the equipment of the repair and maintenance base, which today does not meet the needs of industrial agricultural enterprises and leads to unplanned downtime of equipment during seasonal agrotechnical works. This state of affairs has determined the need to develop an affordable method for predicting the technical condition of the hydraulic transmission drive.

As a result of processing the data obtained during observations of the dynamics of changes in the performance indicators of agricultural machines and working fluid viscosity indicators, the working hypothesis of the study was confirmed and a method for predicting the technical condition of hydraulic transmission drives was proposed, which is based on monitoring and extrapolating the performance indicators of agricultural machines and the kinematic viscosity of working fluid samples. The accuracy of theoretical controlled indicators calculated using the proposed method has minor deviations from the models the substantiality of which has been confirmed, relative to empirical ones within the limits of [0.34%; 1.12%] for pressure and [1.3%; 4.12%] for kinematic viscosity. The proposed method creates sufficient requirements for forecasting the technical condition of the hydraulic transmission of agricultural machines for one season, with little labour intensity of its implementation, which does not provide for the dismantling of hydraulic machines and does not have a substantial impact on the maintenance work regulations.

Forecasting the technical condition of the hydraulic drive by the proposed method will allow owners of hydrofected equipment to respond in a timely manner to the dynamics of changes in its operability, which provides the following advantages: the ability to determine the need for repairs in the early stages of operation; prevent increased costs for eliminating emergency failures due to reducing the likelihood of their occurrence; reduce unproductive time spent associated with downtime of equipment; ensuring an economical mode of operation of machines. In addition, the implementation of this method is based on available equipment, which makes it highly important in the field.

Improving the quality of forecasting using this method is possible by creating conditions for conducting a complete factor experiment with an expanded set of Integral diagnostic features, which will allow more accurate tracking of patterns of changes in the functional parameters of the hydraulic drive and draw

conclusions about the residual resource of hydraulic machines. Further prospects for applying the method consist in its adaptation to the regulations of the planned-preventive system for construction and road equipment equipped with hydrostatic transmission.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Прогнозування технічного стану гідравлічних трансмісій сільськогосподарських машин за показниками кінематичної в'язкості і тиску оливи

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Анотація. Підтримка технічного стану гідростатичної передачі сільськогосподарських машин не забезпечується наявною ремонтно-обслуговуючою системою України у повній мірі, що обумовлює пошук доступних методів для завчасного виявлення несправностей гідроприводів. Мета роботи полягала у синтезі методу прогнозування технічного стану гідравлічної трансмісії сучасних сільськогосподарських машин за контролем динаміки зміни значень емпіричної залежності тиску від кінематичної в'язкості оливи в умовах недостатнього матеріально-технічного оснащення виробничої бази. Для досягнення поставленої мети були застосовані загально-прийняті методи: аналіз-синтез, індукція, спостереження, експеримент, графічний метод. У результаті проведеного дослідження підтвердилася висунута автором гіпотеза за якою зміна кінематичної в'язкості робочої рідини відносно початкового значення визначається поточним станом гідравлічної трансмісії, контроль якої здійснюється за виміром тиску. На основі виявлених недоліків і проблем діючої системи технічного обслуговування і ремонту було запропоновано методику, яка передбачає контроль експлуатаційних показників сільськогосподарських машин і кінематичної в'язкості проб робочої рідини, взятих з їх гідравлічних трансмісій. Значення кінематичної в'язкості для побудови прогнозуючої моделі були отримані за капілярним методом і розраховувалися за формулою Вальтера, а залежність в'язкості від факторів впливу визначалась методом білінійної інтерполяції. Регресійну модель тиску від кінематичної в'язкості було одержано за методом найменших квадратів, в якості апроксимуючої функції використано експоненту. За результатами перевірки моделей за критерієм Фішера було підтверджено їх адекватність, причому відхилення теоретичних значень контрольованих параметрів, розрахованих за найбільш точною моделлю, від емпіричних склали 0,34 % для тиску і 1,3 % для кінематичної в'язкості. Практична цінність роботи полягає в тому, що результати роботи дозволяють зменшити непродуктивні витрати часу, пов›язані з простоєм техніки, внаслідок аварійних відмов агрегатів гідравлічних трансмісій і сприяють адаптації планово-попереджувальної системи технічного обслуговування сільськогосподарських машин до потреб українського агропромислового комплексу

Ключові слова: зернозбиральний комбайн; гідростатична передача; надійність; діагностування; властивості робочої рідини

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 124-134

UDC 621.73.011.001.5
DOI: 10.48077/scihor3.2023.124

Determination of porosity functions in the pressure treatment of iron-based powder materials in agricultural engineering

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Article's History:
Received: 18.01.2023
Revised: 18.03.2023
Accepted: 16.04.2023

Suggested Citation:
Sivak, R., Kulykivskyi, V., Savchenko, V., Minenko, S., & Borovskyi V. (2023). Determination of porosity functions in the pressure treatment of iron-based powder materials in agricultural engineering. *Scientific Horizons*, 26(3), 124-134.

Abstract. One of the most effective ways to obtain products with the required performance characteristics is the cold plastic deformation of porous workpieces. The relevance of the subject under study is due to the need to increase the reliability of the stress-strain state assessment during the plastic processing of porous workpieces by clarifying the porosity functions. The purpose of the study is to develop a method for describing the mechanical characteristics of porous bodies by single functions, the nature of which is determined by the properties of the base material and does not depend on the initial porosity. Analytical, numerical, experimental, and computational methods using modern specialised software systems were used to examine the processes of plastic deformation. The study presents a method for describing the mechanical characteristics of porous bodies with single functions. A set of interrelated methods and techniques is based

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on the basic provisions of the mechanics of plastic deformation of porous bodies and allows obtaining reliable porosity functions for this material, by clarifying theoretical dependencies by experimental studies. Therewith, experimental data were obtained in experiments on axisymmetric upsetting of cylindrical samples without friction at the ends. Based on the conducted theoretical studies, porosity functions for iron-based materials are obtained. Samples of five different initial porosities were used for the study. As a result of processing experimental data, final expressions for the porosity functions of the iron-based powder workpiece material are obtained. The study also presents a method for calculating the accumulated deformation of the base material. Flow curves for iron-based powder materials are plotted. The obtained results will allow formulating the practical recommendations for the development of technological processes for the plastic processing of powder materials by pressure to obtain products with specified physical and mechanical properties

Keywords: material; porosity function; pressure treatment; cold plastic deformation; flow curve; stress

INTRODUCTION

Information about the effect of shape change on each material particle in the volume of the workpiece is necessary to ensure the technological quality of finished products in pressure processing. Reliable information about the stress-strain state and the regularity of its change can be obtained by solving the boundary value problem of plasticity theory. Various types of surface plasticity and the associated flow law allow considering the influence of hardening and the type of stress state when solving problems in the theory of plasticity of a porous body. Therefore, the development and improvement of plastic deformation processes of porous materials depend on the accuracy of the stress-strain state assessment since the result substantially affects the idea of rheological properties in real pressure treatment processes.

The damage accumulation model is based on the hypothesis (Grushko *et al.,* 2017) that changes are directed in nature and are described by a second-rank tensor. The components of this tensor are determined by the mechanics of plastic deformation in a particular technological process, and functions that describe the physical and mechanical properties of the material. The accuracy of determining the value of the plasticity resource used depends not only on the criteria that consider the tensor nature of damage accumulation (Titov *et al.,* 2018; Puzyr *et al.,* 2021) but also on the reliability of the stress-strain state assessment. The considered criteria for estimating the value of the plasticity resource used include determining the stress-strain state considering the strain anisotropy. The formulation and solution of problems of the theory of plasticity of a porous material differs substantially from the formulation of a similar problem for a solid body. Not all the main provisions of the theory of irreversible deformation of compressible media are fully established. Model representations are most widely used to solve technological problems of pressure treatment of porous bodies (Shtern *et al.,* 2021), which are based on a continuous approach. A locally inhomogeneous medium is considered as a continuous medium, the state of which can be described using force and kinematic parameters that obey the laws of a continuous medium. When mathematically modelling the process of irreversible shape change of a porous body, it is necessary to determine the rheological properties of porous materials, which is the main condition. Therefore, theories that define plasticity surfaces of various types and use the flow law associated with them have become widespread. This approach allows considering the effect of hardening caused by the amount of shape and volume change and the type of stress state.

K. Gogaev *et al.* (2017), I. Prikhod'ko *et al.* (2016) proposed a model of a nonlinear viscous-elastic medium for examining the extrusion of powder materials through axisymmetric matrices, which allowed for formulating and solving the boundary value problem. Therewith, experimental data obtained on field samples using the coordinate grid method were used to determine the velocity field in the strain cell.

The development of various generalisations of the simplest theory of plasticity of a porous body towards accounting for strain hardening in the solid phase of a porous body was conducted in two ways: using independent experiments on a porous material (Beygelzimer *et al.,* 2021) and using a static model of a porous body and the law of strain hardening of a solid (non-porous) base material (Shtern & Kartuzov, 2016). Modification of the load surface in the form of an ellipsoid of rotation, which is shifted relative to the origin (Aliieva *et al.,* 2020), allows considering the difference in deformation resistance and changes in volume at hydrostatic pressure. Along with considering the macroscopic features of the deformation of porous bodies, attempts are made to analyse the nature of changes in the porous structure. Therewith, visual representations related to the shape and location of the load surface are used. This type includes a model (Shtern *et al.,* 2021), which considers the presence of two-dimensional defects along with pores.

A general constraint (Skorokhod & Shtern, 2019) linking porosity functions follows from the analysis of known models. Expressions for the material constant from the Mises plasticity condition for a porous billet based on iron and copper, depending on the porosity

functions, are obtained by V. Rud *et al.* (2020). At the stage of isostatic loading and subsequent unloading, with combined deformation (Abdelmula *et al.,* 2017), an established seal is established. However, it is believed that the reduction in porosity during unloading can be ignored. Therefore, for the final stage of combined deformation under axial load, the initial porosity is greater than at the first stage under isostatic load. The density increase at the last stage under axial load is reduced to solving the Cauchy problem for an ordinary differential equation, in which the porosity function satisfies the expression with respect to the radial stress component and the initial conditions.

Thus, it can be argued that in most cases the solution of pressure treatment problems using the developed mathematical models of various processes and phenomena that occur during plastic deformation of porous bodies is reduced to the formulation of boundary value problems for certain systems of differential equations. The reliability of mathematical methods of the theory of plasticity of porous bodies directly depends on how accurate the porosity functions are. Therefore, the purpose of the study is to increase the reliability and accuracy of determining the real physical and mechanical properties of porous materials by experimentally clarifying the porosity functions, which is considered an important stage in the creation of new technological processes for plastic processing.

MATERIALS AND METHODS

The plasticity equations of a porous body were used to develop the theory of forming powder materials (Shtern *et al.,* 2021). In this case, the basic equations of the theory of porous body flow have the form:

$$\tau_0^2 = \frac{p^2}{f_2(\theta)(1-\theta)} + \frac{\tau^2}{f_1(\theta)(1-\theta)}; \quad (1)$$

$$\dot{e}_{ij} - \frac{1}{3}\dot{e}\delta_{ij} = \frac{\dot{\gamma}}{\tau}\left(\sigma_{ij} - p\delta_{ij}\right); \quad (2)$$

$$pf_1(\theta)\dot{\gamma} = \tau f_2(\theta)\dot{e}; \quad (3)$$

$$\dot{\gamma}_0^2 = \frac{f_2(\theta)\dot{e}^2}{(1-\theta)} + \frac{f_1(\theta)\dot{\gamma}^2}{(1-\theta)}; \quad (4)$$

$$G_0 = \int_0^t \dot{\gamma}_0 d\tau, \quad (5)$$

where τ_0 – intensity of the stress deviator in the base material; p – average voltage, $p = \frac{1}{3}\sigma_{ij}\delta_{ij}$; θ – porosity; τ – intensity of the stress deviator,

$$\tau = \sqrt{(\sigma_{ij} - p\delta_{ij})(\sigma_{ij} - p\delta_{ij})}; \quad (6)$$

$\dot{e}_{ij}$ – components of the strain velocity tensor; $\dot{e}$ – rate of relative volume change, $\dot{e} = \delta_{ij}\dot{e}_{ij}$; $\dot{\gamma}$ – intensity of the strain velocity deviator,

$$\dot{\gamma} = \sqrt{\left(\dot{e}_{ij} - \frac{1}{3}\dot{e}\delta_{ij}\right)\left(\dot{e}_{ij} - \frac{1}{3}\dot{e}\delta_{ij}\right)} = \sqrt{\frac{2}{3}}\dot{\varepsilon}_u; \quad (7)$$

σ_{ij} – components of the stress tensor; $\dot{\gamma}_0$ – intensity of the strain velocity deviator in the base material; G_0 – accumulated deformation of the base material.

The following expressions for porosity functions are obtained from theoretical references (Beygelzimer *et al.,* 2022):

$$f_{10}(\theta) = (1-\theta)^2; \quad (8)$$

$$f_{20}(\theta) = \frac{2}{3}\cdot\frac{(1-\theta)^3}{\theta}. \quad (9)$$

The theoretical dependencies (8) and (9) for the porosity functions will be clarified according to the data of M. Shtern *et al.* (2021), via coefficients *m* and *n*, which are determined experimentally and are different (Sivak, 1996) for each porous material:

$$f_1(\theta) = (f_{10}(\theta))^{n+1} = (1-\theta)^{2n+2}. \quad (10)$$

According to the studies by I. Sivak (1996), function $\alpha(\theta)$ has the form:

$$\alpha(\theta) = \frac{1}{6}\cdot\frac{f_1(\theta)}{f_2(\theta)}. \quad (11)$$

Theoretical expression for the porosity function:

$$\alpha_0(\theta) = \frac{1}{6}\cdot\frac{f_{10}(\theta)}{f_{20}(\theta)} = \frac{\theta}{4(1-\theta)}. \quad (12)$$

Function $\alpha(\theta)$ considering the parameter *m* takes this form:

$$\alpha(\theta) = \alpha_0^m(\theta) = \left(\frac{\theta}{4(1-\theta)}\right)^m. \quad (13)$$

Experimental values *m* and *n* will be calculated for axisymmetric upsetting of cylindrical samples without friction at the ends in experiments. Since the deformation is axisymmetric, then . The rate of volume change is:

$$\dot{e} = \dot{e}_z + 2\dot{e}_\phi, \quad (14)$$

and the intensity of the strain velocity deviator is described by the expression

$$\dot{\gamma} = \sqrt{\left(\dot{e}_z - \frac{\dot{e}_z + 2\dot{e}_\varphi}{3}\right)^2 + 2\left(\dot{e}_\varphi - \frac{\dot{e}_z + 2\dot{e}_\varphi}{3}\right)^2} = \sqrt{\frac{2}{3}}(\dot{e}_\varphi - \dot{e}_z). \quad (15)$$

In addition, with the frictionless upsetting $\sigma_r = \sigma_\varphi = 0$, $\sigma_z = -\sigma$, then the relations have the form:

$$p = \frac{\sigma_r + \sigma_\varphi + \sigma_z}{3} = -\frac{\sigma}{3}; \quad (16)$$

$$\dot{\gamma} = \sqrt{\left(\dot{e}_{ij} - \frac{1}{3}\dot{e}\delta_{ij}\right)\left(\dot{e}_{ij} - \frac{1}{3}\dot{e}\delta_{ij}\right)} = \sqrt{\frac{2}{3}}\dot{\varepsilon}_u. \quad (17)$$

The volume deformation rate is equal to:

$$\dot{e} = \frac{1}{V}\cdot\frac{dV}{dt} = -\frac{1}{\rho}\cdot\frac{d\rho}{dt}. \quad (18)$$

The density of the material is:

$$\rho = \rho_0(1-\theta), \quad (19)$$

where ρ – density of the porous body; ρ_0 – density of the base material.

The following is considered time parameter:

$$t = |e_z| = ln\frac{h_0}{h}, \quad (20)$$

where h_0, h – initial and current height of the upsetting sample.

The expression for axial deformation has the form:

$$\frac{de_z}{dt} = -1. \quad (21)$$

Since the accumulated deformation of the base material G_0 depends on the time and porosity, the following can be written:

$$\frac{dG_0}{dt} = \frac{dG_0}{d\theta} \cdot \frac{d\theta}{dt}. \quad (22)$$

Equivalent stress intensity in the base material τ_0 corresponds to the upsetting stress:

$$\sigma = |\sigma_z| = \frac{P}{A}, \quad (23)$$

where P – upsetting force; A – cross-sectional area of the sample.

It is necessary to determine parameter m numerically by solving the differential equation for different initial porosities. Integration of a system of differential equations and calculation of the corresponding values of the stress intensity of the base material at an arbitrary initial porosity and parameter n is performed using methods of approximate or precise solution of applied mathematics problems. The curves of the upsetting stress dependence on time must be approximated by a power dependence. Approximation coefficients are determined by the least squares method. Implicit dependencies of the stress intensity of the base material on the accumulated deformation of the base material are also approximated by power functions using the least squares method. Values m and n which are included in the porosity functions obtained as a result of processing experimental data.

Experiments on axisymmetric upsetting of cylindrical samples with low friction at the ends were conducted to determine porosity functions $f_1(\theta)$, $f_2(\theta)$, and $\alpha(\theta)$ (Ogorodnikov *et al.,* 2018). The studies were conducted on samples made of powder material PZh4M2, height h_0=15.9 mm and diameter d_0=4.32 mm. The samples had five different initial porosity values: 1) θ_0=0.283; 2) θ_0=0.246; 3) θ_0=0.208; 4) θ_0=0.164; 5) θ_0=0.126. The density of the samples was determined by hydro-weighing in distilled water. The sample was weighed in a dry state (weight G_d), and then, to protect against liquid ingress into the pores of the material, it was soaked with paraffin. After wiping, the sample with the filler was weighed (weight G_f). Then a prototype, on a thin (d=0.05 mm) copper wire, was weighed in water (weight G_w). The experimental density value was determined by the formula:

$$\rho = \frac{G_d}{G_f - G_w}\rho_w, \quad (24)$$

where ρ_w – water density at the measurement temperature.

The experimental value of porosity was calculated from the relation:

$$\theta = 1 - \frac{\rho}{\rho_0}, \quad (25)$$

where ρ_0 – density of iron, the base material of a porous body, ρ_0=7.85 g/cm^3.

After hydro-weighing, the paraffin was removed. Complete removal of the mixture was monitored during subsequent weighing. upsetting of 2-4 samples of each initial density was performed in 10-15 stages. At each stage, the upsetting force P was determined, and the height h and diameter d of the sample were measured. In addition, the distance between two labels applied in the middle of the sample in the axial direction was measured. The density of the samples was determined by hydro-weighing in 5-8 stages. Low friction at the ends was ensured by the use of lead gaskets and lubrication with graphite grease lubricant. Compressive stresses were determined from the upsetting results:

$$\sigma = \frac{4P}{\pi d^2}, \quad (26)$$

and deformations

$$e_z = -ln\frac{h_0}{h}; \quad (27)$$

$$e_r = e_\varphi = ln\frac{d}{d_0}. \quad (28)$$

In addition to hydro-weighing, the variation in the porosity of the material was determined by the change in the average calculated volume:

$$V = \frac{\pi d^2}{4}h. \quad (29)$$

RESULTS AND DISCUSSION

As a result of the development of mathematical methods of the theory of plasticity of porous bodies, a harmonic theory was obtained (Shtern *et al.,* 2021). It is based on the hypothesis of the existence of a surface plasticity of a porous body:

$$3I_2(D_\sigma) + \alpha I_1^2(T_\sigma) - \beta k^2 = 0, \quad (30)$$

where α, β – porosity functions; $I_2(D_\sigma)$ – the second invariant of the stress deviator; $I_1(D_\sigma)$ – the first invariant of the stress tensor; k – flow stress of the base material.

The plasticity condition proposed by Y. Beygelzimer *et al.* (2022) is slightly different and has the form:

$$3I_2(D_\sigma) - (1 - 2\upsilon)I_2(T_\sigma) + \varphi^2 k^2 = 0, \quad (31)$$

where υ – coefficient of transverse deformation; ϕ – porosity function.

Analysis of known experimental and theoretical results shows that the plasticity conditions (30) and (31) qualitatively describe the mechanism of plastic deformation of porous materials. The main dependencies of the flow theory, in particular, the increase in plastic deformations from stresses, are determined from the plasticity condition and the associated flow law, according to which, the vector of increasing plastic deformations is perpendicular to the load surface at the point that corresponds to the stresses.

A. Kuzmov *et al.* (2020), M. Shtern, and E. Kartuzov (2016) used an approach related to the need to set the properties of a dissipative function when formulating the defining equations. Based on the assumption that

the third invariants do not affect the behaviour of a porous body and considering isotropy, the plasticity condition of the compacted material was obtained. This condition is used quite widely (Skorokhod & Shtern, 2019) and is usually written as:

$$\frac{p^2}{f_2(\theta)}+\frac{\tau^2}{f_1(\theta)}=(1-\theta)k^2, \quad (32)$$

where $f_1(\theta)$, $f_2(\theta)$ – porosity functions; $k=\sqrt{\frac{3}{2}}\sigma_f$, σ_f– the flow stress of the solid phase under uniaxial tension.

The plasticity conditions (30), (31), and (32) are symmetric with respect to the plane p=0. However, this requirement is not mandatory. E. Beygelzimer and Y. Beygelzimer (2022) experimentally established that the plasticity condition of porous bodies under the bulk stress state is described by the expression:

$$\frac{(p-p^*)^2}{f_2(\theta)}+\frac{\tau^2}{f_1(\theta)}=(1-\theta)k^2, \quad (33)$$

where p^* – function of internal stresses and porosity.

If p=0, then the flow law associated with this plasticity condition leads to the fact that the volume deformation rate is:

$$\dot{e}=-\frac{f_1(\theta)}{f_2(\theta)}\cdot\frac{\dot{\gamma}}{\tau}p^*. \quad (34)$$

It follows from expression (34) that during the plastic deformation of a porous body, there is a change in volume in the absence of a spherical component of the stress tensor.

The material model is one of the main components in the research on the processes of forming porous materials. This model is formed in the form of defining equations that relate the components of stress tensors and strain rates to the state parameters of the deformable material (Shtern & Kartuzov, 2016). One of these parameters is the current porosity. Therefore, the relationship between stress tensors and strain rates contains internal variables for which conditions are formulated in the form of equations for state parameters. The kinetic equation of conservation of mass for materials the behaviour of which depends on porosity can be used as these relations. The defining relations for such materials are shown as a generalised model, which is a partial case of the equations of sensitivity of the plastic potential to the Nadai-Lode parameter (Skorokhod & Shtern, 2019) or the third invariant of the stress tensor (Sivak, 2017). In most cases, the porosity functions included in these equations are determined from experimental data.

Since the experimental values m and n will be calculated for axisymmetric upsetting of cylindrical samples without friction at the ends in experiments, the relation (3) is reduced to the form:

$$\frac{\dot{\gamma}}{\dot{e}}=\frac{f_2(\theta)}{f_1(\theta)}\cdot\frac{\tau}{p}=\frac{1}{6\alpha(\theta)}\cdot\frac{\tau}{p}. \quad (35)$$

The relations (16) and (17) are substituted in equation (35) and the expression is written:

$$\frac{\dot{\gamma}}{\dot{e}}=\frac{1}{6\alpha(\theta)}\cdot\frac{\sqrt{\frac{2}{3}}\sigma}{-\frac{\sigma}{3}}=-\frac{1}{\sqrt{6}\alpha(\theta)}. \quad (36)$$

After substituting the relations (14) and (15) into equation (36), the following expressions are obtained:

$$\dot{e}_z+2\dot{e}_\varphi=-\sqrt{\frac{2}{3}}(\dot{e}_\varphi-\dot{e}_z)\sqrt{6}\alpha(\theta); \quad (37)$$

$$\frac{\dot{e}_\varphi}{\dot{e}_z}=-\frac{1-2\alpha}{2(1+\alpha)}=-\frac{1}{2}+\frac{3}{2}\cdot\frac{\alpha}{1+\alpha}. \quad (38)$$

It follows from expression (38) that:

$$\dot{e}_\varphi=-\dot{e}_z\frac{1-2\alpha}{2(1+\alpha)}. \quad (39)$$

Expression (39) is substituted to relation (14) and the following equation is obtained:

$$\dot{e}=\dot{e}_z-\frac{1-2\alpha}{2(1+\alpha)}\dot{e}_z=\frac{3\alpha}{1+\alpha}\dot{e}_z. \quad (40)$$

Using expressions (18) and (19), the volume strain rate is calculated:

$$\dot{e}=\frac{\dot{\theta}}{1-\theta}. \quad (41)$$

It follows from expressions (40) and (41) that:

$$\frac{\dot{\theta}}{1-\theta}=\frac{3\alpha(\theta)}{1+\alpha(\theta)}\dot{e}_z, \quad (42)$$

given function (13), the following relation is obtained

$$\frac{\dot{\theta}}{1-\theta}=\frac{3\alpha_0^m(\theta)}{1+\alpha_0^m(\theta)}\dot{e}_z, \quad (43)$$

or:

$$\frac{d\theta}{dt}=\frac{3(1-\theta)\alpha_0^m(\theta)de_z}{1+\alpha_0^m(\theta)dt}. \quad (44)$$

Expression (21) is substituted into relation (44), and as a result, the following is obtained:

$$\frac{d\theta}{dt}=-\frac{3(1-\theta)\alpha_0^m}{1+\alpha_0^m}, \quad (45)$$

then the differential equation is obtained

$$\frac{dt}{d\theta}=-\frac{1+\alpha_0^m}{3(1-\theta)\alpha_0^m}, \quad (46)$$

solving which, the following is calculated

$$t=-\int_0^\theta\frac{1+\alpha_0^m(\theta_*)}{3(1-\theta_*)\alpha_0^m(\theta_*)}d\theta_*. \quad (47)$$

The solution of equation (47) allows determining the value of the parameter m, at which the calculated curves coincide with the experimental ones.

The intensity of the deformation rates of the base material $\dot{\gamma}_0$ is expressed through the volume deformation rate $\dot{e}$ with a frictionless draft. Expression (4) is reduced to this form to do this:

$$\dot{\gamma}_0^2=\frac{f_1(\theta)\dot{e}^2}{1-\theta}\left(\frac{f_2(\theta)}{f_1(\theta)}-\frac{\dot{\gamma}^2}{\dot{e}^2}\right). \quad (48)$$

Expressions (11) and (36) are substituted in equation (48) and the following the relation is obtained:

$$\dot{\gamma}_0^2=\frac{f_1(\theta)\dot{e}^2}{1-\theta}\left(\frac{1}{6\alpha}+\frac{1}{6\alpha^2}\right). \quad (49)$$

Considering expressions (40) and (21), the relation (49) is reduced to the form:

$$\dot{\gamma}_0^2=\frac{3}{2}\frac{f_1(\theta)}{(1-\theta)(1+\alpha)}, \quad (50)$$

hence

$$\dot{\gamma}_0 = \sqrt{\frac{3}{2}}\sqrt{\frac{f_1(\theta)}{(1-\theta)(1+\alpha)}}. \quad (51)$$

Expressions (46) and (51) are substituted in equation (22), considering that $\dot{\gamma}_0 = dG_0/dt$, the following is calculated:

$$\frac{dG_0}{d\theta} = \frac{dG_0}{dt}\cdot\frac{dt}{d\theta} = -\frac{1}{6}\sqrt{\frac{f_1(\theta)}{(1-\theta)^3}}\cdot\frac{\sqrt{1+\alpha}}{\alpha}. \quad (52)$$

Given that $f_1(\theta) = f_{10}^{1+n}(\theta) = (1-\theta)^{2+2n}$, the following expression is obtained:

$$\frac{dG_0}{d\theta} = -\frac{1}{\sqrt{6}}(1-\theta)^{n-0.5}\frac{\sqrt{1+\alpha_0^m}}{\alpha_0^m}. \quad (53)$$

Equation (1) is transformed considering the relations (11), (16), and (14) and the following is obtained:

$$\tau_0^2 = \frac{1}{f_1(\theta)(1-\theta)}\left(p^2\frac{f_1(\theta)}{f_2(\theta)} + \tau^2\right) = \frac{\frac{2}{3}\sigma^2(1+\alpha)}{f_1(\theta)(1-\theta)}. \quad (54)$$

As a result, the equivalent stress intensity of the base material during frictionless upsetting is determined by the relation:

$$\tau_0 = \sqrt{\frac{2}{3}}\frac{\sqrt{1+\alpha}}{\sqrt{f_1(\theta)(1-\theta)}}\sigma = \sqrt{\frac{2}{3}}\frac{\sqrt{1+\alpha_0^m(\theta)}}{(1-\theta)^{n+1.5}}\sigma. \quad (55)$$

Parameter value *n* can be determined from relation (55) by the iteration method, based on the condition that the dependence $\tau_0 = f(G_0)$ must be uniform for any initial porosity of the material.

Therefore, to estimate the stress-strain state in the plastic region, the flow curve of the deformable material is necessary. In terms of plastic deformation of porous bodies, the problem is complicated by the fact that the type of flow curve depends on both the base material and the initial porosity (Sivak, 1996). The presented method allows constructing the dependence of the intensity of the stress deviator in the base material τ_0 from accumulated deformation G_0, which is uniform for this material and does not depend on the initial porosity. It is necessary to know the porosity functions to examine the processes of plastic deformation of porous bodies and construct a single flow curve $\tau_0(G_0)$.

From the storage conditions of the mass:

$$\rho V = \rho_0 V_0; \quad (56)$$

$$\rho_0(1-\theta)V = \rho_0(1-\theta_0)V_0, \quad (57)$$

finding the porosity

$$\theta = 1 - \frac{V_0}{V}(1-\theta) = 1 - \frac{d_0^2 h_0}{d^2 h}(1-\theta_0). \quad (58)$$

Dependency graphs $e_\varphi(t)$, $\sigma_z(t)$, $\theta(t)$ obtained from the equations (26), (28), and (58) are shown in Fig. 1-3. In graphical dependencies $t = ln\frac{h_0}{h} = -e_z$ – time parameter.

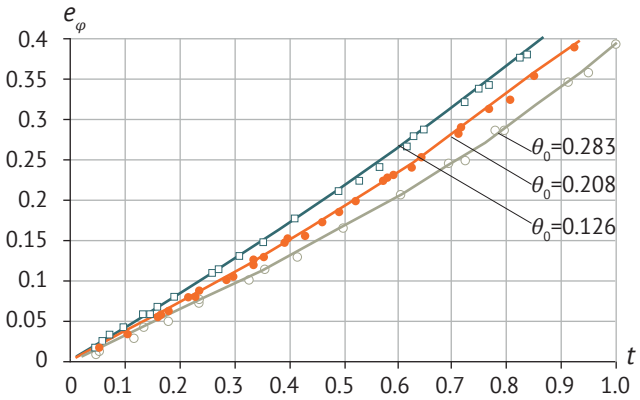

Figure 1. *Strain dependence e_φ depending on the degree of upsetting (iron)*

Source: *compiled by the authors*

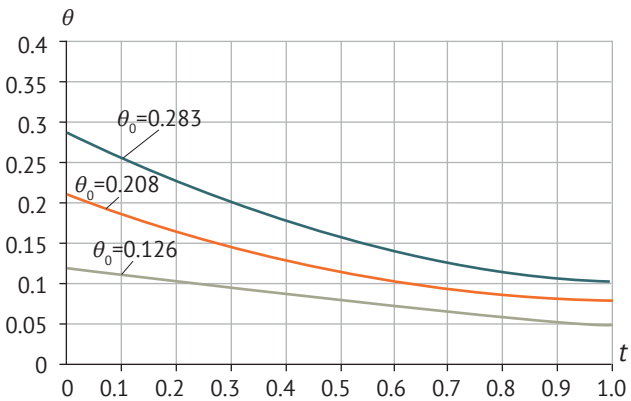

Figure 2. *Porosity dependence θ depending on the degree of upsetting (iron)*

Source: *compiled by the authors*

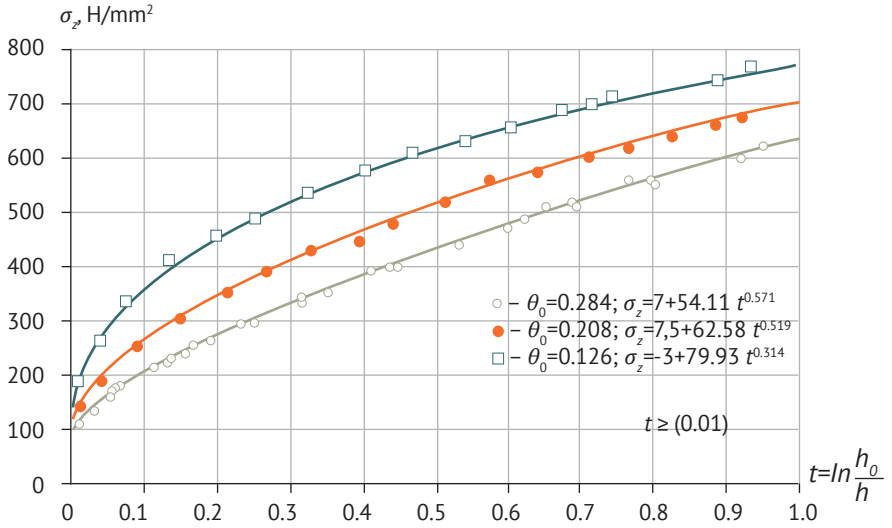

Figure 3. *Axial stress during upsetting of samples with different initial porosity* θ_0

Source: *compiled by the authors*

Parameter *m* was determined numerically by solving equation (46) for various initial porosities θ_0. Analysing the dependency $t(\theta)$ at different *m*, the following value was eventually identified (*m*=0.86), at which the experimental curve was identified to be close to the calculated one at the initial porosity θ_0=0.208. The following calculations showed that when *m*=0.86, calculated curves $\theta(t)$ coincide with the experimental ones for the remaining initial porosities. Integration of the system of differential equations (46), (53), and calculation of the corresponding values τ_0 according to relation (55), for arbitrary initial porosity and parameter *n* was performed using numerical methods. Under this condition, the coefficient was entered as the initial data *m*=0.86, and curves $\sigma_z(t)$ (Fig. 3). Therewith, curves $\sigma_z(t)$ were approximated by power dependence:

$$\sigma_z(t) = a_0 + a_1 t^{a_2}. \quad (59)$$

The approximation coefficients depending on (59) were determined by the least squares method. As a result, it is established that the accepted expression is a valid approximation for describing the experimental dependence $\sigma_z(t)$. When solving the system of equations (46), (53), and calculating the ratio (55), data for two initial porosities were applied simultaneously θ_0. The obtained implicit dependencies $\tau_0=f(G_0)$ were approximated by power functions:

$$\tau_0 = b_0 + b_1 {G_0}^{b_2}, \quad (60)$$

using the least squares method.

Curves (60) for both initial porosities were obtained at different values of the parameter *n* starting from *n*=0. When *n*=0.75, curves $\tau_0=f(G_0)$ coincided for both initial porosities. Applying the resulting value *n*=0.75 in the programme for other initial porosities confirmed the uniqueness of the curve $\tau_0=f(G_0)$. Thus, as a result of processing experimental data, the values *m* and *n* were obtained, which are included in the porosity functions of the workpiece based on PZh4M2 powder. Finally, the following dependencies are obtained for the porosity functions:

$$f_1(\theta) = f_{10}^{1+n}(\theta) = ((1-\theta)^2)^{1+1,75} = (1-\theta)^{3,5}; \quad (61)$$

$$f_2(\theta) = \frac{1}{6\alpha(\theta)} f_1(\theta) = \frac{1}{6\alpha_0^m(\theta)} f_2(\theta) = 0.546 \frac{(1-\theta)^{4,36}}{\theta^{0,86}}. \quad (62)$$

For the flow curve, when $G_0 \geq 0.01$ the following expression was obtained:

$$\tau_0 = -15 + 83{,}73 G_0^{0,186}. \quad (63)$$

Dependencies (61), (62), and (63) are used to calculate stresses during plastic deformations of porous workpieces in pressure treatment processes. Functions $\alpha(\theta), f_1(\theta), f_2(\theta)$ are shown in Fig. 4, 5, and the flow curve $\tau_0(G_0)$ – in Figure 6.

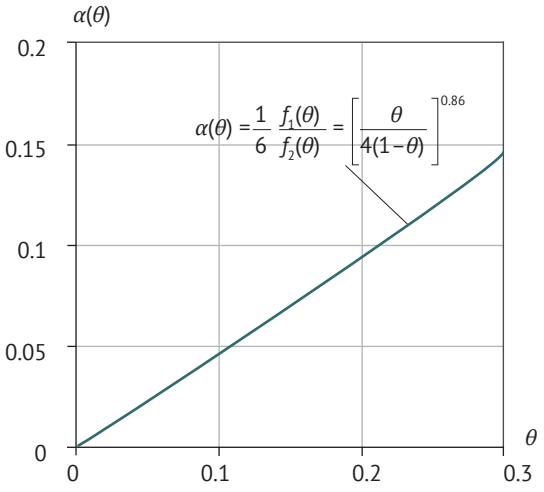

Figure 4. *Porosity function α(θ) for the PZh4M2 iron*

Source: *compiled by the authors*

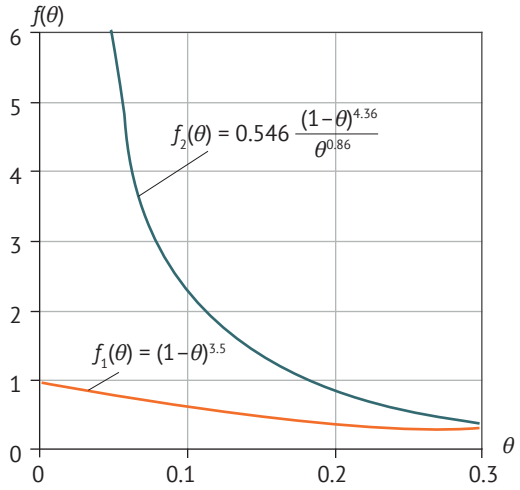

Figure 5. *Porosity functions $f_1(\theta)$, $f_2(\theta)$ for the PZh4M2 iron*

Source: *compiled by the authors*

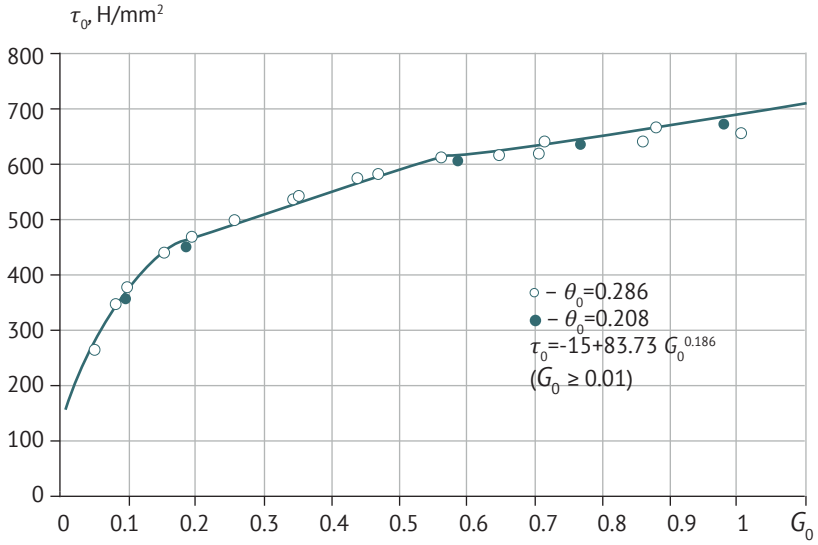

Figure 6. *Flow curve of the porous PZh4M2 iron base material*

Source: *compiled by the authors*

Mathematical models created based on ideas about the concept and methods of continuous environment mechanics are used to solve specific technological problems. These are mainly problems for determining the fields of residual porosity and deformation. Methods of mechanics of deformable powder materials allow explaining quite a lot of regularities at the macro level. However, the task of modelling the processes of obtaining powder materials, which consists in establishing the relationship between the deformation scheme and the properties of the product, cannot be reduced only to calculating residual deformations. It is necessary to consider changes in the parameters that determine the structure and physical properties. During research in the field of physics of dispersed and porous media, a number of important, qualitative results were obtained regarding the influence of porosity on elementary deformation processes and mechanical characteristics of porous bodies. The most common theory of plasticity of porous bodies in the form of condition (30) emerged as a generalisation of the Mises plastic body model (Green, 1973; Kuhn & Downey, 1971). The first stress tensor invariant included in the load function (30) makes the load surface closed, convex, and smooth. The closeness of the load surface reflects the property of volume-deformed bodies, which consists in the occurrence of plastic deformations at any monotonous trajectory of the applied forces. The most common modification of the theory of plasticity of porous bodies is based on the fluidity condition (32). In stress space, condition (32) corresponds to an ellipsoid of rotation relative to the hydrostatic axis. There are at least two ways to determine the half-axes of a given ellipsoid. The first method is based on independent experiments

(Kuhn & Downey, 1971) to obtain the relationship between stress and strain for a porous material under the stress state of simple types.

The second is the way to determine the porosity and flow stress functions under uniaxial compression. It is based on ideas about the mechanics of a micro-inhomogeneous continuum. Assuming a certain type of real microstructure of a porous body, the relative position of the pores, the nature of their interaction, and using known solutions to problems about the behaviour of an isolated pore in deformable space, it is possible to determine the effective characteristics of media that have an infinite number of pores. V. Skorokhod and M. Shtern (2019) calculated various boundaries of the flow stress of a porous body based on the static model of a porous body and solved the simplest macroscopically homogeneous problems of the theory of plasticity of compressible materials. Another area is based on the assumption of regular pore stacking (Green, 1973). Using the solution of two problems on the behaviour of an isolated pore in an infinite perfectly plastic medium, porosity functions such as the semi-axis of an ellipsoid were determined. This path allows considering the features of the porous structure. Consistent softening of the initial assumptions can lead to a change in the porosity functions and lead to a more complete consideration of physical and structural factors in the framework of the described theory of plasticity of porous bodies. In this form, the theory of plasticity of porous bodies is widely recognised and has allowed explaining quite a lot of the regularities of volume changes identified at the macro level in the most common deformation schemes. This method also helped to solve boundary value problems on density distribution and determine the fields of residual deformations. Based on the postulate of exact certainty of the dissipative function (Skorokhod & Shtern, 2019), the measure of accumulated deformation of the solid phase is calculated by formula (5), considering expression (48). A. Kuzmov *et al.* (2020) suggested that the relationship between the flow stress for uniaxial compression and accumulated deformation is identical to the deformation hardening curve of the solid phase.

N. Abdelmoula *et al.* (2017), A. Kuzmov *et al.* (2020) analysed the evolution of porosity for porous workpieces. As a result, by solving the equation and determining the radial stress component, the dependence of porosity on axial strain is obtained for three values of the initial porosity. Analysis of the results shows that the number of cavities increases for materials with lower initial porosity. Therewith, a decrease in the number of cavities is observed in blanks with high initial porosity. The initial porosity is also indicated, which corresponds to the absence of volume changes. It is necessary to consider that at the first stage, under isostatic load, there is a temporary decrease in pressure to coordinate the theoretical and experimental results, so in this case, it is necessary to use a certain law of change in the radial stress component. At the initial stage of deformation, such a replacement ensures that the calculated data correspond to the experimental curves "porosity – axial deformation".

CONCLUSIONS

Using the basic provisions of the mechanics of plastic deformation of porous bodies, a method for describing the mechanical characteristics of porous bodies by single functions was developed, the nature of which is determined by the properties of the material from which the workpiece is made, and does not depend on the initial porosity. The considered approach allows for obtaining reliable porosity functions for this material by clarifying the theoretical dependencies through experimental studies. Porosity functions for iron-based materials were obtained. A method for calculating the accumulated deformation of the base material was developed. A flow curve was plotted for iron-based materials, which, regardless of the initial porosity, describes the dependence of the stress intensity in the base material on the accumulated deformation of the base material as a single curve. Porosity leads not only to quantitative changes in the service and mechanical properties of materials but also makes them more susceptible and quite sensitive to the type of stress-strain state. Porous materials have a number of properties that are not inherent in solid bodies. In particular, the dependence of the flow stress on hydrostatic pressure, dilatancy, multi-resistance during tension and compression, etc. These features are reflected in mechanical models of porous bodies. However, research in the field of mechanics of porous media should also be aimed at further creating theories focused on solving the problems of compaction and shaping of porous materials, determining the boundary states that characterise the structural properties of powder materials.

AKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Визначення функцій пористості при обробці тиском порошкових матеріалів на основі заліза в агроінженерії

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Анотація. Одним із ефективних способів отримання виробів з необхідними експлуатаційними характеристиками є холодна пластична деформація пористих заготовок. Актуальність досліджуваної теми обумовлена необхідністю підвищення достовірності оцінки напружено-деформованого стану при пластичній обробці пористих заготовок шляхом уточнення функцій пористості. Метою дослідження є розробка методики описання механічних характеристик пористих тіл єдиними функціями, характер яких визначається властивостями матеріалу основи і не залежить від початкової пористості. Для дослідження процесів пластичної деформації використані аналітичні, числові, експериментально-розрахункові методи із застосуванням сучасних спеціалізованих програмних систем. В статті представлена методика описання механічних характеристик пористих тіл єдиними функціями. Сукупність взаємопов'язаних способів та прийомів базується на основних положеннях механіки пластичної деформації пористих тіл і дозволяє отримувати достовірні функції пористості для даного матеріалу, шляхом уточнення теоретичних залежностей експериментальними дослідженнями. Водночас експериментальні дані отримували в дослідах на осесиметричну осадку циліндричних зразків без тертя на торцях. Ґрунтуючись на проведених теоретичних дослідженнях отримано функції пористості для матеріалів на основі заліза. Для досліджень використовували зразки п'яти різних початкових пористостей. В результаті обробки експериментальних даних отримані остаточні вирази для функцій пористості матеріалу заготовки з порошку на основі заліза. Також в статті представлена методика розрахунку накопиченої деформації матеріалу основи. Побудовано криві течії для порошкових матеріалів на основі заліза. Отримані результати досліджень дозволять сформулювати практичні рекомендації з розробки технологічних процесів пластичної обробки порошкових матеріалів тиском для одержання виробів із заданими фізико-механічними властивостями

Ключові слова: матеріал; функція пористості; обробка тиском; холодна пластична деформація; крива течії; напруження

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(3), 135-145

UDC 338
DOI: 10.48077/scihor3.2023.135

Financial markets and price increases in Europe after the russian-Ukrainian War

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Article's History:
Received: 21.01.2023
Revised: 21.03.2023
Accepted: 13.04.2023

Suggested Citation:
Nimani, A., & Spahija, D. (2023). Financial markets and price increases in Europe after the russian-Ukrainian War. *Scientific Horizons*, 26(3), 135-145.

Abstract. The research relevance is predefined by the fact that the European financial market has suffered a direct negative impact due to the russian aggression and violation of the territorial integrity of Ukraine. All these processes are accompanied by several previously formed and unfavourable trends for socio-economic and financial development, which have become even more severe due to the hostilities. In particular, COVID-19, environmental degradation, rising inflation, deglobalization, insufficient social development of individual countries, as well as fuel and food shortages. The research aims to conclude a comparative analysis of financial policy in European countries and individual countries of the Balkan Peninsula, as well as substantiation of the financial risk management features and the formation of a forecast model of economic stabilization. To achieve the set objectives, scientific methods were used, including analysis method, analogy method, and modelling method. The article analyses expert reports and the results of scientific research on the current state of the financial market and monetary policy in Europe as a result of the russian-Ukrainian war, in particular in the Balkans and Kosovo. The analogy of the directions of financial policy in the period before the russian invasion of the territory of Ukraine with the period of direct aggression of the russian federation is conducted. The fundamental reasons for changes in pricing policy, in particular pricing mechanisms, are characterized. The determining factors of financial risks, tools for assessing the consequences, as well as generalization of management methods for their reduction and elimination in the future are substantiated. The directions of European financial support aimed at the defence sector and socio-economic needs are considered. The practical value of the work is that the conceptual model of strategic development of the European financial market in the context of stabilization processes of international financial policy, as well as food and energy security was formed

Keywords: financial risk management; russian aggression; monetary policy; food and energy safety; global economic tendency

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INTRODUCTION

Carrying out a comparative analysis of the financial market and monetary policy is due to an even greater deepening of negative and unpredictable political and, as a result, economic factors. The economic system underwent significant metamorphoses as a result of the outbreak of the coronavirus pandemic. Then there was an urgent need for a quick response of financial institutions to restrictions. As a result, the economy of many countries suffered significantly. It is also worth remembering the post-war years in cases of world military conflicts, when the existing algorithms for exiting the crisis turned out to be ineffective. Along with the mentioned factors, which in one way or another affect the general state of the economy in the state, there are also less visible ones in the short term, such as inflation, environmental difficulties, and so on. That is why it is important to conduct a preliminary economic analysis so that the consequences of the post-war crisis in Ukraine are not critical for the countries of Europe and the Balkans.

The financial market crisis in the European Union has significantly worsened since the russian invasion of Ukraine and the violation of its sovereignty. Indeed, by February 24, 2022, there were already unfavourable economic trends, in particular, high inflation rates in some regions, and low socio-economic levels of life and welfare, which was expressed in the impoverishment of certain segments of the population (International Monetary Fund…, 2022). Therefore, with the beginning of full-scale actions in Ukraine, there was a decline in market sentiment, which consisted of the termination of peace dividends, which were used to address issues of sustainable development and social security, as well as rebalancing fiscal priorities (Qureshi *et al.,* 2022). Overall, the situation in Ukraine is characterized by a decrease in the population due to death or fleeing. At the same time, a large number of able-bodied citizens are in combat zones and conflict regions. All these events are undoubtedly accompanied by the economic crisis and mass impoverishment. Considering how all the above events have affected the international economic system, according to World Bank experts, the number of people living below the poverty line has increased from 100 million to 700 million (International Monetary Fund…, 2022).

It is worth noting the financial risks in food and energy security, which are the basis of the economic security key figures (Zhou *et al.,* 2022; Osička & Černoch, 2022). After all, the failure of logistics chains as a result of the pandemic has significantly intensified with the outbreak of active hostilities, which has significantly worsened the situation in the monetary market and caused a shock of supply and demand, respectively, the overall price increase. The leading Eurozone countries in terms of socio-economic welfare before the aggravation of the military conflict had an inflation rate of more than 5% (International Monetary Fund…, 2022). In particular, Ukraine and russia were exporters of wheat, which accounted for about 25% of the world's share of exports (International Monetary Fund…, 2022). At the same time, russia until recently was one of the main suppliers of natural energy sources – fossil fuels, to the European Union. Therefore, a direct violation of procurement logistics led to a rise in prices. In general, the financial market may become more vulnerable due to the unpredictable escalation of the russian-Ukrainian war and the untimely normalization of the European Union's leading countries' socio-economic development (Santorsola *et al.,* 2022). This situation will lead to a slowdown in economic activity, increased financial risks, and even higher inflation.

Researchers A. Bougias *et al.* (2022) study dynamic changes in the value of assets of the European business sector in the context of the financial market functioning during the russian-Ukrainian war using the Merton structural model (1974). Scientists W. Boungou and W. Yatié (2022) study the impact of the russian-Ukrainian war on global energy, food security, and pricing policy. In particular, the authors suggested using special approaches to assess the reliability and sustainability indicators employing modelling under different development prospects. K. Kuzemko *et al.* (2022) justifies the need to use the latest approaches to accelerate the supply of clean energy to the Eurozone. The authors also note that the so-called reset of the entire energy system is the basis of future geopolitical security. P. Zhuk (2022) explores promising directions of energy policy in the post-war, unpredictable period. K. Limonier (2022) emphasizes the importance of information technology in the investigation of open sources and the "digital field" of geopolitics in modern conditions. Yet, despite much scientific research on the current economic situation and analytical reports on prospects, the impact of the war, as well as its key segments, is not sufficiently defined due to underestimated financial risks and possible general destabilization.

The article aims to conclude a comparative analysis of the financial market and monetary policy development in European countries and individual countries of the Balkan Peninsula, as well as to substantiate the peculiarities of financial risk management and the formation of a forecast model of market stabilization.

MATERIAL AND METHODS

Analysis of financial reports and relevant financial documentation of the Central Bank, European Union institutions, International Monetary Fund, World Bank was presented as part of the work. In particular, the scientific works created by such authors as Adekoya *et al.* (2022), P. Żuk and P. Żuk (2022), Bougias *et al.* (2022) and others, related to the research in the field of the humanitarian and economic impact of the geopolitical conflict on the main areas of financial and economic activity within the Eurozone, in particular on the situation in the sphere

of food and energy security, turnover of major financial assets, the emergence of financial risks in the markets of various goods and services were studied.

The basis of scientific research is the methods of scientific knowledge, which are used at the stage of formation of the main issue, namely: synthesis method – the results and conclusions of analytical reports on the problems of the European Union financial market development in the conditions of war and economic crisis, in particular the main directions of monetary policy, are substantiated; analysis method – actual research and comparison of economic activity indicators before the beginning of active, destructive actions of the aggressor on Ukraine and actual and forecast indicators during the war, which are to ensure the production, social, and investment needs of the population of the European Union; analogy method – on the example of a single European Union country – Kosovo (Western Balkans), the author substantiates and summarizes the consequences of the war in Ukraine at the regional level in the context of the current financial position, the impact of external pressure and the main directions of monetary and investment policy of the state; modeling method – the main directions of reducing the negative impact of the war and the elimination of destructive factors on a balanced and stable macroeconomic environment are highlighted, as well as a conceptual model for strengthening the regulatory, and recovery policy concerning the global socio-economic and industrial spheres of the Eurozone and concerning its financial segments are developed. The study covered data analysis from 2019 to 2022. The study also analysed the gross domestic product of the USA, European countries, and the UK.

The first stage researched the overall situation in the European financial market after the escalation of the russian-Ukrainian war. At this stage, the analysis method was used, because it was this method that was best suited for considering the issue from different angles. Next, the fundamental financial problems were highlighted, in particular financial risks, rising prices, deterioration of profitability, the decline in investment flows, etc. In the next stage, the analysis of statistical information and the formation of graphic material reflecting the processes of increasing inflation, gross domestic product, and energy pricing policy were carried out. The factors that caused the change of indicators in connection with the problems of destabilization of the European macroeconomic environment were determined. For these stages the analysis scientific method was used as well. The third stage considered the monetary policy of the Western Balkan countries and the general economic situation under the influence of the war. The issues of Kosovo's development in pre-war conditions and during the war were studied separately, addressing the negative factors caused by the pandemic. The projected aspects of the socio-economic and financial development of Kosovo until the end of 2022 were also substantiated. In particular, the importance of improving the direction of fiscal policy in the issues of export and import of energy resources and agricultural products is substantiated. For this stage creation, the analogy method was used. The last stage was dedicated to the substantiation of the main directions to eliminate the imbalance and stabilize the financial market of the Eurozone, as well as building a conceptual model of the main European institutions activity in overcoming the causes of the economic crisis. Described discoveries at this stage were made by using of modeling method.

RESULTS

According to experts, the European financial market perceived the aggravation of the russian-Ukrainian war, which escalated into a war, as quite orderly (European Central Bank…, 2022). However, some areas of the market have suffered significant consequences (Aslan & Posch, 2022). In particular, since the beginning of the full-scale invasion, an increase in prices for energy and food needs, which were unstable before, has been noted (Umar *et al.*, 2022). The derivatives market for the above goods and services is exposed to obvious financial risks (Fig. 1).

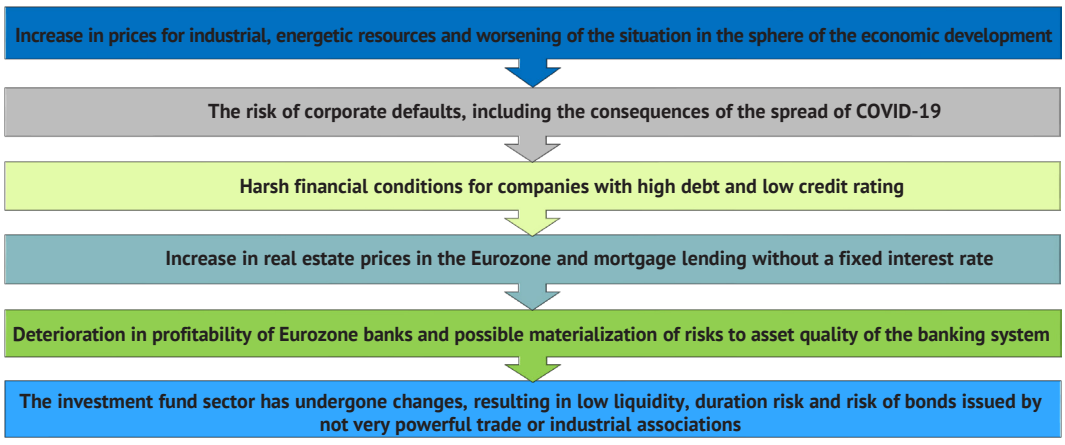

Figure 1. *Eurozone financial market issues*
Source: *compiled by the authors following the "European Central Bank" (2022)*

Thus, the war led to an increase in inflation in 2022 (Table 1) compared to 2021 (Fig. 2). It is worth noting that the European Union countries were importers of russian fossil fuels. However, since October 2021, there have been restrictions on energy exports from russia, which has led to higher energy prices and, accordingly, an increase in overall inflation (Fig. 3) (Soriano & Torró, 2021). Thus, inflation in the Eurozone consumer sector in February 2022 increased from 3.9% to 6.8% in April, which meant an increase of 2.9 percentage points and was reflected in real GDP (gross domestic product) growth (Fig. 4) (European Investment Bank..., 2022).

Table 1. *Analysis of GDP and inflation a few weeks before the full-scale invasion of Ukraine by russia and a month of hostilities*

	GDP parameter, 2022			The inflation rate, 2022		
	February	**May**	**Difference**	**February**	**May**	**Difference**
Eurozone	3.9	2.7	-1.2	3.9	6.8	+2.9
Great Britain	4.3	3.8	-0.5	7.0	9.7	+2.7
USA	3.7	2.7	-0.9	5.2	7.2	+2.0

Source: *compiled by the authors following the European Investment Bank (2022) report*

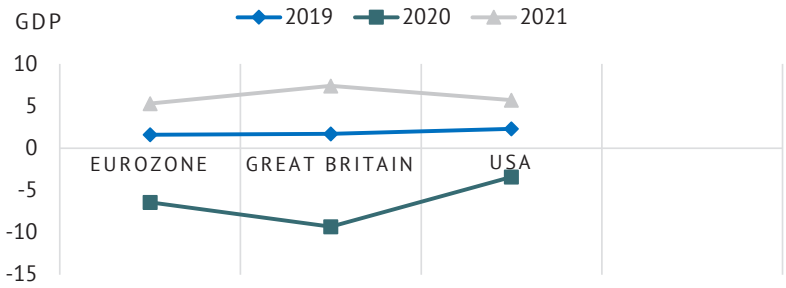

Figure 2. *Actual GDP from 2019 to 2021 in the US, the Eurozone, and the UK*
Source: *compiled by the authors following the European Investment Bank (2022) report*

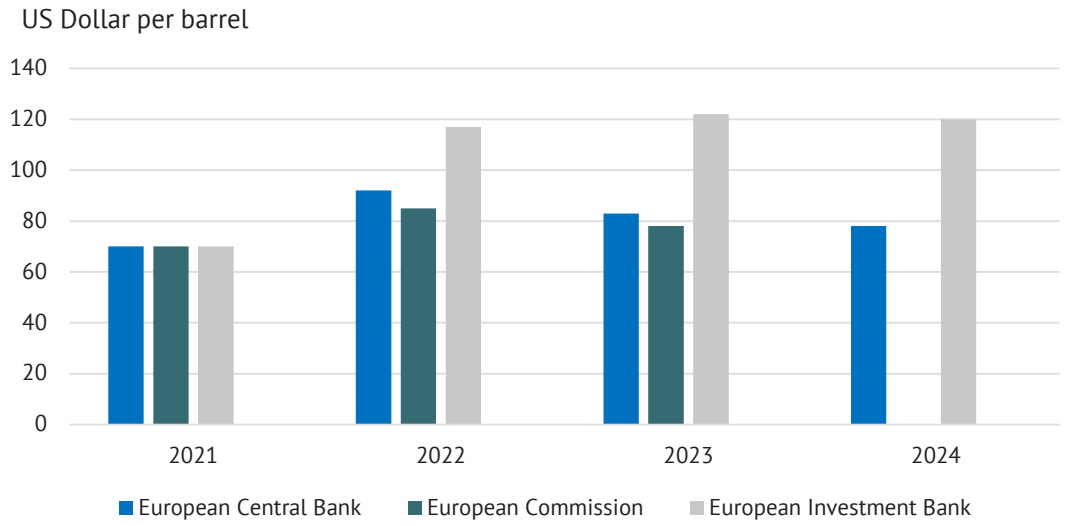

Figure 3. *Comparative analysis of the projected fuel price policy in 2021-2022 and 2023-2024 calculated by experts of leading institutions of the European Union*
Source: *compiled by the authors following the European Central Bank (2022)*

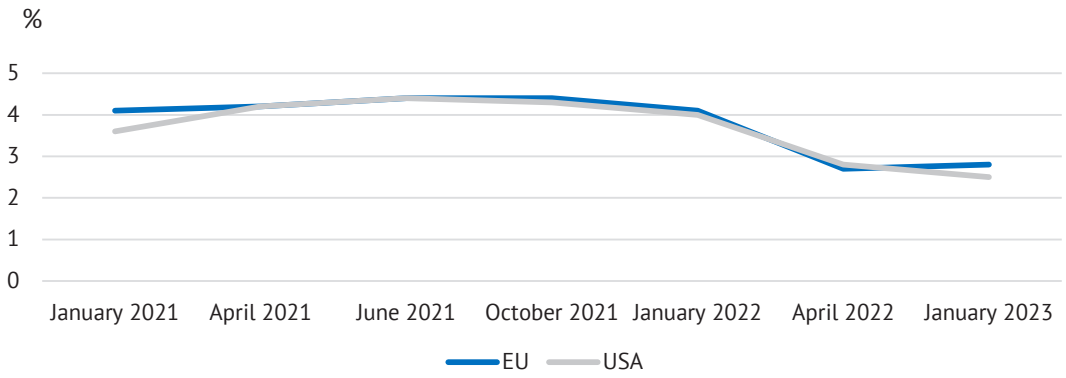

Figure 4. *Comparative analysis of real GDP growth in 2021-2022 and projection of GDP growth in 2023 (in %) in the European Union and the United States*

Source: *compiled by the authors following the European Investment Bank (2022) report*

After the financial market crisis caused by the pandemic, the European Union was expected to stabilize the economic situation in 2022 in a shorter time than the United States. However, Figure 3 shows that the forecast for real GDP growth in the Eurozone is close to that of the United States (International Monetary Fund..., 2022). Thus, the immediate consequences of the russian-Ukrainian war may be a decrease in GDP growth to 1.5 percentage points in 2022 and 2023 (European Central Bank..., 2022). Therefore, a significant amount of financial market indices of the European Union was predicted at the beginning of the military conflict escalation (Tosun & Eshraghi, 2022). Currently, changes in the functioning of the balanced market environment allow us to analyse and calculate the impact of hostilities on socioeconomic development.

The financial market development perspective until 2024 also assumes that the pricing policy for goods and services will remain at the level of March 2022. It is also assumed that the financial stress index should stabilize by the end of 2022 (European Central Bank..., 2022). Monetary policy in the Western Balkans region has also changed and strengthened its position since March 2022. Therefore, the Central Bank has set a discount rate ranging from 1 to 1.5% since April 2022 due to high liquidity (European Investment Bank..., 2022). High inflation and its gradual increase, and growing financial risks led to the optimization of monetary policy directions.

A significant increase in the energy and food supplies caused a short-term amortization, which is noted at the end of February 2022 in the confrontation of the Serbian and Albanian currencies against the euro and the dollar. However, according to experts, the financial market of the Western Balkans was stable even despite the existing economic risks, loans, and equity (Western Balkans Regular Economic..., 2022). As for Kosovo, the country has strengthened its fiscal rates thanks to the functioning of the private sector**,** a significant increase in exports, credit growth, and significant economic stimulus. With the economic balance restored, the fiscal policy has been strengthened and the level of public indebtedness has slowed down due to sufficient state budget revenues. However, all these developments took place in the context of extremely high inflationary pressures and rising import prices.

It should be noted that the long-term impact of external pressure may worsen the social and economic development perspectives of Kosovo due to its outdated energy production capacities. According to expert estimates, inflation is expected to slow down to 3-4% in 2022, provided that prices normalize during the second half of the year (Western Balkans Regular Economic..., 2022).

Directions for the financial market development, monetary and investment policy of Kosovo, which are expected by the end of 2022: the growth of credit rates should slow down to 3.9 percent, under the influence of the economic consequences of the russian-Ukrainian war and the imposed sanctions (Western Balkans Regular Economic..., 2022); inflationary pressures will ease due to real incomes and the impact on consumer confidence; increase in the investment flows in the business sector due to the continuation of the current construction, as well as due to preferential financing from European financial institutions; exports will remain negative as import needs will increase to meet growing domestic demand and regulate external private investment; prolonged resilience to the energy crisis and global inflationary pressures may worsen the development perspectives and reduce real GDP growth; due to the internal energy crisis, consumer needs and production capacity will increase, which will lead to destabilization and high demand for imported energy resources; import price growth may remain high and will affect both consumer and producer prices as well as government spending; meanwhile, the ongoing war in Ukraine could affect future profits through the income of the Ukrainian diaspora living in the European Union through remittances, travel, exports, real estate; in the context of an unstable economic situation, overall inflation may increase to 5.4% in 2022 (Western Balkans Regular Economic..., 2022); an increase in the

budget deficit by the end of 2022 due to a decrease in national budget income (Western Balkans Regular Economic..., 2022).

Concerning imports, Kosovo is an importer of about 40% of all its agricultural products, namely wheat (Western Balkans Regular Economic..., 2022). This also applies to other agricultural products, depending on consumer needs. The country also imports fuel and energy resources, which creates a stable pricing policy despite the current energy crisis in the Eurozone. It is worth noting the importance of the research on the directions of Kosovo's fiscal policy for the possibility of decisive actions that will influence the change of the macroeconomic environment. That is, at present, a cautious attitude is needed toward policy directions that will have high long-term fiscal costs, such as public sector compensation reform. And in the medium term, there is an urgent need to use economic stimulus to increase the share of exports, as well as to increase competitiveness, in particular, to overcome constraints to increase productivity and investment flow for overall socio-economic development. Thus, the actions of the main institutions of the European Union should be quite tough and decisive to eliminate the consequences of the economic crisis caused by the russian-Ukrainian war (Fig. 5) (Zielinska *et al.,* 2022).

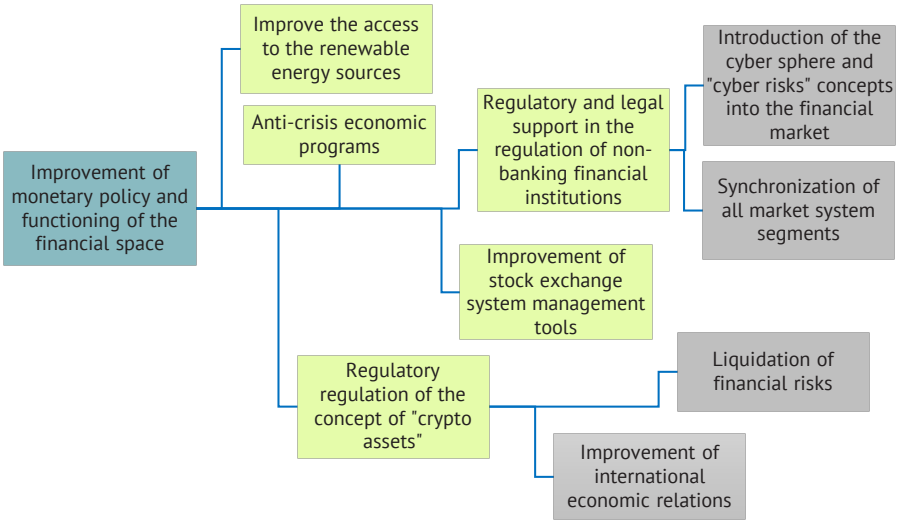

Figure 5. *Conceptual model on the activities of the main European institutions in overcoming the economic crisis caused by the russian-Ukrainian war*

Source: *compiled by the authors following the International Monetary Fund (2022) report*

Therefore, to reduce the risks of an unstable financial market, the Central Bank experts should develop special anti-crisis programs with specific areas of activity to optimize the determining aspects of functioning, considering real and prospective development indicators. The directions of monetary policy and the functioning of the financial space as a whole should be in line with the cyclical indicators with the elimination of the most vulnerable components of the integral system, especially considering the economic consequences of the pandemic and further military actions. Due to the tense situation regarding the supply of fuel and energy resources, it is necessary for the main institutions of the European Union to rapidly support and implement the energy efficiency and energy-saving areas that were formed at the UN Climate Change Conference in 2021. Such measures should establish balanced prices and improve access to renewable energy sources and alternative fossil fuels (Lambert *et al.,* 2022). It is also necessary to develop the areas of "green economy".

The European Union's governance system should include directions for the development of "crypto-assets" regulations, including their use and possible risks. Regulatory policy should be aimed at improving the management tools of the exchange system and the balance of trade and economic systems. In particular, relevant information about the exchange and over-the-counter markets should be as transparent and accessible to the public as possible. Significant attention should be devoted to addressing issues related to the process of financial risk formation and their early elimination. It is necessary to synchronize the work of commodity markets and, for example, securities markets because the failure of the system of one of the markets leads to a failure in the functioning of other economic sector segments. Recently, this issue needed to be addressed in the functioning of the nickel market on the London Metal Exchange. This situation has caused concern on the part of reputable participants of exchange trade and financial specialists. In particular, regarding the risks of migration of important contracts

to OTC derivatives, which are not as transparent and without risk-mitigating instruments.

The lack of possible solutions to resolve the russian-Ukrainian war and the tense geopolitical situation requires the inclusion of such a component as cyber risks in the financial market. After all, the cyber sphere plays a crucial role in the smooth, safe implementation of all economic operations, as well as in the balanced, stable development of the market. European financial institutions should direct their management levers to overcome possible financial risks in non-banking financial institutions. After all, this sector of the economy plays an increasing role as an intermediary in international capital flows. Currently, the Financial Stability Board of the European Union is working on the development of mechanisms to establish standards and norms to regulate and monitor the work of non-banking institutions.

The current stage of development requires stable functioning of the international payment system and balanced operation of all its elements. This concerns the prevention of fragmentation, i.e., the elimination of possible differences between the algorithms of state and cross-border payment transactions. An important factor is the strengthening of international economic ties. The fiscal policy directions should be aimed at restoring a favourable financial space and introducing special anti-crisis measures, which are subject to adjustment in the context of the reliability of macroeconomic policy. Currently, the risk of solvency for small and medium-sized companies in some countries that are members of the European Union remains large-scale. That is why the government should develop programs of financial support and prevention of mass bankruptcy. Of course, such financial support will depend on the viability of the company and the available fiscal space (International Monetary Fund..., 2022).

The war in Ukraine has led to a sharp increase in inflation and a decrease in economic potential in European countries. GDP indicators by the end of 2022 may decrease by 3%, which will mean a decrease of almost 1.5 percentage points compared to forecasts before the start of active hostilities (European Investment Bank..., 2022). Since Ukraine and russia were the main importers of agricultural products and energy resources, there is an increase in the risks of food and energy threats. This situation is unfavourable for the development of related production capacities, respectively, in the absence of the main product. Of course, the failure of logistics chains will be more noticeable in countries with low socio-economic development and living standards. That is, the financial market and most economic segments have already felt the negative impact of the military conflict. It is also important to note the general increase in recession rates as a result of the COVID-19 pandemic, the impact of which was quite active before the war. However, the main financial institutions of the European Union and the government are developing several programs for financial support, algorithms for reducing and eliminating risks, as well as adapted standards and regulations for the functioning of key sectors of the global financial market and the introduction of strict monetary policy measures.

As such, the regulation of aggregate demand and real national income, i.e., fiscal policy, is characterized by the short-term consequences of martial law in Ukraine for countries with a high level of economic development and is moderate compared to the long-term consequences of the pandemic (International Monetary Fund..., 2022). However, the growing long-term consequences in terms of dividends for peaceful needs may turn out to be larger than most government programs predicted. For example, since the beginning of the war, the European Union has been allocating from 100 to 500 million euros per month to support Ukrainian defence and social protection. World Bank experts predict that the total financial assistance to Ukraine for the reconstruction of settlements and critical infrastructure may amount to more than 100 billion euros.

DISCUSSION

Scientists from France and the United States G.-D. Lo *et al.* (2022) in their research demonstrate that the financial market of Europe is characterized by vulnerability to the consequences of the war in Ukraine due to the long dependence on the firm position of Ukraine and russia as large-scale logistics chains, namely, the sale of food products and energy resources. Accordingly, this dependence has led to a decrease in financial profitability and a kind of imbalance. The authors support the opinion of French and American colleagues justifying the concept of a supply shock in the financial market due to the war. In particular, the authors in their study point to the risks and unfavourable conditions for the formation of price policy.

Chinese scientists Y. Wang *et al.* (2022) characterize volatility indicators that reflect changes in the price policy of the financial market in the context of the level of income over a certain period. According to researchers, the volatility rate during the war in Ukraine increased from 35% to 85%, which of course was affected by the pandemic and became much higher in 2022. Such an increase in the indicator is observed due to changes in the role of commodities in the financial market sector and the overall profitability system, that is, the volatility spill over indicator is directly affected. The authors also note that the volatility effect and its accompanying elements are associated with increased geopolitical risk. Comparing their research results and the work of Chinese scientists, the authors did not consider a specifically defined concept of volatility and changes in its indicators under the influence of the war in Ukraine but substantiated the current problems of pricing, as well as the main levers that determine the

stability of the financial market of the European Union and Kosovo. However, the authors also emphasize the importance of considering financial risks at the level of geopolitical development for the formation of clear, balanced algorithms and scenarios for the further economic recovery of the European Union.

Indian scientists D. Rawtani *et al.* (2022) substantiate the statement that russia's full-scale invasion of Ukraine is considered similar to World War II. The current conflict in Europe includes several political, spatial, socio-economic, and environmental consequences. The safety of life and health of the population is concerned. In particular, the war has caused devastating consequences for the world community and violated the integrity of natural ecosystems. The damage to the energy, engineering, and communication infrastructure has led to degradation processes such as pollution with heavy metals, and hazardous chemical compounds of water, land, and natural resources. In particular, this concerns the destruction of the fertile layer of soil cover and, as a result, a decrease in the productivity of agricultural land use. The study also described the issues related to the disruption of energy supplies to the European Union due to the devastating consequences of the military conflict. That is why the implementation of energy efficiency and energy saving through the use of renewable energy sources is an important issue.

The researcher M. Baranowski (2022) sees the ambiguous position of some countries regarding the war in Ukraine due to economic circumstances. Thus, the author emphasizes the dependence of some states on russian gas or the territorial proximity to the aggressor country as primary factors in the formation of political and economic decisions. The author notes that prosperity shapes not only society's attitude to war, but also corrects the government's position. From an economic point of view, this mode may have negative consequences in the context of European countries' support for Ukraine, and therefore may provoke new economic obstacles for European countries.

Borko *et al.* (2022) investigated the ways of restoring the economic potential of Ukraine after the end of military operations on the territory of the country. According to scientists, the main economic factors that will affect the economic power of Ukraine are the reduction in the production of goods and the provision of services, the growth of inflation, the destruction of the material and technical base, the outflow of intellectual labour, and others. Countries importing goods from Ukraine partly depend on the level of economic development. If the post-war crisis becomes too large, Ukraine can choose a strategy of reducing the volume of exports of food and other types of products abroad, including to the countries of Europe and the Balkan Peninsula, in order to keep the economy at a stable level.

Researchers from the UK and Nigeria O. Adekoya *et al.* (2022) note the serious impact of the war in Ukraine on the change of the European oil market. This segment of the economy is inseparably linked with the functioning of the energy, food, financial markets, and current assets. That is why the scientists study the relationship of the oil market with such financial assets as foreign exchange and precious metals funds, bitcoins, and stocks while conducting a comparative analysis of indicators before the active military invasion and directly during the war. The results of the scientific analysis show that the oil market is affected in the short term, i.e., depending on one-day indicators, and has a significant spill over effect on the European financial market. Researchers continue their scientific activities on forecasting the development of the oil market and its spill over effects on the economic situation in general. The authors agree with the conclusions of scholars from Nigeria and the UK on the importance of studying the relationship between the oil market and the current assets of investors in the financial market. In their research results, there are no specific comparisons of the situation with oil supply, but the authors substantiate the disruptions in the supply of energy resources in general and the current problems that have arisen as a result of the disruption of logistics connections.

It is worth noting that there is an issue of gradual termination of international economic ties with the aggressor state (Dolnicar & Mc Cabe, 2022). As for the European Union, this concept concerns the maximum severance of ties with russia, which will mean the restoration of environmental sustainability, energy, and social justice. Such changes in the macroeconomic environment expedite the promotion of strategic programs for the use of clean energy and alternative fuels. After all, a conscious, adapted to modern development energy sector is an important issue of geopolitical security during the crisis, which affects all sectors of economic and industrial activity.

CONCLUSIONS

Since 2020, the global economic system has been seriously affected by the epidemiological crisis caused by the coronavirus infection. The pandemic has had a negative impact on the development of many sectors of the economy, including the financial, transport, social, medical, educational, manufacturing, and logistics sectors. Since the end of 2021, the general rates of economic development, in particular real GDP, have almost reached the level of the last month of 2019. That is why the expert estimates in the field of economics and analytics indicated an increase in the main indicators, considering the future potential. Accordingly, at the time of calculations, the main European institutions were based on strong geopolitical ties and investments. The impact of the russian-Ukrainian war did not allow for the achievement of the necessary, balanced level of socio-economic development that was observed before the pandemic. After all, due to the long-term supply of

energy resources and agricultural products by russia, both russia and Ukraine have experienced disruptions in the work of logistics chains, which has led to the danger of energy, food, and commodity crises, as well as rising prices and inflation. It was determined that the general level of inflation in 2022 increased compared to 2021. The study also predicted the stabilization of the financial stress index in European countries until 2024. With regard to the Western Balkans, it was determined that from the beginning of March 2022, the monetary policy in the region strengthened. However, Kosovo may have negative development prospects due to the lingering impact of external economic pressure. However, it will be possible to avoid such pressure due to real incomes and influence on consumer sentiment. Import prices may gradually increase, which in turn may cause a rise in consumer and producer prices and affect the volume of government spending.

Another problem is the uncertainty about the possible consequences, as the deployment and escalation of the military conflict can be unpredictable and cause even greater economic shock, which has already been felt by financial and non-banking institutions, the government, and individual households. That is why the governing sector of the European Union should introduce strict regulatory measures in the field of monetary, innovation, and fiscal policy. Certainly, the war has changed the priority areas of development in which current assets were actively invested. Future promising areas of development should be the digitalization of development, strengthening the position of the "green economy". However, at the moment, additional cash flows are needed to maximize the transition to the use of environmentally friendly energy resources and means of electricity supply. That is why a regulated policy can reduce uncertainty and reduce the risks of a new recession.

Further areas of research should be a rational search for optimal conditions for the acquisition of assets to confirm inflation expectations and preserve the political confidence of all financial market participants in the Euro area. Special attention should be devoted to the choice of special macroprudential instruments to address the tightening financial conditions. The main European institutions should agree on global standards for the effective use of crypto assets in the context of their risks and activities.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Фінансові ринки та зростання цін у Європі після російсько-української війни

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Анотація. Актуальність дослідження зумовлена тим, що європейський фінансовий ринок зазнав прямого негативного впливу внаслідок російської агресії та порушення територіальної цілісності України. Всі ці процеси супроводжуються низкою раніше сформованих і несприятливих для соціально-економічного та фінансового розвитку тенденцій, які ще більше загострилися через військові дії. Зокрема, COVID-19, погіршення стану довкілля, зростання інфляції, деглобалізація, недостатній соціальний розвиток окремих країн, а також дефіцит палива та продовольства. Метою дослідження є проведення порівняльного аналізу фінансової політики європейських країн та окремих країн Балканського півострова, а також обґрунтування особливостей управління фінансовими ризиками та формування прогнозної моделі економічної стабілізації. Для досягнення поставлених цілей було використано наукові методи, зокрема метод аналізу, метод аналогії та метод моделювання. У статті проаналізовано експертні звіти та результати наукових досліджень щодо поточного стану фінансового ринку та монетарної політики в Європі внаслідок російсько-української війни, зокрема на Балканах та в Косово. Проведено аналогію напрямів фінансової політики в період до російського вторгнення на територію України з періодом прямої агресії російської федерації. Охарактеризовано фундаментальні причини зміни цінової політики, зокрема механізмів ціноутворення. Обґрунтовано визначальні чинники фінансових ризиків, інструменти оцінки наслідків, а також узагальнення методів управління для їх зниження та усунення в майбутньому. Розглянуто напрями європейської фінансової підтримки, спрямованої на оборонний сектор та соціально-економічні потреби. Практична цінність роботи полягає в тому, що сформовано концептуальну модель стратегічного розвитку європейського фінансового ринку в контексті стабілізаційних процесів міжнародної фінансової політики, а також продовольчої та енергетичної безпеки

Ключові слова: управління фінансовими ризиками; російська агресія; монетарна політика; продовольча та енергетична безпека; глобальна економічна тенденція

Журнал
«НАУКОВІ ГОРИЗОНТИ»

Том 26, № 3
2023

(Англійською мовою)

Редагування англомовних текстів:
С. Воровський

Відповідальний редактор:
Д. Кокра

Редагування бібліографічних списків:
Д. Кокра

Комп'ютерна верстка:
М. Кришталь

Підписано до друку з оригінал-макета хх.хх.202х
Ум. друк. арк. 17

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Journal
"SCIENTIFIC HORIZONS"

Volume 26, No. 3
2023

Editing English-Language Texts:
S. Vorovsky

Managing Editor:
D. Kokra

Editing Bibliographic Lists:
D. Kokra

Desktop Publishing:
M. Kryshtal

Signed to the print with the original layout xx/xx/202x
Conventional Printed Sheet 17

Publisher: Polissia National University
10008, 7 Staryi Bvld., Zhytomyr, Ukraine
Tel. (0412) 22-04-17;
E-mail: info@sciencehorizon.com.ua
www: https://sciencehorizon.com.ua/en