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РОСЛИННИЦТВО, ПЛОДООВОЧІВНИЦТВО ТА КОРМОВИРОБНИЦТВО

ТВАРИННИЦТВО

ЕКОЛОГІЯ ТА ОХОРОНА НАВКОЛИШНЬОГО СЕРЕДОВИЩА

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Productivity of Corn Hybrids in the Conditions of the Western Forest-Steppe of Ukraine

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Abstract. The relevant scientific justification for the western region of Ukraine is the comprehensive assessment and selection of maize hybrids with wide environmental plasticity to ensure high and stable grain yield under the influence of specific weather factors. The increase in gross maize yields is possible due to the effective use of the genetic capabilities of new hybrids and is vital for the Western Forest-Steppe where this crop is not selected, and agricultural producers use hybrids of other originator institutions. The purpose of this study was to establish the grain productivity of hybrids of early-maturing and mid-early maturing groups in the soil and climatic zone of Ukraine under study. Generally accepted and special methods were used in this study, such as field, measurement and weight, statistical methods. Based on the obtained research results for 2019-2021, changes in weather conditions in the soil and climate zone under study were confirmed. The duration of the growing season of maize is determined depending on weather factors and the hybrid. The area of the leaf surface in the flowering stage (BBCH 61-69) – development of fruit (BBCH 71-79) and the net productivity of photosynthesis were found. The resistance of hybrid plants to diseases was substantiated and the highest percentage of their damage was found in 2021 with a large amount of precipitation during June-September. The dependence between hybrids and their biological properties was proved to effectively use the existing soil and climatic conditions, which affected grain productivity and the range of variability over the years. The results of this study suggest that changes in weather factors, namely an increase in the sum of active temperatures and sufficient precipitation during the growing season, enable high grain yields of maize hybrids of early-maturing and medium-early maturing groups. Recommendations were given for farms of various legal forms to introduce Ukrainian hybrids into agricultural production: DN Meotyda and Orzhitsa 237 MV

Keywords: FAO, BBCH development stages, leaf area duration, net photosynthesis productivity, diseases, yield

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INTRODUCTION

Currently, an urgent issue is the strategic grain sector of the agricultural sector of Ukraine, which forms food for the population and provides foreign exchange incomes of the state. As described in the article by Hadzalo & Luzan (2020), the conditions of an open economy will bring along an intensive competition with much more advanced foreign firms, and not just with each other. Therefore, more effective measures are required to protect the domestic agricultural market, to adapt the legislation to its European counterparts as much as possible.

M. Cherny (2017) believes that Ukraine has all the opportunities, both in terms of natural factors and the organisational structure of agricultural enterprises, to take a prominent place in the global grain market. However, there are also threats, according to Sabluk & Luzan (2019), which include the lack of reliable safeguards to prevent the shadow economy, unblocking the development of exchange trading as a tool for objectively determining prices in the agricultural sector of the Ukrainian economy.

The leader in grain production is maize – a crop of a wide range of application, used in 60% for animal feed, 25% for nutrition, and the rest – for industrial processing, as described in the studies of Dziubetskyi *et al*. (2020), Belov (2018) and Vozhegova *et al*. (2018). The leading role of maize lies not only in the efficiency of grain production, but also in the economic growth of the livestock industry, as Mason *et al*. (2019), Jareš *et al*. (2019) and Marchenko *et al*. (2021) note.

Ya. Nagy (2012) believes that the crop has recently gained considerable popularity among Ukrainian farmers due to the prominent biological potential of productivity, its demand in the internal and external markets, simplicity of cultivation technologies, low cost of grown products, which contributed to an increase in sown areas.

Currently, the maize collection in Ukraine is represented by 6,340 samples, including 548 local varieties, 532 breeding varieties, 211 synthetic populations, 4,584 self-pollinated lines and 465 lines with a genetically determined genotype. Kuzmyshyna *et al*. (2019) outlined self-pollinated lines of promising hybrids with a complex of valuable economic characteristics, which will improve the breeding process and ensure its acceleration by 4-5 years. Marković *et al*. (2017) indicates a considerable difference between hybrids in terms of productivity indicators due to genetic features.

Voloshchuk *et al*. (2021) concluded that the Western Forest-Steppe of Ukraine is a specific region, since it includes several zones: forest-steppe, Polissia, foothills, and mountains – all with differing soils, sums of effective temperatures, and precipitation. Therefore, to reduce the risks of the negative phenomena from the range of varietal resources of maize, it is advisable to adhere to the approximate ratio of hybrids: for the Forest-Steppe zone – 35% of the early-maturing group, 50-55% – mid-early maturing, 10-15% – mid-late maturing; for the Polissia zone – 100% of the early-maturing group.

Proper selection of hybrids as an effective factor in using their genetic capabilities plays an important role in increasing the gross grain yield of this crop. The desired result can be achieved by considering the biological requirements of the hybrid to the proposed cultivation technology, which includes sowing seeds of high generations, placement according to the best predecessors, sowing dates, seeding rates, plant nutrition system, and protection from diseases and pests, as indicated in the studies of Mazur & Shevchenko (2018), Lemic *et al*. (2019) and Marchenko (2019).

The climate of the Western Forest-Steppe, which has changed towards increasing active temperatures and reduced precipitation in the summer-autumn period, is favourable for growing maize. However, depending on the biological characteristics, the hybrid's response to the same factors is different, which requires identifying the most productive ones based on the principles of adaptability and ecological plasticity to respond positively to weather factors and proposed elements of cultivation technology. The expansion of the assortment of early-maturing hybrids (FAO 100-200) and medium-early (FAO 201-300) allows farms to obtain the required amount of grain and feed products, to sow and harvest at an earlier time, increase the density of agrocenosis and move away from conventional crop rotations, but leads to a slower accumulation of dry matter and accelerated moisture recovery at the final stages of grain maturation. Therefore, establishing the variability of morpho-biological signs under the influence of weather factors, maturity groups, the growing season, grain moisture loss and resistance to major diseases is an urgent issue of scientific research for practical recommendations for production.

The purpose of this study lies in figuring out the duration of interstage periods, leaf area duration, net photosynthetic productivity, disease resistance, and grain yield of maize hybrids of different maturing groups in the Western Forest-Steppe zone of Ukraine.

MATERIALS AND METHODS

Experimental work was performed during 2019-2022 in the Western Forest-Steppe zone. The experiments were conducted on grey forest surface-water gley, light loamy soil, which is the most common in the area under study and occupies over 50%. It has a shallow humus horizon (20-30 cm) with a humus content of 1.7% and is acidic (pH – 5.4). It is characterised by (per 100 g of soil, mg): nitrogen – 8.96, mobile and metabolic phosphorus – 6.95 and potassium – 6.80.

The hybrids of the state institution – the Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine FAO 150-199 and FAO 200-299 were used as the source material. The area of the

experimental plot was: total – 60 m^2, accounting – 50 m^2. Placement of variants was systematic, and replication was threefold. The technology of growing crops was the generally accepted technology for the Western Forest-Steppe zone of Ukraine. The sum of active temperatures in the years of research exceeded the biological requirements of hybrids of the early-maturing and mid-early maturing groups by 211.1-348.5°C and 111.1-248.5°C with slightly lower precipitation in 2020 – 414.8 mm, in 2021 – 432.9 mm (for 450 mm).

The study was conducted according to generally accepted author's methods: phenological observations of plants (Dudka *et al.*, 2019); phytopathological assessment of plants – accounting for diseases and pests of agricultural crops (Omelyuta *et al.*, 1986); determination of plant leaf area duration and net photosynthetic productivity of maize (Peterson *et al.*, 1993); determination of morpho-biological indicators (Fursova *et al.*, 2004); maize grain yield (Methodology..., 2003); general statistical processing of research data ($LSD_{0.05}$ – least significant difference) (Atramentova & Utevskaya, 2014).

RESULTS AND DISCUSSION

Due to the compaction of the soil under the influence of a large amount of precipitation (176% of the average long-term indicator), the duration of the sowing-seedling period in the studies conducted at the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine was 16 days. In 2020, the difference between high day and low night temperatures led to an increase in the duration of this period to 18 days. Low rainfall in 2021 (68%) provided seedling in 13 days. On average, over the years of research, the sowing-seedling period lasted 15 days (Table 1).

***Table 1**. Duration of stages of plant development and grain maturation of maize hybrids (2019-2021)*

Hybrid	FAO	Number of days								Total
		Vegetating period					Grain maturing			
		BBCH 00-09 (germination)	BBCH 10-19 (leaf development)	BBCH 30-39 (stem elongation)	BBCH 51-59 (inflorescence emergence)	BBCH 61-69 (flowering)	BBCH 71-79 (milky)	BBCH 83-85 (waxy)	BBCH 87-89 (full-ripe)	
Pochaevsky 190 MV	150-199	15	44	13	5	7	17	13	11	125
DN Meotyda	150-199	15	45	13	5	7	17	13	11	125
DN Khortitsa	200-299	15	46	14	6	6	16	12	12	127
Orzhitsa 237 MV	200-299	15	47	14	6	6	16	12	12	127
Deviation		0	2	1	1	1	1	1	2	4

According to the duration of the BBCH 10-19 stage (leaf development), the difference between the early-maturing and medium-early maturing groups was 1-2 days. In the stages: BBCH 30-39 (stem elongation), BBCH 51-59 (inflorescence emergence) and BBCH 61-69 (flowering), the difference was one. The duration of milky stage in hybrids varied within 16-17 days, waxy stage – 12-13 days, full-ripe stage – 11-12 days. The total number of days from germination to flowering was 77-82, grain formation and maturation – 41 (early maturing) and 40 (medium-early), the growing season of early-maturing hybrids was 125 days, medium-maturing – 127 days.

The leaf area duration in the flowering stage of maize was formed in the close interaction of the biological characteristics of the hybrid, its maturing group and weather conditions that developed over the years of research. Depending on the weather conditions of the year and the productivity of the hybrid, the average area of the maize leaf area duration ranged from 34.1 thousand m^2/ha up to 40.1 thousand m^2/ha (Fig. 1).

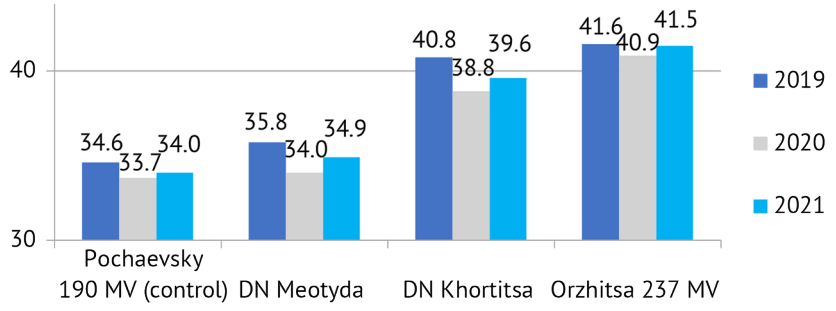

***Figure 1**. The leaf area duration of maize depending on the hybrid maturing group (2019-2021), thousand m^2/ha*

The maximum development of the leaf surface during the flowering period was recorded in 2019 with the sum of active temperatures higher than the annual average by 304°C and precipitation 9.7 mm – 34.6-41.6 thousand m²/ha. In 2020, compared to the previous year, these meteorological indicators were: 178°C, and 45.6 mm. Under such weather conditions, the leaf area duration varied from 33.7 to 40.9 thousand m²/ha, and in 2021 – from 34.0 to 41.5 thousand m²/ha. A significant difference in this indicator was recorded between the groups of hybrids maturing. Due to the longer growing season in the varieties of the medium-maturing group compared to the early-maturing one, it was larger by 5.6-7.2 thousand m²/ha. The range of variability over the years was within the margin of error of 7.0-7.5 thousand m²/ha for LSD_{05}=0.9.

The net photosynthetic productivity of maize hybrids was within 10.5-12.6 g/m² per day – in 2019, 9.8-11.6 g/m² per day – in 2020 and 9.9-12.1 g/m² per day – in 2021 (Fig. 2). The volatility of this indicator ranged from 1.8 (in 2020) to 2.2/m² per day (in 2021).

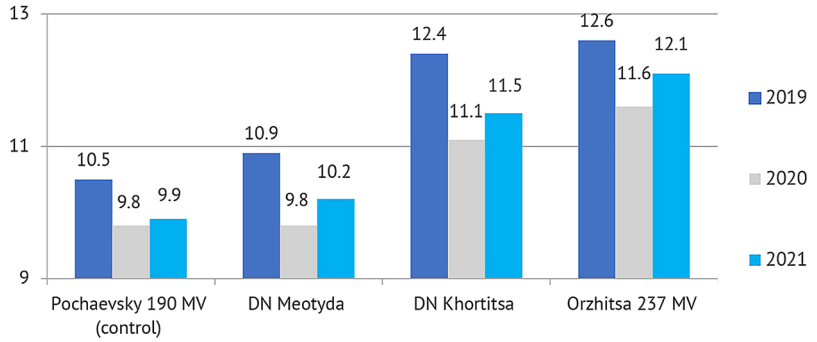

***Figure 2**. Influence of the hybrid maturing group on maize photosynthesis productivity (2019-2021), g/m² per day*

The spread of diseases was affected by hot temperature (20-25°C) and humidity during the flowering period, which contributed to the damage of generative organs (cob, panicle). Plants were evaluated on a 5-point scale, where plant damage of 0-10% corresponds to 9 resistance points. According to this definition, it was found that the maize hybrids under study were resistant to smut (Fig. 3). The percentage of plant damage in the early-maturing hybrid Pochaevsky 190 MV, which was taken as a control, was 12.1%, which corresponds to a resistance score of 7. A 1.5% lower development of the disease was found in a hybrid of DN Meotyda. In medium-early maturing hybrids (FAO 200-299), the development of this disease was significantly lower than the control by 2.6-3.3% per LSD_{05}=1.3%.

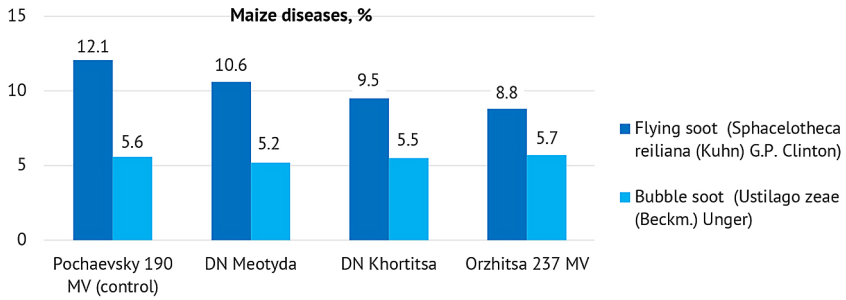

***Figure 3**. Smut development on maize plants depending on the biological characteristics of the hybrid in the BBCH 89 stage (2019-2021), %*

Since maize was sown in a crop rotation with the observed rotation of alternating crops, and the sown seeds were characterised as biologically healthy, the development of this disease was insignificant (5.2-5.7%), i.e., all hybrids were classified as resistant (7 points). There was no significant difference between the maturing groups, and the difference was within the margin of error.

Among the various types of stem rot, the most dangerous is fusarium rot, which affects the roots and lower internodes and affects the lodging of plants, especially if the soils of the soil and climate zone under study are sufficiently moist. The average percentage of disease intensity in the experiments of this study ranged from 13.9% in the early-maturing hybrid Pochaevsky 190 MV (control) to 14.7% in the mid-early maturing Orzhitsa 237 MV (Fig. 4). According to the degree of damage to the cob area, hybrids were classified as medium-resistant – 24.4-29.1%. Group resistance to major diseases of maize from early-maturing (FAO 150-199) hybrids was provided by DN Meotyda, from medium-early maturing (FAO 200-299) – Orzhitsa 237 MV.

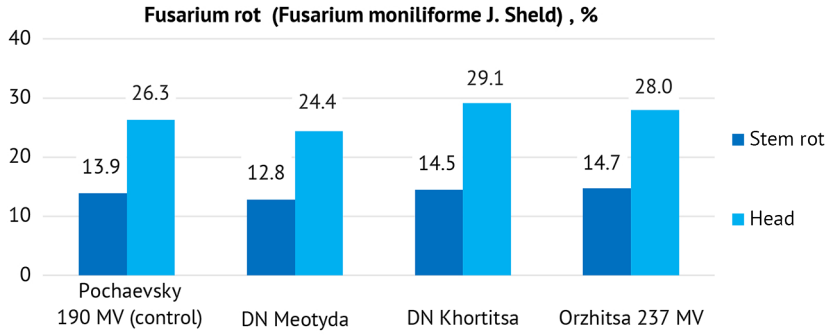

***Figure 4**. Development of fusarium rot (Fusarium moniliforme J. Sheld) on maize depending on the biological features of the hybrid in the BBCH 89 stage (2019-2021), %*

***Note:** the degree of damage: wea – up to 25%, average – 26-50%, strong – above 50%*

In the authors' experiments, the highest grain productivity was obtained in 2019 – 7.49 t/ha in hybrids of the early-maturing group and 7.62 t/ha – in mid-early maturing; the productivity was lower in 2020 – 7.07 and 7.22 t/ha, respectively (Table 2). In terms of average yield, the following hybrids were more productive: DN Meotyda (7.68 t/ha), Orzhitsa 237 MV (7.67 t/ha).

***Table 2**. Maize grain yield depending on the hybrid maturing group (2019-2021)*

Indicator	FAO					
	150-199			200-299		
	Pochaevsky 190 MV	DN Meotyda	Mean	DN Khortitsa	Orzhitsa 237 MV	Mean
2019	7.11	7.87	7.49	7.46	7.78	7.62
2020	6.59	7.55	7.07	6.88	7.56	7.22
2021	6.87	7.63	7.25	7.11	7.67	7.39
Mean	6.86	7.68	7.27	7.15	7.67	7.41
min	6.59	7.55	7.07	7.11	7.56	7.22
max	7.11	7.87	7.49	7.46	7.78	7.62
R	0.52	0.32	0.42	0.35	0.22	0.40
LSD_{05}	0.21	0.17		0.14	0.11	

The range of grain yield variability over the years ranged from 0.22 to 0.52 t/ha, which confirms the individual reaction of the hybrid to growing conditions.

Several institutions of the National Academy of Agrarian Sciences are working on solving the urgent problem of the development of grain production, namely maize, in Ukraine; at the same time, agricultural production declares an elevated practical interest in innovative developments. Since the new maize hybrids included in the Register (Methodology for the examination and state..., 2003) react differently to particular growing conditions of different zones, subzones, and soil differences, their implementation requires a scientific justification of the advantages of genetic productivity. This task is particularly relevant in the Western Forest-Steppe zone, where maize is not selected, and agricultural producers use hybrids of originator institutions located in the Central Forest-Steppe and Steppe zones.

According to the results of the authors' research, hybrids that provided grain yields at 7.07-7.62 t/ha were ecologically flexible to the growing conditions of the Western Forest-Steppe zone. The conclusions made by the authors of this study are consistent with the experimental data of researchers and scientists in various soil and climatic zones of Ukraine.

Andrienko *et al.* (2017a) confirms the effective use of soil and climatic potential by maize hybrids of early-maturing and medium-early maturing groups, which allows obtaining not only high yield and quality of grain, but also save material, technical, and monetary resources. They offer medium-early hybrids with high potential yields for the eastern part of the Forest-Steppe of Ukraine: Lyubchik (FAO 240), Vektor (FAO 270) of the grain direction, Stavr (FAO 290) – universal direction.

According to the recommendations of Shevchuk & Kyriyenko (2022), the best Ukrainian hybrids for the

conditions of the Polessia zone of Ukraine are Pochaevsky 190 SV (early-maturing), Baturinsky 278 MV and Orzhitsky 237 MV (medium-early maturing).

Researchers (Zaplitnyi *et al.*, 2010) believe that for more economical use of energy resources for drying maize grain, considering the level of energy supply in the south-western part of the Forest-Steppe, it is possible to grow hybrids: early-maturing at the sum of active temperatures of 2200°C, medium-early – 2400°C and medium-maturing – 2600°C. Introduction of immune-resistant products is the most effective means of preventing diseases and pests, and therefore agricultural producers should pay special attention to the choice of hybrids considering a complex of biological and economic characteristics.

Andrienko *et al.* (2017b) emphasise that the main step in growing maize for grain and dealing with stress should be the correct identification of the hybrid that best meets the available soil-climatic, agrotechnical conditions and technical support of a particular farm. Increasing the level of production, reducing the cost of post-harvest grain determine the timing of sowing and the choice of maize hybrids of different maturing groups, the share of which in the structure of sown areas for grain should be differentiated and vary depending on the specialisation of the farm and its practical orientation.

Tsekhmeystruk *et al.* (2014) note a 40-50% use of the genetic potential by modern hybrids with a potentially high yield of 16-18 t/ha. The authors present the data of the National Institute of Agricultural Botany of Great Britain on the increase in yield growth due to varieties and hybrids over thirty years. It is indicated that for the first decade it is 38%, the second decade – 42% and the third decade – 60%. It is noted that the maximum yield is provided by hybrids with the optimal FAO for the growing area, since the choice with less than the recommended one leads to incomplete use of solar radiation during the growing season and a shortage of crops, while greater FAO does not necessarily allow achieving full-ripe maturing of grain and unjustified costs for its drying.

Kaminsky & Asanishvili (2020) found a different reaction of hybrids to cultivation technologies. In intensive farming systems, production resources are most effectively used for growing a medium-early hybrid with a high genetic productivity potential. To expand grain production, increase gross grain volumes and land use efficiency, it is advisable to use high-intensity maize cultivation technology, which makes provision for the introduction of $N_{180-240}P_{120}K_{180-240}$ against the background of by-products of the precursor, herbicides, microfertilisers and growth stimulants. With a yield of 11.21-12.10 t/ha, the profitability is 118-128%, which allows agricultural enterprises to conduct large-scale commercial grain production. It is advisable to grow the early-ripening hybrid Trubizh SV using intensive technology with mineral fertilisers in a dose not higher than $N_{120}P_{80-90}K_{100-120}$ against the background of by-products of the predecessor, which provides a profit of 23.0-23.96 thousand UAH/ha, profitability of 121% at a yield of 8.40-8.77 t/ha and a reduction in production costs by 22.7-28.4% due to herbicide control of segetal vegetation in crops, foliar top dressing with microfertilisers, and the use of plant growth regulators in various regulations.

The selection of environmentally friendly maize hybrids of various originator institutions with high productivity and product quality and lower humidity during harvesting will contribute to an increase in gross collections in the zone of excessive moisture in the Western Forest-Steppe of Ukraine, which leads to further research.

CONCLUSIONS

Ukrainian selection has created a number of new maize hybrids that are offered to producers, but they have different morpho-biological features and characteristics, a reaction to favourable and adverse factors of production, which requires differentiated selection to achieve an increase in grain yield and quality.

During the vegetation period of maize plants, the sum of active temperatures varied from 2311°C in 2021 to 2448.5°C in 2019 with a long-term average of 2372.2°C. Moisture supply was at 414.8 mm (2020) – 432.9 mm (2021). Under the influence of weather conditions and the maturing group of the hybrid, the duration of the growing season varied within 125-127 days.

Depending on the biological characteristics, the hybrids provided a different leaf area duration during the flowering stage (BBCH 61-69) – grain formation (BBCH 71-79) (34.1-41.3 thousand m^2/ha) and net photosynthetic productivity (10.1-12.1 g/m^2) per day.

The highest percentage of disease damage was observed in 2021 with a large amount of precipitation during June-September. Group resistance to major diseases of maize from early-maturing (FAO 150-199) hybrids was provided by – DN Meotyda, from medium-early (FAO 200-299) – Orzhitsa 237 MV. Grain yield was ensured by the productivity of the hybrid to effectively use the available soil and climatic resources of the zone under study. In early-maturing hybrids, this economically valuable indicator was formed at 7.07-7.49 t/ha, in mid-early hybrids – at 7.22-7.62 t/ha.

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Продуктивність гібридів кукурудзи в умовах Західного Лісостепу України

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Анотація. Актуальним науковим обґрунтуванням для західного регіону України є комплексна оцінка та добір гібридів кукурудзи з широкою екологічною пластичністю забезпечувати високу і стабільну урожайність зерна під впливом специфічних погодних чинників. Збільшення валових зборів кукурудзи можливе за рахунок ефективного використання генетичних можливостей нових гібридів і є надзвичайно важливим для зони Західного Лісостепу де не ведеться селекція даної культури, а сільськогосподарські виробники користуються гібридами інших установ-оригінаторів. Метою дослідження було встановити зернову продуктивність гібридів ранньостиглої і середньоранньої груп в досліджуваній ґрунтово-кліматичній зоні України. У дослідженнях застосовували загальноприйняті і спеціальні методи: польовий, вимірювально-ваговий, статистичний. На основі отриманих результатів досліджень за 2019–2021 рр. підтверджено про зміну погодних умов у досліджуваній ґрунтово-кліматичній зоні. Визначено тривалість періоду вегетації кукурудзи залежно від погодних факторів та гібриду. Встановлено площу листкової поверхні в фазу цвітіння (ВВСН 61–69) – формування зерна (ВВСН 71–79) та чисту продуктивність фотосинтезу. Обґрунтовано стійкість рослин гібридів до хвороб та виявлено найвищий їх відсоток ураження в 2021 р., за великої кількості опадів впродовж червня-вересня. Доведено залежність між гібридами та їх біологічними властивостями ефективно використовувати наявні ґрунтово-кліматичні умови, що впливало на зернову продуктивність і розмах мінливості за роками. Отримані результати дозволяють зробити висновок, що зміни погодних факторів, зокрема підвищення суми активних температур та достатня кількість опадів впродовж вегетації дозволяють отримувати високі врожаї зерна гібридів кукурудзи ранньостиглої і середньоранньої груп стиглості. Господарствам різних організаційно правових форм рекомендовано впроваджувати в сільськогосподарське виробництво українські гібриди: ДН Меотида та Оржиця 237 МВ

Ключові слова: ФАО, фази розвитку ВВСН, площа листкової поверхні, чиста продуктивність фотосинтезу, хвороби, урожайність

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The Effect of Cultivation Conditions on the Nitrogen Fixation and Seed Yield of three Ukrainian varieties of Soybean

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Abstract. The relevance of the research topic is determined by the search for new technological methods of growing soybeans. Therefore, the specifics of the formation of productivity of different varieties of soybeans were investigated depending on a number of factors, such as: dates, methods of sowing and the rate of sowing. The purpose of the research was theoretical substantiation and practical advises of sowing dates and methods, sowing rates of different varieties of soybeans. Indicators of the influence of light intensity, fertilizer application, changes in seed sowing rates and different variants of soybean sowing distance on biological nitrogen fixation of soybeans were analyzed. As a result, regularities were established and a scientific substantiation of provisions was carried out, recommendations for production and scientifically based methods of soybean cultivation technology were developed, which ensure an increase in crop productivity by 15-25%. The developed practical recommendations for increasing soybean production are used in the farms of the region and beyond to solve an important problem – increasing the production of fodder and food protein and vegetable oil. Changing the sowing rate from 0.5 to 0.8 M seeds/ha for row sowing contributed to an increase in the attachment height of the lower beans, which, in turn, contributes to a reduction in crop losses during crop harvesting. Sowing rate had a greater influence on soybean yield than the sowing method. The best conditions were obtained when sowing 0.7 M seeds/ha of similar seeds. During the research, the Romantyka variety showed the highest yield of 3.07 t/ha under the row method of sowing, the sowing rate of 0.8 M seeds/ha and the second sowing period

Keywords: plant growing, light intensity, sowing terms, norms and methods, root nodule, inter-row distance, seeding rate

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INTRODUCTION

Soybean is the world's most important seed legume, cultivated on an estimated 121 million ha worldwide, with a total production of 334.9 million tons in 2018 (FAOSTAT, 2017). It is one of the largest sources of animal feed in the world (Patil *et al.*, 2017) and is also used as a source of high-quality protein in the human diet (Rizzo & Baroni, 2018). With a protein content of 36-42% protein and an oil content of 15-25%, soybean is a rich source of protein and is the largest oilseed crop in the world (Vinnichek *et al.*, 2018; De Luca & Hungria, 2014). A large amount of nitrogen is required by the grain legumes to synthesize seed storage proteins, a substantial portion of which is obtained by the process of symbiotic biological nitrogen fixation. Out of 193 million tons of nitrogen fixed annually by biological means, crop legumes fix about 21.5 million tons, and the contribution from soybean is about 77% of this amount (Weil & Brady, 2017; Herridge *et al.*, 2008). Therefore, efforts aimed towards increasing the efficiency of symbiotic biological nitrogen fixation and seed yield in legumes, particularly in soybean, can contribute significantly towards sustainable food production.

The nitrogen fixation carried out by plant-bacteria symbiotic association is affected by the environmental factors. Optimization of these factors can potentially increase the seed yield of soybean and that of other legumes and help in reducing the use of chemical fertilizers. Each year >100 million tons of nitrogen is applied to the crops worldwide (Heffer & Prud'Homme, 2016; Umburanas *et al.*, 2018). The production and application of nitrogen fertilizers utilize about 1.1% of the world's energy (IFA, 2009) and represent about 1.5% of the global GHG emissions (CCAFS, 2019). Approximately one-third of the GHG emissions from agriculture is in the form of N_2O, a byproduct of the degradation of nitrogen fertilizers and with a global warming potential 265 times that of carbon dioxide (Blanco *et al.*, 2014). Therefore, gradual replacement of chemical fertilizers with symbiotically fixed nitrogen can play an important role in limiting the environmental damage due to chemical fertilizers. Improvements in the nitrogen fixation capabilities of legumes particularly that of soybean, can contribute significantly towards this transition. Increase in nitrogen fixation efficiency of grain legumes can also reduce the need for bringing additional land under cultivation to keep up with the growing world food demand (Getachew Gebrehana & Abeble Dagnaw, 2020).

D.F. Herridge *et al.* (2008) in their researches calculated nitrogen fixation by the crop legume–rhizobia symbioses. They determined the role of nitrogen fixation in underpinning legume productivity and how highly efficient rhizobia–soybean symbioses might be achieved in commercial practice.

X.-Y. Lin *et al.* (2022) in their researches studied interactions between hydrogen sulphide and rhizobia modulate the physiological and metabolism process during water deficiency in soybeans.

Temperature, soil moisture, soil mineral nitrogen, salinity, soil oxygen (Atieno *et al.*, 2019; Mathenge *et al.*, 2019), and soil acidity are major factors affecting the symbiotic nitrogen fixation in legumes (Pahari *et al.*, 2021).

A study of the influence of light intensity, fertilizer application, irrigation, seeding rate and row spacing on nitrogen fixation and yield for three soybean varieties was conducted.

The purpose of the research was to develop theoretical explanations and practical advice on increasing the productivity of soybeans by improving the elements of the cultivation technology, taking into account the biological characteristics of the varieties.

MATERIALS AND METHODS

Laboratory experiments were carried out at the Institute of Crops and Grassland Science, University of Hohenheim (Stuttgart, Germany) and at the Department of Plant Growing, Poltava State Agrarian University (Poltava, Ukraine). The seeds of Romantica variety were obtained from Yuriev Institute of Plant Breeding, National Academy of Science, (Kharkiv, Ukraine); Ustya variety from Institute of Agriculture, National Academy of Science, (Kyiv, Ukraine) and Vorskla variety from Soy Research Institute (Globyno, Ukraine).

Plant growth conditions. The soybean seeds of Romantica variety were sown in 800 ml pots containing vermiculite and sand in a ratio of 1:1. A single seed was sown in each pot, and 6 pots were maintained in a RK-340 CH growth chamber (Kambič d.o.o, Semič, Slovenia) at 27°C, 70% RH, 460 μmol mol^{-1} CO_2 and 16/8 light/dark photoperiod at 60 W/m^2 or 120 W/m^2. The distance between the plants was 20 cm. The plants were harvested at 5^{th} trifoliate (V5), flowering (R2), and full pod stages (R4). One set of plants at full bloom (R2) stage was used to study the effect of dark periods on the nitrogen fixation by the root nodules. These plants were subjected to a continuous dark period of 48 h before measuring the BNF rate.

Estimation of nitrogenase activity in the root nodules.

The rate of nitrogen fixation in the root nodules was determined by using the acetylene reduction method (Gremaud & Harper, 1989). The roots with attached nodules were placed in a hermetically sealed glass vial of 75 ml capacity, which was filled with 10% acetylene gas. The flask was incubated for 1 h, and the ethylene gas formed in the flask was quantified on a gas chromatograph equipped with a flame ionization detector (Agilent GC system 6850; Agilent Technologies, Santa Clara, CA, USA). The separation of gases was performed on a Supelco Porapak N column at a furnace temperature of 55°C and a detector temperature of 150°C. The carrier gas was helium (50 $ml.min^{-1}$) and the sample volume injected into the gas chromatograph was 1 ml.

The amount of ethylene formed in 1 hour by the action of nitrogenase was expressed as nmol.plant^{-1}.min^{-1}.

Measurement root nodule respiration. The root nodule respiration was studied by the method of Nelson and Wood with some modifications (17). A sample of the test material (2 g) was placed into a gauze bag and fixed with a hook to a rubber cork. Twenty-five milliliters of 0.25 N solution of Ba $(OH)_2$ were quickly poured into a flask, and 3 drops of phenolphthalein were added. The flask was immediately sealed with the cork, bringing the sample inside the flask (the gauze bag could pass easily through the neck of the flask and did not touch the solution present in the flask).

The control flask was set up in the same manner but without the test material. After 20 min the test material was removed from the experimental flask, and it was quickly closed with a stopper. The solutions in the experimental and the control flasks were titrated with 0.01 N HCl until the disappearance of the pink color. The flasks are periodically shaken so that a $BaCO_3$ film does not form on the surface of the liquid. The amount of CO_2 evolved per gram of plant tissue per hour was calculated from the volume of HCl consumed, given that 1 ml of 0.01 N HCl is equivalent to 0.22 mg of CO_2 produced by the plant material.

Field Experiments. Three varieties of soybean, Romantica, Ustya, and Vorskla, were used to study the effect of inter-row spacing and seeding rate on the number and mass of root nodules and the seed yield. The size of the study plots was 25 m^2, and the seeds of each variety were sown in rows with 15 cm or 45 cm spacing and at rates of 0.5, 0.6, 0.7 and 0.8 million seeds/ha. The experiments were conducted between April 26 and May 10 of the year 2017 and repeated three times in the same duration during the years 2018, 2019 and 2020. The average temperatures and rainfalls for the study period were: 2017 – 13.4°C, 7.35 mm; 2018 – 18.3°C, 5.05 mm; 2019 – 15.6°C, 6.08 mm; 2020 – 15.1°C, 12.9 mm. The soil of the experimental site was podzolic medium-textured loam chernozem with a humus content of 3.7%, and a pH 5.6. The nodule mass and number for each variety were determined three times – after the formation of symbiosis (1st selection – 35 days after emergence, 5th trifoliolate stage) and during the period of active nitrogen fixation (2nd and 3rd selection – 45 and 55 days after emergence). At maturity, seed harvesting was carried out using small grain harvesters Sampo (Sampo-Rosenlew, Pori, Finland). The yield of the seeds and the green mass were determined from the samples taken from an area of 1 m^2 from each field. The beans were plucked from the plant and opened to collect the seeds, which were counted and weighed. Statistical analysis was performed using Microsoft Excel and Statistica programs.

RESULTS AND DISCUSSION

The effect of light intensity on the nitrogen fixation. The effect of light intensity on the dry weight of the plants and the nodules, and the rate of nitrogen fixation in the nodules was studied at V1, R1, and R7 stages. The plant and nodule dry weight per plant was significantly increased at 120 W/m^2 light intensity, compared to 60 W/m^2 (Figs. 1; 2).

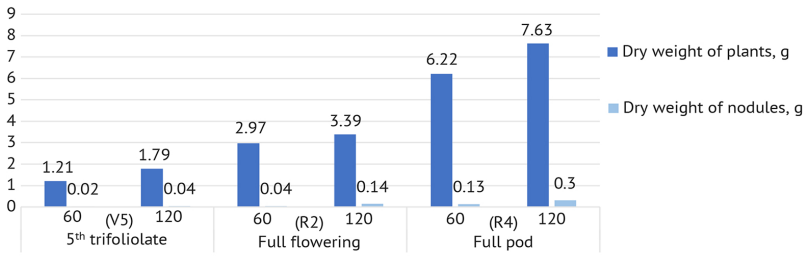

Figure 1. *Effect of light intensity (60 or 120 W/m^2) on dry matter content of plants and nodules*
Source: *authors' development*

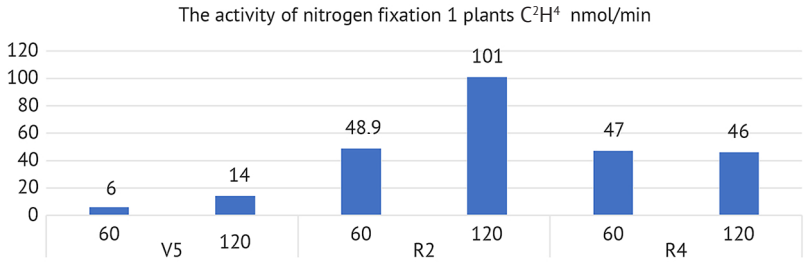

Figure 2. *Rate of nitrogen fixation (measured as rate of acetylene reduction (nmol/plant/min) as affected by light intensity in soybean plants*

The nitrogen fixation rate (expressed as nmol/plant/min of C_2H_4 production) was higher in the plants grown under the light of 120 W/m^2 at the V1 and R1 stages. The nitrogen fixation rate was not affected by the light intensity at the R7 stage and was, in fact, slightly lower at 120 W/m^2 light intensity than at 60 W/m^2. The increased rate of nitrogen fixation during the V1 and R1 stages at higher light intensity was due to greater growth and higher masses of the nodules and not due to greater specific activity of the nitrogenase enzyme in the nodules. At R7 stage though the mass of the nodules per plant is higher than in earlier stages, the nitrogen fixation is reduced, suggesting a decrease in the specific activity of the nitrogenase enzyme at this stage. Earlier studies indicated that a light of 400-500 μmol/m^2/s (~ 87-109 W/m^2) was optimum for soybean growth and development. Therefore, light intensities of 60 and 120 W/m^2 were used in the study. Earlier studies have also reported a positive correlation between the light intensity and the nitrogen fixation rates in soybean up to a certain light intensity. The reduction in nodule mass and number per plant with decreasing light intensity has been reported (Lin *et al.*, 2022; Jańczak-Pieniążek *et al.*, 2021; Yang *et al.*, 2022). The drop-in nitrogen fixation rates in the green bean filing stage have been reported (Prusinski & Nowicki, 2020).

Soybean monitoring the effect of light intensity on the root development, and nitrogen fixation rates at three growth stages of soybean under the conditions of infection by native soil symbiotic bacteria were studied. The research revealed two important characteristic of nitrogen fixation in soybean: 1) at later stages of growth when the rate of nitrogen fixation drops, light of higher intensity cannot boost the nitrogen fixation rate, 2) this drop in nitrogen fixation at later stages of growth is due to decrease in specific activity of nitrogenase in the nodules, as nodule mass and number did not decrease at R7 stage.

Effect of soil nitrogen content on the initiation and development of root nodules.

There are conflicting views on the use of inorganic nitrogen fertilizer for increasing the yields of soybean. Reed *et al.* (2019) have advocated against the use of supplemental nitrogen for legumes, while other authors have recommended the use of small amounts of inorganic nitrogen to achieve good nodulation and yields (Rizzo & Baroni, 2018, Arachchige *et al.*, 2020). The amount of nitrogen required to maintain plant growth and development prior to the initiation of nitrogen fixation in soybean plants is small and can be provided by the soil reserves. During the period of active growth and development of soybeans, especially during the formation of the beans, nitrogen-deficient conditions in the soil lead to the development of a defective photosynthetic apparatus with a low photosynthetic efficiency that cannot be improved without providing supplemental nitrogen. An efficiently functioning photosynthetic apparatus is thus a prerequisite for the development of healthy root nodules. The number of nodules that developed on the roots of the plants varied with the soil nitrogen content and the stage of the plant growth (Table 1).

***Table 1**. The effect of mineral nitrogen fertilizer on the number and mass of root nodules per plant*

Indicators	Phases of growth and development of soybean plants								
	V1-V3 stage			R1-R2 stage			R3-R6 stage		
	Without fertilizers	N_{30}	N_{60}	Without fertilizers	N_{30}	N_{60}	Without fertilizers	N_{30}	N_{60}
Number of nodules per 1 plant, pcs.	3.0±1.2	3.5±1.6	4.0±1.2	7.2±2.0	6.3±1.5	6.1±1.7	12.8±4.3	10.3±1.6	8.1±1.9
The mass of nodules per 1 plant, mg	23±3.5	28±3.6	34±3.4	91±5.4	63±6.3	50±5.6	287±14.9	201±5.8	153±6.5
Nitrogen content in soil (mg/kg of soil) $N-NO_3$	10.8±2.2	17.5±3.9	20.2±2.9	9.4±2.2	19.7±2.6	21.1±2.3	4.1±1.7	6.7±2.5	7.2±2.3
$N-NH_4$	6.8±2.0	8.6±3.0	10.3±3.3	14.8±2.0	15.7±2.5	15.9±3.9	8.0±1.7	9.2±3.3	9.7±3.8
$N-NO_3$: $N-NH_4$	1.59	2.0	2.0	0.64	1.25	1.32	0.51	0.73	0.74

***Source:** authors' development*

During the first three to four weeks of growth, soybeans actively use inorganic nitrogen from the soil. In the first-third trifoliate stage (V1-V3), a greater number of nodules per plant were noted in areas with fertilizer application: 3.5 in areas with 30 kg/ha, 4.0 in areas with 60 kg/ha and 3.0 without fertilizer application. The average mass of the nodules per plant was also higher in the areas with fertilizer: 28 g in plants growing in 30 kg/ha

and 34 g in plants growing in areas with 60 kg/ha fertilizer application. The average mass of the nodules per plant in areas without fertilizer application was only 23 g.

In later stages of plant growth, fertilizer application had a negative effect on the nodule number and nodule mass. In the R1-R2 stages, there was an increase in the number of nodules in areas without fertilizers: 7.2±1.81 in unfertilized areas, 6.3±2.21 in areas with 30 kg/ha and 6.1±1.91 in areas with 60 kg/ha fertilizer application. The mass of nodules was also greater in unfertilized areas: 91 g vs 63 g in 30 kg/ha and 50 g in 60 kg/ha fertilizer application. A similar decrease in number and mass of nodules per plant with fertilizer use was observed in the R3-R6 stage – 12.8±1.55 in areas without fertilizer and 10.3±2.31 in areas with 30 kg/ha fertilizer application and 8.1±1.97 in areas with 60 kg/ha fertilizer application. The mass of nodules was also greater in unfertilized areas – 91 g vs 63 g in 30 kg/ha and 50 g in 60 kg/ha fertilizer application. This observation is consistent with earlier observations that mineral nitrogen in the form of nitrate strongly inhibits the nitrogen fixation process during the later stages of the growth of the plants (Lin *et al.*, 2022). Thus, addition of inorganic nitrogen promotes growth and development during the early stages of growth of soybean plants. However, excess inorganic nitrogen in the soil suppresses the development of root nodules during later stages of growth.

As part of the research, an agrochemical analysis of the soil was carried out to determine the content of ammonia and nitrate nitrogen (Table 1). Fertilized plants showed a higher content of ammonia and nitrate nitrogen at all stages of plant growth and development. No significant difference in the content of nitrate nitrogen was found in unfertilized crops and fertilized soil between the V1-V3 and R1-R2 stages; however, a large drop in the nitrate nitrogen and ammoniacal nitrogen content of non-fertilized and fertilized soil was observed in the R3-R6 stage. This indicates that although soil must contain sufficient nitrogen during the early stages of plant development to enable proper development of photosynthetic apparatus, the amount of nitrogen absorbed from the soil is not much till the plants reach the bean formation stage. At this stage, the growing demand for nitrogen for seed protein synthesis is met by both absorption of large amounts of soil inorganic nitrogen and symbiotically fixed nitrogen. The ammonia nitrogen in the soil is increased in the flowering stage, most likely due to 'leakage' of symbiotically fixed ammoniacal form of nitrogen from the roots. Thus, it may be beneficial to apply a small amount of inorganic fertilizer (depending on soil nitrogen level) during the initial stages of soybean plant growth and then a larger amount at the later stages when the seeds are forming in the pods.

Effect of inter-row distance and the sowing rate on the number and weight of root nodules.

As part of the research, the influence of row spacing and seeding rate on the number and mass of root nodules per plant was determined for three soybean varieties. The seeds were sown in rows, with an inter-row distance of 15 cm (narrow-row sowing method) or 45 cm (wide-row sowing method) and at rates of 0.5 million, 0.6 million, 0.7 million, and 0.8 million seeds/ha. The average number of root nodules and active root nodules on the plants were determined in three varieties at R2 stage and the average data are presented in Figure 3. The narrow-row sowing method resulted in a greater number of nodules per plant on all three varieties. The number of nodules at 0.5 million seeds/ha was 26.3±4.6 for variety Ustya, 27.4±3.1 for variety Romantika, and 23.7±3.1 for variety Vorskla. An increase in seeding rate to 0.8 million/ha helped to increase the number of nodules to 27.5±2.6 in Ustya, 28.1±2.2 in Romantika, and 25.5±3.0 in Vorskla. For wide-row sowing method, the corresponding values were less by 4.5-10.6%.

The average mass of nodules on the plants was also determined in the three varieties. A greater mass of nodules was observed in plants grown with an inter-row spacing of 15 cm. At the seeding rate of 0.5 million seeds/ha, the average mass of nodules was 4.1±1.3 g in Ustya, 4.2±1.3 g in Romantika and 3.9±0.9 g in Vorskla variety. An increase in seeding rate to 0.8 million seeds/ha helped to increase the number of nodules to 4.3±0.9 in Ustya, 4.3±0.8 in Romantica, and 3.9±0.7 in Vorskla variety. For the wide-row sowing method, the corresponding values were 2.5-5.7% less. All data are presented in Figure 4.

Thus 15 cm inter-row distance and a seeding rate of 0.8 million seeds/ha resulted in the highest number and mass of root nodules per plant. The variety Romantica developed the highest number and mass of root nodules under optimal conditions. Effect of inter-row spacing and seeding rate on the nodule number and nodule mass per plant are variety and cultivation location dependent. In a study conducted on Merlin variety of soybean in Poland, the inter-row distance (15 cm or 30 cm) did not affect the nodule mass and number, whereas nodule mass and number showed a decreasing trend with the increasing seeding rate (70, 90, and 110 seeds/m^2) (Kaur, 2018; Kena, 2018). Similar results were obtained by testing the seeding densities from 40,000 to 320,000 seeds/ha in BRS 133 varieties of soybean (Natsumi *et al.*, 2019). At the same time, no correlation between the seeding rate or inter-row distance and the nodule number or nodule mass was found (Sobko *et al.*, 2019; Araujo *et al.*, 2018).

Effect of inter-row distance and seeding rate on the yield of soybean seeds.

The yields of soybean for crops cultivated at different inter-row distances and seeding rates are presented in Figure 5. The data from the third term crops were used to determine the effect of inter-row distance and seeding rate on the yields, as it more closely corresponds to real-world situation of a field being used for soybean cultivation for many consecutive years. A trend of increasing seed yield with the increasing seeding rate was observed in the crops cultivated using narrow-row sowing

method at all sowing rates. In wide-row sowing method the seed yield increased from 0.5 to 0.7 million seeds/ha but dropped at 0.8 million seeds/ha by 6.1% in Romantika, 13.5% in Ustya, and 7.5% in Vorskla variety. Also, the difference in the seed yield between 0.7 and 0.8 million seeds/ha with the narrow-row sowing method, was small (2.9%, 4.3% and 3.2% for Romantika, Ustya, and Vorskla variety, respectively) which does not justify the extra expenditure for the purchase of extra 0.1 million seeds and the associated labor costs. Hence, a seeding rate of 0.7 million/ha was found to be optimum for both narrow-row and wide-row sowing method for all three varieties.

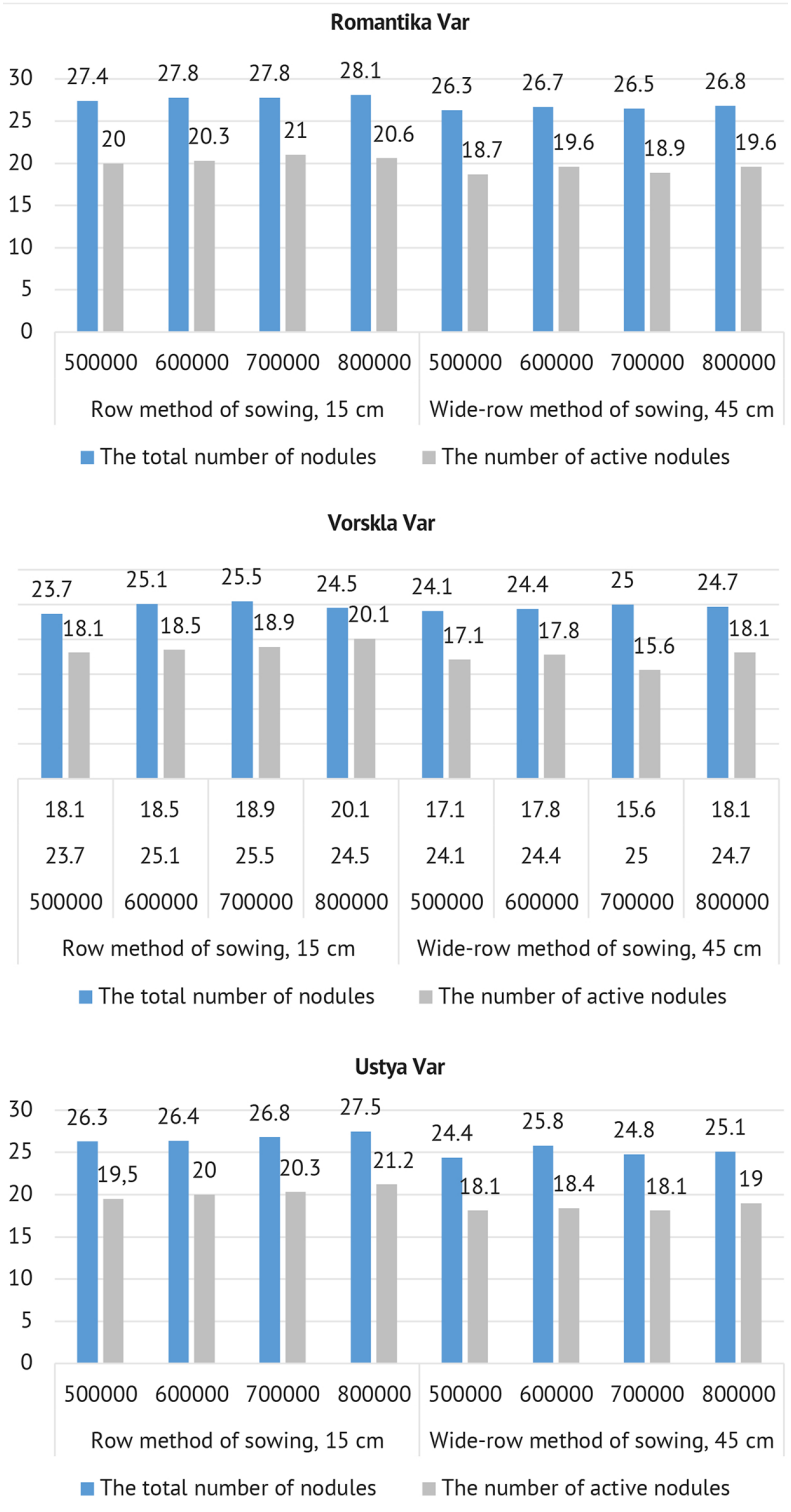

***Figure 3**. The effect of variety, seeding rate and inter row distance plants on number of root nodules per plant in soybean plants*

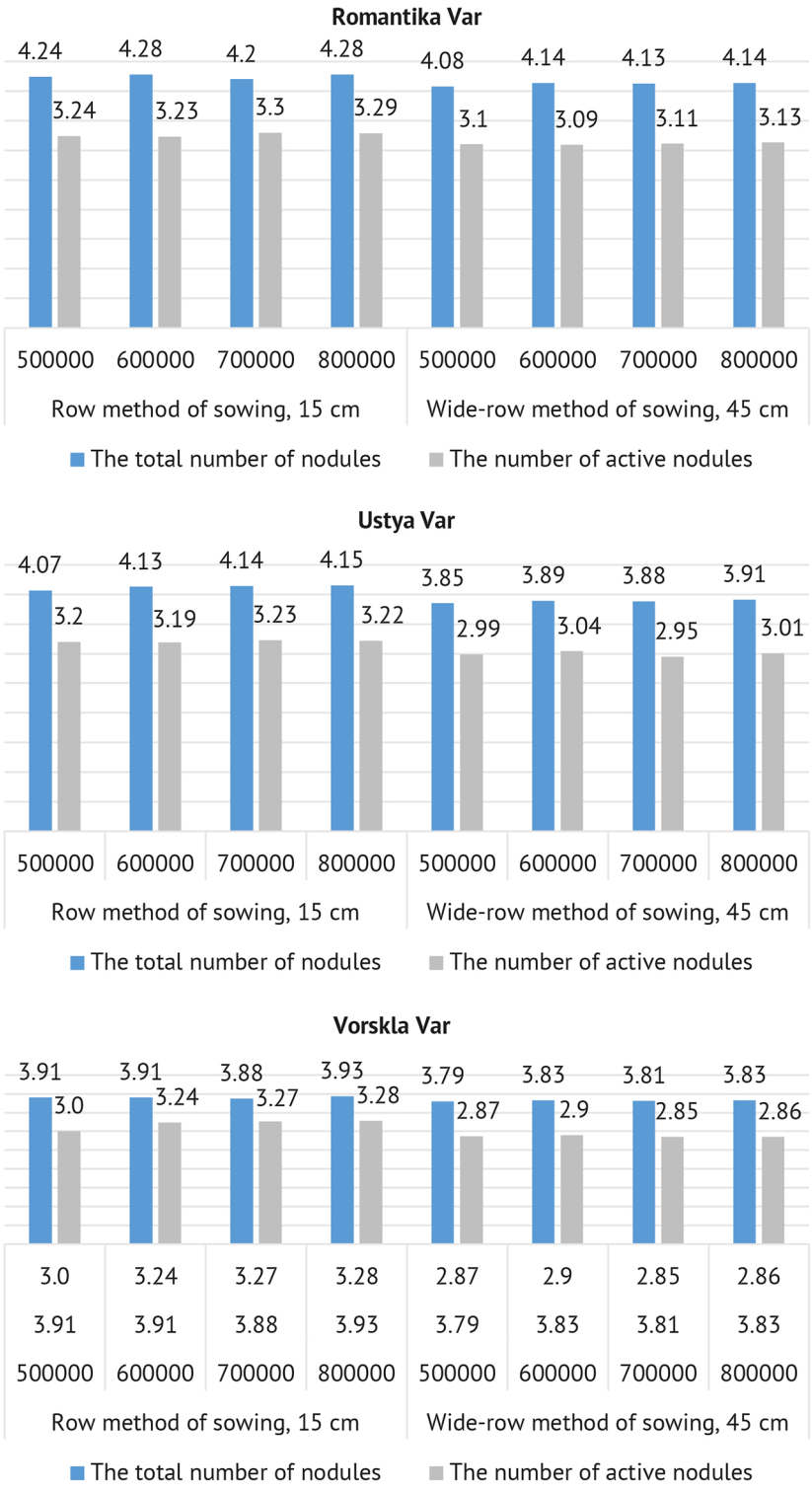

***Figure 4**. The effect of variety, seeding rate and inter row distance plants on mass of root nodules per plant in soybean plants*

At 0.7 million seeds/ha, the wide-row sowing method resulted in greater yield than the narrow-row sowing method by 21.0% for the Romantica, 19.6%, for the Ustya and 9.8% for the Vorskla variety. Under these conditions, the highest yield was obtained for Romantica variety at 2.95 t/ha (Fig. 5). Earlier studies have reported the effect of inter-row spacing and seeding rate on the seed yield in soybean. In the eastern Mediterranean region of Turkey, the highest yield in full-season crop was obtained at 50 cm and that in the late-season crop at 30 m row spacing (Weil & Brady, 2017). Mathenge, Thuita *et al.* obtained the highest seed yields at 25 cm

row spacing in cultivar Ika in Siaya County of Kenya (Mathenge *et al.*, 2019; Leilah & Khan, 2021). A row spacing of 19 cm yielded 0.8-10% more seeds per hectare as compared to 76 cm row spacing in a study in South Dakota, USA. The highest yield was obtained at 506, 500 seeds/ha in this study (Vinnichek *et al.*, 2018). In another study in Western Ethiopia, the authors reported a different optimum inter-row spacing of 40, 50, and 60 cm for three different soybean varieties (Lyu *et al.*, 2019; Schutte & Nleya, 2019). It is likely that apart from the inter-row spacing, the performance of soybean crop is also affected by factors such as the variety, the local climatic conditions, and the properties of the soil, and the best seeding rate and inter-row spacing need to be determined for each soybean variety.

An inter-row spacing of 15 cm was optimal for root nodule development, but an inter-row spacing of 45 cm resulted in better seed yield in all three varieties.

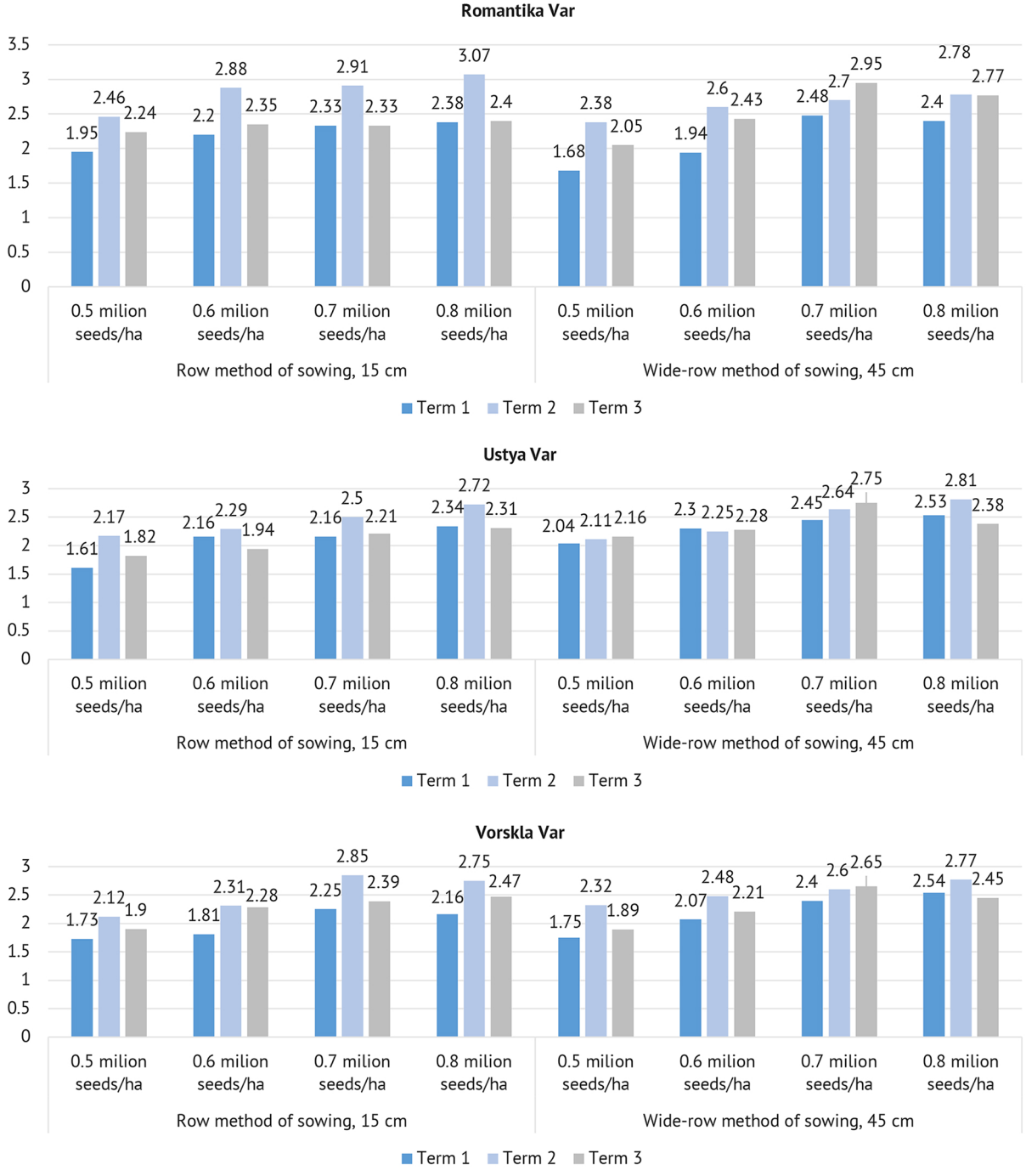

Figure 5. *The effect of variety, seeding rate and inter row distance plants on mass of root nodules per plant in soybean plants*

The infection of root tissues with the symbiotic bacteria is mediated by the chemical mediators secreted by roots. The concentration of these mediators may be higher in the soil when more roots are present in a given area in narrow-row sowing. However, wide-row sowing may minimize the competition for soil resources and allow greater inception of light from different directions for photosynthesis (Schwember *et al.*, 2019; Ulafić *et al.*, 2020).

Thus, the increase in the rate of nitrogen fixation at the V1 and R1 stages at higher light intensity was due to greater growth and greater mass of nodules, and not to greater specific activity of the nitrogenase enzyme in the nodules.

This indicates that the amount of nitrogen absorbed from the soil is negligible until the plants reach the stage of bean formation, but it must be in sufficient quantity to ensure the proper development of the photosynthetic apparatus during the early stages of plant growth and development.

Also, the narrow-row method of sowing ensured a greater number and mass of nodules per plant, in all three varieties. There was also a tendency to increase seed yield with increasing seeding rate, so it can be concluded that 15 cm row spacing is optimal for the development of root nodules, but 45 cm row spacing resulted in better seed yield.

CONCLUSIONS

The effects of light intensity, soil inorganic nitrogen levels, seeding rate, and the inter-row distance on the biological nitrogen fixation efficiency and soybean seed yield were studied in three soybean varieties. The light intensity had a significant effect on the biomass accumulation in the nodules and the plants. The nodules accumulated significantly more biomass when grown at higher light intensity. The biological nitrogen fixation was also higher in the plants growing at the higher light intensity at all developmental stages before the ripening of the beans. Excessive fertilizer application was found to suppress the development and growth of nodules in the later stages and may thus affect the seed yield.

The sensitivity of soybeans to changes in the feeding area in the crop was studied. At optimal density, the main mass of beans is formed on the main shoot, in thinned ones – on side branches. Excessive thickening of litter leads to lodging, premature yellowing and falling of leaves on plants. Changing the sowing rate from 0.5 to 0.8 M seeds/ha for row sowing contributed to an increase in the attachment height of the lower beans, which, in turn, contributes to a reduction in crop losses during crop harvesting. The seeding rate and the inter-row distance affected the seed yield, and optimum levels of these parameters have been determined for the three varieties.

Sowing rate had a greater influence on soybean yield than the sowing method. The best conditions were obtained when sowing 0,7 M seeds/ha of similar seeds. Increasing the sowing rate to 0,8 M seeds/ha of similar seeds, especially for late sowing, did not contribute to a significant increase in yield. The early ripening Romantika variety had the maximum yield at the sowing rate of 0.7 M seeds/ha – 2.41 t/ha. Low sowing rates contributed to a decrease in seed yield to 2.07 t/ha – for sowing rates of 0.6 M seeds/ha & to 1.82 t/ha – for 0.5 M seeds/ha. Increasing the sowing rate to 0,8 M seeds/ha was ineffective – 2.39 tons/ha. The optimum growth conditions determined in this study for three soybean varieties will help farmers boost yields in the Romantica, Ustya, and Vorskla varieties of soybean.

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Вплив умов вирощування на азотфіксацію та врожайність насіння трьох українських сортів сої

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Анотація. Актуальність теми досліджень визначається пошуком нових технологічних прийомів вирощування сої. З огляду на це, досліджували особливості формування продуктивності різних сортів сої залежно від низки чинників, таких як: строки, способи сівби та норми висіву. Метою досліджень було теоретичне обґрунтування та практичні рекомендації щодо строків і способів сівби, норм висіву різних сортів сої. Проаналізовано показники впливу інтенсивності освітлення, внесення добрив, зміни норм висіву насіння та різних варіантів ширини міжрядь на біологічну азотфіксацію сої. В результаті встановлено закономірності та здійснено наукове обґрунтування положень, розроблено рекомендації виробництву та науково обґрунтовані прийоми технології вирощування сої, які забезпечують підвищення продуктивності культури на 15–25 %. Розроблені практичні рекомендації щодо збільшення виробництва сої використовуються в господарствах області та за її межами для вирішення важливої проблеми – збільшення виробництва кормового і харчового білка та рослинної олії. Зміна норми висіву з 0,5 до 0,8 млн насінин/га за рядкової сівби сприяла збільшенню висоти прикріплення нижніх бобів, що, в свою чергу, сприяє зменшенню втрат врожаю при збиранні культури. Норма висіву мала більший вплив на урожайність сої, ніж спосіб сівби. Найкращі умови були отримані при висіві 0,7 млн схожих насінин/га. В ході досліджень сорт Романтика показав найвищу врожайність 3,07 т/га за рядкового способу сівби, норми висіву 0,8 млн схожих насінин/га та другого строку сівби

Ключові слова: рослинництво, інтенсивність освітлення, строки сівби, норми і способи, кореневий бульбочок, міжряддя, норма висіву

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Applying of Plants to Regulate Mycobiota of Winter Wheat Seeds

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Abstract. Plants, having a wide array of different substances that are natural to ecosystems, can be effective biofungicides. Most scientific studies have demonstrated the effectiveness of plant extracts against certain phytopathogenic species/genera in vitro. These results do not provide an answer to how certain substances might affect the systems of microorganisms. The aim of the work was to study the influence of plants on isolation of mycobiota representatives of winter wheat seeds, the peculiarities of its germination and seedling development. The mycocomplex of the seeds of the 2017 and 2019 harvests from the North-East of Ukraine was studied. The seeds were kept in aqueous plant solutions and spread on potato-glucose agar. The effects of *Citrus sinensis* L., *Citrus limon* L., *Zingiber officinale* Roscoe, *Larix decidua* Mill., and *Pinus sylvestris* L. were evaluated. All plant solutions changed the quantitative and qualitative composition of seed mycobiota. The negative effect of soaking seeds on the development of wheat seedlings was established, which will not allow them to be used to regulate the seed mycocomplex in the future. *C. limon* (67%) and *Z. officinale* (on average 52%) most effectively reduced the number of dominant *Alternaria* sp. Seed treatment increased the number of fungal colonies compared to the control, except for the 40% ginger solution, and when ginger was used, the spectrum of fungi was expanded, and when citrus and pine were used, it was narrowed. Plant solutions changed the dominance of *Alternaria* sp. in the seed mycobiota on the prevalence of *Penicillium* sp. and *Aureobasidium pullulans* (de Bary) G. Arnaud. The mycobiota of wheat seeds acquired the most significant changes under the influence of *L. decidua* and *P. sylvestris*

Keywords: biofungicides, citrus fruits, ginger, pine needles, seed treatment, fungal complex

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INTRODUCTION

Mycobiota of winter wheat seeds contains endophytic and phytopathogenic fungi. Endophytes are fungi that do not have a negative effect on plants (Chitnis *et al.*, 2020). Scientists are currently actively searching for biological plant protection agents among endophytes. Wheat seeds are a source of infection for phytopathogenic species. One of the elements of plant protection is the treatment of seeds with pesticides of various origins to regulate pathogens. The main purpose of seeds treatment is the destruction of fungi, which is effectively dealt with by modern chemical fungicides. The question of changes in the mycobiota of seeds when individual representatives disappear remains unexplored. Although chemicals are highly effective, they have a negative impact on human health (carcinogenic, teratogenic, acute toxicity) and the environment (prolonged decomposition leads to contamination of soil, water, etc.) (Soković *et al.*, 2013). Continued use of fungicides causes the emergence of resistant forms in populations of phytopathogens: resistance of *Fusarium* to prochloraz, tebuconazole and benomyl (Choi *et al.*, 2017); cross-resistance of *Alternaria alternata* to mancozeb and difenoconazole (Yang *et al.*, 2019). People require natural foods without dangerous substances to improve their health. To date, chemical manufacturers have regained their interest in natural compounds (Soković *et al.*, 2013). These companies used to attract natural compounds. Thus, the active ingredients of Falcon (manufactured by Bayer) include morpholines, which are derivatives of cinnamic acid.

In Ukraine, biological pesticides on wheat based only on microorganisms and their metabolites have been registered. Some plants contain a variety of biologically active chemicals that may be new components for biofungicides. Plant extracts, essential oils, gums, resins etc. are sources for finding natural ingredients. These products are more suitable for natural ecosystems. Plant substances have a specific target effect, without touching the beneficial antagonists, they are quickly destroyed, do not pollute the environment, easily accessible and cost-effective. Plant extracts and oils are most often used against fungal pathogens (Zaker, 2016). The biologically active substances of plants include alkaloids, glycosides, glucosinolates, lipids, phenols, terpenes, polythienes, polyacetylenes, etc. (Borges *et al.*, 2018).

An analysis of scientific studies on the effectiveness of plant extracts against seed fungi of various crops showed 100 percent inhibition of phytopathogens, with most researchers using aqueous plant extracts (Almeida *et al.*, 2021).

Mycobiota of wheat seeds consists of various representatives. As a rule, the most common or most harmful species are first isolated from seeds, and then the effectiveness of plant extracts against phytopathogens is studied in vitro. Thus, Z. Baka & M. Baka (2014) first identified the most common species in wheat seeds (*A. flavus*, *A. niger*, and *F. moniliforme*), and then determined the effectiveness of five medicinal plants before their growth on a nutrient medium. When studying the effectiveness of grain extracts and beekeeping products on fungi from the seeds of buckwheat, wheat, oats and corn, the most harmful species from the genus *Fusarium* were first isolated. And then the influence of the extracts on the growth of these fungi on PDA was studied (Keriene *et al.*, 2020).

Less often, researchers study the effectiveness of plant extracts *in vivo*. The study of four plants on the peculiarities of isolation of fungi from wheat seeds by the Standard Blotter Method (on filter paper) showed their high efficiency (Arshad Ali *et al.*, 2015). The efficiency of five plants was tested by seed treatment followed by incubation on filter paper and agar medium with control of 12 representatives of mycobiota of barley seeds (Ahmad *et al.*, 2016).

Thus, most often investigations do not take into account the changes that will occur in microbial complexes with a decrease in the number or extinction of a species. Important factors in determining the effectiveness of botanical fungicides are the chemical composition of plants, which depends on many factors, as well as the local population of phytopathogens. Therefore, *the goal of the research* was to determine not only the effectiveness of aqueous solutions of plants against certain representatives of the mycobiota of winter wheat seeds, but also the nature of changes in it, taking into account the impact on seed germination and plant development.

MATERIALS AND METHODS

Winter wheat (Bohdana variety) was grown in the North-East of Ukraine (Sumy region, educational and scientific production complex of Sumy National Agrarian University). The seeds of the 2017 and 2019 harvests were analysed.

Lemons, oranges and ginger were bought in the supermarket. Pine and larch needles were torn from the trees of the SNAU arboretum. Lemon and orange fruits were squeezed to obtain juice. Sterilized water was added to the juice to obtain a 10% aqueous solution. The ginger rhizome was crushed in a blender, and then the juice was squeezed through gauze. By adding sterile water, a 40% aqueous solution was obtained. Larch and pine needles (4.5 g) were ground with the addition of water. Then was added 100 ml of sterile water. The seeds were kept in aqueous solutions for 2-3 hours. It was soaked in sterilized water in the control variant. After drying on filter paper, the seeds were spread on potato-glucose agar. Petri dishes were incubated in a thermostat at 22-24°C for seven days. Fungi were identified by the biological method based on colony morphology, mycelium and asexual sporulation based on (Warham *et al.,* 1997; Watanabe, 2002; Leslie & Summerell, 2006; Schubert *et al.,* 2007; Zalar *et al.,* 2008; Walther *et al.,* 2013). The second step was to study the effect of solutions on seed germination: the number of

germinated seeds (on the 7th day) and average length of seedlings were calculated. The length of seedlings to study the effectiveness of solutions of ginger and conifers was measured on the 14th day.

Statistical analysis of the results was performed by the method of one-way analysis of variance in Excel, calculating the LSD_{05}.

RESULTS AND DISCUSSION

The dominance of Alternaria in the mycobiota of winter wheat seeds in the conditions of the North-East of Ukraine was established, as evidenced by other studies (Rozhkova *et al.,* 2021). In addition to these fungi, two genera (*Penicillium* sp. and *Trichoderma* sp.) and five species (*Cladosporium herbarum* (Pers.: Fr.) Link, *Neurospora sitophila* Shear, *Mucor mucedo* L., *Nigrospora oryzae* (Berkeley et Broome) Petch., and *Aureobasidium pullulans* (de Bary) G. Arnaud) were identified in the control. Fungi that germinated from wheat seeds without sporulation, but only in the form of mycelium, were not identified.

Citrus was chosen to regulate the mycobiota of seeds based on their properties: they have an antiseptic effect and contain a significant amount of ascorbic acid (in orange 66, lemon – 52-60 mg). When soaking the seeds for two hours, the number of fungal colonies on variants with the use of plants increased compared to the control (Table 1).

***Table 1**. The effect of aqueous extracts of plants of the genus Citrus on the isolation of fungi mycobiota seeds and the development of seedlings of winter wheat (2017)*

Variants	Isolation of fungal colonies, pcs	Number of colonies, pcs	Seed germination, %	The average length of seedlings, mm
Control (water)	*Alternaria* sp. 78 *Penicillium* sp. 21 *C. herbarum* 9 *N. sitophila* 3 *M. mucedo* 2	113	100	51.4
Orange (10% aqueous solution of fruit juice)	*Alternaria* sp. 65 *Penicillium* sp. 61 *M. mucedo* 5	131	100	40.5
Lemon (10% aqueous solution of fruit juice)	*Penicillium* sp. 105 *Alternaria* sp. 26 *M. mucedo* 6	137	100	20.5
LSD_{05}	*Alternaria* sp. 4.8 *Penicillium* sp. 6.8	10.6	-	4.4

Regarding the effect of lemon and orange on the mycobiota of wheat seeds, the similarity of their action was noted: they reduced the range of its species and genera, the amount of *Alternaria* fungi and increased the number of *Penicillium* sp. These fungi inhibited the development of wheat germ. Moreover, this negative effect was greater in the variant with the use of lemon, where the amount of *Penicillium* fungi was 105 colonies – this is the maximum indicative isolation among all authors' studies.

Alternaria fungi are dangerous pathogens for citrus crops, so most modern research is aimed at studying their species composition, pathogenicity and more. Information on studies on the effectiveness of citrus extracts against fungi was not found, but the results of testing essential oils are known. An in vitro study of the antifungal activity of lemon (*C. limon*) essential oil against three pathogenic fungi that infect grapevine (*Eutypa* sp., *Botryosphaeria dothidea* and *Fomitiporia mediterranea*) has shown its significant effectiveness against all tested fungi. Eutypa sp. was the most sensitive to the essential oil of *C. limon*. The composition of EO was also studied. Ten volatile components were identified by gas chromatography, the most common of which were hydrocarbon monoterpenes (Ammad *et al.*, 2018). The effectiveness of citrus essential oils on *Aspergillus* and *Penicillium* fungi has been studied. The essential oil of *C. sinensis* caused complete inhibition of the growth of *Aspergillus niger* (L.) at 3.0 $\mu g \cdot ml^{-1}$ on agar plates. The oil showed fungistatic activity at 1.5 $\mu g \cdot ml^{-1}$ with approximately 79% growth inhibition after 7 days of incubation and delayed conidiation compared to control. Its use also caused bifurcation of apical hyphae and abundant budding of vegetative hyphae, which led to complete loss of cytoplasm by hyphae (Sharma & Tripathi, 2008). Earlier fungitoxic studies of *C. sinensis* essential oil have shown the antifungal efficacy of citrus oils against *Penicillium digitatum* and *Penicillium italicum* and have shown that P. digitatum has been demonstrated to be the most sensitive (Caccioni *et al.*, 1998).

Thus, citrus changes the mycobiota of winter wheat seeds, reducing the number of *Alternaria* sp., but increasing the number of *Penicillium* sp., which inhibits the development of wheat seedlings (especially lemon).

The influence of garden ginger on the mycobiota of wheat seeds and the peculiarities of the development of its seedlings was carried out in 2017 and 2019 (Table 2).

***Table 2**. The effect of garden ginger (Z. officinale) on the mycobiota of winter seeds and the development of wheat seedlings*

Variant	Isolation of fungal colonies, pcs	Number of colonies, pcs	The average length of seedlings on the 7th/14th day, mm
	2017		
Control (water)	*Alternaria* sp. 78 *Penicillium* sp. 21 *C. herbarum* 9 *N. sitophila* 3 *M. mucedo* 2	113	51.4/-
Ginger (100% juice)	*Penicillium* sp. 64 *Alternaria* sp. 44 *N. sitophila* 4 *C. herbarum* 3 *M. mucedo* 2 *Fusarium* sp. 1 Other fungal colonies 1	119	45.3/-
LSD_{05}	*Alternaria* sp. 6 *Penicillium* sp. 5.3 *C. herbarum* 3.7	6	8.1
	2019		
Control (water)	*Alternaria* sp. 43 *Penicillium* sp. 16 *N. oryzae* 12 *A. pullulans* 10 *Trichoderma* sp. 5 Other fungal colonies 29	115	40.4/97.5
Ginger (40% aqueous solution)	*Penicillium* sp. 18 *Alternaria* sp. 17 *A. pullulans* 16 *N. oryzae* 6 *Arthrinium arundinis* (Corda) Dyko & B. Sutton 1 *N. sitophila* 1 *Fusarium* sp. 1 Other fungal colonies 38	98	28.2/78.9
LSD_{05}	*Alternaria* sp. 5.3 *N. oryzae* 7.7 *A. pullulans* 3.2	8	5.6/8.1

In 2017, the effect of undiluted rhizome juice was investigated, which showed a slight increase in colonies compared to the control.

The use of ginger reduced the amount of *Alternaria* sp. by 43.6%, but increased the number of *Penicillium* sp. (Fig. 1).

Figure 1. *Mycobiota of winter wheat seeds treated with 100% ginger juice (Bogdana variety, 2017)*

Suppression of seedling development was also recorded. In 2019, the seeds were kept in 40% aqueous solution, after which the number of fungal colonies decreased. Uncertain species occupied a dominant position in the mycobiota, and the number of *Alternaria* fungi decreased by 60% compared to the control. The species composition has changed: instead of *Trichoderma* sp. sprouted other fungi (*A. arundinis* (Fig. 2), *N. sitophila*, and *Fusarium sp.*). An inhibitory effect on seedling length on both the 7th and 14th day was also observed.

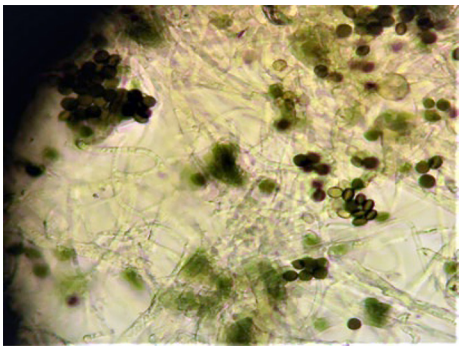

Figure 2. *Mycelium and conidial sporulation of A. arundinis*

A significant effect of aqueous solutions of ginger (15.10 and 5%) on the growth of *Alternaria alternata* (Fr.) Keissl. from tomatoes in Sudan has been shown. The highest concentration contributed to the best inhibition of the fungus. Ginger restrained mycelial growth by 57%, 35% and 20% compared to controls (Osman & Algam, 2016). The effect of aqueous extracts of five different plants on *A. alternata* and *Fusarium oxysporum* was studied in vitro. Ginger solutions have been effective in inhibiting the growth of tested fungi (Fawzi *et al.*, 2009). Ethanol extract of ginger of various concentrations (0.5, 1.5-5.5%) showed high efficiency of inhibition of mycelial growth and sporulation of *A. alternata* – the causative agent of spinach spot, in vitro. The highest concentration (5.5%) was 90.4% inhibition of mycelial growth. The germination of spores was completely suppressed by both 4.5% and 5.5% concentration (Rizwana, 2015). The effect of aqueous, ethanol and methanol extracts and ginger essential oil on the radial growth of *Alternaria solani* and *Phytophthora infestans* was studied. Ginger oil was as effective as a synthetic fungicide. That is, this plant has strong antifungal properties with a high potential for use as a biofungicide (Mugao *et al.*, 2021). A study of the effectiveness of extracts from five plants against *Alternaria alternata* in vitro showed significant antifungal activity of these plants, one of which was ginger. The zone of inhibition of *Z. officinale* ranged from 30 to 48 mm. The highest antifungal value of ginger extract was observed at a concentration of 2.5 $\mu l \cdot ml^{-1}$ – 87.04% (Ghalem *et al.*, 2020).

Thus, ginger alters the mycobiota of wheat seeds, most reducing the amount of *Alternaria* fungi, but this increases the number of *Penicillium* sp. 100% juice and 40% aqueous solution inhibits the development of wheat seedlings.

It was established that *C. limon* and *Z. officinale* are active *Alternaria* reducers. Scientists around the world are actively searching for chemical compounds

to regulate the number of these fungi. In Uruguay, a study of 10 plant species found that extracts of *Salvia sclarea* L., *S. officinalis* L., and *Rosmarinus officinalis* L. were effective against *Alternaria* sp. at the level of chemical fungicides (Dellavalle *et al.*, 2011). In Mexico, the effectiveness of 12 different plants was found to inhibit the growth of *A. alternata* in the range of 2.02-69.07%. *Adenophyllum aurantium* L. was the most effective against this fungus (Lira-De León *et al.*, 2014). In India, aqueous and methanol extracts of *Aloe vera* L., *Polygonum perfoliatum* L., *Cymbopogon citratus* (DC.) Stapf, *Lantana camara* L., and *Mimosa pudica* L. have been shown to have the ability to significantly inhibit the growth of *A. alternata* and *A. tenuissima* (Srivastava *et al.*, 2012).

Quite unexpected results were obtained by studying the effect of aqueous solutions of conifers on the mycobiota of wheat seeds. Soaking the seeds in aqueous extracts of pine and larch needles showed quite similar results (Table 3).

***Table 3**. The effect of aqueous solutions of needles on the mycobiota of winter wheat seeds (Bohdana variety of the 2019 harvest)*

Variant	Isolation of fungal colonies, pcs	Number of colonies, pcs
Control (water)	*Alternaria* sp. 30 *A. pullulans* 18 *N. oryzae* 9 *Trichoderma* sp. 7 *Penicillium* sp. 6 Other fungal colonies 31	103
L. decidua	*A. pullulans* 58 *Alternaria* sp. 32 *Trichoderma* sp. 5 *M. mucedo* 4 *Fusarium sporotrichioides* Sherb.3 *N. sitophila* 1 *Penicillium* sp. 1 Other fungal colonies 3	107
P. sylvestris	*A. pullulans* 42 *Alternaria* sp. 42 *F. sporotrichioides* 16 *Rhyzopus stolonifer* (Ehrenb.) Vuill. 6 Other fungal colonies 1	110
LSD_{05}	*Alternaria* sp. 6.8 *A. pullulans* 5.5	6.3

The amount of *A. pullulans* and *Alternaria* sp. increased, the germination of colonies without sporulation of fungi decreased, *Fusarium* fungi appeared in variants with pine needles. Germination of fungi of the genus Mucor was also observed. Pine needles provoked the release of the largest amount of *F. sporotrichioides*.

The average length of seedlings in the variants with soaking the seeds in the solutions of the needles was less than in the control (Fig. 3). The reduction in plant growth with the use of pine was 26.7% compared to the control and was greater than in the variant with soaking in a solution of larch needles (12%) on the 7th day. This fact may be explained by the greater isolation of Fusarium fungi for soaking the seeds in an aqueous solution of pine needles. Measurement of the length of wheat seedlings on the 14th day demonstrated the preservation of the dominance of the indicator in the control. The picture of the negative impact has hardly changed. The high percentage of isolation of *Fusarium* fungi by treatment with a solution of pine needles suspended the development of seedlings more significantly at this date of accounting – 33% compared to the control. The use of larch suspended germination by 7%.

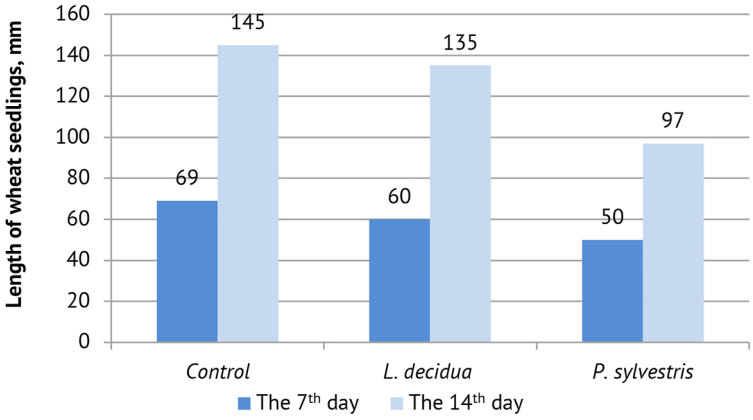

***Figure 3**. The effect of aqueous solutions of needles on the development of wheat seedlings ($LSD_{05}7=5.3$; $LSD_{05}14=4.9$)*

The antimicrobial action of essential oils of the *Pinaceae* family has been proven by various authors. Pine essential oil was very active only against bacteria, but not against fungi (Lis-Balchin *et al.*, 1998). Essential oil (at a concentration of 2%) from North American pine is able to inhibit the growth of two species: *F. culmorum* and *F. solani*. Fungicidal activity against *F. poae* was observed at 5% concentration of pine oil (Krauze-Baranowska *et al.*, 2002).

Pine needles and bark contain a lot of essential oil, so they are used in medicine (Baldan *et al.*, 2017). Studies of the antimicrobial action of larch bark and wood have shown their high effectiveness against *Aspergillus flavus*, *A. niger* and *Penicillium funiculosum*. (Salem *et al.*, 2016).

The obtained results showed the effect of plant extracts on the entire mycobiota of winter wheat seeds, unlike other studies that demonstrated only a decrease in its individual representatives (Arshad Ali *et al.*, 2015 Ahmad *et al.*, 2016).

CONCLUSIONS

Soaking the seeds in aqueous solutions of *C. sinensis*, *C. limon*, *Z. officinale* (as well as its juice), *L. decidua* and *P. sylvestris* led to significant changes in the mycobiota of winter wheat seeds grown in the North-East of Ukraine. The dominance of *Alternaria* sp. in the mycocomplex from winter wheat seeds on control was established. Two genera (*Penicillium* sp. and *Trichoderma* sp.) and five species (*Cladosporium herbarum* (Pers.: Fr.) Link, *Neurospora sitophila* Shear, *Mucor mucedo* L., *Nigrospora oryzae* (Berkeley et Broome) Petch., and *Aureobasidium pullulans* (de Bary) G. Arnaud) were identified here as well.

Solutions of citrus juice increased the number of fungal colonies, did not affect seed germination and significantly lessened the length of seedlings on the 7th day. They reduced the number of *Alternaria* sp., *Penicillium* sp. occupied a dominant position in the seed mycocomplex. *C. limon* had the greatest effect on the length of seedlings, because the maximum amount of *Penicillium sp.* sprouted. These fungi are able to inhibit plant development. Ginger juice and 40% aqueous solution had a citrus-like effect on seed mycobiota, except that they further expanded the range of fungal species. The most unexpected changes in the mycocomplex were caused by soaking the seeds in aqueous solutions of pine and larch needles: the appearance of *F. sporotrichioides*, *Mucor* fungi, an increase in the number of *A. pullulans* and *Alternaria* sp.

These plants cannot be used to regulate the mycobiota of wheat seeds because they adversely affect plant growth. *C. limon* and *Z. officinale* are effective reducers of *Alternaria* sp.

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Застосування рослин для регулювання мікобіоти насіння пшениці озимої

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Анотація. Рослини, маючи широкий набір різних речовин, які є природними для екосистем, можуть бути ефективними біофунгіцидами. Більшість наукових досліджень продемонстрували ефективність екстрактів рослин проти певних фітопатогенних видів/родів в умовах in vitro. Ці результати не дають відповіді на те, як певні речовини будуть впливати на системи мікроорганізмів. Було поставлено за мету вивчити вплив рослин на виділення представників мікобіоти насіння пшениці озимої, особливості його проростання та розвиток проростків. Дослідили мікокомплекс насіння врожаїв 2017 та 2019 рр. з Північного Сходу України. Насіння було витримано у водних розчинах рослин та розкладено на картопляно-глюкозний агар. Оцінили вплив *Citrus sinensis* L., *Citrus limon* L., *Zingiber officinale* Roscoe, Larix decidua Mill. та Pinus sylvestris L. Всі рослинні розчини змінили кількісний та якісний склад мікобіоти насіння. Було встановлено негативну дію замочування насіння на розвиток проростків пшениці, що не дозволить їх застосувати для регулювання насіннєвого мікокомплексу у подальшому. *C. limon* (67 %) та *Z. officinale* (у середньому 52 %) найефективніше знизили чисельність домінуючих *Alternaria* sp. Обробка насіння збільшила кількість грибних колоній порівняно з контролем, за винятком 40 %-го розчину імбиру, та за застосування імбиру розширила спектр грибів, а за використання цитрусових та хвої – його звузила. Рослинні розчини змінили домінування *Alternaria* sp. у мікобіоті насіння на превалювання *Penicillium* sp. та *Aureobasidium pullulans* (de Bary) G. Arnaud. Найістотніших змін мікобіота насіння пшениці набула під дією *L. decidua* та P. *sylvestris*

Ключові слова: біофунгіциди, цитрусові, імбир, хвоя, протруєння насіння, грибний комплекс

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Introduction to Culture, Reproduction, and Productivity of Aromatic Plants of the *Lamiaceae* Family in the Central Polissia of Ukraine

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Abstract. The introduction of new types of aromatic plants of the *Lamiaceae* family into the culture is relevant for the enrichment of the biological diversity of the flora of the Central Polissia of Ukraine, as well as for the expansion of the raw material base of spicy-aromatic, medicinal, food, decorative, and honey-bearing plants. The purpose of this study is to find methods of propagation of aromatic plants, best sowing times and feeding areas, and to obtain phytoraw and seed materials. Research methods: laboratory, field, statistical. It was established that the best period for sowing plants of the *Lamiaceae* family in the conditions of the botanical garden of the Polissia National University is the third decade of April. The use of various methods of propagation proves the expediency of propagation of all annual and perennial plant species under study by seeds, and for *M. didyma*, *S. officinalis*, *L. vera*, and *O. vulgare* – also by particles, rhizomes, transplanting, and propagule. It is recommended to place *S. hortensis*, *D. moldavica*, *E. cristata*, *H. officinalis* according to the scheme of 30x45 cm, *L. vera*, *L. anisatus*, *N. transcaucasica*, *S. officinalis* – 30x50 cm, and *O. vulgare*, *S. sclarea*, *M. didyma*, – 40x50 cm. Among the annual species, the highest productive potential was found in *D. moldavica*, the above-ground mass productivity of which was 24.7±1.7 t/ha; among perennials – in *H. officinalis* (38.9±0.2 t/ha) and *L. anisatus* (44.1±0.9 t/ha). The highest yield of essential oil in terms of absolutely dry substance was found in *S. officinalis* (1.2%), *L. vera* (1.808%) and *H. angustifolius* (2.054%). The results of research on reproduction methods can be used for growing new species of aromatic plants of the *Lamiaceae* family both on homesteads and in agricultural enterprises. The most productive types of aromatic plants should be introduced into production for further use of phytoraw materials and essential oil in pharmacy, food, and other sectors of the national economy

Keywords: *Lamiaceae*, introduction, methods of reproduction, productive potential

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INTRODUCTION

Presently, special attention is paid to the issue of manufacturing medicines and food additives from vegetable raw materials. As a result of the search and introduction of rare new crops and possible areas of their cultivation, it is possible to expand the raw material base of medicinal and aromatic plants (Zharinov & Ostapenko, 1994; Rakhmetov, 2017). Plants belonging to the *Lamiaceae* family, which are new to the conditions of the Polissia of Ukraine, have a wide range of uses. It is the sixth-largest family of angiosperms (Ahmad *et al.*, 2021; Napoli *et al.*, 2020; Zhao *et al.*, 2021), which includes over 245 genera and 7,886 species, as well as many economically important species distributed in all climatic zones of the planet, with the greatest species diversity found in the Mediterranean (Fedoronchuk, 2022).

Representatives of the genera *Ajuga* L., *Lamium* L., *Dracocephalum* L., *Glechoma* L., *Mentha* L., *Salvia* L., *Thymus* L., *Galeopsis* L., *Leonurus* L., *Origanum* L., *Stachys* L., *Elsholtzia* L., *Betonica* L. are found in the natural ecosystems of the Polissia region of Ukraine; however, their industrial use is impossible due to the limited resource base. Therefore, there was a need to expand domestic production of medicinal, spicy-aromatic plants that were not previously cultivated in Ukraine.

The purpose of this study is to find the best breeding methods, sowing and harvesting periods, figure out productivity indicators of rare plants of the *Lamiaceae* family in the conditions of the Central Polissia of Ukraine. Thanks to the resolution of these issues, it is possible to enrich the phytodiversity of the region due to new species. This will expand the raw material base of medicinal and aromatic plants, increase the ecological and economic effect, and improve the health of the population.

LITERATURE REVIEW

To expand the domestic raw material base for obtaining valuable biologically active substances, some researchers propose to introduce new promising plant species from different botanical and climatic zones into the culture. Thus, T. Ivanova *et al.* (2022) reported the introduction into culture of 27 taxa of the *Lamiaceae* family in Bulgaria, L.A. Kotyuk *et al.* (2022) reported 17 taxa in Ukraine, Sharafzadeh & Zare (2011) – 10 taxa in Iran.

K. Carović-Stanko *et al.* (2019) note that spicy and aromatic crops of the *Lamiaceae* family (*Hyssopus officinalis*, *Lavandula angustifolia*, *Monarda fistulosa*, *Nepeta cataria*, *Origanum vulgare*, *Salvia officinalis*, *Salvia sclarea*, *Satureja hortensis*, etc.) are used for flavouring, preservation of food products. Dry raw materials of *Origanum vulgare* and *Satureja hortensis* plants contain vitamins, proteins, sugars, lipids, amino acids, macro- and microelements, and therefore Skendi *et al.* (2019) suggest adding it to flour when baking bread. Ukrainets & Frolova (2010) established that "obtaining natural flavours by processing essential oils synthesised by aromatic plants and their introduction into production will enable food industry enterprises to produce products that meet global quality standards."

According to R.R. Raja (2012), plants of the Lamiaceae family are described by considerable medicinal potential, and J. Michel *et al.* (2020) recommend the use of phytoraw material and essential oil of *Dracocephalum moldavica*, *Lavandula angustifolia*, *Origanum vulgare*, *Salvia officinalis*, and *Satureja cuneifolia* for the treatment of cardiovascular diseases. E. Napoli *et al.* (2020) note the radioprotective properties of *Origanum*, *Salvia*, and *Lavandula* essential oils.

M. Kozlowska *et al.* (2015) established the bactericidal properties of ethanol extracts of *Origanum vulgare*, *Salvia officinalis* against *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Proteus vulgaris* and *Listeria monocytogenes*, S.I. Dubinin *et al.* (2020) – antihelmintic properties of *Origanum vulgare*, *Hyssopus officinalis* and *Satureja hortensis plants*, and S. Bedini *et al.* (2021) – insecticidal properties.

O.S. Demianiuk *et al.* (2022) suggest the use of aromatic plants *Lavandula angustifolia*, *Origanum vulgare*, *Satureja hortensis* and *Salvia officinalis* for vertical greening of the external and internal walls of premises, and consider it necessary to popularise them.

T.M. Manushkina (2021) noted that "essential oil crops have important agroecological importance. It is advisable to grow biennial or perennial ether-bearing plants on low-productivity, stony soils, since they protect the soil from wind and water erosion, inhibit the germination of weeds, and activate soil microflora. Cultivation of essential oil crops provides an increase in biodiversity in agroecosystems, air purification from pathogenic bacteria due to the release of essential oil with antiseptic properties, aesthetic beauty in the flowering phase; they are valuable honey plants" (Manushkina, 2021).

Industrial areas of rare plants of the *Lamiaceae* family are concentrated mainly in Kherson (Ushkarenko *et al.*, 2020), Poltava (Shatkovskyi *et al.*, 2021), and Dnipropetrovsk oblasts (Baranets & Korshykov, 2020). Skybitska & Mohylyak (2013) report the successful introduction of aromatic plants of the *Lamiaceae* family in the West, and L.A. Kotyuk *et al.* (2021) – in the Polissia of Ukraine.

L.A. Kotyuk (2015, 2017) notes that reproduction by seed is an essential condition for the preservation of plant species, population growth and the ability to adapt to new living conditions, while D.B. Rakhmetov (2011) points to its advantages when introducing new types of plants into culture. The studies of Shatkovskyi *et al.* (2021) proved that when planting seedlings of the *Lamiaceae* family in open ground, watering and additional care is necessary. Therefore, they recommend that perennial species be propagated by a vegetative method, which ensures the rapid distribution of the species and the preservation of genetic traits.

MATERIALS AND METHODS

The study used sparsely distributed annual and perennial plant species: summer savory (*Satureja hortensis* L.),

vietnamese balm (*Elsholtzia cristata* Willd.), Moldavian dragonhead (*Dracocephalum moldavica* L.), lavender (*Lavandula vera* D. C.), narrow-leaved hyssop (*Hyssopus angustifolius* M. Bieb.), hyssop (*Hyssopus officinalis* L.), bee balm (*Monarda didyma* L.), oregano (*Origanum vulgare* L.), cat mint transcaucasica (*Nepeta transcaucasica* Grossh.), anise lofant (*Lophanthus anisatus* Adans), clary sage (*Salvia sclarea* L.), common sage (*Salvia officinalis* L.).

The experiment was established in the botanical garden of the Polissia National University (Zhytomyr) during 2008-2021 in an illuminated area. The soil of the experimental plots was described by the following parameters: *Ph*-saline humus horizon – 6.23±0.051, N_k – 90,543,731 mg/kg soil, K_2O – 84,03±3,859 mg/kg, P_2O_5 – 458,01±4,771 mg/kg, humus content – 2.967±0.082%.

The climate of the Central Polissia of Ukraine is moderately continental. Average long-term air temperatures above 0°C are maintained for 150 to 160 days, so the conditions for the cultivation of spicy and aromatic plants are quite favourable. Average long-term temperature of the coldest month (February): from -1 to -6°C, the warmest (July): from +18.4 to +23°C. The annual amount of precipitation was recorded both below the norm (600 mm) and above the norm: from 550 to 920 mm. The average annual relative humidity was 71-78%. The end of spring frosts was observed during the third decade of April, and the beginning of the first autumn frosts – in late September – early October.

The specific features of plant development were investigated according to the methods (DSTU 7160-2010; Methodology for examination..., 2016; Rakhmetov, 2011). The essential oil content was determined according to the Clevenger method (Raw medicinal plant..., 1988).

The study used seed material from the exchange funds of botanical gardens of Ukraine and the world. Plants were grown by sowing seeds directly into the soil or by seedling method. Sowing was performed during the last decade of April – the first decade of May.

Plants *H. officinalis*, *S. hortensis*, *D. moldavica*, *E. cristata* were placed according to scheme 45×30 cm, *S. sclarea*, *O. vulgare*, *M. didyma*, – 50×40 cm, and *L. vera*, *L. anisatus*, *N. Transcaucasica*, *S. Officinalis* – 50×30 cm, four-fold repetition. Fertilisers, pesticides, and irrigation were not used during plant cultivation. During the growing season of the plants, weeds were removed, the rows were loosened, spring pruning was carried out (*H. officinalis*, *H. angustifolius*, *S. montana*) or dead shoots of perennial plants were removed (*O. vulgare*, *L. anisatus*, *M. didyma*, *S. sclarea* and *S. aethiopis*).

RESULTS AND DISCUSSION

The introduction of new aromatic, medicinal, food, and honey-bearing plants of the *Lamiaceae* family is necessary for the enrichment of the biological diversity of the flora of the Polissia of Ukraine. The main criteria that indicate the perspective of introduction into culture are the establishment of propagation methods, optimal sowing dates and feeding areas, features of plant care during their growing season, methods of obtaining phytoraw materials and seed material.

Introductory research carried out in the Central Polissia of Ukraine used seed material from different botanical and geographical zones of the globe. According to the origin of the plant of the *Lamiacea* family, it is assigned to four genetic centres: the Mediterranean (*S. officinalis*, *H. angustifolius*, *H. officinalis*, *S. hortensis*, *L. vera*, *O. vulgare* and *S. sclarea*), to the North American (*L. anisatus* and *M. didyma*), European-Siberian (*E. cristata* and *D. moldavica*), Western Asian (*N. transcaucasica*) (Kotyuk, 2022).

Studies have established different life expectancy of spicy-aromatic plants in the conditions of the Central Polissia of Ukraine. Thus, under the study conditions, the maximum duration of the life cycle of *S. sclarea* plants was 3 years, *L. anisatus* – 6 years, *N. transcaucasica* – 9 years, *S. officinalis* – 10 years, *M. didyma* – 10 years, *L. vera*, *O. vulgare*, *H angustifolius* – 12 years, *H. officinalis*, *S. montana* – 15 years (Fig. 1).

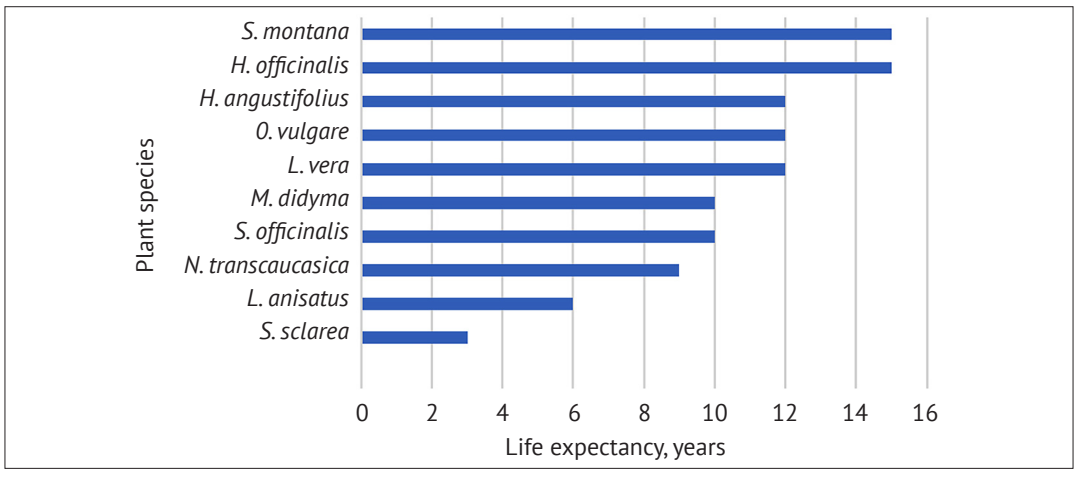

Figure 1. *Life cycle of the Lamiacea family plants under cultivation in the botanical garden of the Polissia National University (2008-2021)*

According to V.O. Ushkarenko *et al.* (2020), during the industrial cultivation of *S. sclarea* plants under drip irrigation conditions in the Southern Forest Steppe of Ukraine (Kherson Oblast), the life cycle of *S. sclarea* plants was four years. T.M. Manushkina (2021) notes that *S. sclarea* is a biennial plant in the conditions of the Mykolaiv Oblast, and a triennial plant in the conditions of the study, which, apparently, is caused by the difference in soil and climatic conditions. As for the life span of other perennial plants, there is no information in the scientific sources of the last decade.

The seed material of representatives of the *Lamiacea* family is formed in the fruits – cenobia, which are located in the calyx of the flower. The fruit develops from a cenocarpous bipartite gynoecium, which, when ruptured, forms four one-seeded fragments – erems (Novikoff & Barabasz-Krasny, 2015). In the new conditions of growth, the erems of aromatic plants matured at different times, which is conditioned upon features of the species, different duration of fruiting and acropetal order of flowering in inflorescences. When the fruits ripened in the lower semi-rings of the inflorescences, the buds in the upper ones had not yet opened. Therefore, to obtain seed material, the plants were cut during the period when most of the inflorescence was in the fruiting phase, they were maturated for 7-10 days, after which they were threshed.

Erems from the calyx of the flower can release themselves and form self-sown plants. In the conditions of the growth of aromatic plants in the botanical garden of the Polissia National University, their ability to self-renew, forming self-sown plants, was found, which is evidence of their adaptation. Observations showed that under the conditions of culture, the vast majority of plants formed self-sown plants, which overwintered or died due to the effects of negative temperatures. Annual plants *S. hortensis*, *D. moldavica*, *E. cristata* formed abundant or moderate self-sowing plants in autumn, after the fall of erems, but the seedlings died during the winter, so their sub-winter sowing is not advisable. In some places, self-sowing plants' shoots appeared in the spring, which formed viable seedlings. Abundant self-seeding and frost-resistant seedlings were formed by *H. angustifolius*, *H. officinalis*, *S. sclarea*, *L. anisatus*, *O. vulgare* and *N. transcaucasica*. *N. transcaucasica* bore fruit 2-3 times during the season and were resistant to low temperatures during the growing season. Self-seeding was not found in *S. officinalis*, *M. didyma*, *L. vera* (Table 1).

Table 1. *Characterisation of the viability of self-sowing plants of the Lamiaceae family in the conditions of the Central Polissia of Ukraine*

Evaluation criteria	Abundant	Moderate	Thinned	Missing
Species	*N. transcaucasica** *S. sclarea** *H. officinalis** *D. moldavica***	*E. cristata*** *S. hortensis***	*O. vulgare** *L. anisatus** *H. angustifolius**	*S. officinalis* *M. didyma* *L. vera*

Note: * *– self-sowing plant is resistant to negative temperatures,* ** *– unstable*
Source: *compiled by the authors*

Studies have shown that in the conditions of the Central Polissia of Ukraine, the most optimal time for sowing aromatic plants is the last decade of April. Depending on features of the species, soil moisture and temperature conditions, plant seedlings appeared after 8-20 days (*H. officinalis*, *N. transcaucasica*, *D. moldavica*, *S. sclarea*) or 14-30 days (*E. cristata*, *S. hortensis*, *L. vera*, *H. angustifolius*, *O. vulgare*, *M. didyma*). Sowing in the early spring period (the first decade of April) caused very sparse shoots and a delay in their emergence.

When sowing in the first decade of June (summer sowing), there was a delay in germination and a slowdown in plant development due to insufficient moisture supply in the soil. In this case, flowering of plants was observed during September-October; during autumn frosts, inflorescences were often damaged, so seed material was not formed.

The authors' research found that sowing for winter can be successful for *H. angustifolius*, *H. officinalis*, *N. transcaucasica*, *L. anisatus*, *S. sclarea*.

V.O. Ushkarenko *et al.* (2020) believe that under the conditions of the Kherson Oblast, the best sowing time for *S. sclarea* is in the winter, in the first decade of December. This information does not contradict the results obtained.

S. hortensis, *E. cristata*, and *D. moldavica*, whose life cycle is one year, were propagated by the seed method. The depth of seed wrapping is recommended to be 10-15 mm, after which the soil must be compacted. Seedlings of *E. cristata* and *S. hortensis* appeared in an average of 18 days, *D. moldavica* – in 12 days.

Annual species are described by a long pre-emergence period and slowed plant growth at the first stages of ontogenesis; therefore, during this period, it is necessary to remove weeds that develop more intensively. Due to the signs of xerophilic of the plants, added watering was not performed. With the beginning of the generative period, plants did not need added care.

The aerial part (shoots with leaves and inflorescences) of annual plants for the food industry and pharmacy was collected during the flowering phase (July-August) at a height of 10 to 25 cm relative to the soil surface.

The productive potential of plants is evidence of their adaptation to new living conditions. Among the aromatic plants whose life cycle ends in one year, the

highest productivity was noted in *D. moldavica*. Productivity of the aerial part of *D. moldavica* was 24.7±1.7 t/ha, seeds – 0.073±0.028 t/ha, weight of 1000 erems – 2.29±0.39 g (Table 2).

***Table 2**. Productive potential of annual and perennial plants of the Lamiaceae family in the conditions of the botanical garden of the Polissia National University*

Plant type	Year of life	Productivity, t/ha		Weight of 1000 erems, g
		Green mass	Erems	
Annual plants				
E. cristata	**I**	16.2±0.57	0.267± 0.013	0.22±0.01
S. hortensis	**I**	14.0±0.63	0.387± 0.024	0.49±0.04
D. moldavica	**I**	**24.7±1.7**	**0.733± 0.028**	**2.29±0.39**
Perennials				
S. sclarea	**I**	4.3± 0.2	–	–
	II	37.1±6.5	**0.58±0.053**	3.42±0.15
S. officinalis	**I**	0.9±0.1	–	–
	IV	26.0±1.3	0.40±0.038	**7.15±0.27**
H. officinalis	**I**	2.8± 0.2	0.06±0.008	1.17±0.03
	IV	38.9±0.2	0.54±0.052	1.08±0.13
H. angustifolius	**I**	0.72±0.07	–	–
	IV	8.91±0.11	0.27±0.02	0.57±0.02
M. didyma	**I**	1.1± 0.1	–	–
	IV	28.6±3.4	0.38±0.027	0.46±0.02
O. vulgare	**I**	0.9± 0.1	–	–
	IV	33.0±2.0	0.18±0.024	0.10±0.01
L. vera	**I**	0.7± 0.1	–	–
	IV	19.6±1.1	0.45±0.029	1.05±0.11
L. anisatus	**I**	6.8±0.2	0.03±0.006	0.42±0.03
	III	**44.1±0.9**	0.33±0.064	0.41±0.02
N. transcaucasica	**I**	0.65±0.04	0.045±0.004	0.65±0.04
	III	13.2±0.3	0.33±0.058	0.67±0.059

***Note:** "–" seed material is absent*
***Source:** compiled by the authors*

Perennial species of aromatic plants were propagated both by seeds and vegetatively. It was found that the best coverage depth for *O. vulgare* and *L. anisatus* is 10 mm, and for *H. angustifolius*, *L. vera*, *N. transcaucasica*, *H. officinalis*, *M. didyma*, *S. sclarea* and *S. officinalis* – 15 mm. Advantages of vegetative reproduction were found in *M. didyma*, *L. vera*, *S. officinalis* and *O. vulgare*.

H. officinalis plants were propagated by the seed method. At the first stages of ontogenesis, seedlings developed slowly, but during the first year of life they bloomed and bore fruit. The best sowing time: the third decade of April. Friendly seedlings were obtained during summer sowing, but the seedlings did not always form generative organs. During winter sowing, *H. officinalis* plants were overwintered in case of the formation of mature immature individuals even before the onset of persistent frosts. During the first year of vegetation, *H. officinalis* formed one vegetative-generative shoot with second- and third-order shoots. In the second and subsequent years of life, the number of vegetatively generative shoots increased, the maximum indicators of productivity were found in the fourth year of life. In the collection plots, seedlings of *H. officinalis* grow for 15 years, bloom and bear fruit every year, regardless of the appearance of signs of ageing.

It was found that the vegetative reproduction of *H. officinalis* plants of the third and subsequent years of life by particles in April or October is quite effective.

The raw material of *H. officinalis* is green, non-woody leafy shoots with inflorescences. With age, the area of lignification of the shoots increases, the lignified part of the shoots of hyssop becomes unusable. Therefore, during the harvesting of raw materials, the above-ground part of the plants of 1-3 years of life was cut at a height of 10-15 cm, and the 4-year and subsequent ones were cut at a height of 20-30 cm above the soil surface.

The highest indicators of productivity of *H. officinalis* were recorded in the fourth year of life. Thus, the productivity of above-ground mass was 38.9±0.2 t/ha, seeds – 0.54±0.052 t/ha, weight of 1000 erems – 1.08± ±0.13 g. At the end of the first year of life, these indicators were, respectively, 2.8±0.2 t/ha, 0.06±0.008 t/ha, weight of 1000 erems – 1.17±0.03 g (see Table 2).

H. angustifolius plants were propagated by the seed method and vegetatively. Plant seeds were sown in the soil in April, after sowing plant seedlings appeared within 14-17 days. In the first year of life, individuals of *H. angustifolius* formed one vegetative branched shoot, the seedlings did not flower and did not form seeds. Flowering

was observed in the second year of life. During the following years of vegetation, the spring growth of plants began in the first decade of April, when the temperature reached above +10°C, flowering in July (during the 2nd and 3rd year of life) –August (during the 4-12 years of life). The growth processes of *H. angustifolius* plants were completed in October-November. Plants of *H. angustifolius* grow under the conditions of introduction for 12 years.

Plants of *H. angustifolius* were propagated vegetatively, which was simplified by the particulation of individuals. During the third year of life in culture conditions, the number of particles was from 3 to 4, in the fifth and subsequent years – from 10 to 12 pieces. The phytoraw material of *H. angustifolius* (green shoots with inflorescences) was harvested by cutting them at a height of 10-15 cm relative to the soil surface.

Observations have shown that *H. angustifolius* plants are described by lower performance indicators compared to *H. officinalis*. In the first year of life, plant productivity was 0.72±0.07 t/ha, seeds were not formed. The highest productivity was found in plants of the fourth year of life. Thus, the yield of above-ground mass was 8.91±0.11 t/ha, erems – 0.27±0.02 t/ha, weight of 1000 erems – 0.57±0.02 g (see Table 2).

L. anisatus plants were propagated by seed and vegetative methods. When sowing erems in the third decade of April, seedlings appeared after 18-23 days. During the first year of life, seedlings formed one vegetative-generative shoot with shoots of the second order. Growth of *L. anisatus* plants of the second and subsequent years of life after overwintering in the absence of snow cover and air temperature exceeding +10°C was observed in April. In the second and subsequent years of life, plants formed several generative shoots that branched, flowered, and bore fruit.

L. anisatus plants of the second and subsequent years of life were propagated by division into parts. The seedlings took root well, bloomed and bore fruit.

Compared to other species, *L. anisatus* plants were less winter-hardy. The death of 5% of three-year-old individuals in winter and more than 60% of plants in the fifth year of life was noted. Observations showed that the maximum lifespan of *L. anisatus* plants under the conditions of introduction was 6 years.

The raw material of *L. anisatus* – aerial leafy shoots and inflorescences, was cut at a height of 15-20 cm relative to the soil surface. The highest productivity of aboveground raw materials of *L. anisatus* was noted in the third year of life – 44.1±0.9 t/ha, seed material – 0.33±0.064, weight of 1000 erems – 0.41±0.02 g (see Table 2).

L. vera plants were propagated by seeds and vegetatively. During seed propagation of *L. vera* plants without stratification, low field germination was noted (5-10%), seedlings appeared after 25-30 days. During cold stratification for 30 days at a temperature of +5-7°C, the similarity of *L. vera* erems increased to 43%. During the first year of life, plants formed one vegetative shoot, on which shoots of the second order were laid, in the second year of life – shoots of the third order. Flowering and fruiting were observed in the third and subsequent years of life, when plants created a significant number of vegetative-generative shoots. Flowering of plants was observed in June, fruiting in August. When peduncles were cut in the flowering phase, re-formation of inflorescences of *L. vera* plants was observed in August-September.

It is known that *L. vera* plants are propagated by cuttings or seedlings, but these methods require additional care and watering. *L. vera* plants of the third and subsequent years of life took root well when divided into parts, which indicates the advantages of vegetative propagation.

For the economic needs of industries, inflorescences are mainly used, which is about 30% of the above-ground part of plants. However, green shoots with leaves, which are cut at a height of 20-25 cm above the soil surface, are no less valuable phytoraw material and a source of biologically active compounds. The maximum productivity of L. vera was noted in the fourth year of life. Productivity of above-ground plant material was 19.6±1.1 t/ha, erems – 0.45±0.029 t/ha, weight of 1000 erems – 1.05± ±0.11 g (see Table 2).

M. didyma plants were propagated by seeds, seedlings, and vegetatively. The best results were obtained during the spring reproduction of individuals of the third and subsequent years of life by dividing the rhizome with recovery buds into parts. The cuttings took root well, formed generative organs.

Reproduction of *M. didyma* plants by the seed method was accompanied by some difficulties – seedlings appeared 18-21 days after sowing, field germination of seeds was 40 to 50%, seedlings developed very slowly during the first year of life. In addition, the results of the splitting of parental traits were observed and seedlings with different leaf colours (dark green and light green), with different stem lengths (short and tall), variable flower colours (dark purple, pink, or light pink) were obtained. Different resistance to damage by powdery mildew (relatively resistant and unstable). One-year seedlings of *M. didyma* formed one unbranched vegetative shoot, the number of shoots increased in the second and following years (from 8-10 to 20-50 pcs.). Generative organs formed some plants in the second year of life, in the third and subsequent years of vegetation – all plants.

When propagated by the seedling method, 30% of *M. didyma* individuals took root, the plants turned out to be unstable to drought, and summer thunderstorms caused lodging and damage to the stem, which led to their death. Under the conditions of introduction today, individuals of *M. didyma* grow for 10 years, the death of 40% of individuals was found.

The raw material of *M. didyma* – the aerial part of plants with leaves and inflorescences, was cut at a height of 10-15 cm relative to the soil surface. The

maximum productivity of *M. didyma* plants was observed in the fourth year of life. Phytomass productivity was 28.6±3.4 t/ha, erems – 0.38±0.027 t/ha, weight of 1000 erems – 0.46±0.02 g (see Table 2).

Erems of *O. vulgare* plants are petite, have low laboratory similarity (about 20%). Seedlings of *O. vulgare* in the first year of life formed one vegetative shoot, in the second and subsequent years of life, the number of vegetative-generative shoots increased. *O. vulgare* plants flowered and bore fruit from the third year of life.

It has been established that the best method of reproduction for *O. vulgare* plants is vegetative, by dividing the rhizome with regeneration buds into parts. The mentioned method of reproduction made it possible to quickly increase the number of plants of this species since they took root well and grew to the size of the parent in 1-2 years.

Twelve-year-old plants currently grow in the collection of aromatic plants and are quite productive. The raw material of *O. vulgare* is shoots with leaves and inflorescences, cutting them at a height of 10 cm from the soil surface. The highest productivity of above-ground mass of *O. vulgare* (33.0±2.0 t/ha) was recorded in the fourth year of life. Among all studied species, *O. vulgare* plants have the lowest seed productivity (0.18±0.024 t/ha) and weight of 1000 seeds (0.10±0.01 g).

According to the results of research by Shatkovskyi *et al*. (2021) when planting seedlings in open ground according to the scheme of 60x10 cm, the dry mass productivity of *O. vulgare* under drip irrigation conditions was 3.16 t/ha (in terms of raw mass – 26.3 t/ha). The yield of plants in the conditions of the Polish region is higher, in addition, their cultivation does not require added costs for irrigation.

Plants of *N. transcaucasica* were propagated both by seeds and vegetatively, by division into parts. The plants formed viable self-seeding throughout the growing season, sprouts appeared after 8-20 days, depending on moisture conditions. During the first year of life, the seedlings developed one vegetative-generative shoot, flowering and fruiting were observed during August-September. In the second and subsequent years of life, *N. transcaucasica* plants flowered and bore fruit 3 times during the growing season.

The maximum productivity of *N. transcaucasica* plants was observed in the third year of life. Plant phytomass productivity during this period was 13.2±0.3 t/ha, seed material – 0.33±0.058 t/ha, weight of 1000 erems – 0.67±0.059 g (see Table 2).

S. officinalis plants were propagated by seeds, seedlings, green cuttings, and division into parts. During the first year of life, seedlings of *S. officinalis* formed a rosette of leaves, later one vegetative shoot. In one-year individuals, generative shoots were not formed. Plants of the second year of life developed several branched shoots, on which shoots of the 2nd, 3rd and 4th orders were formed. Flowering was observed in the last decade of June, ripening of erems – in the third decade of August.

In the third and fourth year of life, the plants exceeded quantitative indicators of growth and productivity in comparison with plants of the first and second years of life. Flowering was observed during the first-second decade of June, ripening of erems – at the beginning of August. Re-flowering of some *S. officinalis* plants in September was noted. At this time, individuals of *S. officinalis* have been growing under the conditions of introduction for ten years, a decrease in productivity indicators and signs of plant death have been detected.

The raw material of *S. officinalis*, mainly leaves, was collected by cutting them together with green shoots at a height of 14-18 cm relative to the soil surface. The highest indicators of productivity of *S. officinalis* were observed in the fourth year of life: productivity of phytomass was 26.0±1.3 t/ha, erems – 0.40±0.038 t/ha, weight of 1000 erems – 7.15±0.27 g (see Table 2).

S. sclarea plants were propagated by the seed method and division into particles. When propagating by seeds during the first year of vegetation, seedlings formed a rosette of leaves, in the second and subsequent years of life – generative shoots. Flowering of *S. sclarea* plants was observed in July, fruiting in August.

S. sclarea plants of the second or third year of life were propagated by division into parts, which was facilitated by the particulation of the root system. In the conditions of introduction, abundant self-sowing of *S. sclarea* and high frost resistance of seedlings were found, so we believe that the vegetative method of plant propagation is not appropriate. The raw material of *S. sclarea* – leaves and vegetatively generative shoots (including inflorescences, which make up to 40% of the entire phytomass) was cut 10-15 cm above the soil surface. The maximum productivity of *S. sclarea* plants was established during the second year of life: above-ground mass – 37.1±6.5 t/ha, erems – 0.58±0.053 t/ha, weight of 1000 erems – 3.42±0.15 g (see Table 2).

In the conditions of the Central Polissia of Ukraine, the productivity *of S. sclarea* inflorescences was 14.84 t/ha, which does not contradict the information about other researchers. Thus, according to the report of Ushkarenko *et al*. (2020), under the conditions of the Kherson region, when *S. sclarea* was sown in the first decade of December with a row width of 45 cm, a yield of inflorescences was obtained at the level of 15.01-14.61 t/ha. At the same time, additional costs for irrigation affect the profitability of production, and in the conditions of the Polish region, plants do not need watering.

An important indicator of the adaptation of rare plant species to new living conditions is not only phytomass productivity, but also the possibility of synthesis of biologically active compounds by the plant organism. It is common knowledge that glandular structures are formed on the vegetative and generative organs of plants of the *Lamiaceae* family: trichomes, peltate

glands, in which aromatic substances in the form of essential oils accumulate. Thanks to this, biologically active compounds are obtained from the above-ground mass of plants, which are used as natural flavourings of food products, medicinal, and perfumery and cosmetic products. The essential oil of each studied plant has a wide range of effects on the body, as it is a multi-component mixture of chemical compounds, mainly terpenoids and aromatic components (Shanayda & Pokryshko, 2015). In Ukraine, natural essential oils are imported from abroad, and they are costly. Therefore, the cultivation of aromatic essential oil crops on the territory of the state can provide industries with ecologically safe raw materials.

Research has established that the natural and climatic conditions of the Central Polissia of Ukraine are quite suitable for growing crops that are a source of obtaining essential oils. The highest yield of essential oil in terms of dry mass during flowering was found in plants: *Hyssopus angustifolius* (2.054%), *Lavandula vera* (1.808%), *Salvia officinalis* (1.2%) and *Monarda didyma* (1.07%), the lowest – in *Origanum vulgare* (0.197%) (Fig. 2).

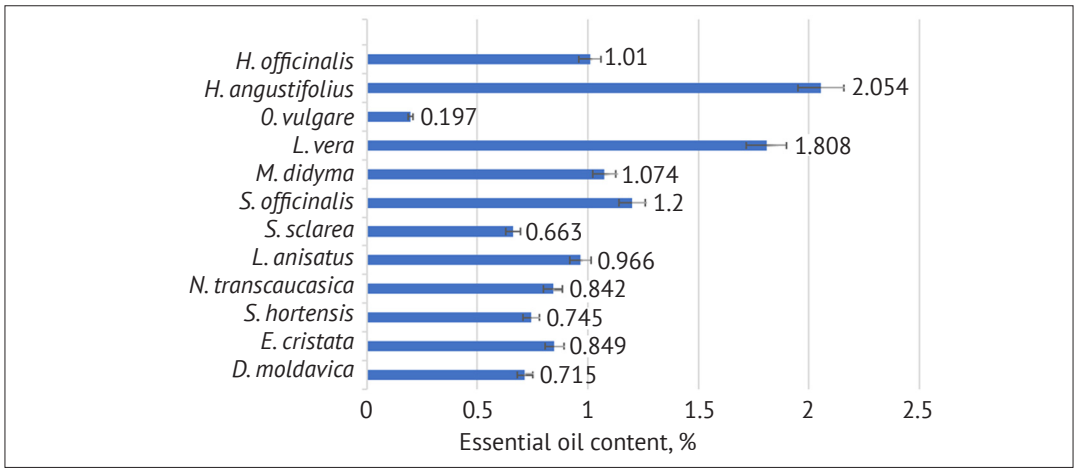

***Figure 2**. Essential oil content of phytoraw materials of aromatic plants in the conditions of the botanical garden of the Polish National University, % by absolute dry weight*

Considering the different timing of the beginning of flowering and the considerable duration of this period, all species of plants of the *Lamiaceae* family turned out to be quite promising for use in landscape design (Fig. 3). It is advisable to use compositions of aromatic plants in diverse types of flower design – aroma beds, landscape slides, flowerbeds, mono- and multi-species compositions, mix borders with decorative species of bushes and trees, to improve the condition of administrative premises, recreation, and health areas. Plants *D. moldavica*, *S. sclarea*, *H. angustifolius*, *H. officinalis*, *N. transcaucasica*, *L. anisatus*, *O. vulgare* are summer-blooming plants, the flowering of which began in July. Flowering of the mentioned species is long-lasting – from 30 to 50 days. The shortest flowering period (20-30 days) was observed in the early summer flowering species *M. didyma* (Table 3).

***Table 3**. Groups of aromatic plants depending on the timing of flowering in the botanical garden of the Polissia National University*

Group	Phase start time		Species
	Decade	Month	
Spring blooming	II-III	May	*N. transcaucasica*
Early summer blooming	I-IV	June	*L. vera, M. didyma, S. officinalis*
Summer blooming	I-IV	July	*D. moldavica, S. sclarea, H. angustifolius, H. officinalis, O. vulgare, L. anisatus, N. transcaucasica*
Late summer blooming	I-IV	August	*S. hortensis, E. cristata*
Autumn blooming	I-IV I-II	September-October	*N. transcaucasica, L. vera* (2nd and subsequent years of life), *H. officinalis* (1st year of life)

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

Figure 3. *Aromatic plants of the Lamiaceae family in the flowering phase in the botanical garden of the Polissia National University: 1 – Satureja hortensis; 2 – Dracocephalum moldavica; 3 – Elsholtzia cristata; 4 – Monarda didyma; 5 – Hyssopus officinalis; 6 – Lavandula vera; 7 – Hyssopus angustifolius; 8 – Salvia sclarea; 9 – Nepeta transcaucasica; 10 – Lophanthus anisatus ; 11 – Salvia officinalis ; 12 – Origanum vulgare*
Source: *photographed by the authors*

Plants *S. hortensis* and *E. cristata*, which began to bloom in August, are classified as late-summer blooming plants.

H. officinalis plants of the first year of life began to bloom in September-October. In the case of cutting the above-ground mass of plants at the beginning of the flowering phase, the re-formation of inflorescences was observed in the autumn period. This method allows adjusting the timing of repeated flowering of species during the growing season. These species with remontant properties are classified as autumn-blooming.

The research of Skybitska & Mohylyak (2013) confirms the repeated flowering of *H. officinalis*, *L. vera* and *N. transcaucasica* plants in the conditions of the Western Forest Steppe of Ukraine and notes the special decorativeness during the flowering of *Hyssopus officinalis*, *Origanum vulgare*, *Salvia officinalis*, *Salvia sclarea*, *Satureja hortensis*.

The obtained research results are marked by the fact that in the conditions of the Central Polissia of Ukraine, 12 uncommon plant species were analysed regarding the peculiarities of their introduction into culture and methods of reproduction. Similar research was carried out in the Polish region for the first time, and therefore there is almost no information on the cultivation of new species of aromatic plants in the scientific literature. Garden centres that sell some types of plants (*Lavandula vera*, *Origanum vulgare*) in the retail network do not share information about their cultivation and propagation technology. Seeds of aromatic plants offered by domestic and foreign enterprises do not always germinate due to ignorance of cultivation technology. Therefore, the information presented in this paper can be useful not only for farmers, but also for owners of homesteads.

CONCLUSIONS

The third decade of April turned out to be the best period for sowing plants of the Lamiaceae family in the conditions of the botanical garden of the Polish National University. Sowing before winter gives the best result for plants L. anisatus, H. angustifolius, H. officinalis, N. transcaucasica, S. sclarea. The optimal seed sowing depth is 10-15 mm, after which the soil is compacted.

It is advisable to propagate annual and perennial species of plants by seed, and *M. didyma*, *S. officinalis*, *L. vera* and *O. vulgare* by vegetative method (cuttings, particles, cuttings, rhizomes). For *L. vera* seed germination, it is necessary to stratify the erems in a moist substrate at a temperature of +5-7°C for 30 days.

Plants *H. officinalis*, *H. angustifolius*, *S. sclarea*, *N. transcaucasica*, *L. anisatus*, and *O. vulgare* can spread through self-sowing and the formation of seedlings resistant to winter temperatures. However, under culture conditions, *M. didyma*, *L. vera*, and *S. officinalis* plants did not reproduce by self-sowing.

It is advisable to harvest phytoraw materials for further use in the food industry and pharmacy during the flowering phase, cutting annual plants above 10-20 cm above the ground, perennial plants above 10-30 cm.

The productive potential of plants is evidence of their adaptation to new living conditions. Among the annual species, the highest productive potential was found in D. moldavica plants, the productivity of aboveground mass was 24.7±1.7 t/ha, seeds – 0.733±0.03 t/ha; among perennials, plants of *H. officinalis* (38.9±0.2 t/ha) and *L. anisatus* (44.1±0.9 t/ha), and seeds of *L. vera* (0.45±0.029 t/ha) and *S. sclarea* (0.58±0.053 t/ha). The highest yield of essential oil in terms of absolute dry matter was found in plants of *S. officinalis* (1.2%), *L. vera* (1.808%) and *H. angustifolius* (2.054%).

Depending on the features of flowering, plants of the *Lamiaceae* family are divided into groups: spring-blooming (1 species), early summer-blooming (3 species), summer-blooming (7 species), late summer-blooming (2 species) and autumn-blooming (3 species with remontant properties).

Aromatic plants are characterised by different periods of flowering, a significant duration of the named period, and therefore it is advisable to use them in landscape design, to improve the condition of recreational areas and administrative premises.

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Введення в культуру, розмноження та продуктивність ароматичних рослин родини *lamiaceae* у Центральному Поліссі України

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Анотація. Впровадження в культуру нових видів ароматичних рослин родини *Lamiaceae* є актуальним для збагачення біологічного різноманіття флори Центрального Полісся України, а також для розширення сировинної бази пряно-ароматичних, лікарських, харчових, декоративних та медоносних рослин. Мета дослідження – встановлення методів розмноження ароматичних рослин, оптимальних строків посіву й площ живлення, отримання фітосировини і насіннєвого матеріалу. Методи дослідження: лабораторні, польові, статистичні. Було встановлено, що найкращий період сівби рослин родини *Lamiaceae* в умовах ботанічного саду Поліського національного університету – третя декада квітня. Використання різних методів розмноження свідчить про доцільність насіннєвого розмноження усіх досліджуваних одно- та багаторічних видів рослин, а рослин *M. didyma*, *S. officinalis*, *L. vera* і *O. vulgare* – також партикулами, кореневищами, відсадками, живцями. Рослини *S. hortensis*, *D. moldavica*, *E. cristata*, *H. officinalis* рекомендовано розміщувати за схемою 30х45 см, *L. vera*, *L. anisatus*, *N. transcaucasica*, *S. officinalis*, – 30х50 см, а *O. vulgare*, *S. sclarea*, *M. didyma*, – 40х50 см. Серед однорічних видів найбільший продуктивний потенціал виявлено у рослин *D. moldavica*, продуктивність надземної маси яких становила 24,7±1,7 т/га; серед багаторічних – у рослин *H. officinalis* (38,9±0,2 т/га) та *L. anisatus* (44,1±0,9т/га). Найбільший вихід ефірної олії у перерахунку на абсолютно суху речовину встановлено у рослин *S. officinalis* (1,2 %), *L. vera* (1,808 %) та *H. angustifolius* (2,054 %). Отримані результати досліджень щодо способів розмноження можуть бути використані для вирощування нових видів ароматичних рослин родини *Lamiaceae* як на присадибних ділянках, так і в аграрних підприємствах. Найбільш продуктивні види ароматичних рослин доцільно впроваджувати у виробництво з метою подальшого використання фітосировини й ефірної олії у фармації, харчовій та інших галузях народного господарства

Ключові слова: *Lamiaceae*, інтродукція, методи розмноження, продуктивний потенціал

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Immune Status of Turkeys in Industrial Cultivation Conditions

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Abstract. The intensification of turkey farming is accompanied by the impact of various dangerous factors on the poultry's body. This leads to a violation of metabolic processes, an imbalance in the absorption of nutrients, and immunity decrease in turkeys, which determines the relevance of the study in this area. In this regard, figuring out when immunity reduces and, in the future, increasing its effectiveness in the body of turkeys, improving metabolic processes, growth, and development of poultry determined the purpose of this study. It was found that during the first six weeks of intensive cultivation of turkeys, the body's immune response, the activity of non-specific resistance factors on the influence of biological factors and the intensification of poultry feeding processes were effective. However, from 42 days of poultry rearing, depletion of the immune defence of the turkey body and a decrease in the activity of non-specific resistance factors were observed, which is manifested by a likely decrease in the content of total protein, albumins, and class G and M immunoglobulins in the blood of poultry ($P<0.01$). Analysis of the protein spectrum of turkey blood serum indicates an immunosuppressive state of the body, probably caused by the action of biological factors. By 42 days, the bactericidal and lysozyme activity of blood serum, phagocytic activity of neutrophils, and T-cell activity of lymphocytes decrease in turkeys. Non-specific changes in the components of the functional element of the liver were detected, which are accompanied by an increase in the number of lipid inclusions of various sizes, destructive changes in mitochondria, and a decrease in the synthetic activity of cells. Studies of the immune state of the body of turkeys, the activity of factors of non-specific resistance and liver in the cycle of intensive cultivation from 7 to 120 days revealed the presence of a critical period of decrease in the effectiveness of the body's protection and further adequate correction. The results obtained during this study will be used for educational purposes, implemented in growing turkeys in the production conditions of "Indychka" LLC (Sumy Oblast). They are offered to all farms in Ukraine to produce turkey farming products

Keywords: T-lymphocytes, immunoglobulins, albumins, poultry liver

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INTRODUCTION

Turkey farming is one of the most efficient branches of the agro-industrial complex. Presently, in Ukraine, poultry meat production meets 40% of the population's needs for this product (Karpenko, 2016). The development of poultry farming is determined by a single vector – the progress of technological processes. The new strategy is to keep poultry physiologically, provide nutritious feed that positively affects productivity and reduces the cost of poultry production (Petrenko, 2015). This determines the purpose and relevance of the study on this issue.

Authors (Nagaraja *et al.*, 2006; Zamazii *et al.*, 2017) found that the body of animals and turkeys is adversely affected by stress. They indicate that under conditions of non-prolonged stress, the immune system is activated, and more antibodies are synthesised. The proliferation of immune system cells is stimulated. Under conditions of severe stress, the functions of the immune system are suppressed (Zamazii *et al.*, 2017). It was found that regulatory molecules interact with the receptors of immune cells – lymphocytes, monocytes, macrophages, and neutrophils. Stress occurs due to the activated release of adrenaline and norepinephrine into the blood. Their content correlates with the number of B-lymphocytes and T-lymphocytes, as the researchers point out (Kotlyarova *et al.*, 2019; Davison *et al.*, 2008). Adaptive responses to adverse factors are aimed at preserving the body's haemostasis.

Complete feeding is of great importance in the intensification of production of turkey farming products (Ridla *et al.*, 2019; Leeson, 2022). However, the use of high-energy feeds violates the compliance of the needs of the body and the conditions for providing them with energy, violates the conditions of physiological and morphological adaptation of the digestive system to the effective use of feed and requires normalisation of metabolic processes in the poultry's body. Authors (Rychen *et al.*, 2017) suggest correcting the microbiocenosis of the gastrointestinal tract in young turkeys during the immune system development.

Recently, a decrease has been observed in the immune response of poultry to the action of abiotic factors in the conditions of production. The occurrence of acquired (secondary) immunodeficiency is accompanied by a violation of the immunological status of the body, reproductive abilities (Ryabinina *et al.*, 2019).

Minimising the use of biological factors (Khodorovich, 2022) is a topical issue today. It requires determining the immune state of the poultry's body. This is important when using immunocorrectors and preparations. They should not adversely affect the physiological activity of poultry in the conditions of industrial rearing of turkeys.

White blood cells play a special role in protecting the body (Uchida, 2019). They selectively accumulate in tissues affected by adverse factors and provide protective immune responses. The number of killer cells changes under the influence of glucocorticoids. It is proved that the membranes of all immunocytes have receptors for glucocorticoids and catecholamines. Killer cells have high-density adrenoreceptors. Limited-density adrenoreceptors were found on T-lymphocytes. During the development of stress, immunocytes are subject to mobilisation into the bloodstream. They migrate through various body organs. Immunocytes are known to activate or inhibit cytokine synthesis and secretion (Kadmiel & Cidlowski, 2013).

The body of poultry of new crosses (Agunos *et al.*, 2012) has a genetically determined growth rate. Such a poultry is extremely sensitive to minor fluctuations in feeding conditions and to the influence of biological factors. Violation of keeping technology, unbalanced feeding, are the main aetiological factors of immunodeficiency in the body of turkeys. A decrease in the body's natural resistance and reactivity are signs of secondary immune deficits. The bird does not develop intense post-vaccination immunity. Susceptibility to abiotic factors is the main manifestation of severe immunodeficiency (Dougal, 2019).

To increase the safety and productivity of poultry, it is important to identify the period of reduced immunity in turkeys and conduct adequate correction.

Specialists of powerful poultry breeding complexes are developing fundamentally new preventive techniques (Jankowski *et al.*, 2011). They are aimed at increasing the immunity of poultry and their productivity by using environmentally friendly preparations. Reduced effectiveness of the body's immune system (Elmore, 2012) and liver health (Carson & Kunkel, 2017) occupy a considerable part of the processes in the structure of poultry morbidity (Karin *et al.*, 2020). The degree of decrease in the activity of the body's defence mechanisms correlates with dysproteinaemia. When figuring out the state of non-specific reactivity, special attention is paid to the blood protein spectrum. It is important to control the concentration of the γ-globulin fraction, which is the main carrier of antibodies in poultry (Anderson & Transey, 2012).

According to the author (Koncicki *et al.*, 2015) the poultry's immune system begins to function as soon as it hatches from the egg. Non-specific innate immunity is developed quite slowly and is crucial. It is the first to defend the body against foreign agents, being provided by embryonic cells with phagocytic activity. The body is protected by avidin, lysozyme, and immunoglobulins contained in the egg, as well as complement and interferon. Complement lyses cells. Interferon is described by antiviral activity, exhibits the properties of an immunomodulator.

Lymphocytes are involved in the immune response of the poultry's body. They differ in immunological functions. If lymphocytes enter the thymus (Meintlein & Kendall, 2000), they form T-lymphocytes. As they mature, they leave this organ and settle in the lymphoid tissues.

One of the key indicators of immunological restructuring of the body, the intensity of which is a criterion of resistance to bacterial infections, is the phagocytic activity of leukocytes. Pseudoeosinophils protect the body from the effects of abiotic factors in poultry. They have phagocytic activity and bactericidal action. In solving theoretical and practical issues, the estimation of factors of natural resistance of the body (Davison & Karel, 2008), namely the bactericidal activity of blood serum (BABS) and lysozyme activity of blood serum (LABS), occupies a prominent place. According to their data, immunisation adversely affects non-specific humoral immunity.

MATERIALS AND METHODS

The experimental part of this study was performed during 2018 based on the "Indychka" Limited Liability Company (Sumy Oblast).

At the Department of Anatomy, Normal and Pathological Physiology of the Sumy National Agrarian University, blood and liver samples were prepared for research in the conditions of the departments of the Faculty of Veterinary Medicine of the Sumy National Agrarian University. Indicators of the immune state of turkeys were investigated in the research and production laboratory "Hranum", Kharkiv. Liver samples were histologically examined at the S.Z. Gzhytskyi Lviv National University of Veterinary Medicine and Biotechnology, at the Department of Normal and Pathological Morphology and Forensic Veterinary Medicine.

To figure out the manifestation of the critical period of influence of industrial production factors and the effect of biological factors on immunity and liver condition, a group of turkeys was selected in the amount of 250 heads on the 7th day after birth. From 7 to 120 days of life of turkeys, with an interval of 14 days, blood samples were taken from 25 turkeys.

In blood samples, indicators of the body's immune state were found according to the generally accepted methods. Total protein – according to the Reis method. Protein fractional composition – according to the electrophoresis method on cellulose acetate. Microzone electrophoresis Scan Power 300 and Scanion Lira 400, Hospitex Diagnostics, were used. Phagocytic activity of pseudoeosinophils – according to V.Yu. Chumachenko's method.

The content of T-lymphocytes, B-lymphocytes, and NK cells in EDTA-stabilised blood was investigated using monoclonal antibodies and the immunofluorescence method. Class G and M immunoglobulins were detected using in vitro test systems according to the ELISA method and using a Thermo Scientific Multiskan FC photometer.

The organs of the immune system – the cloacal sac, thymus, and liver of turkeys – were histologically examined. A 10% neutral formalin solution was used to fix the organ pieces. Dehydration was provided in an ascending series of alcohols. Tissue compaction was performed in chloroform and chloroform paraffin. Filling was carried out in paraffin blocks.

Histosections were made on a sledge microtome MC-2, 5-7 μm thick and stained with haematoxylin and eosin. For histochemical detection of RNA and DNA, histosections were stained with methyl green pyronin (Brache). Preparations were photoregistered using light microscopy. For this purpose, a Leica DM-2500 microscope (Switzerland) was used. For ultra-thin sections, liver fragments were selected and fixed in a Millonig retainer, pH 7.36. The preparations were retained for 2 hours. The process took place in a thermos at the melting temperature of ice. Subsequently, the preparations were washed in chilled Millonig's phosphate buffer. The samples were dehydrated in high-strength ethanol for 10 minutes. The samples were incubated in 3 servings of absolute ethanol for 10 minutes. Subsequently, semi-thin sections with a thickness of 1 μm were made. The process was performed on an LKB-2188 ultramicrotome (Sweden).

Sections were stained with methylene blue and basic fuchsin. For electron microscopy studies, ultra-thin sections with a thickness of 90 nm were passed through water. The sections were dried for 2 hours at t=60°C. Contrast was performed with Reynolds' uranyl acetate and lead citrate. The sections were washed and then dried. The samples were examined in a Tesla-BS 500 electron microscope at an accelerating voltage of 60 kW. Photoregistration was performed on PT-41P films. The resulting negatives were digitized. For this, a photo scanner and Epson Perfection V 500 software were used. Ethical principles were observed during experiments on poultry. The obtained material is processed statistically, with the determination of probability according to the student's t-test.

RESULTS AND DISCUSSION

The production of turkey farming products in conditions of intensive cultivation is accompanied by the impact of adverse factors on the poultry's body. In turn, this requires figuring out the time of decrease in the immune state of the poultry's body under the conditions of using various rearing schemes and carrying out timely, adequate correction.

Analysis of the protein spectrum (Table 1) in the blood serum of turkeys from 7 to 28 days of life allowed establishing that the total protein content was within 29.05±0.87–30.23±0.77 g/l, which corresponds to the physiological norm for poultry of this age. On the 42nd day after the birth of turkeys, in conditions of intensive production and exposure to abiotic factors, a decrease in the total protein content was observed by 23.02% ($p<0.05$). On the 56th day, its level was only 25.37±0.59 g/l, and on the 70th day – 25.02±1.12 g/l, which is 12.68% and 13.87% lower than in turkeys of 28 days of age, respectively.

***Table 1**. Indicators of protein fractions of turkey blood (n=25, M±m)*

Days	Total protein, g/l	Albumin, %	γ-globulin, %	β-globulin, %	α-globulin, %
7	30.23±0.77	52.43±0.73	29.63±0.71	8.24±0.41	9.66±0.37
14	29.18±0.32	52.25±0.59	26.36±0.56	8.25±0.37	13.14±0.94
28	29.05±0.87	52.77±0.63	29.44±0.64	8.47±0.93	9.32±1.03
42	22.36±0.74***	40.13±0.93***	34.06±0.62***	9.03±0.57**	16.78±1.12***
56	25.37±0.59**	46.24±1.09**	34.65±1.05***	8.06±0.66	11.0±1.07*
70	25.02±1.12**	52.22±1.21	32.92±1.02**	7.52±0.34	7.34±0.96
84	35.35±1.01	49.33±0.56	30.72±0.84	7.07±0.43	12.88±0.92
100	40.27±0.77	52.96±1.07	27.97±1.03	6.33±0.43	12.74±0.72
120	39.53±1.07	53.05±1.03	28.62±0.76	6.01±0.39	12.32±0.73

***Note:** the degree of probability for indicators on the 28th day: *p<0.05; **p<0.01; *** p<0.001*
***Source:** compiled by the authors*

However, in turkeys aged 84-120 days, a tendency was found for the total protein content to increase in the blood serum of poultry, which positively correlates with body weight indicators. In older turkeys, as the results of research prove, the body adapts to the conditions of industrial production and a gradual increase in the indicator under study to the physiological norms for poultry of the corresponding age.

When analysing the blood serum of turkeys according to the protein spectrum, in certain periods of the poultry's life, an immunosuppressive state was noted, probably caused by the influence of biological factors, especially in the period after vaccination. The content of the γ-globulin fraction in the blood of turkeys on the 42nd and 56th days of the study was 34.06±0.62% and 34.65±1.08%, respectively, which indicates a prominent activity of the protective and adaptive capabilities of the poultry's body after exposure to abiotic stimuli. Turkeys aged 70 days showed a decrease in the γ-globulin fraction. However, during the study period (from 7 to 120 days of life of turkeys), the γ-globulin fraction stayed at an elevated level.

In sections of the liver of 28-day-old turkeys, hepatocyte nuclei, homogeneous cytoplasm, and intra-sinusoidal capillaries were clearly visible, in the lumen of which single red blood cells were located (Fig. 1). At the same time, in the liver of turkeys on the 50th day of life, a decrease in the content of RNA and the activity of reductases was noted. Glycogen was detected between fatty inclusions in the cytoplasm of hepatocytes (Fig. 2).

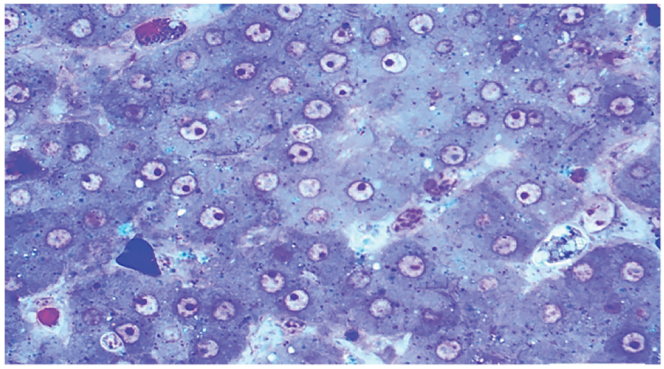

***Figure 1**. Turkey liver, 28 days*
***Note:** hepatocytes with uniformly coloured cytoplasm and centrally placed round nuclei. Semi-thin cut. Methylene blue. 10 oc x 100 ob*
***Source:** photographed by the author V.M. Petrenko*

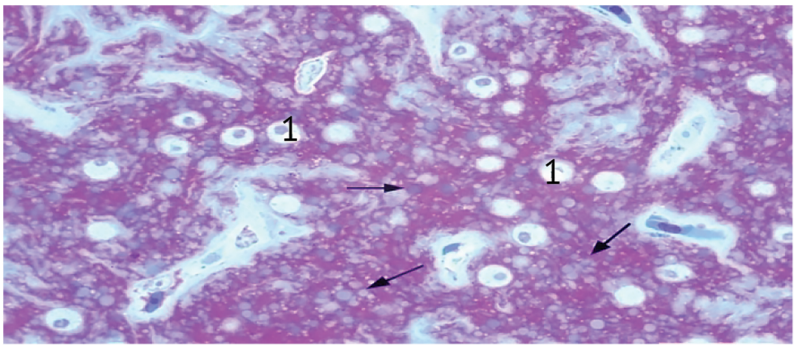

***Figure 2**. key liver, 50th day*
***Note:** semi-thin section. Methylene blue with additional staining – periodic acid-Schiff reaction. Lipid inclusions are blue (shown by the arrow), hepatocyte nuclei (1), and glycogen (pink). 10 oc x 100 ob*
***Source:** photographed by the author V.M. Petrenko*

According to electron microscopic examination of the liver of turkeys on the 42nd day of life, the cytoplasm of hepatocytes contains a large number of mitochondria, an extensive network of channels of the granular and agranular endoplasmic reticulum, single lipoprotein granules of medium electron density. The mitochondria and channels of the endoplasmic reticulum are surrounded by fine-grained hyaloplasm, which contains granules of α-glycogen. Mitochondria are described by the presence of outer and inner membranes. They form an insignificant number of crysts surrounded by the mitochondrial matrix.

Immunosuppressive effect on the 42nd day of life in turkeys was not manifested. At that time, the content of the γ-globulin fraction remained at the level of 28th day, and the content of albumins in the blood serum of poultry decreased. The level of α-globulins fluctuated during the life of turkeys under intensive rearing conditions. From the 42nd day, an increase in the content of α-globulin was found by 7.41% and on the 56th day – by 1.72%. The analysis of these indicators suggests that it is during these periods of the life of turkeys that, against the background of stress factors and various biological factors, considerable changes occur in the immune system. Changes in the level of β-globulins were insignificant, and only on the 42nd day of life of turkeys, its increase was noted, respectively, by 6.61%. From 56 to 120 days of the poultry's life, its level tended to decrease.

There was a slight fluctuation in the level of β-globulins, α-globulins, an increase in the γ-globulin fraction of proteins in the blood in the period after vaccination. During intensive cultivation of turkeys, it was found that in the period from 28 to 42 days, the indicators of the immune defence of the poultry's body were at a prominent level due to biological stimuli. On the 56th day, and especially in turkeys aged 70 days, the content of Immunoglobulin G decreased by 2.03 and 3.21 times ($p<0.001$), respectively.

The content of immunoglobulin M decreased during this period by 2.70 and 4.48 times ($p<0.001$), respectively. The tendency for the content of Ig G and Ig M immunoglobulins to decrease in the blood serum of turkeys persisted for up to 120 days. The detected increase in the level of Ig A in the period from 28 to 42 days can be associated with the activation of secretory immunoglobulin synthesis. It is synthesised in the mucous membranes and enters the blood through epithelial cells, where it is included in the Ig A monomer molecule and takes part in the formation of immunity, especially under oral and aerosol exposure to biological factors.

The results of studies show (Table 2) that the BABS of turkeys from 7 to 28 days was at 72.92±2.76% and 89.74±3.70%, respectively. On the 42nd day, a decrease in its activity was found by 1.17 times ($p<0.05$) compared to the indicator of turkeys aged 28 days. In turkeys aged 70 days, BABS activity was at 72.30±5.0% and indicated a decrease in non-specific resistance and suppression of the immune reactivity of the poultry's body.

***Table 2**. Indicators of non-specific resistance of the body of turkeys (n=25, M±m)*

Poultry age, day	Indicators		
	BABS, %	LABS, %	NPA, %
7	72.92±2.76	54.24±2.22	23.72±1.24
14	84.34±3.56	59.36±4.34	27.26±1.36
28	89.74±3.70	59.72±2.66	27.93±0.91
42	76.96±2.62*	46.84±2.12**	21.12±1.60**

Table 2, Continued

Poultry age, day	Indicators		
	BABS, %	LABS, %	NPA, %
70	72.30±3.85***	51.14±3.32*	20.48±1.32**
84	72.12±4.22	49.16±3.34	20.77±0.81
100	70.96±2.94	45.28±2.26	19.36±1.32
120	68.14±4.32	41.4±1.90	19.14±0.92

Note: *the degree of reliability for indicators on the 28th day: *p<0.05; **p<0.01; ***p<0.001*
Source: *compiled by the authors*

The lysozyme activity of turkey blood serum repeats the dynamics of its bactericidal activity. Thus, analysing the LABS of turkeys from day 7 to day 28, it was noted that lysozyme activity ranged from 54.24±2.22% on the 7th day and amounted to 59.72±2.66% on the 28th day. In the period from 28 to 42 days of life of turkeys, a decrease in LABS was found by 12.90%, on the 56th day – by 14.00%, and on the 70th day – by 8.60%. From day 84 to day 120, the LABS activity of turkey was stable, from 49.16±3.34% to 41.44±1.90%. On the 42nd day of commercial rearing of turkeys, a significant decrease in the phagocytic activity of pseudoeosinophils was observed by 24.38%, on the 56th day – by 29.32% (p<0.001) and on the 70th day – by 28.68% (p<0.001) compared to this indicator on the 28th day.

Thus, with intensive rearing of turkeys and the action of abiotic factors, a decrease in BABS, LABS, and neutrophil phagocytic activity (NPA) was established from the 42nd to the 70th day of poultry life. From the 42nd to the 70th day, a decrease in the concentration of class G, M and A immunoglobulins in the blood of turkeys was observed. Assessment of the level of T- and B-lymphocytes in the blood of turkeys at 120 days of age indicates instability and changes in the cellular defence system. The level of T-lymphocytes in the blood of turkeys from 7-14 days ranged from 6.92±0.43 g/l to 8.12±0.21 g/l. This may be due to the immune response and the appearance of antibodies after exposure to biological factors. Then, both on the 28th and 42nd days of life of turkeys, a secondary immune response was noted, due to the strengthening of both cellular and humoral immunity. The secondary immune response in turkeys develops rapidly and is accompanied by a sharp increase in the content of Ig G and intensive proliferation of B-lymphocytes, which is especially clearly noted in the period from 28 to 42 days of poultry life (Table 3). The level of B-lymphocytes on the 56th day of life of turkeys significantly decreases by 37.93% (p<0.001) against the background of this indicator of turkeys on the 28th day and indicates secondary immunological insufficiency, which leads to partial loss of immunity.

Table 3*. Factors of specific immunity of the blood of turkeys during intensive cultivation (M±m, n=25)*

Poultry age, day	Indicators, g/l	
	T-lymphocytes	B-lymphocytes
7	6.92±0.43	2.37±0.05
14	8.12±0.21	3.72±0.08
28	9.07±0.02	5.75±0.05
42	8.21±0.17*	5.88±0.08
56	6.39±0.26**	3.65±0.05***
70	6.34±0.81**	3.42±0.06***
84	5.92±0.54	3.40±0.11
100	4.27±0.34	3.33±0.12
120	3.22±0.31	3.28±0.08

Note: *the degree of reliability for indicators on the 28th day: *p<0.05; **p<0.01; ***p<0.001*
Source: *compiled by the authors*

In experimental turkeys from the 7th to the 42nd days of life, the level of T- and B-lymphocytes was at a fairly elevated level, providing an active immune response, while from the 56th day, under the influence of abiotic

factors, a significant decrease in the level of all lymphocytes and the development of secondary immunological insufficiency were found.

Thus, turkey farming is an ideal branch of poultry farming. The technological process is described by well-established feeding mechanisms and veterinary measures in the scheme of growing turkey meat crosses. Complex vaccination schemes, the use of high-energy feeds and biological preparations lead to functional overload of the body, a decrease in natural resistance due to the development of stress. The effect of abiotic factors in poultry farming is one of the key points affecting the productivity of turkeys, since it is directly related to the metabolic processes in the poultry's body, its detoxification properties (Petrenko, 2015). The indicators of the protein fractions of blood serum indicate that under intensive cultivation and the action of abiotic factors on the body of turkeys, hypoproteinaemia is observed, caused by a decrease in the content of albumin in the blood from the 42nd to the 70th day of the poultry's life. Due to the influence of abiotic factors, the protein content in the blood decreases. A similar dynamics of protein fractions in poultry blood under the influence of abiotic factors was observed by another researcher (Davison & Karel, 2008). Hypoproteinaemia is probably a consequence of inhibition of plasma protein synthesis in the liver. The reason may be a decrease in the absorption of amino acids into the blood (Boyko *et al.*, 2015). (Romanovych *et al.*, 2019) and (Wynn, 2009) believe that the reason for the decrease in the protein content in the blood may be the fact that there is a violation of the absorption of amino acids. The emergence of "protein loss syndrome" in the intestine is the cause of hypoproteinaemia. Furthermore, protein deficiency increases due to reduced absorption of fats and carbohydrates. To prevent violations of the use of amino acids in the gastrointestinal tract, it is proposed to use probiotics.

Protein metabolism (Stepchenko, 2004) is defined by the influence of many exo- and endogenous factors. Deviations in the physiological state of the body are reflected in protein metabolism. The introduction of humic preparations into the diet of chicken broilers was accompanied by a decrease in the content of albumins in the blood. At the end of the experiment (85 days), their content remained 10% less in experimental chickens. They attribute this to the intensification of the breakdown of albumins or their transformation into globulins.

The concentration of total protein, class G immunoglobulins, and alkaline phosphatase activity in the blood of 10-, 20-, and 30-day-old turkeys was significantly (1.31, 1.36, 1.34 times; 1.28, 1.31, 1, 24 times, and 1.5, 2.15, 1.47 times, respectively) lower compared to the control under the effects of a thermal stimulus (Kambur *et al.*, 2009). Under the influence of Hydrohumate, the concentration of immunoglobulin G (Kovalenko & Stepchenko, 2008), which handles antitoxic, antibacterial, and antiviral antigenic activity, decreased in 10-day-old broiler chickens to 6.24±0.36 mg/ml against 7.04±0. 60 mg/ml in control. The concentration of immunoglobulin G (Kovalenko & Stepchenko, 2008), which is responsible for antitoxic, antibacterial and antiviral antigenic activity, in 10-day-old broiler chickens under the influence of Hydrohumate decreased to 6.24±0.36 mg/ml against 7.04±0.60 mg/ml in control.

Under conditions of exposure to stress on chickens (Baidevlyatov & Baidevlyatov, 2017), a 5.9% decrease in the level of total protein in the blood of the experimental group's poultry was found, and γ-globulin – by 18%. The researcher (Khodorovych, 2022) proves that the adverse impact of immunisation is less pronounced if vaccination is performed in ovo. Under the conditions of vaccination of poultry, it is suggested to use a high-purity solution of sodium hypochlorite. Its use prevents the destruction of follicles of lymphoid formations, causes lymphoreticular hyperplasia, and ensures expansion of the area of lymphoid nodules (Stoyanovsky *et al.*, 2010).

The influence of biological factors, the intensification of feeding processes (Havilei & Pankova, 2022) and the maintenance of turkeys adversely affects not only the immune system of poultry, but also liver cells, slowing down the synthesis of serum albumin (Kambur *et al.*, 2018). In sections of the liver of 28-day-old turkeys, hepatocyte nuclei and homogeneous cytoplasm, and intra-sinusoidal capillaries were clearly visible, in the lumen of which single red blood cells were located. At the same time, in the liver of turkeys on the 50th day of life, a decrease in the content of RNA and the activity of reductases was noted. Glycogen was detected between fatty inclusions in the cytoplasm of hepatocytes.

Intensification of growth and development of broiler chickens with biologically active substances (Kush & Musienko, 2008) from 25 to 30 days of rearing was manifested by a morphological reaction of liver protective structures. Delayed development of the liver lymphoid complex was detected. It was manifested by a decrease in the number of lymphoid formations, plasmocytes.

There was a slight fluctuation in the level of β-globulins, α-globulins, an increase in the γ-globulin fraction of proteins in the blood of turkeys in the period after vaccination. During intensive cultivation of turkeys, it was found that in the period from 28 to 42 days, the indicators of the immune defence of the poultry's body were at a prominent level due to biological stimuli. On the 56th day, and especially in turkeys aged 70 days, the content of Immunoglobulin G decreased by 2.03 and 3.21 times ($p<0.001$), respectively. Researchers (Stepchenko, 2004), (Kambur *et al.*, 2018) point out that immunisation causes a decrease in the body's immune defence. Under the intensive cultivation of turkeys and the influence of abiotic factors, a decrease in BABS, LABS and neutrophil phagocytic activity was established in the period from the 42nd to the 70th days of the poultry's life. A decrease in BABS, LABS, and fibronectin was observed

(Kovalenko & Stepchenko, 2008) in chickens from 10 to 39 days of rearing. Under the influence of Hydrohumate, the concentration of fibronectin decreased from 207.43±4.12 μg/ml to 201.89±4.75 μg/ml, and then increased and amounted to 222.8±3 μg/ml in the plasma of 39-day-old broiler chickens.

In experimental turkeys from the 7th to the 42nd days of life, the level of T- and B-lymphocytes was at a fairly elevated level, providing an active immune response, while from the 56th day, under the influence of abiotic factors, a significant decrease in the level of all lymphocytes and the development of secondary immunological insufficiency were found.

The formation of the immunophysiological status of the organism of quails of the Pharaoh breed in production conditions occurs through critical periods of postnatal ontogenesis (Stoyanovskyi *et al.*, 2016). Low activity of humoral and cellular factors of non-specific resistance of the quail organism was detected at 85 days of age, while at 20 days of age, the values of BABS and LABS reliably increased by 13.6%, and the values of the phagocytic index and phagocytic activity increased by only 20.3% at the age of 75 days. A critically low level of immunoreactivity is observed up to 75 days of age, as evidenced by a decrease in T-helpers at this stage of ontogenesis by 30.8-33.7%. At the age o 90 days, the number of T-active lymphocytes increases by 16.3-26.7%, the number of T-suppressors decreases by 39.9-55.7%. The number of B-lymphocytes with high receptor capacity increased by 41.6-51.7%, and the immunoregulatory index increased by 1.8-2.2 times compared to the 5-day age of quails. The action of industrial stress at various stages of development is accompanied by suppression of the humoral and cellular link of non-specific resistance of the poultry organism, which is evidenced by a decrease in BABS indicators by 23.6%, LABS – by 20.0%, phagocytic activity – by 14.1%, phagocytic index – by 21.4%. It was noted that under the complex influence of technological stress factors on the 20th day of life (stage of resistance), the blood system of quails reacted with a decrease in the numerical values of the formed elements, with an increase in the number of leukocytes against the background of a low lymphocyte content. With repeated exposure to a stressful stimulus, the haematopoietic function of blood in quails aged 41 to 75 days had a similar dynamic. Adaptive changes in the glands under the influence of a complex of technological stress factors were found. A decrease in the secretory activity of the adrenal glands and liver is observed in 41-75-day-old quails after repeated exposure to the stimulus (Stoyanovskyi *et al.*, 2016).

CONCLUSIONS

1. In the conditions of industrial production, on the 42nd day of keeping turkeys, the body's defence mechanisms decrease under the influence of biological factors.

2. On the 42nd day, the total protein content in the blood serum of turkeys decreases by 23.02% ($p<0.01$) compared to the indicator on the 28th day, and on the 56th day it is 12.68% lower, which is probably a consequence of inhibition of plasma protein synthesis in the liver.

3. On thin liver sections of the 28-day-old turkeys, hepatocyte nuclei, their homogeneous cytoplasm and intrasinusoidal capillaries with single red blood cells are clearly visible, and on the 50th day, NPA content and reductase activity are reduced, glycogen is detected between fatty inclusions in the cytoplasm of hepatocytes.

4. The BABS of turkeys aged from 7 to 28 days was at 72.92±2.76% and 89.74±3.70%, respectively, and on the 42nd day there was a decrease in its activity by 1.16 times ($p<0.05$) in comparison with turkeys aged 28 days under conditions of intensive cultivation and exposure to abiotic factors.

5. On the 56th and 70th days of life, the level of Immunoglobulin G in the blood serum decreased by 2.03-3.21 times, and the level of Immunoglobulin M – by 2.70-4.48 times ($p<0.001$). The tendency to decrease the level of Ig G and Ig M in the blood serum of turkeys persisted until the age of 120 days.

6. The content of Ig A and Ig M in the blood of 56-day-old turkeys was 1.98-2.70 times lower than in 28-day-old turkeys ($p<0.001$). The level of Ig M in the blood of 28-day-old turkeys was 2.96 times higher than in 42-day-old turkeys and 5.25 times higher in 120-day-old turkeys ($p<0.001$), which indicates a decrease in immunity in poultry, starting from 42-day-old under the influence of intensive rearing factors.

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Імунний статус індиків в умовах промислового вирощування

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Анотація. Інтенсифікація виробництва продуктів індиківництва супроводжується впливом різноманітних небезпечних факторів на організм птиці. Це призводить до порушення обмінних процесів, дисбалансу засвоєння поживних речовин, зниження імунітету у індиків, що визначає актуальність досліджень даного напряму. У зв'язку з цим, визначення часу зниження імунітету та, в наступному, підвищення його ефективності в організмі індиків, покращення обмінних процесів, росту та розвитку птиці зумовило мету науково-дослідної роботи. Встановлено, що продовж перших шести тижнів інтенсивного вирощування індиків імунна відповідь організму, активність факторів неспецифічної резистентності на вплив біологічних чинників та інтенсифікацію процесів годівлі птиці виявилась ефективною. Однак, з 42 доби вирощування птиці спостерігали виснажування імунного захисту організму індиків та зниження активності факторів неспецифічної резистентності, що проявляється вірогідним зниженням вмісту загального білка у крові птиці, альбумінів та імуноглобулінів класу G та M ($p<0,01$). Аналіз білкового спектру сироватки крові індиків свідчить про імуносупресивний стан організму, ймовірно, викликаний дією біологічних чинників. До 42 доби у індиків знижується бактерицидна та лізоцимна активність сироватки крові, фагоцитарна активність нейтрофілів, Т-клітинна активність лімфоцитів. Виявлені неспецифічні зміни компонентів функціонального елементу печінки, які супроводжуються збільшенням кількості ліпідних включень різної величини, деструктивними змінами в мітохондріях, зниженням синтетичної активності клітин. Дослідження імунного стану організму індиків, активності факторів неспецифічної резистентності та печінки у циклі інтенсивного вирощування від 7 до 120 доби дозволили виявити наявність критичного періоду зниження ефективності захисту організму та подальшого проведення адекватної корекції. Результати отримані в процесі досліджень використовуються у навчальному процесі, впроваджені у процес вирощування індиків в умовах виробництва ТОВ «Індичка» (Сумська область). Пропонуються усім господарствам України з виробництва продуктів індиківництва

Ключові слова: птиця, Т-лімфоцити, імуноглобуліни, альбуміни, печінка птиці

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Relationship Between Globulins in the Late Dry Period with Biochemical Parameters, Fertility and Culling of Cows within 90 Days after Calving

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Abstract. Diseases of the transition period in cows and their culling after calving attract considerable attention. Therefore, early diagnosis and prediction of pathological processes during the transition period in cows using biochemical markers stays relevant. The purpose of this study was to find the relationship of globulin levels in the late transition period with biochemical parameters and the level of fertilisation and culling of cows within 90 days after calving. The blood serum of cows of the main herd was investigated 10-15 days before calving, based on which the animals were conditionally divided into three groups (with signs of hypogammaglobulinemia (less than 30 g/l)), as well as with normal and elevated (more than 40 g/l) globulin levels. Apart from indicators of protein-nitrogen metabolism, enzymatic activity was also found in the blood serum and the state of carbohydrate-lipid, mineral, and vitamin metabolism was assessed using biochemical, chromatographic, and spectrophotometric research methods. It was found that cows with hypoglobulinemia showed substantially lower activity of asparagine transaminase, as well as differences in carbohydrate-lipid metabolism (high glucose levels and reduced concentration of high-density lipoproteins). Furthermore, these cows were found to have a decrease in the content of magnesium, as well as copper. It was discovered that within 90 days after calving, the highest level of culling was observed among cows with reduced globulin levels, and the lowest – in animals with normoglobulinemia. Therefore, a direct relationship between the level of globulins in the blood serum 10-15 days before calving with the reproductive capacity and the level of culling of cows was proved. This allows promptly diagnosing and predicting the development of post-partum pathology and reproductive disorders. The results obtained can be used by practical specialists and scientists to plan and investigate the effectiveness of preventive measures to improve the safety of cows and their reproductive capacity in the post-calving period

Keywords: transition period, post-partum pathology, globulins, biochemical parameters, mineral metabolism, reproductive ability

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INTRODUCTION

In dairy cows, transition diseases lead to considerable economic losses in the dairy industry. These losses include the cost of treatment and premature culling of cows. Early diagnosis or prediction of transition pathologies allows developing measures for their prevention, which reduces the incidence rate and reduces economic losses in the dairy industry (Venjakob *et al.*, 2021; Hailemariam *et al.*, 2014).

In the conditions of industrial cattle breeding and high milk productivity, the duration of the reproductive life of cows does not exceed 2.5-3 lactations. One of the reasons for this is a violation of reproductive function, caused by the wide spread of diseases of the reproductive system in the prenatal, birth, and post-partum periods (Yazlik *et al.*, 2020; Sewalem *et al.*, 2008). The rate of culling cows from the herd on dairy farms during the year is about 21.0-38.2% (Pinedo *et al.*, 2010; Stojic *et al.*, 2013). According to Diniso & Jaja (2021), the most common causes of this are reproductive issues, namely infertility (7.9%), reproductive disorders (89.9%) and dystocia (1%). At the same time, successful fertilisation of cows in the post-partum period is crucial for further reproductive efficiency and profitability in modern dairy cattle breeding (Sammad *et al.*, 2022).

Many post-partum diseases of cows are based on a violation of metabolic processes during the transition period, which determine the further condition of animals in the post-natal period, their reproductive ability and the level of culling of animals. The development of energy and protein deficiencies leads to a decrease in the activity of polymorphonuclear neutrophils (Yazlik *et al.*, 2020), as well as the release of inflammatory cytokines (tumour necrosis factor α and interleukin-6), which lead to systemic inflammation and insulin resistance (Wankhade *et al.*, 2017). Systemic inflammation in the early post-partum period is negatively associated with the ovulatory status of the first dominant follicle after calving (Cheong, 2017).

During the transition period, there are substantial changes in the functioning of organs and the hormonal status of the animal body (Kucuk Baykan & Özcan, 2019). Cows' appetite worsens, and the amount of feed eaten does not compensate for the rapidly increasing cost of milk production. Animals compensate for this lack by mobilising the reserves of fats, proteins, micro- and macronutrients of their body. It is no coincidence that it is during this period that dystrophy and cirrhosis of the liver, emaciation (cachexia), rumen acidosis, ketosis, inflammation of the reproductive organs and, as a result, culling and loss of animals take place (Grummer, 1995). The situation is aggravated by the development of hypocalcaemia and the intensification of protein metabolism in the post-partum period, which has adverse consequences for the health and reproductive ability of dairy cows (Sammad *et al.*, 2022).

Violations of metabolic processes occurring in the body are primarily accompanied by changes in several biochemical parameters. In this regard, the search for individual proteins, metabolites, enzymes, and hormones that would have diagnostic and prognostic significance continues. Andjelić *et al.* (2022) show that higher serum calcium concentrations after calving are associated with higher levels of progesterone, glucose, and triglycerides. In turn, subclinical hypocalcaemia leads to the development of metritis, prolongation of the service, period and a decrease in the size of the follicle (Paiano *et al.*, 2020).

Blood serum proteins are also related to the physiological condition of cows. As shown by Stravsky *et al.* (2020), the albumin-globulin ratio can be used as a prognostic factor to identify cows prone to uterine subinvolution. Globulin concentrations decrease 5 weeks before calving and increase after calving, and their change during calving is substantially related to the frequency of fertilisation (Rowlands *et al.*, 1980).

The purpose of this study was to find the level of culling and fertilisation capacity of cows within 90 days after calving, depending on the level of globulins and other biochemical parameters in the blood serum in the late transition period.

MATERIALS AND METHODS

Selection of animals and organisation of the experiment. The experimental part of the studies was performed on 37 dairy cows of 4-7 years of age with an average annual productivity of 7,200 kg of milk on one of the commercial farms of the Astarta-Kyiv agro-industrial holding. Biochemical studies were performed 10-15 days before calving. According to the results of the study, cows were conditionally divided into three groups. The first group (5 animals) included cows with a low globulin level of 25.6±0.8 g/l (in all animals – up to 30 g/l). The second (control) group (10 cows) was formed from animals with an average globulin content of 35.3±0.9 g/l (within 30-40 g/l), which corresponded to the level of conditionally normal indicators, and the third group included 22 cows with a globulin content of 49.9±1.5 g/l (within 40-65 g/l). Thus, according to the level of globulins, the second group was assigned to conditionally healthy animals (the first group included cows with hypogammaglobunemia, and the third group included cows with hypergammaglobunemia).

The general condition of the cows was monitored for 90 days after calving. Therewith, the number of culled cows was recorded due to obstetric pathology, mastitis, rennet displacement, and diseases of the distal extremities. Furthermore, fertilisation and infertility rates were identified in animals of each group.

Sampling. Blood for biochemical studies was taken 10-15 days before calving from the tail vein before feeding the animals. Selected blood samples were used to obtain a serum, which was frozen at -20°C and transported and stored in this state until the time of research. Biochemical studies were carried out under

the conditions of the laboratory of clinical biochemistry of the Research Centre for Biosafety and Environmental Control of Agricultural Resources of the Dnipro State Agrarian and Economic University.

Biochemical studies. The blood serum samples were examined for the content of total protein (with biuret reagent), albumin (with bromocresol green), urea (enzymatically according to the Berthelot reaction), creatinine (by the rate of formation of the creatinine-picrate complex in the Jaffe reaction), glucose (glucose oxidase method), total calcium (with arsenazo III), inorganic phosphorus (with molybdenum reagent), potassium (by turbidimetric method with sodium tetraphenylborate), iron (by reaction with ferrozine). An automatic biochemical analyser Miura-200 (Italy) was used for analysis with ready-made sets of reagents produced by Spinreakt (Spain), Dialab (Austria), Cormay (Poland), and HTI (USA). High-density lipoproteins were determined according to Warnick & Albers (1978).

Sodium levels were found by colorimetric reaction with magnesium-uranyl acetate (Human, Germany), and magnesium – by colour reaction with calmagite (HTI, USA) on a semi-automatic biochemical analyser Humalazer 3000 (Human, Germany).

The activity of transamination enzymes (ALT and AST) was found kinetically using a set of Spinreakt reagents (Spain), alkaline phosphatase – by the rate of 4-nitrophenol formation (Cormay, Poland). The carotene concentration was found spectrophotometrically (Ulab-2, China) after precipitation of serum proteins with ethyl alcohol and extraction of carotene with hexane.

The concentration of vitamins A and E was found using high-performance liquid chromatography on an Agilent Technologies 1260 Infinity liquid chromatograph, column C18 with spectrophotometric detection (Yefimov & Sofonova, 2014). Reagents manufactured by Honeywell (USA) and Carlo Erba (Italy) were used to manufacture the components of the solvent system.

The concentration of copper, zinc, and manganese in blood serum samples was found by Atomic Absorption Spectrophotometry with flame atomisation on a Selmi FCM 115 spectrophotometer (Ukraine).

The globulin content and A/G ratio were found by calculation.

Statistical analysis. In each group of cows, statistical processing of all the biochemical parameters under study was performed. The resulting digital material was processed using variational statistics methods using SPSS Data editor 17.0 version according to the Tukey Test with Bonferroni correction.

RESULTS AND DISCUSSION

When analysing the results of biochemical studies, it was found that the total protein in the peripheral blood serum of cows at the end of the transition period depended mainly on the concentration of globulins, since the level of albumins practically did not change.

With a low level of globulins (the first group), the level of total protein in the blood serum was also 10.5% lower compared to animals with their physiological values (the second group), and 1.4 times lower compared to animals of the third group (Table 1).

Table 1*. Biochemical parameters of blood serum of cows with different levels of globulins (M±m)*

Indicators	Group 1	Group 2	Group 3
Total protein, g/l	57.4±2.542	67.9±2.2**	82.1±2.1***
Albumins, g/l	31.8±2.3	32.6±2.1	32.3±1.0
Globulins, g/l	25.6±0.8	35.3±0.9***	49.9±1.5***
A/G ratio, units	1.24±0.09	0.93±0.06*	0.65±0.02***
Creatinine, μmol/l	110.8±9.5	113.0±5.0	119.6±4.3
AST, IU/l	55.6±6.8	104.2±12.2**	91.2±7.8**
ALT, IU/l	19.4±1.9	17.6±1.9	19.7±1.5
Alkaline phosphatase, IU/l	96.5±8.0	109.0±12.2	101.3±6.2
Glucose, mmol/l	2.68±0.11	2.30±0.06**	2.30±0.05**
High-density lipoproteins, mg/100 ml	773.2±95.1	1,088.1±105.9*	1,073.0±76.2*

Note: ** – p≤0.05; ** – p≤0.01; ** – p≤0.001 – relative to animals of the first group*
Source: *compiled by the authors*

Accordingly, the A/G ratio was highest in cows of the first group and amounted to 1.24±0.09, in the second group it was lower by 33.3% (p≤0.02), and in the third – by 1.9 times (p≤0.001).

Apart from the above data on the indicators of total protein, globulins and albumins, certain differences in the activity of transamination enzymes were noted. The activity of AST, which is an indicator enzyme for the liver in cattle, in animals of the first group was almost 2 times lower compared to the second and third groups (p≤0.01) and by 64.0% (p≤0.01), respectively. Indicators of carbohydrate-lipid metabolism in cows of the first group were

described by a high level of glucose and, at the same time, a low content of lipoproteins. The concentration of glucose in the blood of cows of the first group was 1.17 times higher (p≤0.01), and lipoproteins – 1.4 times (P≤0.05) lower than in animals of the second and third groups. Considering the importance of indicators and the nature of mineral and vitamin metabolism in the pathogenesis of various pathologies of the transition period, the level of basic macro- and microelements, as well as vitamins A, E and carotene was investigated (Table 2).

***Table 2**. Indicators of mineral and vitamin metabolism in cows in the transition period with different levels of globulins (M±m)*

Indicators	Group 1	Group 2	Group 3
Total calcium, mmol/l	2.40±0.14	2.13±0.16	2.25±0.10
Inorganic phosphorus, mmol/l	1.54±0.15	1.86±0.16	2.04±0.10*
Magnesium, mmol/l	0.92±0.02	2.02±0.66	1.53±0.31°
Potassium, mmol/l	5.02±0.78	4.53±0.62	4.98±0.40
Sodium, mmol/l	137.6±8.3	136.9±2.9	137.2±3.2
Iron, μmol/l	28.2±2.3	25.1±1.7	23.3±1.6
Copper, μg/100 ml	55.4±4.2	74.3±3.5**	82.5±3.0***
Zinc, μg/100 ml	76.0±4.5	76.5±7.3	83.8±4.7
Manganese, μg/100 ml	2.4±1.2	1.6±0.2	1.8±0.2
Vitamin A, μg/100 ml	18.3±0.6	19.1±2.6	19.3±1.0
Vitamin E, μg/ml	2.2±0.4	2.9±0.5	3.1±0.3°
Carotene, μg/100 ml	306.2±11.6	261.2±15.4*	287.3±10.9

***Note:** °p≤0.1; * – p≤0.05; ** – p≤0.01; ** – p≤0.001 – relative to animals of the first group*
***Source:** compiled by the authors*

Considering the indicators of mineral metabolism, one should pay attention to the level of calcium, phosphorus, and its ratio in the blood serum of cows with various levels of globulins. The total calcium content in animals of separate groups did not significantly differ. At the same time, animals of the second and third groups showed an increase in the level of inorganic phosphorus, which was significant in cows with a globulin content of more than 40 g/l. A violation of mineral metabolism is indicated by a tendency to reduce the level of magnesium in the blood of cows of the first group. Copper levels were 1.3 (p≤0.01) and 1.5 (p≤0.001) times lower than in animals of the second and third groups, respectively.

The content of other macro- and microelements in the blood serum of cows of all groups did not differ. The frequency of culling and the results of the diagnostic stage of obstetric and gynaecological medical examination in all groups of cows during 2-3 months of lactation are presented in Table 3.

***Table 3**. Results of obstetric and gynaecological medical examination of cows within 90 days after calving*

Indicators	First group		Second group		Third group	
	n	%	n	%	n	%
Culled	4	80.0	1	10.0	5	22.7
Pregnant	0	0	7	70.0	5	22.7
Barren	1	20.0	2	20.0	12	54.6

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

Within 2-3 months after calving, 4 cows (80%) were culled from the herd in the first group, which is significantly more than in the second group – 1 cow (10%) and third group – 5 cows (22.7%). The reasons for culling were obstetric and gynaecological pathology (development of chronic mastitis and/or displacement of the rennet), as well as diseases of the distal extremities. At the same time, the metabolic status of cows in the second and third groups was affected during the post-partum period and reproductive function during the experiment. The fertilisation rate of cows of different groups within 3 months after calving also differed. In cows of the second group, it was 70.0%, which is 47.3% higher than in the third group, and the number of infertile cows was 34.6% higher in the third group.

Studies have shown that before calving, the majority of cows (73%) had globulin levels higher or lower than animals with conditionally normal values (Brscic

et al., 2015; Alberghina *et al.*, 2011; Kahn *et al.*, 2010). It is known that among the protein globulin fractions, gamma globulins predominate, which provide the function of immune protection of animals (Elshahawy & Abdullaziz, 2017; Bertoni *et al.*, 2008). Therefore, the low concentration of these proteins in cows of the first group has a low level of their nonspecific resistance. At the same time, elevated globulin levels in cows of the third group may be due to increased protein levels during the acute phase of inflammation. As noted by Tothova *et al.* (2016), they belong to the α-fraction, and their level increases when there is a focus of inflammation or a systemic inflammatory response in the body. That is, the noted changes may indicate the activation of the immune system and the activation of inflammatory processes before calving, including in the liver. This is indicated by the research of Bertoni *et al.* (2008), who established the dependence of the level of α-globulins in the first weeks after childbirth and the frequency of violations of reproductive ability in cows.

In animals with reference globulin levels, the concentration of total protein and albumins also did not exceed normal values. Notably, the concentration of albumins did not differ between animals of different groups. According to Spaans *et al.* (2022), the globulin concentration decreases 7-14 days before calving, but the albumin content remains relatively stable.

Changes in the content of globulins in the blood serum are probably closely related to general disorders of protein metabolism. Cows with low levels of globulin protein fractions also had low levels of total protein. On the one hand, this may be caused by the high intensity of the use of the total pool of amino acids in the mother's blood for protein synthesis in the foetal body. At the same time, this may indicate the use of immunoglobulins G for colostrum formation during the transient period (Conneely *et al.*, 2013).

Ingvartsen (2006) indicates that AST levels in healthy cows range from 78 to 132 IU/l. Its increase can be observed at the end of the transition period, since uterine tissues have a fairly high activity of this enzyme (Sattler & Fürll, 2004). Presumably, a decrease in AST activity in cows against the background of a decrease in globulin levels may indicate a decrease in the number of functionally active hepatocytes due to the previous cytolytic syndrome and replacement of parenchymal cells with connective tissue. Thus, the hepatocyte resource of the liver is depleted with damage to hepatocytes because of autointoxication with decay products and xenobiotics (Djoković *et al.*, 2013).

Changes in carbohydrate-lipid metabolism indicate that cows of the second and third groups had a lower glucose level against the background of an increase in the concentration of high-density lipoproteins in their blood serum. Such biochemical changes are inherent in the development of a negative energy balance, which begins to develop in highly productive cows at the end of the transient period (Ha *et al.*, 2022). At the same time, blood glucose levels in cows with low globulin levels were higher than in animals of the second and third groups. The content of lipoproteins, on the contrary, was lower. Such dynamics of indicators can be explained by a lower intensity of colostrum formation and, accordingly, lower requirements for metabolic energy for its production.

Analysing the reduced copper content, Kaya *et al.* (2016) indicates that 95% of the copper in serum or plasma is part of the protein ceruloplasmin, which is synthesised in the liver. Therefore, it can be assumed that it is functional liver failure that causes a decrease in copper concentration. Nobili *et al.* (2013) noted a decrease in ceruloplasmin activity in children with non-alcoholic fatty hepatodystrophy. Such changes lead both to a decrease in neutrophil activity in cows and to a decrease in the level of antioxidant protection, which depends on the level of ceruloplasmin (Hernández *et al.*, 2022).

The obtained research results coincide with the data of Rowlands *et al.* (1980) who indicate that pre-calving globulin concentrations are related to subsequent reproductive performance of cows. Thus, at the end of the transition period, changes in metabolic processes and the development of immunodeficiency in cows with hypoglobulinemia are noted. Among these animals, 80% were subsequently culled within three months of calving. Apparently, cows with weakened immunity, especially after calving, are more prone to many diseases of the transient period, which is also indicated by Zhelavskyi *et al.* (2020). As a result of culling up to 28.0% in the first 100 days after calving (Kucuk Baykan & Özcan, 2019). Therewith, the reasons for culling of animals from the herd are different – from ketosis to rennet displacement, mastitis, limb pathology, which coincides with the results obtained.

CONCLUSIONS

Given that the limits of globulin levels did not overlap between the groups of animals under study, it became possible to identify pathognomic indicators of metabolic disorders and use them to diagnose and predict the complicated course of the transient period, which leads to premature culling of animals. These pathological processes are accompanied by an increased or reduced content of globulins, due to the pathological condition of the liver and/or other organs that can be detected even before calving.

In the blood serum of cows with reduced globulin levels, AST activity decreases, glucose levels are increased, as well as lower concentrations of copper and lipoproteins, which indicates damage to the liver and other organs. As a result, their culling from the herd in the first 90 days after calving reaches 80%. At the same time, an increased level of blood globulins in the pre-pregnancy period is associated with an increased level of infertility, which reaches 54.6%. This

may indicate the development of a general inflammatory syndrome due to pathological processes in the organs of the reproductive system. In the blood serum of cows with reduced globulin levels, glucose was 1.17 times higher, while lipoproteins were 1.4 times lower than in the second and third groups. Cows with hypogamaglobulinemia develop mineral metabolism disorders, specifically a decrease in the level of magnesium and copper in the blood. Therefore, the level of globulins in the blood serum of cows in the late transition period can be used as a prognostic indicator of the complicated course of the post-calving period. Globulin levels below 30 g/l 10-14 days before calving should be considered the greatest risk for the culling of cows. Exceeding the indicator over 40 g/l in the future significantly increases the frequency of reproductive function disorders.

Further studies may be aimed at evaluating the effectiveness of therapeutic and preventive measures in animals with detected violations of globulin levels in the late transition period.

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Взаємозв'язок рівня глобулінів у пізній сухостійний період з рівнем запліднення та вибуття корів протягом 90 діб після отелення

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Анотація. Захворювання транзитного періоду у корів та їх вибуття після отелення привертають значну увагу. Тому рання діагностика та прогнозування патологічних процесів у перехідний період у корів із використанням біохімічних маркерів залишається актуальною. Метою роботи було визначити взаємозв'язок рівня глобулінів у пізній сухостійний період з біохімічними показниками та рівнем запліднення та вибуття корів протягом 90 діб після отелення. Було проведено дослідження сироватки крові корів основного стада за 10-15 діб до родів, на підставі чого умовно розділено тварин на три групи (з ознаками гіпогамаглобунемії (менше 30 г/л), а також з нормальним та підвищеним (понад 40 г/л) рівнем глобулінів. Крім показників білково-азотистого метаболізму, в сироватці крові також визначали ензиматичну активність та оцінювали стан вуглеводно-ліпідного, мінерального і вітамінного обмінів з використанням біохімічних, хроматографічних та спектрофотометричних методів досліджень. Було встановлено, що у корів з проявом гіпоглобулінемії спостерігалася суттєво нижча активність аспарагінової трансамінази, а також відмінності показників вуглеводно-ліпідного обміну (вищий рівень глюкози та знижена концентрація ліпопротеїдів високої щільності). Крім того, у цих корів було виявлено зниження вмісту магнію, а також міді. Досліджено, що впродовж 90 діб після отелення спостерігався найвищий рівень вибуття серед корів зі зниженим рівнем глобулінів, а найнижчий – у тварин з нормоглобулінемією. Отже, доведено безпосередній зв'язок між рівнем глобулінів у сироватці крові за 10–15 діб до отелення з репродуктивною здатністю та рівнем вибуття корів. Це дає змогу проводити ранню діагностику та прогнозування розвитку післяродової патології та порушення репродуктивної функції. Одержані результати можуть бути використані практичними фахівцями та науковцями для планування та вивчення ефективності профілактичних заходів з підвищення збереженості корів та їх відтворювальної здатності у післяотельний період

Ключові слова: сухостійний період, післяродова патологія, глобуліни, біохімічні показники, мінеральний обмін, репродуктивна здатність

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Interrelation of Kinetic Parameters of Sperm of Servicing Bulls of the Holstein Breed with Its Fertilising Ability

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Abstract. Sperm motility is an essential indicator that characterises the viability and structural integrity of sperm. This parameter is closely related to the fertilisation capacity of male germ cells, so its assessment is an integral part of sperm analysis. The purpose of this study is to investigate the possibility of predicting the fertilisation capacity of sperm of servicing bulls based on kinetic indicators. The study involved laboratory, zootechnical, and statistical methods. A significant variability in the kinetic parameters of sperm of servicing bulls was revealed – from 6.2 to 16.1%. The variation in the percentage of motile sperm in the ejaculate was 78.9-89.8; the percentage of progressive sperm – 50.0-74.5; velocity average path of sperm (VAP) – 132.6-163.7 μm/s; velocity straight line (VSL) – 99.2-138.2 μm/s; curvilinear velocity (VCL) – 223.7-272.3 μm/s; straightness of sperm (STR) – 73.9-85.0%, linearity (LIN) – 45.1-56.1%, wobble (WOB) – 57.2-63.8%. The difference between the minimum and maximum values for all the parameters under study is highly likely ($P<0.001$). A correlation between various kinetic parameters of sperm is established. Sperm movement rates and their relative values are largely conditioned upon the percentage of progressive sperm in the ejaculate ($r=+0.231-0.761$). VAP, VSL, and VCL indicators are interrelated ($r=+0.550-0.887$). The study investigated the average fertilising ability of the sperm of servicing bulls based on the results of insemination of 8,594 cows and 992 heifers in four farms of Zhytomyr and Kyiv oblasts, the variation was within 40.7-61.4%. It was proved that bulls with higher and average fertilising capacity are described by a higher percentage of progressive sperm in ejaculates, and VAP, VSL, and VCL indicators of sperm movement compared to bulls with low fertilising capacity. This pattern is confirmed by correlation analysis ($r=+0.538-0.675$). Kinetic parameters identified using the CASA system allow predicting the fertilising capacity of sperm and identify servicing bulls with reduced reproductive function

Keywords: bull, CASA system, sperm motility, VAP, VSL, VCL, fertilising capacity of sperm

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INTRODUCTION

The dairy industry is an important link in the food market of Ukraine, which accounts for about 11% of the total sales of the food industry. Due to their beneficial properties, milk and dairy products are in high demand among consumers. Approximately 18% of the total food costs of the Ukrainian population belong to dairy products (Korman *et al.*, 2022). Currently, there is a rapid decline in milk production, one of the reasons for which is a substantial decrease in the number of cattle. The solution to this problem is partly possible due to the proper organisation of herd reproduction.

Pedigree bulls with high genetic potential play a vital role in the successful breeding of highly productive cows, since thousands of offspring can be obtained from a single male by artificial insemination in a short period of time (Kyzebnyy & Boiko, 2018).

Assessment of the reproductive capacity of producers is based on the analysis of sperm quality. One of the indicators that is considered most associated with the fertilisation capacity of sperm is motility (Gillan *et al.*, 2008; Hering *et al.*, 2014; David *et al.*, 2015). It is the ability of male cells to actively move that allows them to overcome the anatomical and physiological barriers of the female genital organs and fertilise the egg (Suarez & Pacey, 2006). Assessment of sperm motility by the conventional microscopic method is quite subjective (Singh *et al.*, 2021), and therefore it does not always correlate with fertilising capacity (Farrell *et al.*, 1998). In the 1980s, Computer Assisted Semen Analysis (CASA) was created, which, unlike conventional analysis methods, provides objective, accurate, and fast results of the quality of ejaculates (Yaniz *et al.*, 2018). The basic elements of this system include a phase contrast microscope, a video camera, and a computer with software. Apart from the concentration and quantification of motile and progressive sperm, CASA technology determines a wide range of kinetic parameters for each cell: velocity average path (VAP), velocity straight line (VSL) and curvilinear velocity (VCL), μm/s; straightness (STR), linearity (LIN) and wobble (WOB), %; amplitude of lateral head displacement (ALH), μm; beat cross frequency (BCF), Hz (Tanga *et al.*, 2021). Furthermore, this technology allows identifying subpopulations of sperm in each field – stationary, slow, medium, and fast (Ibanescu *et al.*, 2020).

Numerous scientific studies indicate a relationship between various sperm counts determined by CASA and its fertilising capacity in males (Ahmed *et al.*, 2016; Suliman *et al.*, 2020; Barquero *et al.*, 2021; Gliozzi *et al.*, 2017) found that Holstein bulls with high reproductive potential significantly outnumbered animals with low sperm motility, STR and LIN indicators, and the percentage of active cells. Zăhan *et al.* (2018) found a significant correlation between sperm fertilising capacity and sperm motility (r=0.878), VSL (r=0.648), and VAP (r=0.684) motility in Simmental bulls. Bernecic *et al.* (2021), having investigated a wide range of functional, morphological, and intracellular parameters of cryopreserved sperm, concluded that only the viability and integrity of the acrosome can serve as indicators of bull fecundity.

The purpose of this study is to figure out the kinetic parameters of native sperm of servicing bulls and investigate the relationship of these parameters with the fertilising capacity of sperm to predict it. To fulfil the purpose of the study, the following tasks were set: to find and investigate the kinetic parameters of sperm using the IVOS semen analyser; to figure out the fertilising capacity of sperm of experimental bulls; to investigate the relationship between the kinetic parameters of sperm and its fertilising capacity.

MATERIALS AND METHODS

The experiment was conducted in the conditions of "Ukrainian genetic company" LLC. The study used 11 servicing bulls of the black and red-spotted Holstein breed, aged from 4 to 8 years. Bulls of foreign origin, imported to pedigree enterprise from Germany and the Netherlands.

Ejaculates from servicing bulls were obtained according to the schedule twice a week by a double mount with an interval of 5-10 minutes, using a dummy bull. Sperm was taken into a shortened artificial vagina using a disposable sperm receiver, which was sealed and passed through a sterile airlock to a production laboratory.

At the initial stage, the obtained ejaculates were evaluated visually, after which the following indicators were identified using the IVOS computer analysis system (Hamilton Thorne Research, USA): percentage of motile and progressive sperm in the ejaculate, velocity average path (VAP, μm/s), straight-line velocity (VSL, μm/s), curvilinear velocity (VCL, μm/s), straightness (STR, %), linearity (LIN, %), wobble (WOB, %). The quality of native sperm was evaluated according to DSTU 3535-97.

Dilution of sperm suitable for cryopreservation took place at a temperature of +35°C with AndroMed medium (Germany). One spermodose contained at least 20 million active sperm cells.

Rarefied sperm was packed into 0.25 ml straws using IS4 automatic equipment (IMV Technologies, France). After packaging and labelling, the spermodoses were kept in a refrigerated display case (IMV Technologies, France) for 3-4 hours to undergo the balancing process. The straws cooled to 4°C were cryopreserved in a MiniDigitcool programmable freezer (IMV Technologies, France) in three stages: I – the rate of lowering the temperature was 5°C/min., cooling from +4 to -10°C; II – speed of 40°C/min., freezing from -10 to -100°C; III – speed of 20°C/min., freezing from -100 to -140°C. Cryopreserved sperm products were stored in HB-200 bio-storage facilities in liquid nitrogen at -196°C.

Cryopreserved straws were thawed in a water bath at +35°C for 30 s. The motility of thawed sperm

was determined on an IVOS analyser. Sperm survival was studied by incubating samples at +38±0.5°C for 5 hours. Sperm products that had an initial motility of less than 4 points and a survival rate of less than 5 hours were subject to culling.

To determine the fertilising capacity of sperm, 8594 were used cows and 992 heifers of Ukrainian black-and red-piebald dairy breeds, which were inseminated with sperm products of experimental bulls in the farms of Zhytomyr (PAF "Yerchiki", SE EF "Nova Peremoha", ALLC "Ptahoplezavod "Korobovskyi") and Kyiv (AF "Kyivska") oblasts. Females were artificial inseminated according to the recto-cervical method, twice at one sexual excitement with an interval of 10-12 hours. Fecundation was determined on the 90th day after insemination using an ultrasound machine.

The indicator of the average fertilising capacity of sperm was determined according to the formula (Maiboroda *et al.*, 2019):

$$AFC_j = \frac{\sum N_{ij} \frac{kK_{ij} + T_{ij}}{N_{ij}}}{\sum N_{ij}} \times 100, \quad (1)$$

where AFC_j is the average fertilising capacity of j-th bull's sperm, %; k is the correction factor for cows for the level of fertilisation of heifers; K_{ij} is the number of cows fertilised from the first sperm insemination by the j-th bull in the i-th herd; T_{ij} is the number of heifers fertilised from the first sperm insemination by the j-th bull in the i-th herd; N_{ij} is the total number of cows and heifers fertilised from the first sperm insemination by the j-th bull in the i-th herd.

The obtained data were processed according to the methods of mathematical statistics on a personal computer using the programs "STATISTICA 10.0" and MS Excel.

RESULTS AND DISCUSSION

Experimental servicing bulls of the Holstein breed differ substantially in all the indicators considered (Table 1).

***Table 1**. Kinetic parameters of sperm of servicing bulls*

Nickname and bull identification No.	Quantity ejaculates	Motile sperm, %	Progressive sperm, %	VAP, μm/s	VSL, μm/s	VCL, μm/s	STR, %	LIN, %	WOB, %
Argonaut DE 538441348	61	89.7±0.55	67.3±1.00	157.2±1.20	127.1±1.81	271.0±1.85	79.7±0.47	47.7±0.45	58.0±0.30
Asall DE 579542573/42573	24	82.2±1.56	55.3±2.39	133.0±3.16	104.9±2.04	223.7±5.75	77.8±1.10	48.6±1.15	59.6±0.67
Bugatti DE 538441328/41328	57	83.5±0.59	66.3±0.90	163.7±0.94	138.2±1.06	265.8±1.87	82.5±0.40	51.9±0.45	61.7±0.24
Glamour NL 713313332	35	78.9±0.77	59.9±1.04	152.5±1.20	126.4±1.08	267.5±3.33	81.7±0.45	48.4±0.58	57.2±0.46
Chancellor DE 768305280/5280	21	83.3±1.10	50.0±2.25	132.6±1.92	99.2±2.04	228.6±4.00	73.9±0.98	45.1±1.04	58.1±0.70
Carmello DE 349214122/14122	18	81.3±1.91	50.8±2.74	132.6±2.47	104.0±2.61	227.0±3.40	76.3±1.10	46.6±1.06	58.4±0.80
Lasky NL 762041879/41879	43	84.8±0.75	61.5±1.14	155.6±1.46	125.6±1.84	272.3±2.15	79.0±0.62	47.1±0.65	57.2±0.50
Lafard DE 121030279	22	84.4±0.90	66.7±1.57	147.0±2.69	127.2±2.42	231.5±6.05	85.0±0.59	56.0±0.72	63.8±0.68
Levitz DE 356447182	30	89.8±0.60	74.5±1.45	158.6±2.00	137.9±2.16	253.6±3.84	84.5±1.28	56.1±1.27	62.7±0.57
Masiro DE 354071654/71654	47	83.2±0.63	68.6±0.92	149.7±1.25	129.2±1.35	255.5 ±2.85	85.0±0.50	51.7±0.65	58.8±0.46
Fawn DE 356552537	71	89.4±0.55	73.6±0.91	155.8±1.72	134.0±1.58	247.3±3.03	84.9±0.34	54.7±0.52	63.1±0.37
Max-min		10,9c	24.5c	31.1c	39.0c	48.6c	11.1c	11.0c	6.6c
Cv, %		7.0	16.1	9.2	12.3	10.0	6.2	10.9	6.2

***Note:** The results are statistically significant at a – P<0.05, b – P<0.01, c – P<0.001*
***Source:** compiled by the authors*

The variability of kinetic parameters was within 6.2-16.1%. Traditionally, when evaluating sperm at pedigree enterprises, the main and only kinetic indicator that determines the suitability of the ejaculate for use is sperm motility. In the samples under study, it varies from 78.9 (Glamour) to 89.8% (Levitz), i.e., the max-min difference is 10.9%. More variable is the percentage of progressive sperm in the ejaculates of bulls, its variation is 50.0% (Chancellor) – 74.5% (Levitz), max-min 24.5%. Therewith, there were cases when the difference between the number of motile and progressive sperm was 20-30%, and a bull with a motility of 81-83% had only 50% of progressive sperm (Chancellor, Carmello), or vice versa with a motility of 78.9% – almost 60%

of progressive sperm (Glamour). The largest percentage of progressive sperm in ejaculates (66.3-74.5%) was recorded in the bulls Agronaut, Bugatti, Lafard, Levitz, Masiro, Fawn.

Significant differences in servicing bulls were also found in the velocity of sperm. The minimum VAP value is 132.6 μm/s (Chancellor), the maximum is 163.7 μm/s (Bugatti); the minimum VSL value is 99.2 μm/s (Chancellor), the maximum is 138.2 μm/s (Bugatti); the minimum VCL value is 223.7 μm/s (Asall), the maximum is 272.3 μm/s (Lasky). The highest sperm movement rates (VAP over 155 μm/s) were found in bulls Argonaut, Bugatti, Lasky, Levitz, Fawn. Three calculated indicators that characterise the velocity ratio were also found. The minimum STR value is 73.9% (Chancellor), the maximum is 85.0% (Masiro); the minimum LIN value is 45.1% (Chancellor), the maximum is 56.1% (Levitz), the minimum WOB value is 57.2% (Glamour), the maximum is 63.8% (Lafard).

The difference between the extreme values according to VAP is 31.1 μm/s, VSL – 39.0 μm/s, VCL – 48.6 μm/s, STR – 11.1%, LIN – 11.0%, WOB – 6.6%. In all cases without exception, the difference is highly probable (P<0.001).

Correlation analysis revealed the interdependence of sperm parameters of servicing bulls (Table 2).

***Table 2**. Relationship between kinetic parameters of servicing bull sperm (n=429)*

Correlation coefficient	Progressive sperm, %	VAP, μm/s	VSL, μm/s	VCL, μm/s	STR, %	LIN, %	WOB, %
Motile sperm, %	+0.396^{c}	+0.275^{c}	+0.225^{c}	+0.105^{a}	+0.020	+0.133^{b}	+0.247^{c}
Progressive sperm, %		+0.555^{c}	+0.743^{c}	+0.231^{c}	+0.761^{c}	+0.641^{c}	+0.458^{c}
VAP, μm/s			+0.887^{c}	+0.807^{c}	+0.320^{c}	+0.242^{c}	+0.180^{c}
VSL, μm/s				+0.550^{c}	+0.649^{c}	+0.556^{c}	+0.435^{c}
VCL, μm/s					-0.054	-0.281^{c}	-0.431^{c}
STR, %						+0.706^{c}	+0.575^{c}
LIN, %							+0.844^{c}

***Note:** The results are statistically significant at a – P<0.05, b – P<0.01, c – P<0.001*
***Source:** compiled by the authors*

A positive relationship of average strength is observed between the percentage of motile and progressive sperm (+0.396, P<0.001). Sperm motility rates positively and reliably correlate with the percentage of motile and progressive sperm in the ejaculate, but the dependence on the percentage of progressive sperm is much higher – VAP+0.555 vs +0.275, VSL +0.743 vs +0.225, VCL +0.231 vs + 0.105. It is clear that all velocities are interrelated, which is confirmed by high and probable correlation coefficients between them – from +0.550 to +0.887.

As for the relative velocity indicators that describe the STR, LIN, and WOB degrees, they are most conditioned upon the percentage of progressive sperm in the ejaculate (+0.458-0.761) and VLS (+0.435-0.649), and negatively correlate with VCL (-0,431-0,054).

Fertilising capacity is the main criterion for sperm quality. To evaluate it, the results of insemination of 9,586 cows and heifers of mating age with the sperm of experimental bulls in 4 farms of Zhytomyr and Kyiv oblasts were analysed (Table 3).

***Table 3**. Fecundity rate of livestock with sperm of experimental servicing bulls*

Nickname and bull identification No.	Farm	Number of inseminations			Fertilising capacity capacity, %*	Average fertilising capacity of sperm, %*
		Cows	Heifers	Total		
Argonaut DE 538441348	"AF "Kyivska" LLC	921	–	921	61.4	61.4±1.60
Asall DE 579542573/42573	PAF "Yerchyky"		40	40	70.0	49.2±4.33
	"Ptahoplemzavod "Korobivskyi" ALLC	61	32	93	40.2	
Bugatti DE 538441328/41328	"AF "Kyivska" LLC	487	–	487	44.0	51.2±1.05
	PAF "Yerchyky"	1604	102	1706	52.7	
	"Ptahoplemzavod "Korobivskyi" ALLC	65	28	93	60.2	
Glamour NL 713313332	"Ptahoplemzavod "Korobivskyi" ALLC	123	19	142	54.2	54.2±4.18
Chancellor DE 768305280/5280	PAF "Yerchyky"	172	20	192	41.9	41.9±3.56

Table 3, Continued

Carmello DE 349214122/14122	PAF "Yerchyky"	263	29	292	61.8	49.7±1.14
	"AF "Kyivska" LLC	1190	10	1200	49.7	
	SE "EF "Nova Peremoha"	330	88	418	41.3	
Lasky NL 762041879/41879	PAF "Yerchyky"	230	7	237	52.2	52.2±3.24
Lafard DE 121030279	PAF "Yerchyky"	95	10	105	40.7	40.7±4.79
Levitz DE 356447182	PAF "Yerchyky"	301	64	365	44.4	60.0±1.41
	"AF "Kyivska" LLC	383	361	744	67.1	
	SE "EF "Nova Peremoha"	60	42	102	64.4	
Masiro DE 354071654/71654	PAF "Yerchyky"	175	–	175	54.2	54.4±1.19
	"AF "Kyivska" LLC	1546	42	1588	54.4	
Fawn DE 356552537	PAF "Yerchyky"	299	46	345	51.7	53.9±1.90
	"AF "Kyivska" LLC	94	–	94	52.6	
	"Ptahoplemzavod "Korobivskyi" ALLC	195	52	247	57.5	

Note: *Corrective factor for cows for the fecundity level of heifers is 1.3*
Source: *compiled by the authors*

For some servicing bulls, the fertilisation rate of livestock did not significantly differ between farms (Masiro, Fawn), for others it varied quite widely (Asall, Bugatti, Carmello, Levitz). This is because apart from the quality of sperm products of the servicing bull, the results of livestock fertilisation are affected by factors such as the state of reproductive health of the herd, the method of insemination, the level of training of artificial insemination technician, the organisation of feeding and conditions of keeping animals on the farm, etc. (Kebede, 2018).

Sperm fertilisation rate of 60% or more is found in bulls Argonaut and Levitz; 50% or more – Bugatti, Glamour, Lasky, Masiro, Fawn; 40-50% – Asall, Chancellor, Carmello, Lafard. In general, there is a tendency that bulls with higher and average fertilising capacity are described by a higher percentage of progressive sperm (66.3-74.5%), VAP (149.7-163.7 μm/s), VLS (125.6-138.2 μm/s) and VCL (247.3-272.3 μm/s) indicators of sperm motility compared to bulls with low fertilising capacity, in which these parameters were 50.0-66.7%; 132.6-147.0; 99.2-127.2, and 223.7-231.5 μm/s, respectively.

The results of correlation analysis confirm the relationship between the parameters of native sperm and its fertilising capacity (Table 4)

Table 4*. Relationship between kinetic parameters of servicing bull sperm and fertilising capacity*

Indicator. units of measurement	Correlation coefficient(r±m)	td
Motile sperm, %	+0.491±0.229	2.15
Progressive sperm, %	+0.550±0.210	2.61[a]
VAP, μm/s	+0.604±0.192	3.15[a]
VSL, μm/s	+0.538±0.214	2.51[a]
VCL, μm/s	+0.675±0.164	4.11[b]
STR, %	+0.317±0.271	1.17
LIN, %	+0.116±0.297	0.39
WOB, %	-0.136±0.296	0.46

Note: *The results are statistically significant at a – P<0.05, b – P<0.01, c – P<0.001*
Source: *compiled by the authors*

Sperm kinetic parameters, in addition to the degree of deviation of sperm movement, are positively correlated with fertilising capacity. The relationship between the conventional sperm motility index in bull ejaculates and fertilising capacity is positive of medium strength, but improbable (+0.491). Probable correlation coefficients were obtained with the percentage of progressive sperm (+0.550) and their movement rates (+0.538-0.675).

Modern comprehensive assessment of sperm motility of producers includes determination of total motility (percentage of sperm showing any movement), progressive motility (percentage of sperm with rectilinear translational movement) and kinetic parameters (Berg *et al.*, 2018). Analysis of sperm movement patterns, their velocity, and head movement trajectory helps to better understand the functional capacity of sperm and select the highest quality bull ejaculates for further cryopreservation (Perumal *et al.*, 2014). The possibility of selecting the highest quality ejaculates is clearly confirmed by the authors' research, as they prove their high variability in the investigated kinetic parameters in different bulls. Variability can be caused by both the bull genotype and a wide range of other factors,

such as age, season, mode of use of the servicing bull, the interval between ejaculations, etc. (Gopinathan *et al.*, 2018; Islam *et al.*, 2018; Murphy *et al.*, 2018).

Studies have found a correlation between different kinetic parameters of sperm. The strongest positive relationship is observed between VSP and VSL (r=+0.887), VAP and VCL (+0.807), and LIN and WOB (+0.844). Similar results were obtained in the study of native (Khan *et al.*, 2017) and cryopreserved sperm of gayals (Perumal *et al.*, 2014) and Simmental bulls (InanÇ *et al.*, 2018). All parameters of sperm movement correlate with the percentage of progressive sperm, which indicates the possibility of sperm with straight-line movement to pass the distance in a short period of time (InanÇ *et al.*, 2018).

Numerous scientific studies indicate a relationship between sperm motility indicators and sperm fertilising capacity. Singh *et al.* (2016) found that buffaloes with high fecundity have a considerably higher percentage of motile sperm, curvilinear (VCL), and average (VAP) rates compared to buffaloes with medium and low fecundity. Guilherme *et al.* (2020), having investigated the fertilising capacity of bull sperm of the local Brazilian breed Girolando, concluded that VCL, VSL, and VAP are the main indicators by which it is possible to predict ovum fertilisation in vitro.

According to the results of studies, the fertilising capacity of Holstein bull sperm depends on the percentage of sperm with progressive movement (r=+0.550), VCL, VAP, and VSL values (+0.538-0.675). A strong positive association of fertilisation results with the percentage of progressive sperm in bulls was also recorded by foreign researchers (Kathiravan *et al.*, 2008; Li *et al.*, 2016). The results obtained in this study are in good agreement with Nagy *et al.* (2015), who established a high-probability correlation between sperm motility velocities (VAP, VSL, and VCL) of Holstein bulls based on the results of insemination of 9,000 cows.

Therewith, Nagy *et al.* (2015), Page & Rosenkrans (2019) consider VAP to be the most informative indicator of native sperm quality and the main factor affecting fertilising capacity. According to the results of studies, among all indicators, VCL correlates most with the fertilising capacity of sperm. Fertilisation of the ovum is impossible without hyperactivation of sperm. It is hyperactive sperm that is described by energetic curvilinear movement due to an increase in the amplitude of tail beating (Harayama, 2018). This movement allows them to overcome the viscous environment of the reproductive organs of the female and penetrate the Zona Pellucida of the ovum (Perez-Cerezales *et al.*, 2015).According to Mortimer *et al.* (1998), spermatozoa are classified as hyperactive if they show high curvilinear velocity (≥150 μm/s), amplitude of lateral head displacement (≥7 μm), and low linearity (≤50%), while the criteria of De Lamirande & Gagnon (1993) are, respectively, ≥80 μm/s; 6.5 μm; ≤65%.

Studies have not found a reliable correlation between the relative velocity parameters (STR, LIN, WOB) and the fertilising capacity of sperm, which is consistent with data from InanÇ *et al.* (2018).

CONCLUSIONS

The results of the evaluation of Holstein bulls of the "Ukrainian genetic company" LLC according to the kinetic parameters of native sperm indicate their difference in the quality of ejaculates. Variation limits of the percentage of motile sperm 78.9-89.8%, progressive – 50.0-74.5%, VAP – 132.6-163.7 μm/s, VSL – 99.2-138.2 μm/s, VCL – 223.7-272.3 μm/s, degree STR – 73.9-85.0%, LIN – 45.1-56.1%, WOB – 57.2-63.8%. In all cases without exception, the difference between the extreme values is highly probable (P<0.001).

Sperm motility parameters and their relative indicators depend to a greater extent on the percentage of progressive sperm in the ejaculate (r=+0.231-0.761) than motile ones (r=+0.020-0.275). VAP, VLS, and VCL indicators are strongly correlated with each other (r= +0.550-0.887).

According to the results of insemination of brood stock in farms of the Zhytomyr and Kyiv oblasts, the average fertilising capacity of the sperm of experimental servicing bulls ranges from 40.7% to 61.4%. The fertilising capacity of frozen-thawed sperm largely depends on the kinetic parameters of native sperm – a probable correlation is observed with the percentage of progressive sperm in the ejaculate (r=+0.550) and the velocities of its movement (r=+0.538-0.675).

The results of this study prove the possibility and feasibility of a comprehensive assessment of ejaculates obtained from bulls by motility, including kinetic parameters. Indicators such as the percentage of progressive sperm can be used to predict the fertilising capacity of sperm, the velocity average path (VAP), straight-line velocity (VSL) and curvilinear velocity (VCL).

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Взаємозв'язок кінетичних параметрів сперми бугаїв-плідників голштинської породи з її запліднювальною здатністю

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Анотація. Рухливість сперми є важливим показником, який характеризує життєздатність та структурну цілісність сперміїв. Цей параметр тісно пов'язаний із запліднювальною здатністю чоловічих статевих клітин, тому його оцінка є невід'ємною частиною аналізу сперми. Метою досліджень є вивчення можливості прогнозування запліднювальної здатності сперми бугаїв-плідників за кінетичними показниками. В ході досліджень використано лабораторні, зоотехнічні та статистичні методи. Виявлено значну мінливість кінетичних параметрів сперми бугаїв-плідників – від 6,2 до 16,1%. Варіація відсотка рухливих сперміїв у еякуляті склала 78,9–89,8; відсотка прогресивних сперміїв – 50,0–74,5; середньої швидкості руху сперміїв (VAP) – 132,6–163,7 мкм/с, прогресивної (VSL) – 99,2–138,2 мкм/с, трекової (VCL) – 223,7–272,3 мкм/с; ступеня прямолінійності руху сперміїв (STR) – 73,9–85,0%, ступеня лінійності (LIN) – 45,1–56,1%, ступеня відхилення (WOB) – 57,2–63,8%. Різниця між мінімальними і максимальними значеннями за усіма дослідженими параметрами є високовірогідною ($P<0,001$). Встановлено кореляційний взаємозв'язок між різними кінетичними параметрами сперміїв. Швидкості руху сперміїв та їх відносні показники значною мірою обумовлені відсотком прогресивних сперміїв у еякуляті ($r=+0,231$-$0,761$). Середня, прогресивна та трекова швидкості взаємопов'язані ($r=+0,550$-$0,887$). Досліджено середню запліднювальну здатність сперми бугаїв-плідників за результатами осіменіння 8594 корів та 992 телиць у чотирьох господарствах Житомирської та Київської областей, варіація склала від 40,7 до 61,4 %. Доведено, що бугаї із вищою та середньою запліднювальною здатністю характеризуються вищим відсотком прогресивних сперміїв у еякулятах, середньою, прогресивною та трековою швидкостями їх руху порівняно з бугаями із низькою запліднювальною здатністю. Цю закономірність підтверджено кореляційним аналізом ($r=+0,538–0,675$). Кінетичні параметри, визначені за допомогою системи CASA, дають можливість прогнозувати запліднювальну здатність сперми та виявляти бугаїв-плідників зі зниженою репродуктивною функцією

Ключові слова: бугай, система CASA, рухливість сперміїв, VAP, VSL, VCL, запліднювальна здатність сперми

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The Study of the Effectiveness of the Use of Ash and Slag in the Construction of Road Pavement During Maintenance

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Abstract. There is a global problem of effective use of ash and slag waste for practical purposes. The relevance of the subject under study is conditioned by the prospects for the use of ash and slag in the design and planning of pavement structures during the road maintenance and, consequently, the need for the effectiveness of the practical use of such technologies in road construction and repair. The purpose of the presented article is to study the effectiveness of the use of ash and slag in the practical field in creating high-quality road pavement during roadway repair works. The leading method in this study is a systematic analysis, with the help of which a comprehensive assessment of the prospects of using ash and slag waste in the construction of road surfaces was carried out. In addition, the methods of generating statistical data and graphical modeling of the obtained results were applied. It was established that the road surface made with the use of ash slag had higher strength indicators compared to the surface made by traditional technologies. It was determined that an important factor in the use of ash and slag as composite additives was a significant reduction in the cost of the road surface repair process. In addition, it was determined that ash and slag mixtures could be successfully used as effective additives in the creation of new building materials. The effectiveness of the use of ash and slag waste in the construction of the road surface during repair work has been fully proven. The findings of this study are of considerable practical value for employees of road services, whose duties include solving issues of road surface repair, and for researchers involved in the practical development of alternative methods for improving the strength and quality of road pavement

Keywords: road surface, waste from thermal power plants, road repair, road construction, waste use

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INTRODUCTION

Road transport holds a leading place in the transport system of any state, providing the social and economic needs of society in the transportation of goods and passengers. The increase in traffic volumes, including international ones, requires the availability of roads with transport and operational characteristics that meet the traffic requirements. The current condition of roads in Ukraine, especially local ones (IV-V technical categories) does not always meet the current regulatory requirements. Therefore, it is urgent to carry out repair works aimed at improving the condition of roads to ensure optimal traffic conditions using modern materials and technologies (Indukuri *et al.*, 2020).

According to M. Salimi & A. Ghorbani (2020), in conditions of limited financing of the road industry, preference is given to economic technologies with maximum use of cheap local materials and industrial waste. The problem of using multi-tonnage industrial waste from various industries is of great environmental and economic importance for all developed countries of the world. T.M. Pavlenko (2017) admitted that accumulating in large quantities, waste occupies significant land areas that cannot be used for agricultural needs. In the road industry, waste from mine production is widely used – burnt rocks, limestone dust that remains after crushing limestone, cement dust – the residue of cement production, oil tar and others.

T. Poltue *et al.* (2020) estblished that due to the increase in construction and repair work on roads, the need for the use of secondary resources was constantly growing. One of such resources, which can be recommended for use in a mixture with traditional road-building materials for the repair and construction of roads, is the waste of energy enterprises: ash and slag mixtures. According to C. Sénquiz-Díaz (2021), ash and slag mixtures are formed in thermal power plants during the joint hydraulic removal of ash and slag during the combustion of pulverised coal. They are used as a component for the manufacture of building mortars, heavy, light and porous concretes for precast and monolithic concrete and reinforced concrete structures and products. H.A. Shahane & S. Patel (2021) established that fuel slags and pulverised fly ash of various thermal power plants could be used as an additive to strengthen uncemented clastic and sandy loam soils, for the construction of the foundation of road surfaces in a mixture with crushed stone materials, as a mineral powder in the preparation of asphalt concrete mixtures, etc. But all these works were not widely distributed. Currently, with a significant increase in the volume of repair and construction work on roads, much attention is being paid to the use of energy waste from thermal power plants (TPP) in various layers of road structures (Chomicz-Kowalska & Maciejewski, 2020). According to S.-L. Lin *et al.* (2021), the technical feasibility and economic efficiency of using ash and slag waste in the layers of road structures should be established based on laboratory studies, taking into account the peculiarities of the location of the object.

The scope of application of fly ash in construction is determined by DSTU V.2.7-205:2009. "Construction Materials. Fly ash from thermal power plants for concrete. Specifications" (2009). SOU 42.1-37641918-104: 2013 "Fly Ash and Ash Mixtures of Thermal Power Plants for Road Works. Specifications" (2013) establish technical requirements for fly ash and ash-slag mixtures that are used for construction, maintenance, capital and current repairs of public roads in all road-climatic zones of Ukraine according to DBN V.2.3-4 (2015) and are divided by physical and technical indicators into two types that can be used for cement-concrete mixtures in the construction of the base of road pavement; for gravel-sand mixtures reinforced with cement. According to DSTU B V.2.7-211 (2009), the main parameters and types of ash and slag mixtures are determined. Ash and slag mixtures with selection by hydraulic removal consist of an ash component (particles less than 0.315 mm) and a slag component (slag). The slag may include slag sand-grain size from 0.315 mm to 5 (3) mm and slag crushed stone – grain size of more than 5 (3) mm. According to SOU 42.1-37641918-104 (2013) by the type of slag component – ash-slag mixtures are divided into mixtures with dense slags (Sh), with an average grain density of more than 2.0 g/cm^3, and ash-slag mixtures with porous slags (Po), with an average grain density of less than 2.0 g/cm^3.

It can be seen that for the use of large-tonnage ash and slag waste, a sufficient number of regulatory documents have been developed regarding their use in the construction and road industries. But the question of the practical implementation of ash and slag mixtures has not yet been solved at a sufficient level. Thus, the aim of this article is to study the effectiveness of the use of ash and slag in the construction of road pavement during repair works remain relevant in the context of finding effective ways to create high-quality road pavement.

MATERIALS AND METHODS

In the course of the study, the system analysis was used, which allows performing a qualitative and comprehensive assessment of the prospects for the use of ash and slag in the construction of road pavements. This method involves conducting a study in the theoretical sphere, with the definition of the most important theoretical prerequisites and prospects for the practical use of industrial waste in repair works when creating a high-quality roadway, empirical studies involving the study of practical experience of specific repair operations, existing regulatory documentation and features of ensuring the proper level of quality of the road surface created with the introduction of industrial waste

into its design. Furthermore, the methodology of this study includes methods for generating statistical data and graphical modelling of the results obtained.

This study is based on numerous papers dedicated to the practical use of ash and slag in the construction of road pavement and the creation of a high-quality road surface in general. For the sake of creating an objective picture of this study and to facilitate the perception of information, all the developments of researchers submitted for consideration of the issues cited in this study were translated into English.

The study was performed in three stages:

1. A theoretical study of research papers available within the framework of the subject matter was performed to identify the current opinions of researchers on the subject and the available practical methods for resolving the application issues of ash and slag in the construction of road pavement.

2. The effectiveness of ash and slag in the construction of road pavement during road maintenance and the prospects for expanding the range of applications of such technology were assessed from a practical standpoint. In addition, comparative studies were conducted to refine the results obtained and compare them with the results and conclusions of other researchers who were engaged in the study of issues included in the subject of the study, to form final conclusions based on them.

3. The final conclusions were formed based on the study results.

RESULTS AND DISCUSSION

According to the provisions of DSTU B V.2.7-211 (2009), ash and slag mixtures, depending on the grain composition, are divided into three types: coarse-grained, medium-grained, and fine-grained. The requirements for such mixtures are presented below (Table 1).

***Table 1**. Requirements for coarse-grained, medium-grained, and fine-grained ash and slag mixtures*

Indicator name	Indicator value for various types of ash and lag mixtures		
	Coarse-grained (C)	Medium-grained (M)	Fine-grained (F)
The maximum size of the slag grains of the slag component, mm, not above	40	20	5(3)
Content of the slag component, % by weight	From 50 to 90	From 10 to 50	From 0 to 10
The content of slag crushed stone in the slag component, % by weight	Over 20	Up to 20	–

***Note:** in ash and slag mixtures of various types, the content of slag grains exceeding the maximum grain size should be no more than 10% by weight*

According to SOU 42.1-37641918-104 (2013), ash and slag mixtures, depending on the amount of mass loss during calcination, are divided into three types: ash, slag with porous slag, slag with dense slag. The requirements for each type are listed below (Table 2).

***Table 2**. Requirements for ash, slag with porous slag, slag with dense slag mixtures*

Ash and slag mixture type	The component of the ash and slag mixture	Mass loss of the ash-slag mixture during calcination, % by weight, not above		
		Anthracitic	Carbonous	Lignitic
I	Ash	20	10	3
	Slag with porous slag	–	5	3
	Slag with dense slag	Not standardised		
II	Ash	25	15	5
	Slag with porous slag	–	7	3
	Slag with dense slag	Not standardised		
III	Ash	10	7	5

According to SOU 42.1-37641918-104 (2013), ash and slag mixtures, depending on the amount of ash in the mixture, are divided into three groups, the properties of which are presented below (Table 3).

***Table 3**. Properties of groups of ash and slag mixtures*

Indicator name	Ash and slag mixture group		
	I	II	III
Fly ash content, % by weight	Less than 25	From 25 to 50	Over 50
Humidity, % by weight, not above	7	10	15
Brand of the ash and slag component by strength	300	200	Not standardised
Brand of the ash and slag component by frost resistance	F50	F25	Not standardised

According to SOU 42.1-37641918-104 (2013), fly ash as an integral component, depending on the type (I, II), can be used in the preparation of a mixture of cement and concrete for the construction of the foundation of road pavement structures of rigid and non-rigid types and for gravel-sand mixtures reinforced with cement. Ash and slag mixtures of group I are intended for the construction of additional layers of the base of road coverings (drainage and frost-proof layers), and as an integral component of a mixture of crushed stone-sand or a mixture of soil. Ash and slag mixtures of this group, reinforced with inorganic binders, are suitable for the construction of the upper and lower layer of the base of road pavements. Ash and slag mixtures of group II can be used for the construction of a base only together with the addition of at least 50% of crushed stone or after their strengthening with inorganic binders. Ash and slag mixtures of group III can be used for the construction of embankments of the roadbed according to DBN V.2.3-4 (2015), VBN 2.3-218-171 (2002).

The road surfaces of public roads made of stone materials, industrial waste and their mixtures and soils reinforced with cement in all road-climatic zones of Ukraine should be designed, constructed, and repaired in accordance with DBN V.2.3-4 "Transport Structures. Motor Roads. Part I. Designing. PART II. Construction" (2015) and DSTU-N B V.2.3-39:2016. "Guidelines for the Installation of Layers of Pavement Made of Stone Materials" (2016).

The use of ash and slag mixture or slag mixed with stone materials, crushed stone or gravel, reinforced with a mineral binder is possible when selecting the grain composition meets the requirements of DSTU-N B V.2.3-39: 2016 (2016) (Table 3). The brand of the reinforced mixture used for the base layers should be assigned depending on the type of road surface, the intensity of automobile traffic and climatic conditions in accordance with the requirements of DSTU-N B V.2.3-39:2016 (2016).

Ash and slag materials of thermal power plants can be used in the preparation of asphalt concrete mixtures as an additive to mineral powder or as a substitute for small fractions of granite bran. Asphalt concrete mixes with ash and slag materials are used for the construction of the upper layer of the road surface of the lower technical categories, that is, IV-V or the lower layer of two-layer road coverings of the III-IV technical category. Studies to determine the properties of asphalt concrete mixtures using ash and slag materials of thermal power plants were carried out according to standard methods per the requirements of DSTU B V.2.7-119:2011 "Asphalt concrete mixes and asphalt concrete for roads and airfields" (2011).

The study was carried out with the following materials:

– asphalt concrete hot dense fine-grained type "B";
– crushed stone;
– stone screening dust according to DSTU B V.2.7-210 (2010);
– limestone mineral powder;
– petroleum bitumen of the BND 90/130 brand produced by CJSC Linik;
– polymer additives in bitumen: Butonal NS198;
– fly ash;
– ash and slag mixture;
– slag.

Determination of the composition of soil mixtures with the addition of fly ash is reduced to the choice of such a ratio between the constituent components, which most reliably and economically provides the mixtures with a given strength and frost resistance. (Bellum *et al.*, 2020). Soil mixtures with ash and slag materials reinforced with Portland cement or lime should have an optimal moisture content of no more than 0.75 WT (yield strength) for clay soils (clays and loams) (Fedje & Andersson, 2020). To determine the optimal amount of fly ash to be added to the soil, from the standpoint of studying the effectiveness of the practical use of ash and slag waste in the construction of road pavement, a study of the physical and mechanical properties of such mixtures was conducted. The results of the conducted studies are presented below (Table 4).

***Table 4**. Investigation of soil properties with the addition of fly ash and ash-slag mixture*

Name of the soil, sample No.	Quantity of introduced ash and slag materials	Indicator names					
		Particle density, g/cm^3	Density of the dry unit of mixture, g/cm^3	Optimal soil moisture with standard compaction, %	Point of yielding W_L (PL), %	Swinging limit (plasticity) Wp (Pp), %	Plasticity number, Ip (PL)
Fly ash (example No. 1)							
Sample No. 1	15	2.24	1.84	12.05	26.10	20.03	6.07
	20	2.29	1.86	11.94	25.82	20.01	5.81
	25	2.33	1.95	11.12	25.61	19.94	5.67
	30	2.45	2.04	11.03	25.54	19.90	5.64
Sample No. 2	15	2.26	2.06	12.51	26.93	20.12	6.75
	20	2.25	2.10	12.02	26.14	19.60	6.54
	25	2.38	2.14	11.84	25.92	19.43	6.49
	30	2.51	2.26	11.78	26.13	19.40	6.70
Fly ash (example No. 2)							
Sample No. 1	15	2.25	1.85	11.04	26.20	20.18	6.02
	20	2.27	1.88	11.16	25.74	19.80	5.94
	25	2.36	1.92	10.91	25.68	20.15	5.53
	30	2.48	1.96	10.56	25.36	20.08	5.28
Sample No. 2	15	2.22	1.81	11.76	25.89	19.68	6.21
	20	2.24	1.83	11.21	25.54	19.54	6.00
	25	2.39	1.92	10.75	29.12	20.38	5.74
	30	2.45	1.99	10.68	25.32	19.69	5.63
Ash and slag mixture							
Sample No. 1	10	2.22	1.84	12.90	26.44	19.54	6.9
	15	2.19	1.82	13.05	27.56	20.36	7.2
	20	2.09	1.81	13.15	28.02	20.62	7.4
Sample No. 2	10	2.26	1.74	12.96	27.19	19.99	7.2
	15	2.17	1.75	13.20	27.32	19.82	7.5
	20	2.16	1.74	-	28.01	20.41	7.6
Fly ash (example No. 3)							
Sample No. 1	15	2.22	1.79	9.3	18.3	13.1	5.2
	20	2.26	1.81	8.9	17.5	12.3	5.2
	25	2.35	1.86	8.8	17.3	12.2	5.1
	30	2.51	1.95	8.3	16.8	11.8	5.0
Sample No. 2	15	2.21	1.88	10.4	19.4	12.4	7.0
	20	2.27	1.93	9.2	18.8	11.9	6.9
	25	2.34	1.99	8.6	17.9	11.3	6.6
	30	2.48	2.06	8.1	17.2	11.7	6.5

The ash-slag mixture is not quite suitable for adding to the soil due to the fact that the grain composition does not have a sufficient number of small fractions. That is, a dense mixture is not created. In this regard, the soil density decreases and the optimal humidity increases, that is, the ash-slag mixture can be used in soils only together with Portland cement in an amount of up to 10-15% of the soil mass. Given that the traffic intensity of cars is constantly increasing, with the introduction of fly ash into the soil, it is also better to use cement, which will increase the strength and frost resistance of the mixture. The introduction of fly ash has a positive effect on the properties of the soil (samples 1 and 2), a greater reduction in the plasticity of the soil, that is, ensuring density and strength.

Ash and slag materials of thermal power plants (TPP) can be used in the preparation of asphalt concrete mixtures as an additive to mineral powder or as a substitute for small fractions of granite bran. Asphalt concrete mixtures with ash and slag materials are used for the construction of the upper layer of the road surface of the lower technical categories, that is, IV-V or the lower layer of two-layer road coverings of the III-IV technical category. When using fly ash (sample 2), fly ash can be fed into the mixer simultaneously with mineral materials. Mixing takes place after the bitumen is supplied. But the fly ash is better to be supplied by closed transport-like mineral powder, to prevent pollination.

Ash and slag concretes have higher strength properties compared to road surface materials, for the manufacture of which traditional methods were used. One of the effective methods of obtaining a high-quality coating should be considered the improvement of the technology of road construction with the use of industrial waste and cement concrete. The use of mixtures of special rigidity is more appropriate compared to conventional mixtures due to the lower cement consumption. The rolled concrete meets these requirements to the greatest extent. The use of this concrete requires low energy consumption, while providing less shrinkage, increasing the distance between the expansion joints, and most importantly, shortening the duration of construction work. The practical use of this kind of road surface in the construction of road pavement directly solves the actual problems of rational use of industrial waste. Thus, by combining two urgent problems – road paving and the practical use of industrial waste, it is possible to achieve a significant increase in road construction efficiency through the integrated use of waste from TPPs (fly ash), secondary raw materials (asphalt concrete granulate) and modern rolling technologies.

M. Miljković *et al*. (2019) expressed a reasonable thought, as according to researchers, the use of ash and slag waste from TPP activities for practical purposes contributes to the qualitative solution of numerous problems: environmental protection is ensured, the rational use of raw materials is ensured, the total energy intensity is significantly reduced, consequently, the prime cost of construction materials is reduced. This is despite the fact that the shortage of natural raw materials for the construction sector is increasing every year, while the practical use of ash and slag waste should be considered a good alternative to the use of expensive natural aggregates in road construction. F. Russo *et al*. (2021) convinced that the use of conventional stone structural materials in road construction works is often not widespread due to the high cost of materials of this kind and their relative scarcity. Therefore, recently, the practical application of multi-tonnage industrial waste in road construction has become an effective alternative solution to this problem.

In addition, G. Jing *et al*. (2020) think that such materials are often modified with various stabilising additives. The activities of modern industrial enterprises have gradually led to the accumulation of more than 1.5 billion tons of ash and slag waste in dumps, as well as about 120 million m^3 of crushing screenings, which in turn is the reason for the deterioration of the overall environmental situation in the region of industrial activity and significant soil grinding, and changes in the terrain (Murmu *et al.*, 2020). For this reason, the development of effective methods for creating effective composite materials in road construction based on the use of multi-tonnage industrial waste seems to be a particularly relevant and promising direction in the current economic situation (Chen *et al.*, 2020).

P. Shekhawat *et al*. (2020) consider that the most massive scale of the utilisation of such waste can be achieved with their practical application in road construction as aggregates for concrete. Nevertheless, it is necessary to take into account that ash and slag mixtures in TPP dumps do not have a constant grain composition, both in terms of the fine-grained fraction content and in terms of the slag contained in them. It is also essential that the optimal ratio between the fine-grained fraction and the slag in concrete with a change in the consumption of the binder element does not exist in practice, since these indicators are constantly changing (Dulaimi *et al.*, 2020). This should be considered the main reason for the excessive consumption of cement in the production of concrete of a given strength (class) on existing ash and slag mixtures in comparison with concretes of the optimal composition according to the parameter of the size of the filling elements. At the same time, TPP slags are already widely used in road construction today (Bakare *et al.*, 2019). The ash produced by TPPs is very well studied and is recommended to builders as an active mineral additive in the industrial manufacture of binders, and in the production of concrete and mortar, as a mineral powder in asphalt concrete. Ash is also actively used in the manufacture of silicate and ceramic products (Abdullah *et al.*, 2021).

The problem of effective use for practical purposes of industrial waste, which is formed when using

such technologies – ash-slag mixtures, has been observed all over the world. In this context, it is necessary to explain that during the period under review, the volume of practical use of ash and slag mixtures of thermal power plants in road construction and repair, and in the industrial sector engaged in the creation of building materials, began to increase very rapidly (Mavi *et al.*, 2021). According to R.R. Pai *et al.* (2021), this is partly conditioned by mass engagement of numerous organisations in road repair and construction works who have become aware of the high efficiency of the practical use of waste from TPPs in creating a high-quality road surface, which causes the widespread use, in particular, of ash-slag mixtures in the creation of road coverings that have a longer period of practical operation compared to those that were created by more traditional methods.

Such statements are also reasonable, as long as ash-slag mixtures, ash and slag of thermal power stations may be of particular interest to the construction industry as an effective binder component of concrete. The reserves of this raw material, which are constantly increasing in the course of augmenting of the volume of industrial production, can significantly reduce the existing shortage of aggregates for high-quality concrete. According to B. Adhikari *et al.* (2021), it is necessary to take into account the variability of the grain composition of ash and slag mixtures in various places of the dump, which significantly complicates their practical application as effective aggregates. The multiplicity of components of such mixtures and the variability of their properties significantly complicate the choice of the optimal composition of the concrete mixture for road repair and construction works (Han *et al.*, 2020). Cement consumption during the use of ash and slag raw materials was often higher than in the manufacture of concretes of the same characteristics on familiar aggregates, and, as is known, this parameter is one of the determining criteria by which conclusions are made regarding the effectiveness of developments, including those aimed at using industrial waste in road construction and repair (Hoy *et al.*, 2018).

Today, fly ash is the most well-known of all industrial production wastes (Rezaei Lori *et al.*, 2021). Every year, millions of tons of coal and coal dust are burned at fuel and energy enterprises of any state, which leads to the accumulation of millions of tons of ash and slag waste in dumps (Sharma & Kumar, 2021; Edwin *et al.*, 2019). The detailed state of affairs allows formulating a conclusion that fly ash is, in fact, an inexhaustible source of raw materials that can only be obtained from industrial waste. This determines the prospects for the large-scale use of this raw material as a secondary component for creating effective road pavements, as well as during repair and construction work in the transport industry, and a number of other areas of the national economy of any state (Softić *et al.*, 2020).

Fly ash is an industrial waste remaining after the combustion of solid fuel (Susanto *et al.*, 2020). T. Wattez *et al.* (2021) found that most of fly ash of TPPs and boiler houses were characterised by a certain activity, which significantly affected the strength properties of the resulting concrete. The instability of the composition of fly ash removed from the TPP is a limiting factor for practical application and effective use in road construction and repair. In the industrialised countries of North America and in a number of EU countries, fly ash is the same commodity, and it is scarce, like heat and electric energy (Saha *et al.*, 2021). High-quality fly ash that meets all accepted standards and is suitable for use expands the possibility of effective construction of road surfaces from rigid concrete mixtures that are compacted by a roller. According to D. Foti *et al.* (2019), in developing and industrially developed countries, to improve this situation, options to improve the quality and strength characteristics of the road surface are being actively sought, and the latest modern technological solutions are neing developed and implemented. They can accelerate the repair of coatings of modern highways or perform the construction of layers of pavement with significantly increased strength characteristics that could ensure greater durability of the road surface and increase the efficiency of its operation.

Thus, the experience of many foreign countries in the practical application of composite materials (fly ash) in rolled concrete and the achieved result of the positive interaction of two components (fly ash and asphalt granulate) in the concrete mixture make it possible to preserve all the properties of concrete per the requirements of DSTU and effectively use this mixture in the construction of bases and road surfaces. The use of fly ash and asphalt-concrete granulate in rolled concrete reduces the cost by 2-2. 5 times due to energy consumption savings, which allows, with equal economic indicators, significantly increasing the length of roads and their operational characteristics. It should be considered that the high practical efficiency of use of ash and slag in road construction during repair work, since it has been experimentally proven to obtain higher, compared with conventional methods of preparing the construction of road pavement, indicators of the strength of the roadway, its frost resistance, and a longer period of practical operation. In general, the practical benefit and ultimate effectiveness of using ash-slag mixtures in the construction of road surfaces during repair and construction works can be considered fully proven, which makes it necessary to continue using these mixtures.

CONCLUSIONS

The use of ash and slag in the construction of road pavement during the repair should be considered effective from the standpoint of multi-aspect consideration of this issue. First of all, this is an effective method of practical use of multi-tonnage industrial waste, which

contributes to the successful practical solution of a whole range of issues related to improving the overall environmental situation, due to the release of areas allocated for the storage of ash and slag waste of industry. The problems of preventing soil erosion in places of forced storage of such waste and changes in the terrain associated with this factor are being successfully solved. Furthermore, ash and slag mixtures can be successfully used as effective additives in the creation of new construction materials that qualitatively solve the problems of constructing a new roadbed to replace damaged road sections.

The high efficiency of the practical use of ash and slag as a component of the road surface design can be significantly higher by achieving a high-quality solution to the issues of storage of ash and slag and their timely transportation to the place of use in construction and repair works. This will significantly reduce the time of road works, which in general would contribute to improving their efficiency. In general, the effectiveness of the practical use of ash and slag should be considered fully proven, which determines the need for further study in this line, in order to find and implement effective methods for the practical use of ash and slag mixtures in road works.

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Дослідження ефективності використання золошлаків при будівництві дорожнього покриття під час ремонту

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Анотація. У всьому світі існує проблема ефективного використання золошлакових відходів для практичних цілей. Актуальність досліджуваної тематики обумовлена перспективами використання золошлаків при проектуванні та плануванні конструкцій дорожнього одягу під час утримання автомобільних доріг і, як наслідок, необхідністю ефективності практичного застосування таких технологій при будівництві та ремонті автомобільних доріг. Метою представленої статті є дослідження ефективності використання золошлаків у практичній сфері при створенні якісного дорожнього одягу при виконанні робіт з ремонту проїзної частини автомобільних доріг. Провідним методом в даному дослідженні є системний аналіз, за допомогою якого проведено комплексну оцінку перспектив використання золошлакових відходів при будівництві дорожніх покриттів. Крім того, застосовано методи формування статистичних даних та графічного моделювання отриманих результатів. Встановлено, що дорожнє покриття, виготовлене з використанням золошлаків, має більш високі показники міцності в порівнянні з покриттям, виготовленим за традиційними технологіями. Визначено, що важливим фактором використання золошлаків в якості композиційних добавок є значне здешевлення процесу ремонту дорожнього покриття. Крім того, визначено, що золошлакові суміші можуть бути успішно використані в якості ефективних добавок при створенні нових будівельних матеріалів. Повністю доведено ефективність використання золошлакових відходів у будівництві дорожнього покриття при проведенні ремонтних робіт. Результати даного дослідження мають значну практичну цінність для працівників дорожніх служб, в обов'язки яких входить вирішення питань ремонту дорожнього покриття, а також для науковців, які займаються практичною розробкою альтернативних методів підвищення міцності та якості дорожніх покриттів

Ключові слова: дорожнє покриття, відходи теплових електростанцій, ремонт доріг, будівництво доріг, використання відходів

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Diagnostics of Transparency of Ukrainian Banking Institutions Using Multivariate Analysis Methods

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Abstract. Due to the imperfect state of transformations in the financial system of Ukraine and the banking sector, there is a steady tendency to increase the number of financially insolvent enterprises in various industries. This is especially true for the banking market, where considerable qualitative and quantitative changes have occurred recently. The purpose of this study is to investigate the problem of managing the of banking institutions by diagnosing the transparency level of their activities. The research methodology lies in forming a system of indicators to estimate the transparency level of business entities' activities, assessing the level of direct impact on the level of transparency, and classifying business entities according to a two-level system of factors influencing transparency. The final stage of the methodology is the positioning of banks according to transparency level to formulate vectors for improving transparency management policies. The combination of multidimensional analysis methods, namely applied econometric methods, cluster and variance analysis, allows classifying business entities according to the transparency level, considering differentiation. The result of the differentiation is a matrix of positioning the transparency level of banking institutions according to a two-level system of factors. The proposed scientific and methodological approach to calculating the transparency level of a business entity, namely banking institutions, which, apart from the financial block, includes other criteria, enables a much broader study of the state of activity of the business entity. The use of this scientific and methodological approach helps reduce the level of information asymmetry, increase the flexibility of the business entity's response to external shocks, which increases confidence in business entities, improves their business reputation and is certainly reflected in financial indicators. Positive improvements in the financial performance of individual business entities, increasing the flexibility and trust in them, will help increase the transparency of financial flows that move in the country

Keywords: asymmetry, bank, transparency, business entity, financial flowst

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INTRODUCTION

One of the features of the transformational processes in the country's financial system, and therefore their consequences, is the asymmetry of information and insufficient transparency of the functioning of business entities. In the context of rapid institutional changes, it is important to increase the transparency of the activities of business entities, as well as to fully cover the essential information about their activities, financial condition, and development prospects.

Non-disclosure or improper disclosure of essential information leads to an increase in information asymmetry and can adversely affect not only the financial security of individual business entities, but also the financial system of the entire country. The lack of an effective information disclosure system, which is one of the main elements of building trust in an enterprise, also affects its investment attractiveness and financial stability.

The problem of information asymmetry is one of the most universal in the economy. Information asymmetry hinders the adoption of optimal business decisions, increases transaction costs for producers, and reduces the level of trust in enterprises for customers, partners, counterparties, and investors. The problem of information asymmetry is particularly important in developing countries, as they do not have an effective institutional environment, which leads to the shadowing of business activities (Shkodina & Onishchenko, 2018; Lin, 2016; Zaburanna, 2020).

Analysis of current research and publications (Busko, 2016; Kovalenko, 2019; Nekhili, 2020) has shown that the problem of information asymmetry in Ukraine is becoming critical as the importance of information increases. The economic development of Ukraine demonstrates the formation of a special sector based on the production, distribution, exchange, and use of an important resource – information. However, the dynamism of Ukraine's information economy is considerably limited by the underdevelopment of democratic institutions, the absence of legislation, the imperfect sectoral structure of Ukraine's economic complex, the degradation of the education and science system in Ukraine, the presence of administrative barriers, and the low financial situation of the vast majority of the population (Azarenkova *et al.*, 2018; Makarenko *et al.*, 2018; Bukhtiarova *et al.*, 2019; Barna & Ruschyshyn, 2020).

Despite the existing problems, the development of the information economy in Ukraine is still taking place. This is facilitated by the influence of globalization, open information spheres, the use of practices of other countries, and the integration of the state into the world information space. Thus, with the development of the information economy, the level of information asymmetry increases (Shkodina & Onishchenko, 2016; Levchenko & Ostapenko, 2016).

According to the authors, the core motives of this situation include the insufficient transparency level that has developed in the Ukrainian banking sector. This negatively impacts the economic development of the state. Firstly, this reduces the investment attractiveness of enterprises, branches of the national economy, and their competitiveness. This prevents investors from feeling confident in the stability of the "rules of the game", reduces their inflation expectations and suspends economic growth. Thus, effective management of banking transparency becomes a prerequisite for all actors operating in the banking market to be able to make effective financial decisions. It also provides opportunities for analysing, planning and predicting the sustainable socio-economic recovery of the state (Makarenko *et al.*, 2020; Bukhtiarova *et al.*, 2020; Shkolnyk *et al.*, 2019). Therefore, optimal transparency management in the banking sector is an important issue today. This allows developing the banking system at the appropriate, stable level and make effective management decisions by all subjects of the Ukrainian economy. An integral part of reducing the asymmetry of information about the activities of banking institutions in the country is an objective and correct assessment of the transparency of their activities (Onishchenko, 2020).

The purpose of this study is the implementation of diagnostics of the transparency level in the activities of banking institutions of Ukraine based on multidimensional modelling and applied econometric methods, to increase the efficiency of management decision-making. The study of the problem of transparency of banking institutions allows identifying the following tasks:

– analysis and synthesis of indicators reflecting the transparency level of activities;

– assessment of factors of influence and identification of banks according to the level of influence of factors on transparency;

– formation of homogeneous classes of banking institutions in terms of transparency;

– assessment of differences between classes, considering the separate influence of different groups of factors;

– positioning according to a two-level system of factors;

– implementation of research results for the development of appropriate management decisions (Ponomarenko *et al.*, 2013; Kuznetsova, 2014; Sergienko *et al.*, 2018).

MATERIALS AND METHODS

To fulfil the purpose and complete the tasks of this study, the latter was based on data on leading banking institutions in Ukraine, which are presented in Tables 1-2. Table 1 shows the results of assessing the transparency level of leading banking institutions in Ukraine based on an analysis of their official websites on the Internet (Onishchenko, 2020). Table 2 contains the transparency level of the activities of each of the banking institutions in Ukraine under study and their key performance indicators (deposits, equity, assets, net profit).

***Table 1**. Results of the study of transparency of banking institutions of Ukraine based on the scientific and methodological approach to calculating the level of transparency of a business entity's activities using a system of criteria*

No.	Bank	**X1** General information about the business entity ***Max value =12%***	**X2** Legal documents regulating the business entity's activities ***Max value =13.5%***	**X3** Investment activity of the business entity ***Max value =7%***	**X4** Marketing policy of the business entity ***Max value =18.5%***	**X5** General information about the personnel support of a business entity ***Max value =6.5%***	**X6** Information on maintaining environmental friendliness and safety of the business entity's activities ***Max value =2%***	**X7** Cooperation with other business entities ***Max value =5%***	**X8** Financial statements of the business entity ***Max value =22%***	**X9** Results of business entity inspections ***Max value =4%***	**X10** Risk management of the business entity ***Max value =1.5%***	**X11** Rating of the business entity ***Max value =2%***	**X12** Overall performance of the business entity ***Max value =3%***	**X13** Cooperation of the business entity with the media***Max value =2%***	**X14** Tax documents of the business entity ***Max value =1%***	**Y TRANSPARENCY OF THE BUSINESS ENTITY (sum of x1–x14) *Max value =100%***
1	Raiffeisen Bank Aval JSC	6.50%	12.50%	0%	15.50%	2%	0%	5.00%	22.00%	4.00%	1.50%	2.00%	3.00%	2.00%	0%	75.50%
2	Ukrsibbank JSC	9.50%	12.50%	0%	15.50%	2%	0%	0.00%	22.00%	0.00%	0.00%	2.00%	3.00%	2.00%		68.00%
3	Citibank JSC	9.00%	7.50%	2%	18.50%	2%	0%	0.00%	22.00%	0.00%	0.00%	2.00%	3.00%	2.00%		67.50%
4	ING Bank Ukraine JSC	9.00%	12.50%	0%	15.50%	0%	0%	0.00%	22.00%	0.00%	0.00%	0.00%	0.00%	2.00%		61.00%
5	Crédit Agricole Bank JSC	9.50%	12.50%	0%	11.50%	3%	0%	5.00%	22.00%	0.00%	0.00%	2.00%	3.00%	2.00%		70.50 %
6	OTP Bank JSC	6.50%	11.00%	0%	11.50%	2%	0%	5.00%	22.00%	4.00%	1.50%	0.00%	3.00%	2.00%		68.00%
7	Commercial Bank "PrivatBank" JSC	9.50%	12.50%	0%	11.50%	2%	0%	5.00%	22.00%	4.00%	1.50%	2.00%	3.00%	2.00%		74.50%
8	Ukreximbank JSC	6.50%	6.00%	0%	11.50%	2%	0%	5.00%	22.00%	0.00%	0.00%	2.00%	0.00%	2.00%		56.50 %
9	Oschadbank JSC	9.00%	11.00%	0%	11.50%	2%	0%	5.00%	22.00%	0.00%	0.00%	2.00%	0.00%	2.00%		64.00%
10	ProCredit Bank JSC	9.50%	11.00%	0%	11.50%	3%	1%	5.00%	22.00%	4.00%	1.50%	2.00%	3.00%	2.00%		75.50%
11	Pravex Bank JSC	9.00%	12.50%	0%	15.50%	2%	0%	0.00%	22.00%	4.00%	1.50%	2.00%	0.00%	2.00%		70.00%
12	Idea Bank JSC	9.50%	11.00%	0%	12.50%	2%	0%	5.00%	22.00%	0.00%	1.50%	2.00%	0.00%	2.00%		67.00%
13	Piraeus Bank JSC	6.50%	11.00%	0%	8.50%	3%	0%	5.00%	22.00%	4.00%	0.00%	0.00%	3.00%	2.00%		65.00%
14	Alfa-Bank JSC	9.50%	6.00%	0%	11.50%	2%	0%	0.00%	22.00%	0.00%	1.50%	0.00%	0.00%	2.00%		54.00%
15	FUIB (PUMB) JSC	11.50%	6.00%	0%	11.50%	2%	0%	2.50%	22.00%	4.00%	1.50%	2.00%	0.00%	2.00%		64.50%
16	JSB UKRGASBANK PJSC	9.50%	11.00%	0%	15.50%	4%	0%	5.00%	22.00%	4.00%	1.50%	2.00%	3.00%	2.00%		79.50%
17	SEB Corporate Bank JSC	9.50%	11.00%	0%	8.50%	2%	0%	0.00%	22.00%	0.00%	0.00%	0.00%	0.00%	2.00%		54.50%
18	Credit Europe Bank JSC	9.50%	5.00%	0%	8.50%	2%	0%	0.00%	22.00%	4.00%	0.00%	0.00%	0.00%	2.00%		52.50%
19	JSCB "Lviv" JSC	11.50%	0.00%	0%	12.50%	3%	0%	0.00%	22.00%	4.00%	1.50%	2.00%	0.00%	2.00%		58.50%
20	Kredobank JSC	6.50%	6.00%	0%	8.50%	2%	0%	0.00%	22.00%	4.00%	0.00%	0.00%	0.00%	2.00%		50.50%

***Source:** based on the authors' calculations*

***Table 2**. Key performance indicators of the banking institutions of Ukraine understudy, proposed as factors of direct influence on the transparency of their activities*

No.	Bank	Transparency, % (Y)	Deposits, billion UAH (F1)	Equity, billion UAH (F2)	Assets, billion UAH (F3)	Net profit, billion UAH (F4)
1	Raiffeisen Bank Aval JSC	75.50%	61	11.3	77.6	3.2
2	Ukrsibbank JSC	68.00%	41.1	6.2	51.5	2
3	Citibank JSC	67.50%	23.4	2.4	26.5	1.4
4	ING Bank Ukraine JSC	61.00%	6.7	4	10.9	0.5
5	Crédit Agricole Bank JSC	70.50 %	30.3	4.6	37.3	1.2
6	OTP Bank JSC	68.00%	30.5	7	39.3	1.7
7	Commercial Bank "PrivatBank" JSC	74.50%	219.1	45.5	288.9	25.8
8	Ukreximbank JSC	56.50 %	75	8.9	141.6	1.6
9	Oschadbank JSC	64.00%	167.6	18.7	218.1	0.2
10	ProCredit Bank JSC	75.50%	12.8	3.4	21.9	0.5
11	Pravex Bank JSC	70.00%	2.8	2	4.9	-0.04
12	Idea Bank JSC	67.00%	4	0.8	5.1	0.2
13	Piraeus Bank JSC	65.00%	1.8	0.6	2.8	0.03
14	Alfa-Bank JSC	54.00%	54.8	6.3	64.3	1.3
15	FUIB (PUMB) JSC	64.50%	41.2	8.2	52.2	1.8
16	JSB UKRGASBANK PJSC	79.50%	94	6.3	110.1	0.3
17	SEB Corporate Bank JSC	54.50%	1	0.6	1.8	0.05
18	Credit Europe Bank JSC	52.50%	0.4	0.4	1	0.05
19	JSCB "Lviv" JSC	58.50%	1.9	0.3	2.9	0.01
20	Kredobank JSC	50.50%	13	2.3	17.4	0.3

***Source:** compiled by the authors based on (Litvinchuk, 2019)*

The selection of the main groups of criteria was based on the significance of particular transparency-related information about an entity for its users. Each of the 14 categories of evaluated components of transparency in the activities of a business entity comprises separate groups of factors, the description and calculation method of which are presented in Table 3 (Shkodina & Onishchenko, 2018). Each criterion, according to the table above, is assigned a certain proportion, depending on its significance. The maximum values between the 14 components of transparency and their subcomponents in the table were distributed according to the significance of the factor groups of each of the 14 categories, according to the authors. The sum of all criteria is equal to 100%, i.e., to find the transparency level, it is necessary to figure out the percentage of the criteria factually presented on the official website of the business entity. If the official website of a business entity contains information defined by a certain criterion, this criterion is used to assign the corresponding weight percentage defined in Tables 3-4.

***Table 3**. Results of assessing the transparency level of the 1st experimental group of Ukrainian banks using a scientific and methodological approach (detailed assessment according to the selected criteria)*

No.	Criteria group	Composition of criteria	Criterion weight in %	Raiffeisen Bank Aval	Ukrsibbank	Citibank	ING Bank Ukraine	Crédit Agricole Bank	OTP Bank	PrivatBank	Ukreximbank	Oschadbank	ProCredit Bank
1	General information about BE	History of BE creation	0.50%	0.50%	0.50%	0%	0%	0.50%	0.50%	0.50%	0.50%	0%	0,50%
		Organizational structure and information about BE owners	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3,00%	3,00%
		BE goals and strategy	3.00%	0.00%	3.00%	3.00%	3.00%	3.00%	0%	3.00%	0%	3,00%	3,00%
		Reviews about the activities of BE	2.50%	0.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		BE contacts and address	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3,00%	3,00%
2	Legal documents regulating the activities of BE	BE charter	5.00%	5.00%	5.00%	0%	5.00%	5.00%	5.00%	5.00%	0%	5,00%	5,00%
		Licences and certificates for the implementation of BE's activities	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Collective agreement	1.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Laws, regulations, orders, and other regulatory acts based on which the BE carries out its activities	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	0%	1.50%	0%	0%	0%
3	Investment activity of the BE	General information about current BE investment projects	3.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Strategic vectors of the BE's investment policy	2.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Information on the results of BE's investment activities	2.00%	0%	0%	2.00%	0%	0%	0%	0%	0%	0%	0%
4	BE's marketing policy	Characteristics of BE's products, works, and services	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Quality guarantees of BE's products, works, and services (certificates, diplomas, patents, and licences)	4.00%	4.00%	4.00%	4.00%	4.00%	0%	0%	0%	0%	0%	0%
		BE's social policy	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3,00%	3,00%
		Characteristics of innovation of BE's products, works, and services	3.00%	0%	0%	3.00%	0%	0%	0%	0%	0%	0%	0%
		BE's pricing policy	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2,50%	2,50%
5	General information about the BE's personnel support	Quantitative composition	1.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Current vacancies	1.50%	1.50%	1.50%	1.50%	0%	1.50%	1.50%	1.50%	1.50%	1,50%	1,50%
		Conditions and principles of competitive selection to fill vacant positions in the BE	1.50%	0%	0%	0%	0%	1.50%	0%	0%	0%	0%	1,50%
		Staffing table	2.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Activities of the trade union organisation	0.50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6	Information on maintaining environmental friendliness and safety of BE's activities	Standards and regulations governing labour safety of BE's	1.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Documents confirming the environmental friendliness of the BE's activities	1.00%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1,00%
7	Cooperation with other BEs	Domestic partners of the BE and joint projects	2.50%	2.50%	0%	0%	0%	2.50%	2.50%	2.50%	2.50%	2,50%	2,50%
		BE's foreign partners and joint projects	2.50%	2.50%	0%	0%	0%	2.50%	2.50%	2.50%	2.50%	2,50%	2,50%
8	BE's financial statements	Balance	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Statement of financial results	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Statement of equity	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5,00%	5,00%
		Cash flow statement	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5,00%	5,00%
9	Results of BE inspections	Reports on the results of external inspections (audits) of the BE	4.00%	4.00%	0%	0%	0%	0%	4.00%	4.00%	0%	0%	4,00%
10	BE risk management	Information on possible risks and their consequences of BE's activities	1.50%	1.50%	0%	0%	0%	0%	1.50%	1.50%	0%	0%	1,50%
11	BE's place in the ratings	Domestic and international ratings	2.00%	2.00%	2.00%	2.00%	0.00%	2.00%	0%	2.00%	2.00%	2,00%	2,00%
12	Overall results of the BE's activities	Report on the overall results of the BE's activities	3.00%	3.00%	3.00%	3.00%	0.00%	3.00%	3.00%	3.00%	0%	0%	3,00%
13	BE's cooperation with the media	Press, television, radio, social networks	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2,00%	2,00%
14	BE's tax documents	Availability of reports on the results of BE taxation	1.00%	0%	0%	0%	0%	0%	0	0%	0%	0%	0%
		Amount	**100.00%**	**75,50%**	**68.00%**	**67.50%**	**61.00%**	**70.50 %**	**68.00%**	**74.50%**	**56.50 %**	**64.00%**	**75.50%**

***Source:** compiled by the authors based on (Litvinchuk, 2019)*

***Table 4**. Results of assessing the transparency level of the 2nd experimental group of Ukrainian banks using a scientific and methodological approach (detailed assessment according to the selected criteria)*

No.	Criteria group	Composition of criteria	Criterion weight in %	Pravex Bank	Idea Bank	Piraeus Bank	Alfa-Bank	FUIB (PUMB)	UKRGASBANK	SEB Corporate Bank	Credit Europe Bank	Bank Lviv	Kredobank
1	General information about BE	History of BE creation	0.50%	0.00%	0.50%	0.50%	0.50%	0.00%	0.50%	0.50%	0.50%	0,00%	0,50%
		Organizational structure and information about BE owners	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3,00%	0,00%
		BE goals and strategy	3.00%	3.00%	3.00%	0.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3,00%	3,00%
		Reviews about the activities of BE	2.50%	0.00%	0.00%	0.00%	0.00%	2.50%	0.00%	0.00%	0.00%	2,50%	0,00%
		BE contacts and address	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3,00%	3,00%
2	Legal documents regulating the activities of BE	BE charter	5.00%	5.00%	5.00%	5.00%	0.00%	0.00%	5.00%	5.00%	5.00%	0,00%	0,00%
		Licences and certificates for the implementation of BE's activities	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	0.00%	0,00%	6,00%
		Collective agreement	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		Laws, regulations, orders, and other regulatory acts based on which the BE carries out its activities	1.50%	1.50%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
3	Investment activity of the BE	General information about current BE investment projects	3.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		Strategic vectors of the BE's investment policy	2.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		Information on the results of BE's investment activities	2.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
4	BE's marketing policy	Characteristics of BE's products, works, and services	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Quality guarantees of BE's products, works, and services (certificates, diplomas, patents, and licences)	4.00%	4.00%	4.00%	0.00%	0.00%	0.00%	4.00%	0.00%	0.00%	4,00%	0,00%
		BE's social policy	3.00%	3.00%	0.00%	0.00%	3.00%	3.00%	3.00%	0.00%	0.00%	0,00%	0,00%
		Characteristics of innovation of BE's products, works, and services	3.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		BE's pricing policy	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2,50%	2,50%
5	General information about the BE's personnel support	Quantitative composition	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	0.00%	0.00%	0,00%	0,00%
		Current vacancies	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1,50%	1,50%
		Conditions and principles of competitive selection to fill vacant positions in the BE	1.50%	0.00%	0.00%	1.50%	0.00%	0.00%	1.50%	0.00%	0.00%	1,50%	0,00%
		Staffing table	2.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		Activities of the trade union organisation	0.50%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
6	Information on maintaining environmental friendliness and safety of BE's activities	Standards and regulations governing labour safety of BE's	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		Documents confirming the environmental friendliness of the BE's activities	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
7	Cooperation with other BEs	Domestic partners of the BE and joint projects	2.50%	0.00%	2.50%	2.50%	0.00%	2.50%	2.50%	0.00%	0.00%	0,00%	0,00%
		BE's foreign partners and joint projects	2.50%	0.00%	2.50%	2.50%	0.00%	0.00%	2.50%	0.00%	0.00%	0,00%	0,00%
8	BE's financial statements	Balance	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Statement of financial results	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6.00%	6,00%	6,00%
		Statement of equity	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5,00%	5,00%
		Cash flow statement	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5,00%	5,00%
9	Results of BE inspections	Reports on the results of external inspections (audits) of the BE	4.00%	4.00%	0.00%	4.00%	0.00%	4.00%	4.00%	0.00%	4.00%	4,00%	4,00%
10	BE risk management	Information on possible risks and their consequences of BE's activities	1.50%	1.50%	1.50%	0.00%	1.50%	1.50%	1.50%	0.00%	0.00%	1,50%	0,00%
11	BE's place in the ratings	Domestic and international ratings	2.00%	2.00%	2.00%	0.00%	0.00%	2.00%	2.00%	0.00%	0.00%	2,00%	0,00%
12	Overall results of the BE's activities	Report on the overall results of the BE's activities	3.00%	0.00%	0.00%	3.00%	0.00%	0.00%	3.00%	0.00%	0.00%	0,00%	0,00%
13	BE's cooperation with the media	Press, television, radio, social networks	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2,00%	2,00%
14	BE's tax documents	Availability of reports on the results of BE taxation	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0,00%	0,00%
		Amount	**100.00%**	**70.00%**	**67.00%**	**65.00%**	**54.00%**	**64.50%**	**79.50%**	**54.50%**	**52.50%**	**58.50%**	**50.50%**

***Source:** built based on (Shkodina & Onishchenko, 2018)*

The effectiveness of disclosure of this information is ensured by the availability of measures to increase the availability of information for all concerned market participants and ease of interpretation. The scientific and methodological approach is aimed at investigating the transparency of the activities of business entities, since the overall transparency of the financial system in the country depends on the transparency of the activities of business entities. The transparency level of the banking institutions under study is estimated using a four-step scale for assessing the transparency level of the business entity's activities (Table 5).

***Table 5**. Four-step scale for assessing the transparency level of an entity's activities*

The number of points according to the business entity's Transparency Index	Transparency level of the business entity's activities
39-0 points	unacceptably low level, characterised by the absence or brief disclosure of essential information (or disclosure of non-essential information), lack of information about investment, marketing, international, financial activities and prospects for the development of the enterprise.
59-40 points	low level, characterised by insufficient, low level of disclosure of essential information, inadequate coverage of the main key aspects (vectors) of the enterprise's activities.
79-60 points	medium-sufficient level, characterised by partial, incomplete, or delayed disclosure of essential information about the current activities and main results of the enterprise.
100-80 points	high level, characterised by complete and relevant disclosure of all essential information about key aspects (vectors) of the company's current activities and development prospects.

***Source:** compiled by the authors based on (Onishchenko, 2020)*

The authors of this study propose to improve the system and structure of managing the transparency of banking institutions according to two separate levels of factor space and their cross-influence by improving the positioning mechanism of banking institutions through managing differences in two-level classification with common patterns inherent in this process. Figure 1 shows the main stages, tasks, results, and methods of proposed diagnostics of transparency of business entities' activities based on multidimensional modelling and applied econometric methods using the example of banking institutions in Ukraine.

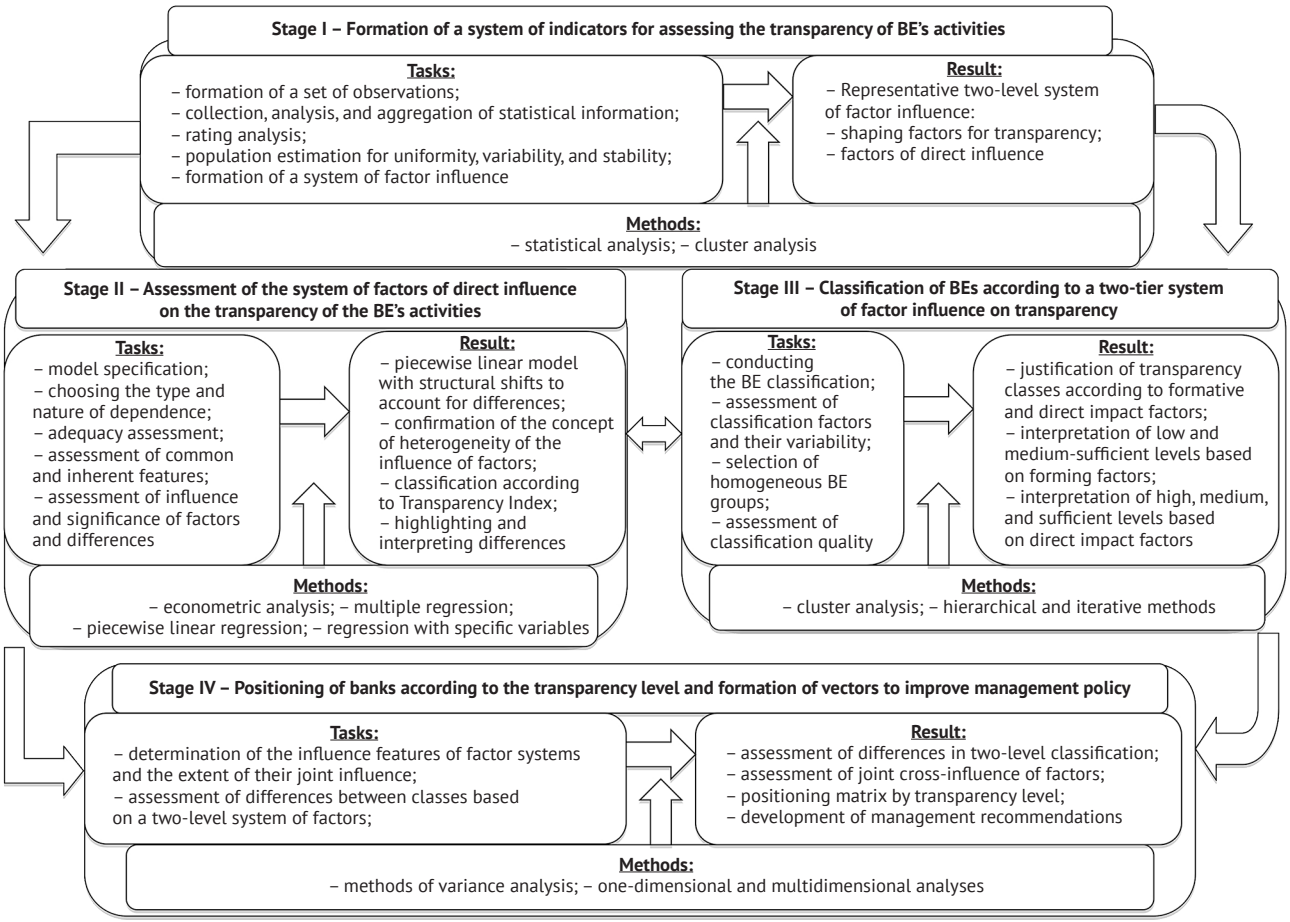


***Figure 1**. Stages of diagnostics of transparency level of the business entity's activities based on multidimensional modelling, applied econometric methods*

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

Next, the authors investigate the essential content of each of the stages of diagnosing the transparency level of a banking institution's activities.

Stage 1 – development of a system of indicators for assessing the level of transparency of business entities' activities.

The main tasks of this stage include estimation and appropriate monitoring of the total transparency of activity.

To solve these problems, the study uses statistical and cluster analysis methods.

Stage 2 – assessment of the system of factors of direct influence on the transparency of business entities' activities.

The main tasks to be solved at Stage 2 are as follows: to specify influence models; to choose the type and nature of dependence; to verify the adequacy of impact models; to estimate the general and inherent features of the population according to the system of influence factors; to evaluate the influence of factors and the significance of differences.

To solve these problems, the study uses the methodology of econometric modelling, namely multiple regression, piecewise linear regression, and regression with specific variables (Guryanova *et al.*, 2016; Maliarets, 2011).

Stage 3 – classification of business entities according to a two-level system of factor influence on transparency.

The main tasks to be solved at Stage 3 are as follows: to classify subjects, form groups and find patterns; to estimate classification factors and their variability; to find homogeneous groups of subjects; to evaluate the quality of classifications.

The authors employed cluster analysis to solve these problems (Klebanova *et al.*, 2018).

Stage 4 – positioning of banks according to the transparency level and development of vectors for improving management policies.

The main tasks to be solved at Stage 4 are as follows: to find the influence features of factor systems and the level of their joint impact; to estimate differences between classes according to the two-level system of factors; to form a transparency matrix; to form management decisions.

To solve these problems, the authors employed variance analysis (Shapran, 2019).

RESULTS AND DISCUSSION

An integral part of supporting a prominent level of transparency of financial flows in the country is their objective and correct assessment. Today, there are several methods for estimating the transparency level, which cover various links and subjects of the country's financial market.

At the beginning of the 21st century, E. Egbuna (2014) was one of the first to suggest the use of the Transparency Index. It included 11 variables that reflected the publicity of monetary policy, the degree of autonomy and independence of the central bank, the way information is presented, and the degree of assessment of the monetary regulation process.

Other researchers (Sylvester & Geraats, 2007) identified 5 transparency components as follows: familiarization with the objectives of monetary policy implementation (political transparency); the degree of openness of economic indicators (economic transparency); the level of publicity of monetary policy (procedural transparency); transparency of methods and techniques of monetary policy implementation (policy transparency); the level of operational openness (operational transparency). Binary indicators (0 and 1) were used during the evaluation. The advantages of using this method include the ease of determining the index; its adaptation to well-known theoretical developments regarding the types of transparency of the central bank; permissibility of use for any central bank (i.e., a high level of universality). But unfortunately, this method also had certain disadvantages. Thus, the central bank's transparency analysis is one-sided, considering only the event of the publication of data on its monetary policy activities. The criteria for analysing certain types of transparency are also not fully detailed. When performing calculations, only the availability of information is considered, without its completeness (Busko, 2016).

N. Dincer & B. Eichengreen (2014) subsequently used a similar technique to find the level of transparency. However, unlike its predecessors, which used information about 20 central banks, 150 central banks already served as the basis for analysis.

Now, one can observe an asymmetry of information related to the fact that banks, as commercial structures, have a certain probability of bankruptcy, which sometimes stays an unknown fact for its clients. In this case, using only financial indicators to evaluate the financial stability of banks may not be sufficient. In this regard, the importance of applying the transparency index increases.

The rating agency Standard & Poor's also proposed its methodology for assessing the transparency of banks (index of information transparency). Its essence lies in the maximum detail of the analysed indicators. A special feature of this method is the use of information obtained from several sources, which is considered when figuring out the final score for each evaluation criterion. Therewith, it is mandatory to consider the profitability of information from the standpoint of a foreign investor and publish indicators in several languages. The disadvantage of this methodology is its low level of transparency: the low level of consideration of the specifics of the legislation of different countries on regulating the transparency of banks; the inability to independently assess the bank; is not exhaustive for diagnosing the transparency of banking risks, since the publication of information on risk management includes a limited number of indicators without detailing them (Onishchenko, 2020).

Considering the previously discussed methods of investigating transparency for various research objects, to find the level of transparency of an enterprise's

activities, the authors of this study offer their methodological approach, which can be used to estimate the transparency of banking institutions using a group of criteria. The main advantage of the proposed method of diagnosing transparency over others is the objectification of research results through the widespread use of multidimensional analysis methods. The authors considered the main shortcomings of previous methods for measuring transparency. The proposed methodological approach provides an extensive number of criteria and sub-criteria that allow assessing the transparency of an enterprise's activities in various aspects of its activities (economic, legal, organisational, social, etc.). Furthermore, the applied transparency diagnostics can be chosen not only to figure out the transparency of banking institutions, but also other business entities, since the proposed transparency assessment criteria are universal.

Next, the authors investigate the results of each of the stages of the proposed method for diagnosing the transparency level of a banking institution's activities.

Stage 1 – development of a system of indicators for assessing the level of transparency of business entities' activities. To perform diagnostics, the study selected a group of indicators that can be used in the rating assessment of the transparency level of banking institutions (14 indicators), namely, forming factors of transparency (Onishchenko, 2020) and a system of key indicators of banking institutions' performance – factors of direct influence (deposits, equity, assets, net profit) (Litvinchuk, 2019). A sample set of observations was checked for robustness and representativeness for the 20 banking institutions under study. For further research, factors X13 (cooperation of the BE with the media) and X14 (tax documents of the BE), which are unstable from the perspective of statistical analysis, were excluded.

Variables were also classified to assess the stability of a set of indicators using hierarchical cluster analysis (Fig. 2) (StatSoft e-textbook, n.d.). The X8 indicator (BE's financial statements) is quite separate, as it is also not variable. The group of indicators X1 (general information about BE), X2 (legal documents regulating the BE's activities), X4 (BE's marketing policy) form a separate cluster, since they have normal scattering and variability for the banks under study, which is considered and will be more investigated at the next stages of diagnosis.

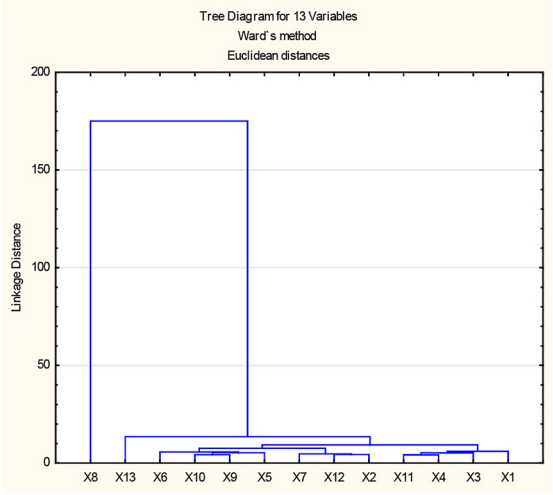


Figure 2. *Dendrogram for classifying variables using hierarchical cluster analysis*
Source: *compiled by the authors*

Thus, the result of this stage of diagnostics is a well-founded representative two-level system of factor influence on transparency: forming transparency factors and direct influence factors.

Stage 2 – assessment of the system of factors of direct influence on the transparency of business entities' activities.

The results of building a linear model of multiple regression analysis in the Statistica Application Software Package in the Multiple Regression module (StatSoft e-textbook, n.d.; Egbuna, 2014) are shown below. The inadequacy of the coupling model (coefficient of determination d=0.2) is confirmed by the heterogeneity of the initial data, their significant differences that make it impossible to combine them within one sample population, which is required by a linear regression model. The scatter plot of variables and their statistical characteristics are presented in Figure 3.

The results of the study indicate that the initial data are heterogeneous. This allows assuming that the selected groups of banking institutions are confirmed according to certain indicators of direct influence factors.

With the help of Statistica (Nonlinear Estimation module), the authors built a piecewise linear regression to confirm the assumption of grouping and correspondingly obtain numerical values of the breakpoint of sets, as well as explain the differences in the level of transparency (StatSoft e-textbook, n.d.; Egbuna, 2014).

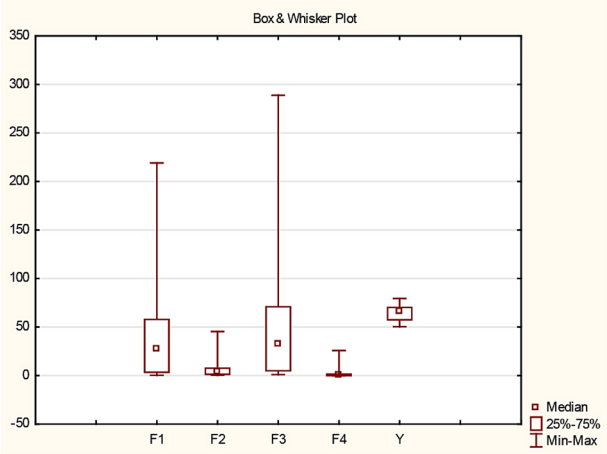


***Figure 3**. Scatter plot according to direct impact and transparency factors and their statistical characteristics*
***Source:** compiled by the authors*

Figure 4 shows the results of constructing a piecewise linear econometric model. The constructed model is adequate (the correlation coefficient is 0.96537, the determination coefficient is 0.9319).

	Model is: Piecewise linear regression with breakpoint (Spreadsheet1) Dependent variable: Y Loss: Least squares Final loss:90,767173080 R= ,96537 Variance explained: 93,194%										
N=20	Const.B0	F1	F2	F3	F4	Const.B0	F1	F2	F3	F4	Breakpt.
Estimate	52,73477	-0,241127	2,820008	-0,004616	-1,58706	66,32458	-1,23987	-0,324704	1,202261	-2,04403	64,85000

***Figure 4**. Results of a piecewise linear econometric model for justifying differences in transparency assessment indicators*
***Source:** compiled by the authors*

Based on the results of the conducted econometric analysis, namely: multivariate regression analysis, piecewise linear regression construction and error analysis of the piecewise linear model, it was found that the resulting model with extended criteria has a gap (corresponding to the point 64.85 for the value of the dependent variable (transparency level)). And the system of equations of the model is as follows (1):

$$y_{(xi)} = \begin{cases} 52.73 - 0.24 * \text{f1} + 2.82 * \text{f2} - 0.005 * \text{f3} - 1.59 * \text{f4}, if\ y_i^* \le 64.85; \\ 66.32 - 1.24 * \text{f1} - 0.32 * \text{f2} + 1.20 * \text{f3} - 2.04 * \text{f4}, if\ y_i^* > 64.85; \end{cases} \quad (1)$$

where f1–f4 are dependent variables

The difference in parameter values confirms the presence of structural shifts (differences), and therefore the heterogeneity of data and the use of more adaptive methods that consider specific effects for a particular group. This model determines the difference in the transparency level of the indicator 64.85, which is confirmed by the adequacy of the model.

Figure 5 presents a graph comparing the parameters of the general and piecewise linear regression models by groups, which is the basis for interpreting the differences.

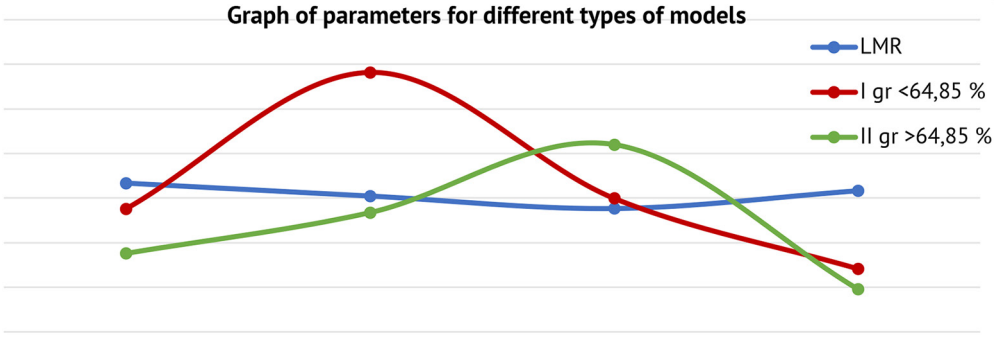
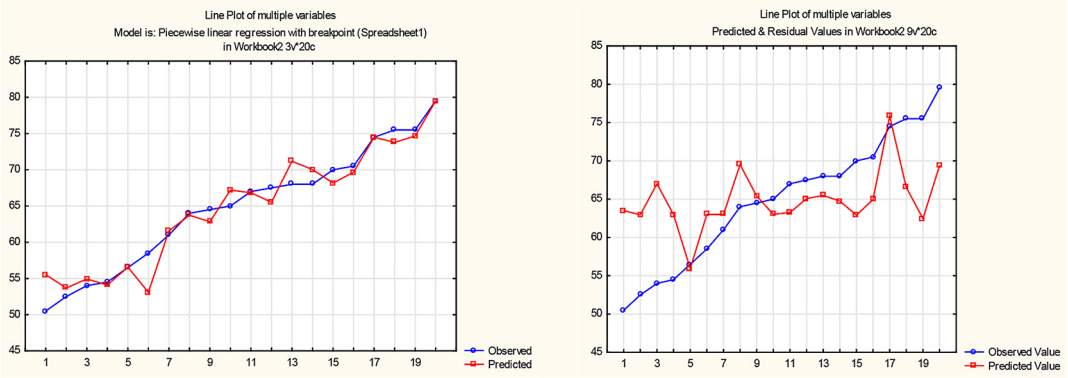


***Figure 5**. Graph comparing the parameters of the general and piecewise linear regression models by groups*
***Source:** compiled by the authors*

Figure 6 presents a graph comparing the empirical values of transparency and theoretical data according to models with a gap and general linear regression, which confirms the hypothesis of using a model with a gap (piecewise-linear) for further research, and the development of recommendations considering the heterogeneity of groups.

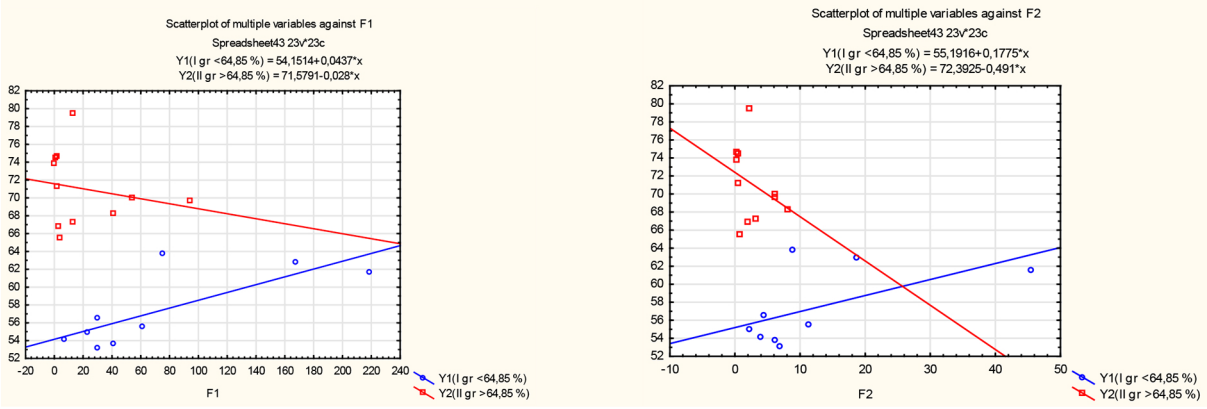


a) general regression with a breakpoint **b)** projected and residual values

Figure 6. *Graph of comparison of empirical values of transparency and theoretical data according to gap and general linear regression models*

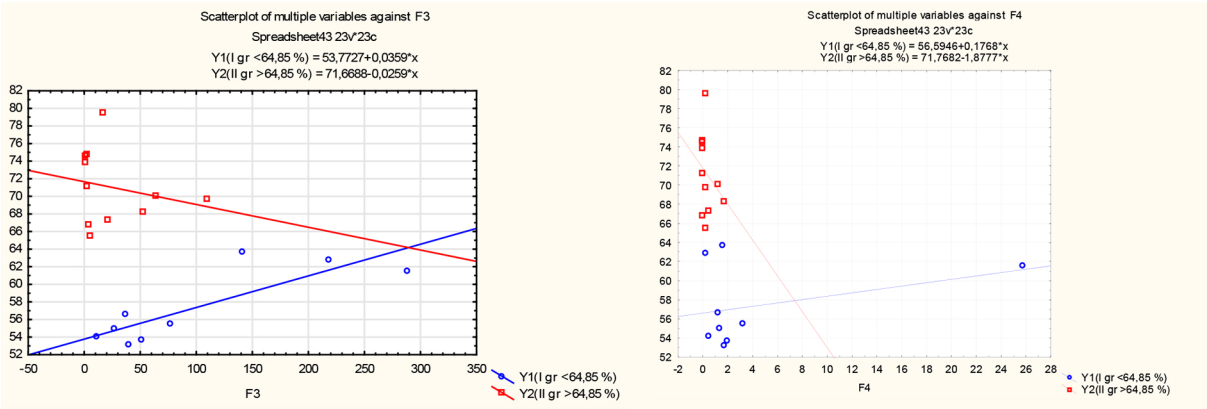
Source: *compiled by the authors*

Figure 7 presents the graphs of the dependence of the transparency level (dependent variable) on the impact factors for isolated groups of observations according to the piecewise linear model, which confirms the hypothesis of further research of isolated groups with defined features of influence.



a) Graph of the dependence of transparency on the "Deposits" impact factor for selected observation groups

b) Graph of the dependence of transparency on the "Equity" impact factor for selected observation groups



c) Graph of the dependence of transparency on the "Assets" impact factor for selected observation groups

d) Graph of the dependence of transparency on the "Net profit" impact factor for selected observation groups

Figure 7. *Graphs of the dependence of transparency on factors of influence for selected observation groups*

Source: *compiled by the authors*

As a result of the simulation, two groups of banks were formed, which differ in the value of the transparency coefficient. The econometric model, which relates these values to the corresponding set of independent factors, is of particular importance.

Figure 7 presents the graphs of the dependence of transparency (dependent variable) on the impact factors for isolated groups of observations according to the piecewise linear model, which confirms the hypothesis of further research of isolated groups with defined features of influence. This allows finding the degree of change in the dependent variable (its increase by one unit provides a different level of increase in probability). Probit-model is based on the law of distribution (2).

$$F(z) = \Phi(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} = e^{-\frac{1}{2}t^2} dt \qquad (2)$$

The probability distribution function of the logistics law has the following form (Eq. 3):

$$\Lambda(z) = \frac{e^z}{1 + e^z} \qquad (3)$$

Based on the results of constructing the probit and logit function models, a model with a gap at point 60 in terms of transparency was tested, but this classification can be refuted, since there are substantial errors in the classification matrix regarding the assignment of banks to a particular group, considering only the rating indicator of transparency.

Figure 8 shows a graph comparing empirical values of transparency levels and theoretical data for probit and logit with models that reflect the probability of assignment to a particular class.

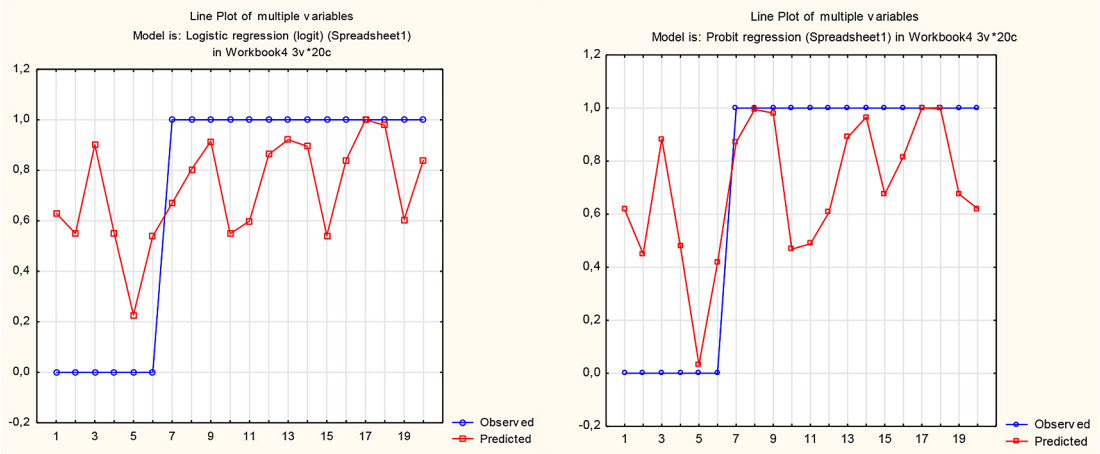


***Figure 8**. Graph of comparison of empirical values of transparency and theoretical data for probit and logit models*
***Source:** compiled by the authors*

Thus, the aggregated results of this stage of transparency diagnostics can be stated as follows:

– the hypothesis of structural heterogeneity of sample data based on piecewise linear regression is confirmed;

– the concept of heterogeneity of the influence of factors based on comparative analysis for different types of influence models is confirmed;

– a classification based on the effective transparency indicator was obtained and a comparative analysis of the breakdown by model was performed;

– features were identified, differences were highlighted and interpreted.

Stage 3 – classification of business entities according to a two-level system of factor influence on transparency. The results of building models of cluster analysis of business entities by factors of transparency formation in Statistica are presented in Figures 9 and 10 without considering indicators X8 and X13, which are non-variable. This hierarchical tree classification serves as the basis for putting forward and confirming the hypothesis of the number of clusters according to transparency level. Classification dendrograms allowed identifying homogeneous groups of subjects and confirming the hypothesis about the presence of a certain structure in the set of objects under study and highlighting the features of the existing structure (StatSoft e-textbook, n.d.).

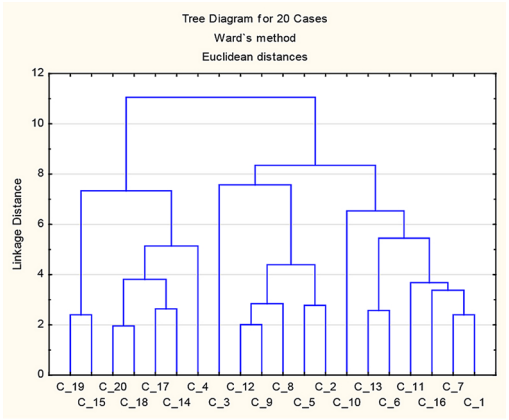


***Figure 9**. Dendrogram for classifying banks using the hierarchical cluster analysis method*
***Source:** compiled by the authors*

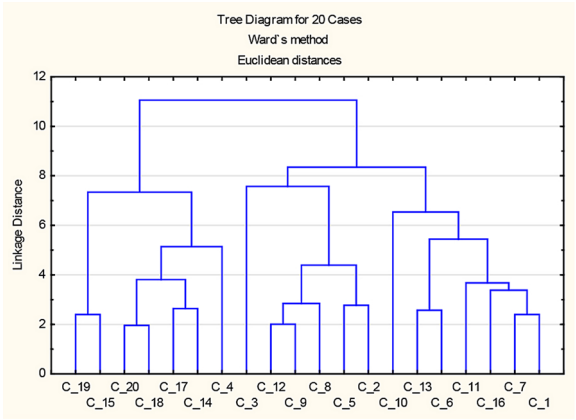


***Figure 10**. Dendrogram for classifying banks using the hierarchical cluster analysis method without indicators X8 and X13*
***Source:** compiled by the authors*

For further studies and classifications, variables X8 and X13 were excluded, and a procedure for iterative clustering of K-averages was implemented to obtain all the necessary statistical characteristics and parameters. A graph of the average values for clusters of states based on transparency factors is presented in Figure 11. The clusters differ most in terms of X2, X5–X10, X12, and less significant differences are observed in the averages for X3, X4, and X11 indicators.

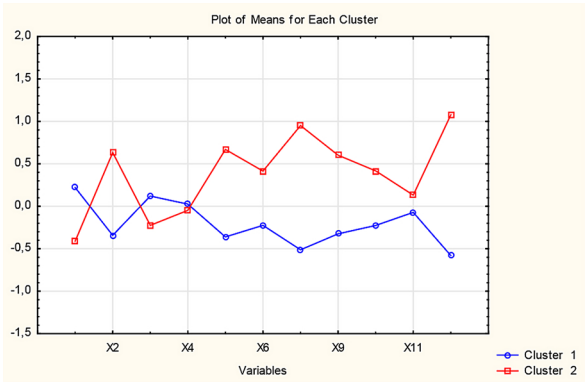


***Figure 11**. Graph of average values for state clusters based on transparency factors*
***Source:** compiled by the authors*

The results of the authors' analysis of variance based on transparency factors are presented in Figure 12. Parameters *F* and *p* determine the attribute's contribution to classification.

Variable	Analysis of Variance (Spreadsheet43)					
	Between SS	df	Within SS	df	F	signif. p
X1	1.81541	1	17.18459	18	1.90155	0.184801
X2	4.31711	1	14.68289	18	5.29242	0.033592
X3	0.53846	1	18.46154	18	0.52500	0.478030
X4	0.02470	1	18.97530	18	0.02343	0.880035
X5	4.83203	1	14.16797	18	6.13895	0.023365
X6	1.85714	1	17.14286	18	1.95000	0.179570
X7	9.74488	1	9.25513	18	18.95250	0.000383
X9	3.89955	1	15.10046	18	4.64832	0.044862
X10	1.87912	1	17.12088	18	1.97561	0.176880
X11	0.18585	1	18.81415	18	0.17780	0.678259
X12	12.50427	1	6.49573	18	34.65000	0.000014

***Figure 12**. Table of variance analysis by factors of transparency formation*
***Source:** compiled by the authors*

Figure 13 shows descriptive statistics for the selected clusters, namely mean, root-mean-square deviation, and variance.

The cluster members presented in Figure 14 and their distances to the centre of the corresponding cluster allow figuring out the composition of each cluster.

Variable	Descriptive Statistics for Cluster 1 (Spreadsheet43) Cluster contains 13 cases		
	Mean	Standard Deviation	Variance
X1	0.221080	0.946439	0.895747
X2	-0.340925	1.094248	1.197379
X3	0.120404	1.240347	1.538462
X4	0.025790	1.092154	1.192799
X5	-0.360684	0.834249	0.695971
X6	-0.223607	0.000000	0.000000
X7	-0.512213	0.878214	0.771260
X9	-0.324018	0.992069	0.984201
X10	-0.224926	0.987096	0.974359
X11	-0.070736	1.034758	1.070724
X12	-0.580219	0.735738	0.541311

a) Descriptive statistics for Cluster 1 according to transparency factors

Variable	Descriptive Statistics for Cluster 2 (Spreadsheet43) Cluster contains 7 cases		
	Mean	Standard Deviation	Variance
X1	-0.410577	1.035666	1.072605
X2	0.633147	0.228891	0.052391
X3	-0.223607	0.000000	0.000000
X4	-0.047896	0.881448	0.776951
X5	0.669842	0.984575	0.969388
X6	0.415270	1.690308	2.857143
X7	0.951253	0.000000	0.000000
X9	0.601748	0.740500	0.548341
X10	0.417720	0.951190	0.904762
X11	0.131367	0.997118	0.994244
X12	1.077549	0.000000	0.000000

b) Descriptive statistics for Cluster 2 according to transparency factors

Figure 13. *Descriptive statistics for clusters by transparency formation factors*
Source: *compiled by the authors*

Case No.	Members of Cluster Number 1 (and Distances from Respective Cluster contains 13 cases
	Distance
C_2	0.832247
C_3	1.552021
C_4	1.051621
C_8	0.833603
C_9	0.664362
C_11	0.780460
C_12	0.716732
C_14	0.650129
C_15	0.779057
C_17	0.726298
C_18	0.792812
C_19	1.116850
C_20	0.927019

a) Cluster 1 according to formation factors

Case No.	Members of Cluster Number 2 (and Distances from Respective Cluster contains 7 cases
	Distance
C_1	0.649016
C_5	0.766295
C_6	0.681963
C_7	0.505970
C_10	1.219111
C_13	0.835141
C_16	0.739147

b) Cluster 2 according to formation factors

Figure 14. *Bank cluster members and their distance to the centre of the cluster according to transparency formation factors*

Source: *compiled by the authors*

Thus, Cluster 1 comprises 13 banking institutions that have lower average values for all indicators that form transparency, except for indicator X1 (general information about BE), X3 (BE's investment activity) and correspond to almost the same average level for indicator X4 (BE's marketing policy). This cluster is interpreted as a cluster with entities with a low transparency level. However, interpretation may have discrepancies, established according to the transparency scale proposed in this paper (Table 3), which have high average values for 7 of the 11 indicators of transparency formation under study.

According to the breakdown by factors of transparency formation, almost all institutions whose transparency rating is below 70 points belong to the low class. According to the results, one has an interval of 60-70 points by which banks can be classified, and it is the ambiguity of the classification within this limit that gives rise to groups differing according to transparency. According to the piecewise-linear econometric model, to justify the degree of differences according to the indicators of the transparency level, the break point of 64.85 was also found, which is practically the middle of this interval. Thus, this fact confirms the need for further research and more detailed classifications on the level of transparency for various factors.

The authors of this paper will further investigate the grouping of banks according to the transparency level for the factors of direct influence to distinguish the general and individual features of the factors and patterns that dictate the transparency level.

The dendrogram of the classification of banks per the Ward's method by factors of direct influence is presented in Figure 15. Based on the results of the

tree classification, one can observe a breakdown into 3 clusters of states, which will serve as the basis for the hypothesis of investigating the classification into three groups based on these factors and their thorough analysis. A graph of the average values for clusters of states by direct influence factors using the K-mean method is presented in Figure 16. Most of all, the clusters differ according to the indicator of the deposit portfolio (F1) and available assets (F3), the smallest differentiation according to the indicator of net profit (F4).

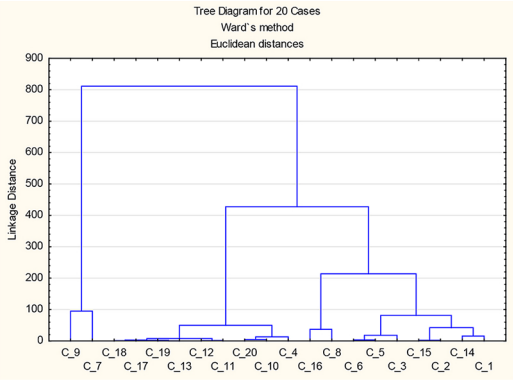


Figure 15. *Dendrogram of the classification of banks per the Ward's method by factors of direct*
Source: *compiled by the authors*

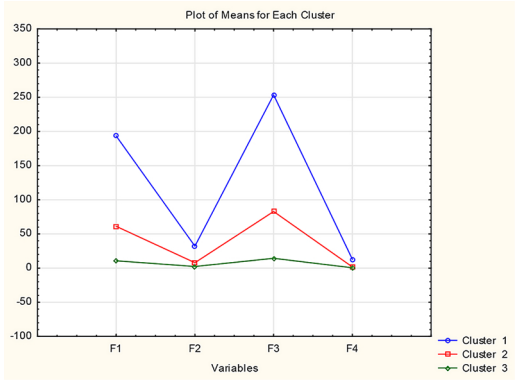


Figure 16. *Graph of average values for state clusters by direct impact factors*
Source: *compiled by the authors*

The table of variance analysis for direct influence factors confirms the significance of variables for classification according to the Fischer criterion (F), and a sufficient level of differences between subjects for the factors under study (Fig. 17).

Variable	Analysis of Variance (Spreadsheet43)					
	Between SS	df	Within SS	df	F	signif. p
F1	59675.5	2	4864.73	17	104.2693	0.000000
F2	1522.1	2	426.94	17	30.3044	0.000002
F3	103041.4	2	11144.47	17	78.5908	0.000000
F4	269.6	2	336.19	17	6.8170	0.006700

Figure 17. *Table of variance analysis by direct impact factors*
Source: *compiled by the authors*

Therefore, the hypothesis regarding the three-class grouping of commercial banks according to the determining factors of activity, which are defined as factors of direct influence, can be confirmed. Members of bank clusters and their distance to the centre of the cluster by factors of direct influence are presented in Figure 18 with the following components and interpretation:

Cluster 1 – 2 banks – prominent transparency;
Cluster 2 – 6 banks – average transparency;
Cluster 3 – 12 banks – sufficient transparency;

Case No.	Members of Cluster Number 1 (Spreadsheet3) and Distances from Respective Cluster Center Cluster contains 2 cases Distance
C_7	23.76774
C_9	23.76774

a) Cluster 1 according to direct impact factors

Case No.	Members of Cluster Number 2 (Spreadsheet43) and Distances from Respective Cluster Center Cluster contains 6 cases Distance
C_1	3.23979
C_2	18.64887
C_8	30.16465
C_14	9.85776
C_15	18.30930
C_16	21.34300

b) Cluster 2 according to direct impact factors

Case No.	Members of Cluster Number 3 (Spreadsheet43) and Distances from Respective Cluster Center Cluster contains 12 cases Distance
C_3	8.80521
C_4	2.76021
C_5	15.14290
C_6	16.11269
C_10	3.96595
C_11	6,15963
C_12	5.75761
C_13	7.33953
C_17	7.97491
C_18	8.48278
C_19	7.29001
C_20	1.92105

b) Cluster 2 according to formation factors

Figure 18. *Bank cluster members and their distances to the cluster centre by direct impact factors*
Source: *compiled by the authors*

The aggregated results of cluster analysis of indicators based on transparency factors and direct impact factors based on the implemented methods are presented in Table 6.

***Table 6**. Aggregated results of cluster analysis of indicators based on factors of transparency and direct impact formation*

	Bank	Transparency level	Based on transparency calculations	Standard Ward's method	Non-standard Ward's method	Method K-mean (without X8 and X13)	Method K-mean (F1–F4)
1	Raiffeisen Bank Aval JSC	75.50%	S-D	S-D	S-D	S-D	S
2	Ukrsibbank JSC	68.00%	S-D	S-D	S-D	N	S
3	Citibank JSC	67.50%	S-D	S-D	S-D	N	D
4	ING Bank Ukraine JSC	61.00%	S-D	N	S-D	N	D
5	Crédit Agricole Bank JSC	70.50 %	S-D	S-D	S-D	S-D	D
6	OTP Bank JSC	68.00%	S-D	S-D	S-D	S-D	D
7	Commercial Bank "PrivatBank" JSC	74.50%	S-D	S-D	S-D	S-D	V
8	Ukreximbank JSC	56.50 %	N	S-D	N	N	S
9	Oschadbank JSC	64.00%	S-D	S-D	S-D	N	V
10	ProCredit Bank JSC	75.50%	S-D	S-D	S-D	S-D	D
11	Pravex Bank JSC	70.00%	S-D	S-D	S-D	N	D
12	Idea Bank JSC	67.00%	S-D	S-D	S-D	N	D
13	Piraeus Bank JSC	65.00%	S-D	S-D	S-D	S-D	D
14	Alfa-Bank JSC	54.00%	N	N	N	N	S
15	FUIB (PUMB) JSC	64.50%	S-D	N	N	N	S
16	JSB UKRGASBANK PJSC	79.50%	S-D	S-D	S-D	S-D	S
17	SEB Corporate Bank JSC	54.50%	N	N	N	N	D
18	Credit Europe Bank JSC	52.50%	N	N	N	N	D
19	JSCB "Lviv" JSC	58.50%	N	N	N	N	D
20	Kredobank JSC	50.50%	N	N	N	N	D

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

The comprehensive results of this stage of transparency level diagnostics, which lies in building factor space classification models, can be formulated as follows:

– justification of transparency classes by formative and direct impact factors;

– interpretation of the states of transparency of economic entities with a low and medium-sufficient level according to the forming factors;

– interpretation of the states of transparency of business entities with a high, medium, and sufficient level by factors of direct influence.

Thus, the implementation of cluster analysis tools for assessing transparency for selected factor systems solves the following diagnostic tasks:

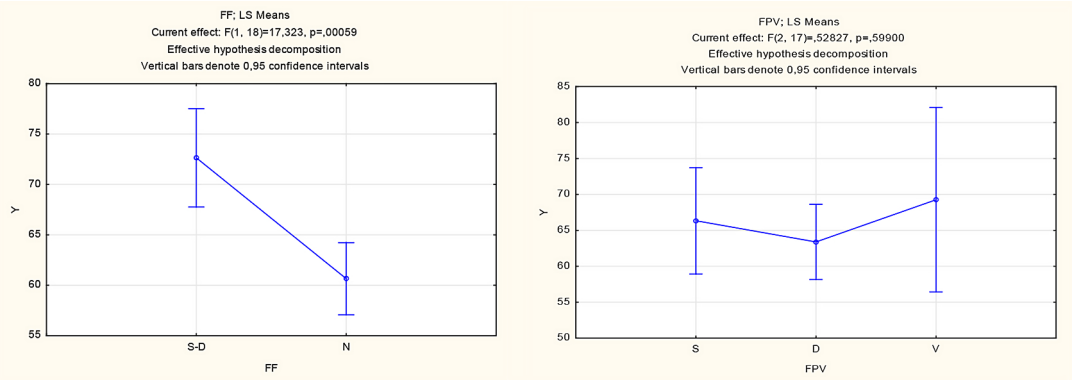
– analysis of the specific features of implementing the factor potential of transparency by identifying homogeneous groups, which allows identifying the weaknesses and strengths of the banking sector in established areas within this market;

– reducing the dimension of data on qualitative signs of transparency by two levels of compliance with the "low" and "medium-sufficient" levels for forming factors and the "high", "medium", and "sufficient" levels for direct impact factors to justify the limits of a multi-level assessment of the impact of indicators on transparency of activities.

Stage 4 – positioning of banks according to the transparency level and development of vectors for improving management policies.

At this stage, the variability of factor space indicators was investigated according to two systems of transparency factors of banking institutions (StatSoft e-textbook, n.d.; Egbuna, 2014).

Figure 19 shows the difference in the values of the ranking index of transparency by the levels of formation factors and direct influence factors according to the methodology of univariate analysis of variance in Statistica in the ANOVA module (StatSoft e-textbook, n.d.).



a) by levels of formation factors **b)** by levels of direct impact factors

***Figure 19**. The difference between the values of the transparency rating indicator by the levels of factors of formation and factors of direct influence*

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

The table of results of variance analysis and analysis of main effects (Fig. 20) by factors of transparency formation, according to which two isolated groups with a low and medium-sufficient level were studied, confirms the quality of the built model (Fisher's criterion), since the value of the indicator in the groups is sufficiently different and the ranges of values do not overlap considering the errors.

Cell No.	FF; LS Means (Spreadsheet43) Current effect: F(1, 18)=17,323, p=,00059 Effective hypothesis decomposition					
	FF	Y Mean	Y Std.Err.	Y -95,00%	Y +95,00%	N
1	S-D	72.64286	2.322337	67.76381	77.52191	7
2	N	60.65385	1.704130	57.07360	64.23409	13

a) analysis of variance

Effect	Univariate Tests of Significance for Y (Spreadsheet43) Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercept	80844.45	1	80844.45	2141.419	0.000000
FF	654.00	1	654.00	17.323	0.000585
Error	679.55	18	37.75		

b) main effects analysis

***Figure 20**. Table of results of variance analysis and analysis of the main effects by factors of transparency formation*

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

The table of results of variance analysis and analysis of main effects (Fig. 21) by factors of direct influence, by which three isolated groups with an average, sufficient, and high level of transparency are investigated, confirms the sufficient quality of the built model. However, it is worth noting the significant influence of environmental factors that are not considered in models. The calculated averages and ranges of their changes show a lower, albeit sufficient, level of variability compared to transparency factors.

The graph of changes in the average values of the dependent variable (rating transparency indicator) depending on two qualitative aggregate factor features is presented in Figure 22, the results of a two-factor analysis of variance to assess the quality of the model are presented in Figure 23.

Cell No.	FPV; LS Means (Spreadsheet43) Current effect: F(2, 17)=,52827, p=,59900 Effective hypothesis decomposition					
	FPV	Y Mean	Y Std.Err.	Y -95,00%	Y +95,00%	N
1	S	66.33333	3.508422	58.93121	73.73546	6
2	D	63.37500	2.480829	58.14091	68.60909	12
3	V	69.25000	6.076766	56.42914	82.07086	2

a) analysis of variance

Effect	Univariate Tests of Significance for Y (Spreadsheet43) Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercept	52779.22	1	52779.22	714.6411	0.000000
FPV	78.03	2	39.01	0.5283	0.598996
Error	1255.52	17	73.85		

b) main effects analysis

Figure 21. *Table of results of variance analysis and analysis of the main effects by direct impact factors*
Source: *compiled by the authors*

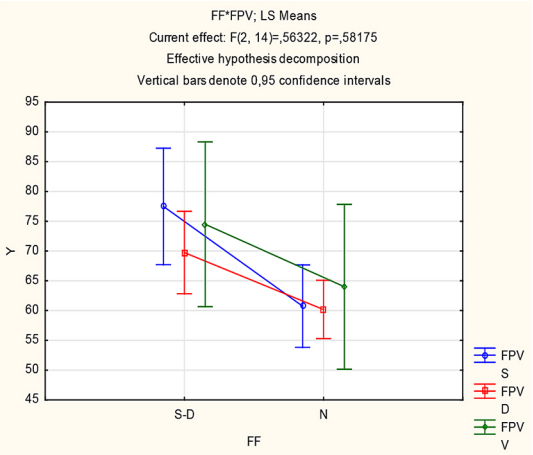


Figure 22. *Cross-sectional analysis of two aspects by levels of formation factors and direct impact factors*
Source: *compiled by the authors*

Effect	Univariate Tests of Significance for Y (Spreadsheet43) Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercept	52926.31	1	52926.31	1272.117	0.000000
FF	433.65	1	433.65	10.423	0.006067
FPV	76.33	2	38.16	0.917	0.422325
FF*FPV	46.87	2	23.43	0.563	0.581754
Error	582.47	14	41.60		

Figure 23. *Results of two-factor cross-variance analysis*
Source: *compiled by the authors*

Figure 24 shows a table with the values of average, and other statistics according to the level of change in intergroup transparency factors.

Thus, there are six groups of banking institutions that can be used to analyse changes in the level of transparency.

Cell No.	FF*FPV; LS Means (Spreadsheet43) Current effect: F(2, 14)=,56322, p=,58175 Effective hypothesis decomposition						
	FF	FPV	Y Mean	Y Std.Err.	Y -95,00%	Y +95,00%	N
1	S-D	S	77.50000	4.560971	67.71769	87.28231	2
2	S-D	D	69.75000	3.225093	62.83286	76.66714	4
3	S-D	V	74.50000	6.450187	60.66573	88.33427	1
4	N	S	60.75000	3.225093	53.83286	67.66714	4
5	N	D	60.18750	2.280485	55.29635	65.07865	8
6	N	V	64.00000	6.450187	50.16573	77.83427	1

***Figure 24**. Comparison of the values of the dependent variable (transparency rating) to the isolated groups by factors*
***Source:** compiled by the authors*

The given results indicate a difference between the average values in the groups for the corresponding intergroup factors. To verify the significance of differences, a posteriori equalisations are used in groups to check the difference in averages. Figure 25 shows the significance levels of the mean equality hypothesis.

Cell No.	LSD test; variable Y (Spreadsheet43) Probabilities for Post Hoc Tests Error: Between MS = 41,605, df = 14,000							
	FF	FPV	{1} 77.500	{2} 69.750	{3} 74.500	{4} 60.750	{5} 60.188	{6} 64.000
1	S-D	S		0.187012	0.709826	0.009579	0.004355	0.109534
2	S-D	D	0.187012		0.520795	0.068542	0.029654	0.438571
3	S-D	V	0.709826	0.520795		0.077298	0.055140	0.268984
4	N	S	0.009579	0.068542	0.077298		0.888787	0.659130
5	N	D	0.004355	0.029654	0.055140	0.888787		0.586147
6	N	V	0.109534	0.438571	0.268984	0.659130	0.586147	

***Figure 25**. A posteriori equalisations for two factors*
***Source:** compiled by the authors*

Thus, the most considerable differences are observed in three groups of banks, the banks of the "medium-sufficient level" cluster in terms of transparency formation factors and "medium" in terms of direct influence factors differ from the "low-medium" and "low-sufficient" clusters in terms of the corresponding set of factors. There is a significant difference in the level of transparency for the "medium-sufficient – sufficient" level according to the two-level system of factors and the "low-sufficient" level according to the corresponding set of factors.

The calculations results show a relationship between transparency indicators. This allowed obtaining the following conclusions:

1) cluster banks with a low level of formation factors, but an average and sufficient level of influence factors, have the lowest level of transparency. Banks belonging to the "medium-sufficient – medium level" cluster (Raiffeisen Bank Aval, UKRGASBANK) have the greatest positive level of transparency;

2) the deviation of the importance of transparency is determined considering the forming factors: the highest values of transparency are characteristic of state banks, and the lowest values are for 40% of banks (8 banks) from the population under study;

3) a cross-sectional two-aspect assessment of the level of transparency and factors of influence and formation indicates sufficient discrepancies for the obtained 6 groups.

Table 7 shows the matrix of banks' positioning by level of transparency according to a two-level system of factors, which is necessary for further analysis and implementation of relevant management decisions.

***Table 7**. Matrix of positioning of banks according to the level of transparency per the two-level system of factors*

		High	**Oschadbank JSC**	**Commercial Bank "PrivatBank" JSC**
Level of transparency by direct impact factors	Average		Ukrsibbank JSC Ukreximbank JSC Alfa-Bank JSC FUIB (PUMB) JSC	Raiffeisen Bank Aval JSC JSB UKRGASBANK PJSC
	Sufficient		Citibank JSC ING Bank Ukraine JSC Pravex Bank JSC Idea Bank JSC SEB Corporate Bank JSC Credit Europe Bank JSC JSCB "Lviv" JSC Kredobank JSC	Crédit Agricole Bank JSC OTP Bank JSC ProCredit Bank JSC Piraeus Bank JSC
			Low level	Medium-sufficient level
Level of transparency by influencing factors				

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

The results of the stage of positioning banks according to the level of transparency allowed figuring out the differences for the population under study and testing the hypothesis regarding the influence of individual factors and establishing their relationship at the appropriate level of significance, namely:

– evaluation of differences in two-level classification;

– assessment of joint cross-influence of factors;

– construction of a matrix of positioning according to levels of transparency depending on the system of assessment factors;

– development of management recommendations on ways to improve transparency policies.

CONCLUSIONS

The considered scientific and methodological approach, which can be used to diagnose the level of transparency of banks' activities, substantially expands the set of transparency indicators. A comprehensive estimation of the current state of transparency improves the system of effective management of both the individual bank, the sample population, and the banking system as a whole.

The introduction of this diagnostic technology in practical management activities allows finding many states of transparency; anticipating possible changes in states and identifying problems in the activities of banking institutions in a timely manner; developing appropriate measures in advance to prevent and avoid a decrease in the level of transparency.

The given scientific-methodical approach to managing transparency based on identified factors of formation and influencing factors will enable managers to improve the quality and efficiency of management decisions, as it provides a thorough diagnosis of the level of transparency based on a set of indicators, considering their differences and commonalities. Furthermore, it provides assessment and analysis, classification by level of transparency according to a two-level system of factors. The given scientific and methodological approach serves as the basis for the future formation and implementation of the selection of activity scenarios of the behaviour of banking institutions based on a two-level matrix of positioning and implementation of managerial decisions in the improvement of management, as a single systemic process of activity development in the banking market.

The proposed approach to estimating the level of transparency of a business entity's activities can be implemented when compiling ratings of various companies by economic sectors. The goals of the rating in this case include identifying the most transparent companies in Ukraine, determining the average level of transparency of Ukrainian business, finding ways and developing measures to increase the level of transparency of Ukrainian companies.

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Діагностика транспарентності банківських установ України за допомогою методів багатовимірного аналізу

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Анотація. У зв'язку з недосконалим станом трансформаційних перетворень в фінансовій системі України та банківському секторі, наявна стійка тенденція до збільшення кількості фінансово неспроможних підприємств у різних галузях; особливо це стосується банківського ринку, де за останні роки відбулися досить значні зміни якісного та кількісного характеру. Метою дослідження є вивчення проблеми управління діяльності банківських установ за допомогою діагностики рівня транспарентності їх діяльності. Методологія дослідження полягає у формуванні системи показників оцінки рівня транспарентності діяльності суб'єктів господарювання, оцінювання рівня прямого впливу на рівень транспарентності, здійсненні класифікації суб'єктів господарювання за дворівневою системою факторів впливу на транспарентність. Заключним етапом методології є позиціювання банків за рівнем транспарентності для формулювання напрямів удосконалення політики управління транспарентністю. Поєднання методів багатовимірного аналізу, а саме прикладних економетричних методів, кластерного та дисперсійного аналізу, дозволяє класифікувати суб'єкти господарювання за рівнем транспарентності з урахуванням диференціації. Результатом проведеної диференціації є матриця позиціювання банківських установ за рівнем транспарентності за дворівневою системою факторів. Запропонований науково-методичний підхід до розрахунку рівня транспарентності суб'єкта господарювання, а саме банківських установ, що включає в себе, крім фінансового блоку, інші критерії, дозволяє набагато ширше дослідити стан діяльності суб'єкта господарювання. Використання цього науково-методичного підходу сприяє зниженню рівня інформаційної асиметрії, підвищенню гнучкості реакції суб'єкта господарювання на зовнішні шоки, що підвищує довіру до суб'єктів господарювання, поліпшує їх ділову репутацію та неодмінно відображається на фінансових показниках. Позитивні покращення в фінансових показниках окремих суб'єктів господарювання, підвищення рівня гнучкості та довіри до них сприятимуть підвищенню рівня транспарентності фінансових потоків, які переміщуються в країні

Ключові слова: асиметрія, банк, прозорість, суб'єкт господарювання, фінансові потоки

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Credit Risk Management: Marketing Segmentation, Modeling, Accounting, Analysis and Audit

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Abstract. The relevance of the research is determined by the urgency of implementing the systems of credit risk management in bank activities based on the international accounting and reporting standards. The high level of complexity of the mentioned problem is related to a significant number of credit market segments and a variety of credit forms. The aim of the research paper is to identify the risk level of individual segments in the loan portfolio at the microeconomic level taking into account macroeconomic factors. The research methods used to identify the credit risk are migration matrices, nonlinear approximation, correlation-regression analysis, statistical distributions, and forecasting. The main research results are as follows: credit segmentation of the loan portfolio was performed, a matrix of credit risk sources was constructed, default probability and default losses were quantified to reflect the expected credit losses in accounting, and the audit of construction of credit risk models was performed. The significance of the research results is determined by the possibility to measure the factors of non-stable macroeconomic situation in Ukraine while estimating the risks of functioning of banking establishments. The proposed approaches to solving the problem of credit risk management allow decreasing the volume of non-operating credits and increasing the profitability of the loan portfolio of a bank. It can be considered that the merits of the research are determining the causal relations between the separate components of credit risk, which can be effectively used to neutralize and decrease them. The emphasis was made on the tools of credit risk management represented by marketing segmentation, modeling, accounting, analysis, and audit. The prospects of further studies include clarification of the methodical approaches to credit risk management in part of the separate market segments

Keywords: bank, reporting standards, loan, risk, migration matrices, control, market, forecasting

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INTRODUCTION

Risks are the category inherent in all spheres of human life and society in general. For banking institutions, they are an integral attribute of almost all transactions, mostly active, as well as of providing services to customers and making agreements with counterparties. In the system of banking risks, credit risk is most significant taking into account the great share of loans in the structure of assets and in the formation of income of banking institutions (both interest and commission). For self-insurance against credit risks, banks form reserves for possible losses, which are recorded in contractual accounts, reducing the initial cost of loans. The procedure for credit risks calculation in Ukraine has seen a complex evolutionary development – from their strict regulation, establishment of mandatory rules for loans classification, determining specific levels of creating reserves to assess the probable losses based on the internal models.

The interest in credit risk management is growing under conditions of implementing by Ukrainian banks the International Financial Reporting Standard 9 Financial Instruments (IFRS 9) (2022), which determines the mandatory nature of modeling to forecast expected credit losses, costs of financial instruments and risky state of credit institutions and investment companies. The complexity of the problem is determined by a significant number of segments of the credit market, the variety of forms of credit, significant differences between consumers – borrowers, the motives for their purchase and behavior.

The problems of credit risk management are the object of research for many scientists. Their views can be grouped as follows: the influence of crises on the level of credit risks was revealed by M. Bofondi *et al.* (2018). The approaches to the management of the systemic aspects of credit risks were developed by such scientists as A. Clements & Y. Liao (2020), A. Kabundi & F. De Simone (2020), J. Kolari *et al.* (2020), A. Zhang *et al.* (2020). The specific features of manifestation of credit risk in certain countries of the world were explored by E. Nedumparambil & A. Bhandari (2020). The models for assessing credit risks as a particular case of the models of risk management are studied by T. Kosova *et al.* (2021). They formalized the content and the purpose, requirements for the information base and the methods for their construction, approaches for their description, practical application, and validation. Special attention is paid to the assessment of the model risk which will contribute to an increase in the quality of the models of credit risk and their adequate application.

The marketing aspects of credit risk management were emphasized by E. Webb & S. Shu (2018), the influence of borrowers' default on the level of credit risk of banking institutions was studied by B. Gopalakrishnan & S. Mohapatra (2020). Estimation of credit risks in agriculture in terms of natural and climatic conditions is rather specific, which was outlined in papers by O. Laktionova *et al.* (2019). The important scientific outcome is the contribution of the authors who explore the influence of the openness of economic systems, liquidity, the innovative component on the level of credit risks (Bui & Bui, 2020; Costello, 2020; Ganushchak-Efimenko *et al.* 2020).

A considerable role in understanding the causes and effects of banking crises under the national conditions belongs to the research by Barna, & Ruschyshyn (2020), in which it is stated that solving the problem of the stabilization of the national economy is complicated by the lack of the banking system that is stable enough to external and internal risks and threats, financial and economic shocks. To decrease financial risks of bank loans, it is proposed that systemic reforms should be based on effective decreasing the discount rate of the NBU, which should be accompanied by strengthening the protection of lenders' rights, de-shadowing, de-offshorization of economy, an increase in the level of capital transparency and solvency of the corporative sector, development of the mortgage market and real estate market, etc. The article by national researchers Sus & Onyshchuk (2019) deals with the influence of the activity of state banks on the risks of the banking system. The risk decreasing factor is a high part of their own capital in total capitalization, at the same time, the leadership of the state banks in the composition and the structure of the deposit portfolio of individuals increases the risk of the burden on the Deposit Guarantee Fund for individuals in case they are recognized insolvent.

Highly estimating the scientific outcome of the above-mentioned authors, it should be acknowledged that the problems of using specific tools, represented by marketing segmentation, modeling, accounting, were not explored enough. The problem under consideration is of interest to science as it explains the dependence of Probability of Default on Loss Given Default. The value of the obtained results for business is the development of the tools for increasing the profitability of the equity capital: for borrowers – an increase of the credit worthiness assessment, for banks – a decrease in losses from borrowers' default.

The scientific problem causes the need to clarify approaches to identification of the sources of risk for separate segments of the loan portfolio at the microeconomic level under condition of universal banking institution, which must be considered to forecast expected credit losses.

The purpose of the paper is to identify the tools of credit risk management: marketing segmentation, modeling, accounting, analysis, and audit.

The objects of the present research are: credit risk management, marketing segmentation, modeling, accounting, credit organizations and their clients, exemplified as corporate enterprises, leasing companies, and households. The research objects include creditworthiness of borrowers, assessment of default probability,

loss given default and forecasting expected credit losses. The research subject lies within the area of credit risk management, financial relations of banks and their customers, marketing segmentation of borrowers by the loan type (commercial, consumer, mortgage loans; leasing; overdrafts).

LITERATURE REVIEW

The problems of multidimensional credit risk management determine the interdependence of its studying at the macro- and microeconomic level from the standpoint of prudential regulation, the realization of business interests of banking institutions and meeting the credit needs of their customers. The main segments of the credit market are bank loan and trade finance. The tools for reducing the risk of the trade finance are bonds and exchange bills (Laktionova *et al.*, 2019). When it comes to crediting innovative projects by a bank, it is reasonable to take into account the risks of their implementation and to use the optimization models of investment management (Ganushchak-Efimenko *et al.*, 2020). The results obtained by Gopalakrishnan & Mohapatra (2020) prove "that a stronger insolvency regime moderates the adverse effects of economic shocks on firms' default risk". According to classical theory of asset pricing, there is a direct relationship between risk and return, and credit risk is measured by credit ratings (Nedumparambil & Bhandari, 2020).

The number of losses from the bank lending activities is determined by the systemic risk and individual risk of borrowers. Development of a structural autoregressive model indicates a systemic risk increase in the banking sector of euro, as well as vulnerability increase of the banking sector due to the spread of negative influences (Kabundi & De Simone, 2020). For example, in the context of the European sovereign debt crisis in 2011, credit restrictions on Italian banks were tougher than those on foreign banks, which suffered less from the sovereign debt crisis, but the credit market had a cumulative deficit (Bofondi *et al.*, 2018).

An increase in the transparency of banking systems could compensate the non-linear impact of financial market integration, reduce systemic risk, as it opens the channel of market discipline, which stabilizes the activities of banking institutions (Bui & Bui, 2020). On the contrary, the level of systemic risk objectively increases in the context of financial crises, shock changes in macroeconomic parameters, sharp depreciation of national currencies and the development of the inflationary spiral (Zhang *et al.*, 2020). The assessment of systemic risk is based on loss of equity, namely: systemic expected shortfall, marginal expected shortfall and delta conditional value at risk (Kolari *et al.*, 2020). Based on these indicators, the risk rating of financial institutions is calculated. Banks with the highest rating are toxic in terms of the spread of crisis and the multiplication of financial risks.

The systemic risk of separate companies is significantly influenced by information and news concerning the events related to an economic agent at the level of the world economy, economy of a country, industry, region, etc. (Clements & Liao, 2020). Shocks of the banking sector are transmitted to the corporate economy by reducing the volume of bank lending, appearance of a lack of liquidity among customers. The opposite effect is manifested in the deterioration of the quality of a loan portfolio, an increase in borrowers' defaults and the unemployment rate (Costello, 2020). Credit constraints of households are affected by the level of their income, consumption, and the borrower's status of being unemployed.

The analysis of the marketing behavior of consumers – individuals (Webb & Shu, 2018) examine how perceived similarity between sequential risks affects individuals' risk-taking intentions. The results demonstrate that the similarity structures that exist between risks have a significant effect on risk-taking preferences in dynamic choice settings. Adapting these provisions to the area of consumer lending, it is possible to assume that the more experience of this kind is gained, the higher the borrower's tendency to take credit risk will be. Mortgage risk is regulated by the dependence of the interest rate of a mortgage loan on its amount. An increase in the availability of mortgages has been influenced by the deregulation of the mortgage market and the use of securitized lending as a tool for risk redistribution.

Each country has its own institutional specific features of management of credit risks of banking institutions. Chernenko *et al.* (2020) include in the characteristics of the banking system the parameters of its liquidity and financial stability, a sufficient capitalization level, profitability, protection from internal and external risks and threats, financial and economic security, adaptability to the development of the global and macroeconomic environment. Sus *et al.* (2020) acknowledge that the guarantee of successful risk management is the existence of the adequate banking capital, in other words, meeting the mandatory economic standards of regulatory capital. The scientific community, specifically, Zaburanna *et al.* (2020), explore the problems of identification and management of systemic risks in the bank sector. Thus, the specialization of banks in servicing separate groups of clients requires to intensify the management of assets, credit risks, to perform diversification in resources distribution, special control over high-risk credit operations, to form the reserves for possible loan portfolio depreciation based on the international standards, etc.

MATERIALS AND METHODS

The methodology of the research is based on the theory of credit risk management, implementation of more effective methods of its evaluation, application of more

transparent and effective procedures for checking the solvency and creditworthiness of borrowers, including those taking into account the experience of foreign banks, systematized by Bodnar *et al.* (2019).

The period of the research covers five years (2017-2021). The information was accumulated on a monthly basis, with each target variable having 60 observations. The sources of analysis were: in terms of macroeconomic indicators – official reporting materials of the State Statistics Service of Ukraine and the National Bank of Ukraine; in terms of microeconomic indicators – the accounting system of the banking institution, default statistics of borrowers, the actual data on losses of the banking institution from loans impairment. Such methods as migration matrices – for forecasting PD (probability of default), non-linear approximation – for prediction of LGD (loss given default); correlation-regression analysis and statistical distributions – to determine the dependence of historical PD and LGD segments of the bank's loan portfolio on macroeconomic indicators, were used in the research. Financial Instruments (IFRS 9, 2022) does not contain a clear definition of default and delegates the establishment of its criteria to the organization that performs credit risk management. For its current assessment, the sign of default is a delay in financial assets: for banks – a 30-day delay, for legal entities and individuals – a 90-day delay; the concept of expected credit losses provides a net default period of 12 months. The research methods also include the evaluation of risk level of individual segments in the loan portfolio at the microeconomic level with regard to macroeconomic factors and designing a matrix of risk sources that must be taken into account in the preliminary, subsequent assessment of credit risk and its forecasting.

Modeling of credit risk of a banking institution is performed for the purposes of reflection of loan portfolio impairment in accounting in accordance with National Bank of Ukraine (2016) bas ed on the forecast calculations of the PD and LGD. The basic formula for the magnitude of Credit Risk (CR) is:

$$CR=PD*LGD*EAD \quad (1)$$

where PD – Probability of Default; LGD – Loss Given Default; EAD – Exposure at Default.

The main stages of credit risk modeling are: marketing segmentation of a loan portfolio; identification of historical PD for segments; formation of migration matrices; selection of macroeconomic factors that are closely correlated with historical PD; constructing a correlation-regression model of dependence of historical PD on macro-factors; checking the level of its adequacy; search for the forecast values of macro-factors for 12, 24 and 36 months according to three scenarios (pessimistic, baseline, optimistic) with determining the probability coefficient, as well as the resulting indicator – forecasted PD.

RESULTS AND DISCUSSION

The level of credit risk of the national banks is extremely high. It influences negatively the stability of functioning of the entire banking system and the country's economy as a whole due to the crisis phenomena in the economy, low solvency of the population, a high level of the actual (effective) interest rate for credits. The adequate evaluation of credit risk allows forming the necessary reserves for possible losses and protecting a bank from the loss of its own capital and from the risk of the violation of the necessary economic rules through the problem and bad loans. K.L. Larionova & T.V. Donchenko (2020) express the reasonable thought that a high level of the latter is a result of the credit expansion of the previous years, when the standards of evaluation of borrowers' solvency were low and the lenders' rights were not protected enough.

To enhance the situation, the research that includes the collection of statistical material, formation of migration matrices, construction of correlation-regressive models and their interpretation was performed.

The marketing segmentation of a loan portfolio is carried out on a hierarchical basis. The two main segments are loans to corporate business and loans to retail business. The first segment includes auto leasing, loans and guarantees, overdraft and factoring, the second segment includes consumer loans, cash loans, car loans, credit cards and overdrafts, mortgage loans. The mortgage loans are divided into loans in national and foreign currency.

The actual level of PD is determined based on the annual matrices of migration of the number of credit agreements differentiated by risk groups (group 1 – the lowest risk, group 5 – default). The purpose of their construction is to determine the probability of a client's movement between risk groups. The cells of the matrix are filled according to the principle: vertically – the number of the client's group at the start, horizontally – the number of the client's group at the finish.

Statistical studies have shown that the following factors have a close correlation with historical PDs for particular segments of a loan portfolio (Table 1):

***Table 1**. Import duty rates for certain Ukrainian goods when imported to the EU*

Number in order	Loan portfolio segment: macroeconomic factors of credit risk (correlation coefficient)	Symbol	Forecast period in months	Forecasted PD, %/Probability coefficient			
				Pessimistic/0.25	Baseline/0.5	Optimistic/0.25	Weighed
1	Loans to corporate business	LCB					
1.1	Auto leasing: – the number of registered unemployed, in % of the working-age population (0.5978)	AL	12	5.09	4.76	4.11	4.68
			24	5.61	4.98	4.49	5.02
			36	6.13	5.44	4.97	5.50
1.2	Loans and guarantees: – actual Gross Domestic Product (-0.6319)	LG	12	7.30	6.23	5.97	6.43
			24	7.78	6.33	5.99	6.61
			36	7.89	6.42	6.17	6.73
1.3	Overdraft and factoring: – weighted average rate of UAH/USD in the interbank market (0.7090)	OvF	12	8.19	7.45	6.83	7.48
			24	8.23	8.17	7.14	7.93
			36	9.12	8.63	7.92	8.58
2	Loans to retail business	LRB					
2.1	Consumer loans: basic consumer price index (cumulatively to the corresponding period of the previous year, %) (0.5919)	CL	12	12.36	11.63	11.12	11.69
			24	13.42	12.52	12.24	12.68
			36	14.60	13.83	12.76	13.76
2.2	Cash loans: – basic consumer price index (cumulatively to the corresponding period of the previous year, %) (0.6863)	Cash_L	12	18.18	17.45	16.78	17.47
			24	19.43	18.31	17.56	18.40
			36	20.93	19.58	18.66	19.69
2.3	Car loans: index of real wages (to the corresponding month of the previous year, %) (-0.7113)	Car_L	12	10.12	9.45	8.13	9.29
			24	11.09	10.33	8.56	10.08
			36	11.97	10.78	9.02	10.64
2.4	Credit cards and overdrafts: – the number of registered unemployed, in % of the working age population (0.6760)	Cards_O	12	6.17	6.03	5.89	6.03
			24	6.26	6.08	5.95	6.09
			36	6.32	6.21	6.07	6.20
2.5	Mortgage loans	ML					
2.5.1	– in national currency: index of real wages (to the corresponding month of the previous year, %) (-0.6908)	ML_NC	12	14.07	12.56	10.11	12.33
			24	16.27	14.78	13.14	14.74
			36	18.92	16.94	15.62	17.11
2.5.2	in foreign currency: – weighted average rate of UAH/USD in the interbank market (0.7498)	ML_FC	12	24.54	16.65	12.17	17.50
			24	30.76	25.87	17.18	24.92
			36	40.17	31.17	24.16	31.67

***Source:** authors' calculation (National Bank of Ukraine, 2022; State Statistics Service of Ukraine, 2022)*

– the number of registered unemployed, in % of the working-age population – correlation coefficient with AL and Cards O is 0.5978 and 0.6760, respectively. The relation is direct because a deteriorating situation in the labor market stimulates the growth of default loans;

– actual Gross Domestic Product has an inverse correlation coefficient (-0.6319) with the LG segment as an increase in the level of defaults occurred against the background of reduced production volumes;

– weighted average rate of UAH/USD in the interbank market has direct correlation with the OvF and ML_FC segments as evidenced by correlation coefficients of 0.7090 and 0.7498, respectively. The logic is as follows: the devaluation of UAH leads to an increase in defaults, because, firstly, corporate clients have a shortage of funds, which leads to an increase in their demand for rapid fundraising in the form of overdrafts and factoring; secondly, retail clients have an increasing debt burden on mortgage holders who finance it through loans in foreign currency;

– basic consumer price index (cumulatively to the corresponding period of the previous year, %) has direct correlation with the segment s CL and Cash L, and correlation coefficients are 0.5919 and 0.6863, respectively. It can be explained from the economic standpoint by the deterioration of the welfare of borrowers – individuals under conditions of rising prices, which complicates their repayment of loans and leads to defaults;

– index of real wages (to the corresponding month of the previous year, %) has a close inverse correlation with the segments Car_L and ML_NC; the corresponding coefficients are (-0.7113) and (-0.6908). This can be explained by the reduction of sources of repayment of car loans and mortgages in terms of declining incomes, which leads to an increase in defaults.

The results of the study are summarized in the matrix (Table 2), which allows identifying clearly the relationship between macro-factors and a loan portfolio segment.

***Table 2**. The matrix of risk sources for a loan portfolio segment*

Loan portfolio segment		Macro-factors			
	Number of registered unemployed	Basic consumer price index	Weighted average rate of UAH/USD	Actual gross Ukrainian product	Real wages
Auto leasing	X				
Credit cards and overdrafts					
Consumer loans		X			
Cash loans					
Overdraft and factoring			X		
Mortgage loans in foreign currency					
Loans and guarantees				X	
Car loans					X
Mortgage loans in national currency					

***Source:** authors' calculation (National Bank of Ukraine, 2022; State Statistics Service of Ukraine, 2022)*

To calculate Forecast PD Weighed, the Probability coefficient was determined: 0.25 – for the pessimistic and optimistic scenarios, 0.5 – for the baseline scenario. The levels of Forecast PD increase as they move from the 12-month horizon to the 36-month horizon and decrease from the pessimistic to optimistic scenarios. According to the results of the assessment of forecast PD for the segments of the loan portfolio (Table 1), their rating places were determined as credit risk decreased for ranges in %: ML_FC (17.50-31.67), Cash_L (17.47-19.69), ML_NC (12.33-17.11), CL (11.69-13.76), Car_L (9.29-10.64), OvF (7.48-8.58), LG (6.43- 6.73), Cards_O (6.03-6.20), AL (4.68-5.50). In general, the PD of loans to retail business is higher compared to those to corporate business. The bank bears the greatest risks when giving mortgage loans in foreign currency and cash loans to borrowers – individuals. The risks in auto leasing transactions between the bank and corporate clients are the lowest because the credit object and the collateral match.

The LGD model is based on the RR (Recovery Rate) indicator as the ratio of the amount of repayment of default loans to the number of debts on default loans for each Month After Default (MAD) (IFRS 9, 2022). By constructing a cumulative curve (RRcum), it was determined that the effective horizon of collecting payments to repay overdue loans is 36 months. After

this period, a monthly increase in the return of funds becomes insignificant. To smooth out the time fluctuations, the RRcum index and the time factor x are linearized according to the formulas:

$$Y=ln(-ln(1-RRcum_t)) \quad (2)$$

$$x=ln(t\ in\ years) \quad (3)$$

Based on the correlation-regression model design, the parameters of linear function $Y=x+b$ are determined, and the scale factor is calculated from formula (4). The above-mentioned indicators are presented in Table 3.

$$\lambda = e^{\frac{-a}{b}} \quad (4)$$

***Table 3**. Results of calculation of RR and LGD indicators for loan portfolio segments*

Number in order	Symbol	RR model				LGD model		Maximum	
		Parameters		Coefficients		Equation	R^2	LGD	PD*LGD
		a	B	γ	R^2				
1	LCB								
1.1	AL	0.340	0.4369	0.4588	0.8593	y=-0.136ln(x)+0.5946	0.9902	0.058	0.0032
1.2	LG	-1,221	0.2132	307,34	0.7799	y=-0.053ln(x)+0.8326	0.9935	0.612	0.0412
1.3	OvF	-1,191	0.2291	180,78	0.7802	y=-0.058ln(x)+0.8349	0.9929	0.591	0.0507
2	LRB								
2.1	CL	-1,498	0.4062	39,949	0.6734	y=-0.093ln(x)+0.9534	0.9767	0.554	0.0762
2.2	Cash_L	-1,166	0.2411	125,82	0.6763	y=-0.063ln(x)+0.8364	0.9925	0.574	0.1130
2.3	Car_L	-0.958	0.4644	7,871	0.8302	y=-0.144ln(x)+0.9162	0.9867	0.312	0.0332
2.4	Cards_O	-1,326	0.5454	11,374	0.9161	y=-0.148ln(x)+1,0069	0.9719	0.376	0.0233
2.5	ML								
2.5.1	ML_NC	-1,493	0.5088	18,808	0.8872	y=-0.124ln(x)+1,0014	0.9687	0.469	0.0802
2.5.2	ML_FC	-1,577	0.5376	18,773	0.9735	y=-0.127ln(x)+1.02	0.964	0.474	0.1501

***Source:** authors' calculation (National Bank of Ukraine, 2022; State Statistics Service of Ukraine, 2022)*

From the mathematical point of view, a-parameter reflects the inclination angle of the straight line, constructed on the linearized indicators RR and MAD and varies significantly from (-1,577) in the segment ML_FC to 0,340 in the segment AL; from the economic point of view, it significantly affects LGD, which are respectively 0.474 and 0.058, in other words, an increase in a-parameter causes a decrease in LGD. As a mathematical magnitude, b-parameter reflects the height of location of the straight line above the X axis, the range of its variation is smaller – from 0.2132 for the LG segment to 0.5454 for the Cards_O segment. The LGD values are 0.612 and 0.376, respectively.

Thus, an increase in b-parameter is accompanied by a decrease in LGD. The generalizing indicator related to the nature of loan repayment is λ-coefficient. Its minimum value (0.4588) corresponds to the minimum value of LGD (0.058) for the AL segment, the maximum value (307.34) corresponds to the maximum value of LGD (0.612) for the LG segment. The value of multiple coefficients of determination R^2 of the linear function reflects the degree of compliance with the exponential law of receipts in loan repayment RR: it is the lowest (about 0.67) for segments CL and Cash_L, it is the highest for ML_FC (0.9735). Approximation of R^2 to 1 means an increase in the predictive power of the RR model.

The RR is approximated according to the formula:

$$RRcum_{apr} = \left(RR_{fact}, if\ MAD \geq 36; 1 - e - (\frac{MAD/12}{\lambda})^b\right) \quad (5)$$

The LGD value is determined using the following model:

$$LGD = 1 - \max(RRcum_{fact}; RRcum_{apr}) \quad (6)$$

LGD models that are constructed based on RR-models are represented by logarithmic functions. The accuracy of their approximation is much higher because R^2 is in the range of 0.964-0.9935. The generalizing indicator of risk is the product of PD and LGD. Its lowest level is characteristic of the following segments: AL (0.0032), Cards_O (0.0233), Car_L (0.0332), its highest level is in the segments Cash_L (0.1130) and ML_FC (0.1501).

The final stage of credit risk management is taking measures for their immunization, reflection of the impairment accounting provisions in accordance with Financial Instruments (IFRS 9, 2022) in accounting and reporting, as well as undergoing internal and external audit procedures.

The results of forecasting PD and LGD indicators for loan portfolio segments are used to calculate expected credit losses based on collective assessment of three Stages. Stage 1 includes loans, for which there have been no significant changes in the migration matrix since the initial recognition, and 12-month expected credit losses are calculated for them. Stage 2 and Stage 3 are used to calculate impairment accounting provisions for the entire period until the loan is repaid. The criterion for referring a loan to Stage 2 is a significant deterioration in credit risk in the absence of default. Stage 3 includes default loans, as well as Purchased or Originated Credit Impaired (POCI).

The models that a bank uses to calculate credit impairment losses can be developed by the bank independently or by third parties, including auditing and consulting companies. They must be approved by the highest collegial bodies of a bank, undergo annual validation, preliminary and subsequent checks on the application of the internal audit service. The order of reflection of impairment losses and provisions of the loan portfolio segment in accounting is a mandatory subject of independent audit in the process of annual confirmation of the bank financial statements. In this case, if an audit company developed models of credit risk management or performed their validation, it has no right to audit financial reporting, according to the principle of ensuring independence of external control.

The results of the research carried out in the part of the evaluation of credit risks of the banking institutions of Ukraine are the development of the scientific ideas of a whole range of the national researchers. In particular, banking lending is considered through the prism of a multi-component hierarchical model, proposed by O.Ye. Hudz (2019) and used for marketing segmentation of the loan portfolio. Credit risk management is considered as a continuous process of the formation, observation, regulation and optimization of this risk. To construct this model, the idea of the life cycle of credit risk that was put forward by Moroz & Seletska (2019) was used for real-time evaluation, monitoring, stress-testing, and visualization of the data and facilities for business analysts and marketers.

When developing the methodological approach to forecasting credit risks, the advanced European experience of banking and the innovative methods of risk management systematized by K.S. Zatvornytskyi (2019) was used. The performed calculations are oriented to the protection of a banking institution from credit risks, their minimization, decreasing the volumes of non-operating credits, their restructuring based on the methods proposed by M.H. Marych *et al*. (2019). The major credit evaluated risk is the concentration risk, to which Moroz & Seletska (2019) attribute the risk of considerable concentration of credit losses related to the existence in the bank of a considerable volume of credit exposition of separate clients or a group of clients, connected in terms of organization and capital and sensitive to the changes in the common risk factors, first of all, economic, industrial, geographical, relations between economic entities. The scientific outcome of the paper is the synthesis of micro- and macroeconomic approach to the evaluation of credit risk. In particular, the factors separated by Shulha & Belianko (2019) (GDP, inflation and unemployment rates, currency exchange rate) were used for its correlation-regressive modelling and supplemented by the new ones (index of actual income of population, volume of construction and assembly works, index of producers' prices). Different approaches taking into account the specific features of the retail crediting market and credit scoring, systematized by Z.V. Yurynets (2019), were used to construct the credit models of risks of corporative and private borrowers. The experience of Pavliuk & Petrovskyi (2020) in terms of the construction of the behavioral statistical models of credit risks of retail borrowers (behavioral scoring), which is a modern-day tool of monitoring and management of limits was used to achieve the enhanced productivity of the banking business. The development of the models of behavioral scoring can be based on various quantitative modeling techniques, depending on the existence of sufficient volume of qualitative data and developer's knowledge. At the same time, behavioral models require much more attention and time compared to application data due to the necessity of check a greater number of potentially useful predictors. To assess the adequacy of econometric models of credit risk, the approaches proposed by A.V. Kolodiichuk (2020) were applied. The developed models may be used for stress testing of credit risks that L.V. Kuznietsova (2019) defines of a key tool of modern risk management and strategic planning.

Thus, the study revealed a phenomenon associated with the inverse relation of PD and LGD. The prospects for further research are to harmonize the methods for assessing objective factors of counterparty risk that affect PD and subjective factors that determine the state of debt service (LGD).

CONCLUSIONS

The article formalizes some stages of credit risk management based on marketing segmentation of a loan portfolio, quantification of probability of default and loss given default, use of the obtained forecast indicators to reflect expected credit losses in accounting, as well as the audit of credit risk models. A matrix of credit risk sources was developed, which links macro factors with specific segments of a loan portfolio. It was established that the variation spread of indicators was: for

PD – 3.73 times on the horizon of up to 12 months; 5.76 times – on the horizon of up to 36 months; for LGD – 10.6 times, for their maximum product on the horizon of up to 36 months – 46.9 times.

The conducted research has the following benefits: for studies – the development of key skills in management, modeling, analysis, accounting and audit of credit risks, their differentiation for individual segments of a loan portfolio; for science – identification of macroeconomic factors – credit risk stimulators and its immunizers, which may become objects of regulatory influence of a bank; identification of inverse relation of PD and LGD, which requires harmonization of their calculation methods; for business – simplification of credit risk modeling procedures according to certain algorithms, reduction of complexity of calculations related to the identification of sources of credit risk for segments.

The obtained results will contribute to the rationalization of the processes of making credit decisions with regard to achieving the balance between the assessment of the financial state of a borrower and the guarantees of a credit agreement. Unlike the existing approaches, the proposed approaches make it possible to coordinate the estimation of the systemic and individual risk based on the marketing segmentation of borrowers. The designed methodical recommendations on modelling credit risk for the segments of a loan portfolio contribute to the harmonization of the institutional specific features of the credit activities in Ukraine and the requirements of the international standards of financial reporting. The proposed tools of credit risk management allow performing an adequate assessment of credit risks based on the construction of a complex of economic and mathematical models, their objective reflection in the accounting system and decreasing the losses of owners of banking institutions due to borrowers' default.

The prospects of further research are clarification of the methodical approaches to the evaluation of credit risks in particular marketing segments.

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Управління кредитними ризиками: сегментація маркетингу, моделювання, облік, аналіз та аудит

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Анотація. Актуальність дослідження зумовлена необхідністю впровадження банківськими установами систем управління кредитними ризиками на основі міжнародних стандартів бухгалтерського обліку та звітності, а складність проблеми пов'язана зі значною кількістю сегментів кредитного ринку та різноманітністю форм кредитування. Метою роботи є дослідження рівня ризику окремих сегментів кредитного портфеля на мікроекономічному рівні у зв'язку з макроекономічними факторами. Методи дослідження: матриці міграції, нелінійна апроксимація, кореляційно-регресійний аналіз, статистичні розподіли, прогнозування. Основні результати: проведено маркетингову сегментацію кредитного портфеля, побудовано матрицю джерел кредитного ризику, визначено кількісну оцінку ймовірності дефолту та збитків у разі дефолту для відображення в обліку очікуваних кредитних збитків, а також проведено аудит в частині побудови моделей кредитного ризику. Значущість результатів дослідження визначається можливістю вимірювання чинників нестабільної макроекономічної ситуації в Україні при оцінці ризиків функціонування банківських установ. Запропоновані підходи до вирішення проблеми управління кредитними ризиками дозволять зменшити обсяг непрацюючих кредитів та збільшити дохідність кредитного портфеля банків. Перевагами дослідження є визначення причинно-наслідкових зв'язків між окремими компонентами кредитного ризику, які можуть бути ефективно використані для їх нейтралізації та зниження. Акцент зроблено на інструменти управління кредитним ризиком, представлені маркетинговою сегментацією, моделюванням, обліком, аналізом і аудитом. Перспективами подальших досліджень визначено уточнення методичних підходів до оцінки кредитних ризиків у частині окремих маркетингових сегментів

Ключові слова: банк, стандарти звітності, кредит, ризик, міграційні матриці, контроль, ринок, прогнозування

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Reforming the Taxation of Agrarian Entrepreneurship (Case Study of Azerbaijan)

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Abstract. The relevance of the stated topic of study is determined by the fact that the bulk of tax revenue in transition economies comes from agrarian entrepreneurship. The purpose of the study was to develop practical recommendations that would resolve most of the issues in the agribusiness sector in transition economies. The key research methods are a qualitative combination of modelling, analogy, deduction, and induction, which allowed for a comparative characterisation and identification of the most effective options for reforms in the agricultural sector. It was determined that the creation of a favorable tax environment would contribute to increasing the efficiency of agrarian business, which in turn would lead to the improvement of basic economic indicators. It was established that over the past ten years, many positive changes have taken place in the tax sector of Azerbaijan, which have improved the overall efficiency of the country's tax system. This made it possible to increase the amount of income to the state budget of the country. Having analysed the experience of other countries and studied in more detail the advantages and disadvantages of the tax system in Azerbaijan, it became possible to provide key recommendations to improve performance in the area. The results of the study present reforms to improve the agricultural taxation system, which account for the socio-economic characteristics of Azerbaijan and can be used as recommendations in further studies aimed at improving the taxation of agribusiness. The impact of various reforms on the functioning of the tax system in light of the proposed changes was estimated. The results of this investigation have practical value for employees of the tax authorities of Azerbaijan and scientists who will continue studies in this regard

Keywords: agro-industrial complex, taxes, tax reform, agriculture, Azerbaijan, CIS

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INTRODUCTION

Taxation is one of the most important instruments of state policy. The tax system cannot effectively perform its functions for decades without any changes. Azerbaijan's tax system today is not perfect and requires global reform and a change in the key principles that underpin its operation. Therefore, at this stage, it is necessary to continue searching for new approaches that will improve the situation.

To facilitate this task, both positive and negative experiences of other countries were studied. This would provide new insights into the current issues and possible perspectives if certain tax policy instruments were to be applied. Since Azerbaijan became independent, the government has prioritised the agriculture sector. In particular, most of the small government loans that are issued through the National Entrepreneurship Support Fund were issued to agribusiness (Sadygov *et al*, 2020).

However, today the agrarian business has certain problems, especially with regard to taxation. As a result of the unfavourable tax regime in Azerbaijan, the agricultural sector is mainly engaged in production for domestic consumption, while at the same time reducing production for sale on the market. Thus, farms reduce their tax deductions (Aliislam, 2021).

Being the largest country in the South Caucasus, Azerbaijan is making some progress both in the economy and in the national legal framework (Doing Business in Azerbaijan, 2022). These developments range from significant changes in legislation, the creation of centralised real estate and movable property registries, the creation of e-government, the adoption of international financial reporting and accounting standards, the creation of special economic zones and industrial and technology parks along with the introduction of a one-stop shop for business registration, including the introduction of simplified procedures in obtaining work permits.

Today, the tax system, which is the basis for the country's economic and social development, is in a state of change. The main efforts are aimed at supporting small and medium-sized businesses, reducing parts of the "shadow economy", increasing tax revenues to the national budget, and improving the tax administration system. Already at this stage, the Azerbaijani government is taking progressive steps in the sphere of optimising the taxation system: non-residents working in Azerbaijan without obtaining a permanent establishment can apply for a provisional exemption or tax reduction for all types of income, including business profits, dividends, interest, and royalties (Taxation and investment in Azerbaijan, 2022).

The main issue with the previously conducted studies in the stated subject area was the lack of comprehensiveness of the investigation and provision of tangible solutions to remedy current issues. Scientific figures of the researchers M. Sadygov *et al*. (2020) have studied a wide list of issues related to the basic principles of the tax system, while also conducting an analysis of the origin and historical development of the taxation system.

The study by E. Kekchabaeva and G. Zhakupuva (2008) has analysed whether agribusinesses can count on state support and investment programs. Using the Azerbaijani Tax Code (2000), the key positions on which Azerbaijan's current tax policy is based have been derived. The study of N. Nizamzadet (2017) was analysed and the key recommendations in this area were highlighted. The thesis of Z. Guseinov (2016), which aims to study the current system of taxation in Azerbaijan, considered the functioning of modern tax policy and the tax system of the country and reviewed the tax system as a factor in improving the efficiency of the economy of the country under study. However, none of the aforementioned studies has provided a comprehensive analysis of possible reforms to Azerbaijan's tax policy and suggested options for addressing problematic aspects.

The main objective of this study is to identify modern mechanisms to optimise the taxation of agrarian entrepreneurs, using the experience of Azerbaijan. The results of the study can then be adapted and used to develop materials for further studies on other countries with similar levels of economic development.

MATERIALS AND METHODS

The methodological basis of the study is the fundamental provisions of the agricultural business taxation system. The qualitative combination of modern methods of system analysis in the investigation of agrarian business taxation with the analytical study of the legal basis for the functioning of agrarian structures allowed to identify the most promising solutions to the key problems of the agrarian sector. The methods used in this study were abstract to concrete, a combination of analysis and synthesis, the structural-systems approach, and the cause-effect method. Using the abstract to the concrete method, the key features of the taxation system were highlighted, and the key anchor points of the system were analysed. The system-structural approach made it possible to consider the functioning of the agricultural tax system in terms of the functioning of the state's economic system. The theory itself was built using historical and logical methods that are interdependent on each other. The historical method has been used to identify the basic principles of the tax sphere, which have been gradually shaped in these lands over the course of evolution. The logical method enabled parallels to be drawn with other countries that have emerged under similar conditions, while the method of structural relationships provided conclusions and concrete steps for improving the agricultural taxation system in Azerbaijan.

This study was conducted on the basis of a previously established theoretical and legal framework that

acts as a qualitative basis for all further investigations. The theoretical basis for this study consists of the results of studies carried out by a number of Azerbaijani and largely international academics focusing on a number of problematic issues related to the main challenges for agriculture and the key imperfections of the tax system.

The study of the theoretical framework is critical to all investigative efforts, regardless of whether quantitative, qualitative, or mixed methods are used. The presented study was carried out in three main stages.

The first stage of the research involved the preparation of a theoretical framework, which was subsequently used as the basic foundation for further investigations, and the examination of the documentary base. Additionally, contributions by researchers who have undisputed professional expertise in this matter have been employed. A conceptual framework was developed to narrow down the theoretical base and operationalise it. Thus, the theoretical framework sets the direction, and the conceptual framework outlines the path to be pursued to achieve the objectives set. The conceptual framework contributed to the development of hypotheses for investigation based on the theoretical basis and variables.

The second stage was an analytical study of the application of the key recommendations for improving the taxation system for agribusinesses. This stage included an analytical comparison of the findings with the results and conclusions of other academics engaged in the practical development of improvements in the taxation system. This contributes to expanding the perspective of studies on the tax laws of different countries.

The final stage of the study resulted in the formulation of the conclusions that summarise the findings and generally identify the main trends in tax legislation.

RESULTS AND DISCUSSION

In most countries, benefits for agricultural enterprises are provided in profit taxation. This practice is popular in Azerbaijan and Poland. In these countries, income received from agricultural activities is not subject to taxation. In Belarus, a preferential rate of 10% is applied to agricultural enterprises that receive profits from production and technical services (the general rate is 30%), while agricultural enterprises that sell their own production of crops, livestock, fishery, and apiculture do not have to pay certain categories of taxes. In Kyrgyzstan, the income tax is not paid by enterprises for which land is the main means of production and the only source of income. In Canada, however, it is possible to pay tax on the average profit for five years and apply a reduced rate of 12% (total – 29%) provided for small businesses and farms, while in France and Germany a number of reductions and exemptions are available, which reduce the amount of tax actually paid to 17% and in the Netherlands to 21.4% (Meshcheryakova, 1995). The main approaches to the design of the taxation system in different countries around the world are shown in Figure 1.

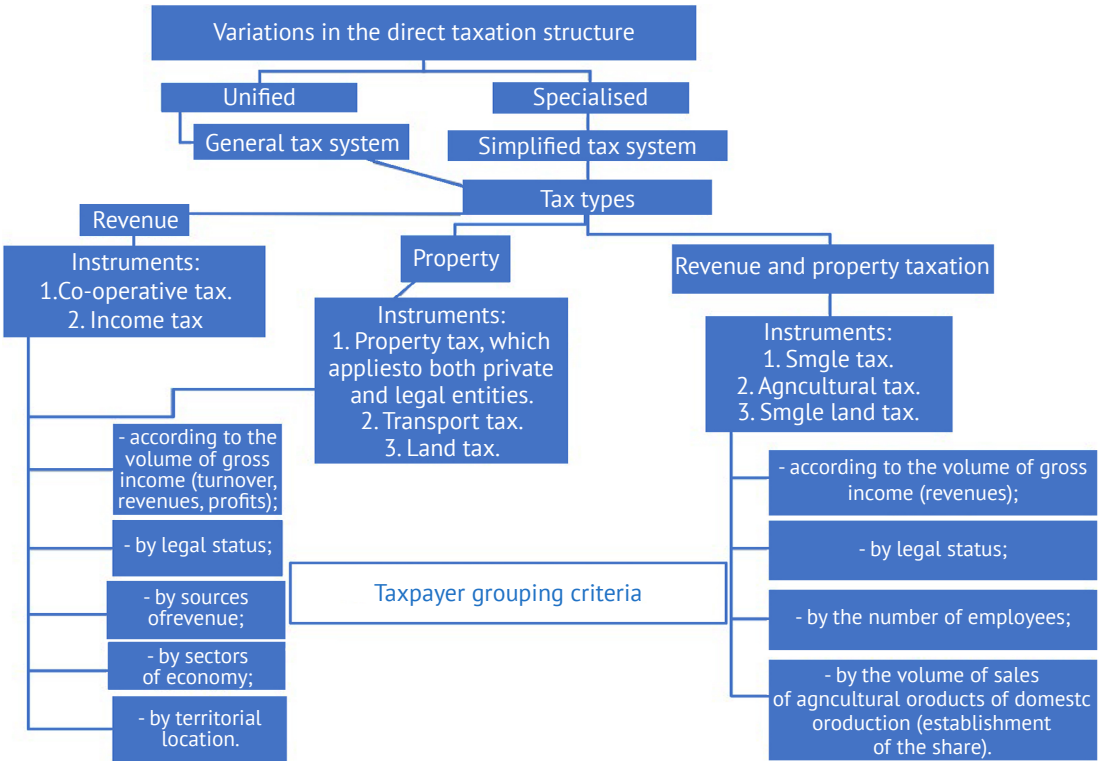

Figure 1. *The Key Concepts of the Agricultural Tax System Worldwide*

In the United States, the most important tax benefits for agriculture under the federal income tax are the averaging of income and the deduction of certain capital expenditures, and the accounting of certain gains from the sale of assets as capital gains. However, the greatest advantage of the US tax system can be considered a reduced farm tax. Most of the tax revenue comes from the provision of public services, including educational. This may account for the reduced tax rates per unit of land. All states have adopted a special assessment programme designed to reduce the amount that farmers are required to pay to the state. The most common type of programme is known as the "use-value assessment" whereby property taxes are based on some version of the hypothetical value of the land if it were to remain in agricultural use in perpetuity. This can provide significant property tax relief, lowering farm operating expenses. In 2021, with this valuation system, entrepreneurs were able to save around USD $59.7 million (Global food security index, 2021).

Under the current US tax structure, farm businesses can be taxed under federal individual income tax or corporate income tax. State-level tax treatment is the same as federal. According to research, in the US, instead of the average effective income tax rate of 17.2%, farms pay 13.9%, and medium-sized farms (those with gross cash farm income of between USD 350,000 and USD 1 million) benefit the most.

It is believed that in agriculture, land use taxes should be primary and only supplemented by profit tax. This situation is common in countries where agricultural production is borderline unprofitable. However, the experience of developed countries shows a reverse correlation – the main type of taxation in the agricultural sector is profit tax (corporate and personal), while land value tax within property taxes only complements tax on profit and serves the function of levelling the business environment for enterprises. Agriculture is a strategic sector for Azerbaijan. In 2021, 37% of the population was employed in this sector (Taxation and investment in Azerbaijan, 2022).

Currently, the total income tax rate in Azerbaijan is 20%. An additional 10% branch transfer tax applies to transfers of profits from the branch to the head office. The taxable base is net profit after taxation (Taxation and investment in Azerbaijan, 2022).

Land tax in Azerbaijan is USD 0.035 per unit of agricultural land used for intended or unintended purposes for irrigation, melioration, and other agricultural purposes, based on conditional units per hectare (Taxation in Agriculture in Azerbaijan, 2020).

The Global Food Security Index (GFSI) considers food affordability, availability, quality, and safety, along with natural resources and resilience, across 113 countries. In 2021, Azerbaijan ranked 56th on this list (Global food security index, 2021). A more efficient agricultural system would allow Azerbaijan to climb up to approximately the 30th position. The establishment of such a system cannot be achieved without an appropriate and motivating regional-specific tax policy. It is also important to recognise that agriculture generates the largest share of the profits of the country under review.

Value Added Tax (VAT) is only levied on surcharges applied to retail sales of agricultural products produced in Azerbaijan. From 1 January 2022, for 3 years, VAT is charged on the mark-up applied to the wholesale and retail sale of agricultural products (local and foreign origin). According to the latest amendments to the Tax Code, the following transactions are not subject to VAT:

1. Wheat import, flour, and bread production (for 7 years from January 1, 2017).

2. Sale of animal and poultry meat (for 4 years from January 1, 2020).

3. Sale of feed additives used in poultry farms (for 4 years from January 1, 2020), (Ivashchenko, 2007).

During the 2020 pandemic, the Azerbaijani government abolished the mandatory requirement to pay land and property taxes for a period of one year, and also reduced the level of income tax and insurance payments of companies, especially for those who suffered the most from the restrictions imposed as a result of the coronavirus pandemic (General overview of tax system in Azerbaijan, 2022). According to the data provided by the World Bank, the value added in agriculture (% of GDP) in Azerbaijan in 2021 amounted to 5.87% (Fig. 2).

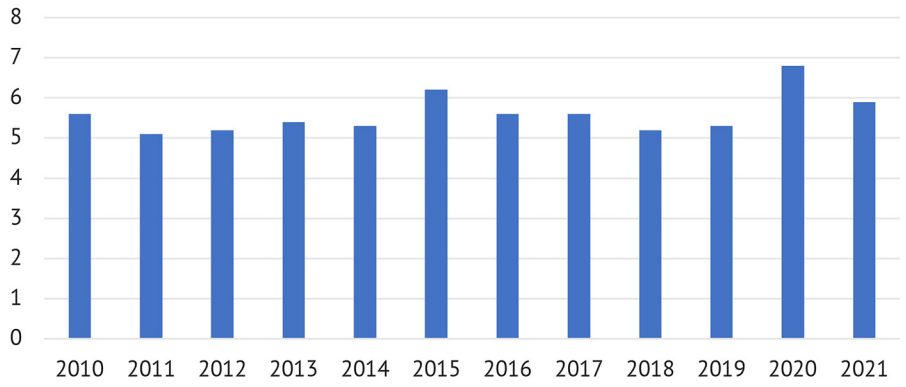

Figure 2. *Value added in agriculture (% of GDP) in Azerbaijan, 2010-2021*

In 2021, more than 45,000 farmers in Azerbaijan received seasonal or annual subsidies. These subsidies apply, according to the Agrarian Credit and Development Agency (AKIA), to an area of more than 82,000 hectares (Marketing research..., 2021). In addition to the above incentives, entrepreneurs can obtain an Investment Incentive Certificate, under which they will be exempt from paying taxes such as VAT (imports of production equipment by individuals and companies), property tax and land tax for 7 years (Doing Business in Azerbaijan, 2022).

However, despite various tax benefits, more than 52% of Azerbaijan's business continues to operate underground. Overall, direct subsidies have a negative impact on agricultural enterprises, as demonstrated in other countries (Bahl & Bird, 2008). Enterprises with and without subsidies are not on an equal footing. In the long term, this will preclude the creation of an efficient agribusiness sector that operates on free market principles. Direct subsidies include the actual cash flow to a particular enterprise. According to the author, it is much more effective to use an indirect subsidy tool. For example, investments in technology, infrastructure, education. This will improve the qualitative performance of agricultural enterprises. A negative aspect of the tax exemption is that some entrepreneurs, not wanting to pay the four per cent simplified tax, registered their business in regions where the simplified tax was half as much, complicating the accounting.

Azerbaijan's most promising sector is oil. However, when looking at other areas, according to the Doing business survey, companies consider agriculture (36%) and manufacturing (22%) to be the two most promising sectors in Azerbaijan in the next 5 years (Figure 3) (Doing Business in Azerbaijan, 2022).

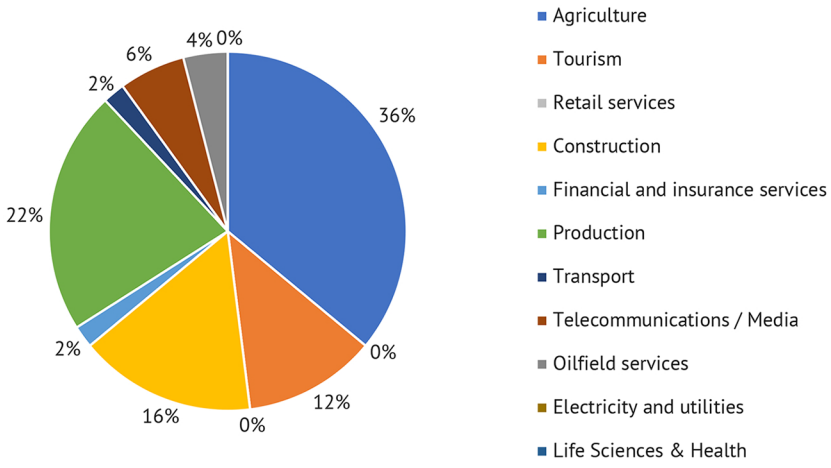

***Figure 3**. VThe most promising investment sectors for entrepreneurs in Azerbaijan*
***Source:** Doing Business in Azerbaijan (2022)*

According to reports from government agencies in Azerbaijan, the issue of abuse of tax exemptions is becoming more and more acute. Thus, over 90% of taxpayers are payers of the simplified tax (State Tax Service, 2022). The most productive reforms of Azerbaijan's agricultural sector would be:

1. Optimisation of the national system of direct taxation by applying a differentiated approach to the subject composition of taxpayers. Various factors should be accounted for when constructing a taxation system, especially the dynamically changing market and the entrepreneurs who follow it. Linear or preferential taxation systems are becoming obsolete.
2. Establishment of a non-taxable minimum in the taxation of income from agricultural activities.
3. Granting the land tax the status of local.
4. Creation of a fiscal cadastre to record the value of real-estate and land sold. This will avoid using different schemes.
5. Introduction of a tax on the misuse of agricultural land. This will motivate agricultural entrepreneurs to develop their businesses in this particular area.
6. Maintaining a simplified taxation system for small agricultural firms. It is very important to provide the greatest number of benefits to small businesses and allow them to get the start-up base they need.
7. Establishment of time limits on the duration of tax exemptions. This will allow agribusinesses to make efforts to develop with further increases in tax deductions.
8. Establishment of control over the use of benefits by agricultural enterprises to avoid fraudulent use at the expense of the state.

Applying the proposals provided will contribute to an even distribution of the tax burden and encourage the further development of agricultural enterprises.

The tax system is a complex ecosystem, the effective operation of which depends on a large number of variables. In developing countries, the agro-industrial complex is a key sector of the economy. Tax policy affects the competitiveness of agriculture by influencing the level of farm income, investment in development and technology, the use of labour and other inputs, and the adoption of the latest agricultural practices. For example, tax

systems can encourage investment in farms by reducing taxable income through depreciation allowances. Revenue levels for income, property and land can affect structural change, while differential tax rates for specific agricultural activities can affect the whole agribusiness system.

Tax policy is often used as a lever to influence entrepreneurial behaviour in the agricultural sector, affecting producer income, investment, and innovation. The success of agribusiness in the long term depends on how effective the tax policy will be built. An analysis of the Tax Code of the Republic of Azerbaijan (2000) showed a lack of a comprehensive approach to the regulation of agricultural taxation. Moreover, it has not been updated timely to reflect new realities and new government bills, unlike Russia, where a flat tax has been in place since 2002.

M. Sadygov *et al*. (2020) consider in detail the history of the formation and development of the tax system of Azerbaijan, along with the key concepts and principles of its functioning. However, they do not address the problems and do not propose concrete solutions to them, recognising the influence of socio-political factors.

Studies by global consultancy and auditing companies, as well as internationally recognised indices that report on the functioning of the agricultural sector, do not analyse in detail the issue of tax efficiency, or provide options to address the problems at hand. These companies do not delve in detail into the historical and economic specifics of the agricultural sector in each individual country. For example, Deloitte provides a general overview of the analysis of the tax environment in the country and assesses the reforms adopted in this area but does not give specific answers regarding the effectiveness of the tax system specifically in the agricultural sector (Taxation and investment in Azerbaijan, 2022). These reports are aimed more at foreign counterparties who are considering the prospect of engaging in agribusiness.

The World Bank Group's annual Doing Business (2022) report also examines different taxes in all areas of the country individually. Information on land tax is not considered comprehensively in the context of agricultural taxation. The varying approaches of legislators in different countries to the application of special tax regimes allow academics to opine on the appropriateness and legality of legislative regulation. N.S. Ivashchenko (2007) believes that the single tax (paid under the simplified system) and the single tax on agriculture are federal taxes. And as for the single tax on presumptive income, such a special tax regime is not actually required, as it can be part of local taxes. From a scientific point of view, it is a question of defining special tax regimes.

The analysis revealed that almost all the erasers share income tax (personal income tax) and corporate tax (corporate income tax) belonged to national taxes. Other taxes can be applied at both national and local levels. It depends on historical factors, the traditions of the country in question, the level of local budgets, and the legislative initiative of local authorities. Similar taxes exist in the United States and Canada, but local rates are significantly lower compared to federal tax rates. In the USA and Canada, VAT is the equivalent of sales tax and refers to local taxes (Kubakh, 2021). The level of income tax in Europe is determined at the national level. The basis for calculating income tax is the net income received by the taxable entity during a certain period of time. The tax is indexed, i.e., the taxable minimum and maximum are periodically revised.

According to T. Zyryanova (2018), states can be categorised according to the directions of tax policy. There are three main types: the policy of maximum taxes (mainly applied to high-margin businesses), the policy of tax neutrality, and the policy of tax favourability. Agriculture falls into the latter category. It is very important to adhere to a policy of reasonable protectionism, to support the Azerbaijan agricultural producer through the application of customs tariffs. A favourable tax policy implies that the taxation of agricultural enterprises is regulated in accordance with the current tax legislation, which provides for various benefits and special tax regimes.

E. Kekchabaeva and G. Zhakupuva (2008) believe that according to the "Kazakhstan 2050" strategy in the agro-industrial complex, the main directions of development in this sphere were the improvement of food security, the formation of a favourable taxation climate in the country, increasing the competitiveness of agricultural enterprises, increasing Azerbaijani production and export, reducing food imports in the domestic and foreign markets, the introduction of an effective system of state support.

A. Allahveranov and E. Huseynov (2013) examine tax reforms that focus on "structural" administrative interventions, such as the shift from income tax to sales tax. However, in this case, income can be accounted for without reducing aggregate profits, despite the inefficiencies in production. The main responsibility for compliance with the tax system, however, lies with the taxpayers, as they can be influenced psychologically. The implementation of such methods may bring tangible results, but only in the long term. The study by N. Nizamzadet (2017) analysed in detail the land tax legislation, including the land tax. The scientist suggests setting up a research and design institute for land relations and land management, which would focus on developing land reforms, investigating the current market situation and assessing the results of the reforms.

Z. Guseinov (2016) believes that in developed countries, one of the ways to improve tax policy is to improve the quality of service (it means servicing taxpayers as users of the services of the tax system). In Azerbaijan, however, the taxation system has been built on the basis of state objectives, without regard to changes in the agricultural business structure. The scholar also recommends to separate the processes of tax policy development and implementation from one another; to implement strategic management using

planning and control cycles; to fundamentally change relationship between tax authorities and taxpayers; and to develop a market-oriented tax structure. Each area of tax policy is unique. There are general principles for building tax policy in each state, but it is important to take into account the specifics of a particular area of regulation (Karpan, 2019; The Economic Cooperation Organisation, 2022).

The main obstacle identified in the process of studying the theoretical framework prior to conducting the present investigation, is that there is no single scientific study that compiles and analyses the key principles of the operation of the tax mechanism for agrarian entrepreneurship in Azerbaijan. Further developments in this area will enable a more comprehensive approach to the study and analysis of this research topic in the future.

CONCLUSIONS

A study of the possibilities for agricultural reform has resulted in the following conclusions. As an analysis of global agricultural experience showed, the effective functioning of the agricultural sector could not be achieved without appropriate regulation of tax mechanisms. In each country, the taxation system has its own specific features, which reflect the current state and trends in agricultural development. Primarily, the income tax system is applied, while land taxation has the function of levelling the conditions of agricultural activity.

Each country adapts its agricultural taxation system according to the current economic situation and specific historical background of the state. There are two main approaches to setting up a taxation system for agricultural producers: unified and specialised. In Azerbaijan, the tax legislation classifies the simplified tax as a state tax, although in terms of content and essence it can be considered a special tax regime. The government provides a large number of benefits for enterprises that are involved in the agricultural sector. Yet, the incentive mechanisms must be used rationally, as poor management will not only fail to achieve the long-term goals but will also deteriorate the overall situation in a particular area.

Based on a system-structural approach, a system of definite steps that would optimise the agricultural taxation system in Azerbaijan has been developed. These can be divided into two key areas: the design of a coherent and transparent system of taxation of agribusinesses and the establishment of a system to monitor the effectiveness of enterprises in utilising the various tax incentives.

The modernisation and efficiency of the tax system and the use of new approaches to taxation have always been and will be of great interest to entrepreneurs and ordinary citizens alike. Efforts towards the improvement of the tax system must be sustained at all times. This issue should always be on the national government's agenda. In summary, the findings of this investigation and the conclusions drawn from it can be used as an effective scientific basis for further studies on the prospects for amending the Tax Code in the agricultural sector. This study may prompt other researchers to approach the issue from a new perspective.

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Реформування оподаткування аграрного підприємництва (на прикладі Азербайджану)

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Анотація. Актуальність заявленої теми дослідження визначається тим, що основна частина податкових надходжень у країнах з перехідною економікою надходить від аграрного підприємництва. Метою дослідження є розробка практичних рекомендацій, які б дозволили вирішити більшість проблем в аграрному підприємництві в країнах з перехідною економікою. Основними методами дослідження є якісне поєднання моделювання, аналогії, дедукції та індукції, що дозволило провести порівняльну характеристику та визначити найбільш ефективні варіанти реформування аграрного сектору. Визначено, що створення сприятливого податкового середовища сприятиме підвищенню ефективності аграрного бізнесу, що призведе до покращення основних економічних показників. Встановлено, що за останні десять років у податковому секторі Азербайджану відбулося багато позитивних змін, які підвищили загальну ефективність податкової системи країни. Це дозволило збільшити обсяг надходжень до державного бюджету країни. Проаналізувавши досвід інших країн та більш детально вивчивши переваги та недоліки податкової системи Азербайджану, стало можливим надати ключові рекомендації щодо покращення показників у цій сфері. За результатами дослідження представлено реформи щодо вдосконалення системи оподаткування сільського господарства, які враховують соціально-економічні особливості Азербайджану та можуть бути використані як рекомендації в подальших дослідженнях, спрямованих на вдосконалення оподаткування агробізнесу. Автором оцінено вплив різних реформ на функціонування податкової системи з урахуванням запропонованих змін. Результати дослідження мають практичну цінність для працівників податкових органів Азербайджану та науковців, які продовжать дослідження в цьому напрямі

Ключові слова: агропромисловий комплекс, податки, податкова реформа, сільське господарство, Азербайджан, СНД

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Development of a Marketing Strategy to Improve the Market Activities of Agricultural and Processing Enterprises on the Example of Company Policy

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Abstract. Marketing strategy plays a huge role in the quality functioning and development of any enterprise. Therefore, the finding of new methods for the development of marketing strategies always remains the relevant moment for both entrepreneurs and scientists. Since the agricultural and processing enterprises play the greatest role for Ukraine, it was decided to pay attention to the creation of marketing strategy specifically for these enterprises. Thus, the purpose of the work is to analyze an example of the development of a company's marketing strategy in the above-mentioned sectors, describe its advantages and disadvantages, as well as draw conclusions regarding the specifics of creating a marketing strategy in Ukraine. The analysis became the fundamental method for completing the research, considering a significant amount of data that needed interpretation, which were used for it. The features of the creation and implementation of the marketing strategy of the company "Myronivsky Hliboproduct" were analyzed. It was shown that the company focused on scaling (expansion to foreign markets), developing the company's innovativeness and achieving the goals of sustainable development. Its peculiarity is considered the special approaches to the formation of management structure, characterized by its complexity and autonomy, and a business model based on the greatest possible independence from external suppliers of goods and services (closed production cycle). It was shown that the Ukrainian approach to the creation of marketing strategy still had some differences from the European approach, since it was characterized by the higher level of aggressiveness in capturing markets and the lower level of enterprises' innovativeness, which was offset by the lower prices for labor and raw materials. The work brings new knowledge regarding the specifics of running the marketing campaigns and creating the marketing strategies among Ukrainian companies, in particular in the agricultural sector

Keywords: marketing, agriculture, enterprise economy, economy of Ukraine, management, business processes

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INTRODUCTION

On its own, marketing performs two tasks at once: the first one is a thorough study of market and identification of the existing needs, the orientation of the enterprise's activities to meet the identified needs, as well as potentially possible needs; the second task is the market stimulation, the formation of demand (Sgroi & Sciancalepore, 2022). There is still no consensus among scientists regarding the real influence of the formation of marketing strategy on the production processes of companies and the efficiency of their operation (Xie *et al.*, 2022; Huang, 2022). Nevertheless, recent research shows that marketing and marketing strategies have a significant impact on the subsequent development of firms (Finoti *et al.*, 2017). Today, the methods of forming a marketing strategy are very changeable, which is primarily due to the low stability of market conditions, frequent changes in the global political situation and the rapid pace of technology development (Flaig *et al.*, 2021; Stocchi *et al.*, 2022). External factors strongly influence the features of creating modern marketing strategies. Thus, after the United Nations General Assembly adopted 17 Goals to Transform Our World (2015), the strategy of many companies began to focus on them, in addition to other strategies: what social or environmental effect the company brings and what global problems the company solves (Ruyter *et al.*, 2022). The manufacturability and creativity of these strategies begun to play a special role. Therefore, it is important to describe the modern methods of their creation.

In this research, it was decided to analyze the formation of marketing strategy in the realities of the Ukrainian economy. Since agriculture is the main industry in the country, it was reasonable to choose a company from this industry as an example for the marketing strategy. A significant number of scientists have been engaged in the study of this topic and the related subjects. Thus, Xie, *et al.* (2022) have conducted the analysis of the features of creating a marketing strategy, and they admit the special importance of creativity and innovation in creating the marketing strategies, their complexity and integrity. C. Huang and Y. Chen (2021) were engaged in the specifics of running a marketing company in the agricultural sector. They appreciated the role of innovation in the modern agriculture (by noting its high role); however, they paid little attention to the specifics of marketing in the sector in individual countries. L. Stocchi *et al.* (2022) also wrote about the importance of using the modern technologies in marketing, although their work is more specialized in the analysis of information technology and its impact on marketing trends. J. Olipra (2020) analyzes the current situation in the agricultural market, and he talks about the likely trends in the future development of companies in the sector, based on the trends in the global pricing policy. The authors' conclusions are really useful for the forming of forecasts for the companies' development; however, a little attention is paid to the influence of the above-mentioned factors on individual regions.

Thus, the purpose of the work is to evaluate the features of developing the marketing strategy among companies in the agricultural sector in Ukraine. In addition, it is important to compare the features of Ukrainian and European marketing strategies, evaluate their advantages and disadvantages. The object of the study is both the features of operation of the company analyzed in the work as a whole, and the Ukrainian business environment in the industry as a whole. The novelty of the work is in the use of a real example for analyzing the features of creating a marketing strategy in Ukraine, as well as in comparing the Ukrainian and European marketing strategies.

MATERIALS AND METHODS

While working on this research, it was required to choose a company and analyze the example of implementation of its marketing strategy in the work. The PJSC (private joint-stock company) "Myronivsky Hliboproduct" (MHP) was chosen due to its high recognizability, rather long history, scale of business and participation of the company in the European markets (2022). It is worth noting that the products of the above-mentioned company in Ukraine are best known under the brand "Nasha Ryaba" (2022). Another important reason for choosing this company is a vivid reflection of all the basic principles of modern development of both the large global agricultural holdings and the Ukrainian companies.

When conducting the research, a significant amount of data was used to describe the features of the formation of marketing strategies in the realities of functioning of business and the Ukrainian economy. Scientific articles became the main source of this information, as they contained useful data for analyzing the role of marketing in the agricultural sector. The official website of the Stock market infrastructure development agency of Ukraine (SMIDA) (2022) became another important source. With its help, it became possible to assess the current financial condition of the analyzed enterprise and draw conclusions regarding its success in achieving the intended objectives of development. In addition, a significant number of official reports of this company is used in the work, which gave an idea of the modern vector of the company's development, its future plans and intentions for scaling.

The method of analysis became the main method in conducting the research. The reason for this is that a significant amount of data used to do the research had to be carefully processed in order to draw conclusions regarding the features of the marketing strategy of the Ukrainian enterprises. In addition, statistical methods were actively used to assess the financial performance of the company selected for analysis, in particular, the graphical method. The historical method also

became an important one, which made it possible to analyze the history of the creation and the company functioning in retrospective. In addition, the methods for forecasting were actively used in the work to form ideas for the possible development of company and the industry in the future. For the formation of forecasts, the abstraction method has also become useful, which gave opportunity to assess the company's capabilities, without considering the influence of external factors. In addition, the induction method was widely used, which made it possible to shift from individual judgments about the development of the company, taken from the various reports and statistical Internet sources, to the general idea of the company development.

All work can be divided into several stages. At the first stage, the general analysis of the company, its financial performance, as well as the features of development, scaling and other business processes was carried out. At this stage, conclusions are drawn regarding the characteristic features of the marketing strategy of this company. At the second stage, a generalization of the main characteristic features of the marketing company of the Ukrainian and European manufacturers was formed, based on the features of the marketing strategy of the "Myronivsky Hliboproduct" company. As part of this stage, the discussion of all the results obtained and a qualitative comparison of the main characteristics of the Ukrainian and European representatives was done.

RESULTS

To consider the example of creating a marketing strategy in this study, the PJSC "Myronivsky Hliboproduct" was chosen, considering the size, recognizability and agricultural focus of the company. First, it is worth considering some indicators of the company's performance. Tables 1; 2 below show the company's main products by years and revenue from them, as well as the percentage of the total number of products sold.

***Table 1**. The number of products manufactured by the PJSC "Myronivsky Hliboproduct" in 2011-2017, billion UAH*

2011		2012		2013		2014		2015		2016		2017	
Total	10.0	Total	11.4	Total	11.8	Total	14.6	Total	24.0	Total	12.7	Total	17.8
P.M.	5.5	P.M.	6.5	P.M.	7.0	P.M.	9.4	P.M.	10.0	P.M.	5.9	P.M.	10.0
Sf.O.	1.7	Sf.O.	1.7	Sf.O	2.0	Sf.O	2.9	M.S.P.	1.0	G.C.	3.0	G.C.	2.3
M.S.P.	0.8	M.S.P.	0.8	M.S.P.	0.8	M.S.P.	0.7	Sf.O	4.3	Services	2.7	Services	3.9
Other	1.9	Other	2.3	Other	2.0	Other	1.6	Other	8.8	Other	1.1	Other	1.6

***Note:** P.M. – poultry meat; Sf.O – sunflower oil; M.S.P. – meat and sausage products; G.C. – grain culture*
***Source:** compiled by the authors based on data from the official website of the SMIDA (2022)*

In the Table 1, it can be seen that the company is experiencing instability in the growth of gross revenue. Thus, in 2011, it was UAH 10 billion, and in 2017 – UAH 17.8 billion. It is worth noting that the real growth in revenue is negative, considering the inflation rate: in 2017, it is equal to about UAH 7.75 billion, as the prices of 2011 (Inflation index 2022 in Ukraine, 2022). Thus, the growth during this time amounted to 22.5%. Table 2 shows the main focus of the company, which is aimed at selling the poultry meat.

***Table 2**. Structure of products manufactured by the PJSC "Myronivsky Hliboproduct" in 2011-2017, %*

2011		2012		2013		2014		2015		2016		2017	
Total	100.0	Total	100	Total	100	Total	100	Total	100	Total	100	Total	100
P.M.	55.7	P.M.	57.3	P.M.	59.6	P.M.	64.2	P.M.	41.6	P.M.	46.4	P.M.	56.2
Sf.O.	17.3	Sf.O.	15.2	Sf.O.	16.8	Sf.O.	19.9	M.S.P.	4.1	G.C.	23.7	G.C.	12.8
M.S.P.	8.0	M.S.P.	7.2	M.S.P.	6.8	M.S.P.	5.1	Sf.O.	17.8	Services	21.4	Services	22.1
Other	19.1	Other	20.3	Other	16.8	Other	10.8	Other	36.5	Other	8.5	Other	9.0

***Note:** P.M. – poultry meat; Sf.O – sunflower oil; M.S.P. – meat and sausage products; G.C. – grain culture*
***Source:** compiled by the authors based on data from the official website of the SMIDA (2022)*

Indeed, when describing the business, the company indicates that its main activities are poultry farming and related industries (production of the chilled chicken, ready-made frozen foods, sunflower oil); crop production (cultivation of corn, sunflower, wheat and rapeseed); other agricultural activities (production of fresh premium beef, foie gras, sausage and smoked products, fruits) (SMIDA, 2022). The company has proactive plans for the subsequent expansion of markets (including Europe, the Middle East and Africa, through

the purchasing of enterprises in these territories) and consolidation of positions in existing sales markets. It also plans to continue its development in the innovative direction, as well as contribute to the achievement of sustainable development goals. It is worth noting that the company already supplies more than half of its products to the markets of Africa and the Middle East (Sobotyuk, 2022). The change in the share of MHP's production of the domestic and foreign markets is shown below in the Figure 1.

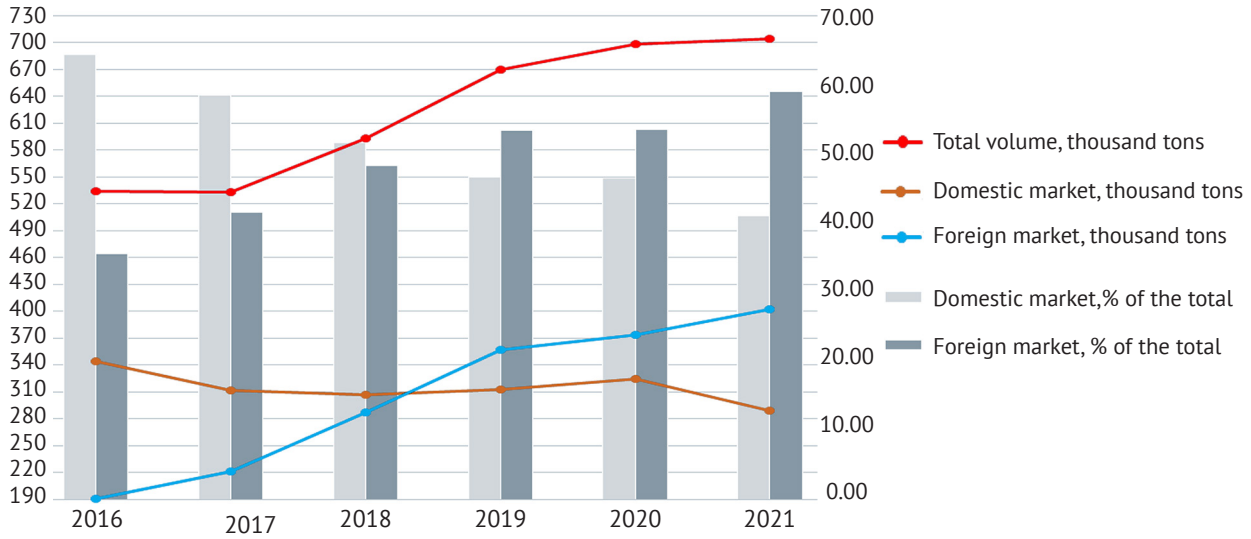

***Figure 1**. Dynamics of changes in trends of sales of MHP products in domestic and foreign markets in 2016-2021*
***Source:** compiled by the authors based on the quarterly MHP Press Releases (2022) on the company's operating results*

Figure 1 shows the change in the share of sales of the company's products in the domestic and foreign markets. In 2016, the share of domestic consumption was 64.4%, and the external consumption – 35.6%, while in 2021 it was 41.03% and 58.97%, respectively. Considering the absolute sales volumes of the company's products in foreign and domestic markets, it is possible to note a certain trend: thus, the number of sales abroad is increasing at a significant pace (on average by 16.17% per year); sales in the domestic market are declining (by 3.44% per year); total sales are also increasing (by 5.67% per year). Such expansion will lead to both an increase in the gross income and to diversification of sales and risk mitigation.

The company describes on its official website the main goals for its development, these are: control over production costs, that is, maintaining the level of production costs at approximately one of the lowest levels in the industry; investing in the modern production capacity and equipment to maintain the status of a modern and innovative European manufacturer; constant increase in the land bank; promotion of brands and support of the existing brands through advertising, which will primarily inspire confidence in the products of MHP company and lead to an increase in sales; increase in the market share, gradual increase in the product range; expansion of the sales system – scaling the franchise network; maintaining the balance of retail sales between franchised stores and supermarkets. Indeed, the work of all these points can be clearly seen on the example of the most famous brand of the company "Nasha ryaba"; its other famous brands are "Legko", "Baschinskyi", "Qualiko" and "Ukrainian Chicken". The actions of this concept are also visible on the Figure 1.

Innovativeness plays an important role in the company, as equipment from various highly developed countries have been installed in its enterprises: Germany, the Netherlands, Switzerland, and Denmark (Sydorchuk, 2019). The company is engaged in the process of strengthening its cyber security methods and strives to fully comply with the European business regulations. Although MHP company (2022) actively introduces new technologies in its operations, most of them are not its own technologies: thus, the company should pay more attention to the development of its own technologies to cover a larger sales market. It should be noted that the company submits reports on the sustainable development goals every year, in which it describes the methods for achieving these goals. This is especially important to consider, because MHP operates in the European markets and it can attract additional investors and consumers by demonstrating that it is aware of the modern trends. The PJSC "Myronivsky Hliboproduct" has a linear-functional management structure, which is characterized by particular complexity in implementation; however, it is likely to be the most efficient due to the size of the company (Sydorchuk, 2019). Due to the clear distribution of responsibilities within this management system, a significant speed of decision-making process is ensured, and the high autonomy of employees leads to an increase in the efficiency of their work. However, this also carries some risks, since the autonomy and

poor communication between the senior management and employees can lead to undesirable results for the company.

For MHP, the vertically integrated business model is relevant. Thus, one enterprise of the holding is engaged in the cultivation of cereals, another one – in the production of combination fodder, and the third one – grows the livestock and poultry. It should be noted that this approach is slightly different from the European one, where separate enterprise is engaged in each of these stages. This allows the company forming the all-production processes within the enterprise, evaluating the quality and real cost of manufactured products at all stages of production (Strachan *et al.*, 2019). According to the results obtained, this business model is one of its main advantages. The MHP has its own capabilities for the cultivation of cereals, the production of sunflower protein, combination fodder; in addition, the company carries out the process of incubation and production of broilers, and the biological residues are turned into biogas, which is also one of the important initiatives to achieve the goals of sustainable development, the formation of more environmentally friendly products (MHP Report, 2010).

Separately, it is worth elaborating on the company's capabilities regarding the production of pollution-free energy. Therefore, the first biogas plant was built by the company back in 2012 in the Dnipropetrovsk region, and by 2014 it reached its maximum capacity. It is still one of the most powerful biogas plants operating on the production wastes of poultry farms (Sydorchuk, 2019). The company reports on the level of transition to renewable energy sources in its annual report on the achievement of sustainable development goals: thus, the part of energy used from the "green" sources reached the mark of 14%, 22% and 18%, respectively, in 2019, 2020 and 2021. This focus of MHP in the development of environmentally friendly methods of energy production cannot but attract investors. Thus, it is possible to characterize the main advantages that the PJSC "Myronivsky Hliboproduct" has in comparison with other competing companies. They are described below in the Table 3.

***Table 3**. Brief description of the main advantages of the company "Myronivsky Hliboproduct"*

No.	Benefits of low order	Benefits of high order
1	Use of cheap materials in the production	Experience in the aircraft repair market
2	Use of cheap labor	Cooperation with more than 10 countries of the world
3	Flexible pricing system	Individual approach to every customer
4	Efficiency of repair	Highly qualified staff
5	Age of technical equipment	Availability of international quality certificates

***Source:** compiled by the authors based on data from R.O. Dovgush (2018)*

Table 3 shows that most of the benefits described as benefits of the low order are inherent to the entire industry in which the MHP operates. At the same time, benefits of the high order can be rightfully considered as benefits earned by the company. They can be singled out as those ones that arise in the case of using the modern methods of building a marketing strategy that will be based not only on maximizing profits, but also on constantly improving the innovative component of production, conducting the market expansion and policies towards the achievement of goals of sustainable development.

However, the "Myronivsky Hliboproduct" company also has some disadvantages. It is worth noting that the MHP still has a low position in the international competitive markets, apart from still existing problems with some old models of technologies in the production and the lack of clear long-term strategic plans. Therefore, its marketing strategy can still be considered to be inferior to similar foreign companies. There are also problems with the quality of the company's products. For example, its main trademark "Nasha Ryaba" is significantly outdated at some points. In particular, there are problems with the packaging: it has an irregular geometric shape and some problems with sealing the container, which became the reason of quick spoilage of meat. In addition, the fact that the raw materials in the container are only covered with a film provokes a loss of attractiveness of the goods during transportation. All these factors are the reasons for the decrease in demand for this product. Therefore, the packaging of this product needs significant improvement. If the company's managers and marketers work together to solve other existing problems in the quality of manufactured products and production processes, the MHP will be able to significantly improve its position in foreign markets.

DISCUSSION

First, it should be noted that the implementation of a company's marketing strategy in the agricultural sector has its own characteristics in comparison with other sectors. Thus, O.V. Mityay (2014) in his work on evaluating the marketing tools to increase the competitiveness of agro-industrial enterprises, defines the concept of "agro-marketing" as a set of marketing methods, tools and actions that are used by participants in the production and sale of goods in the agro-industrial sector of

the economy to maximize the meeting of demand and make a profit. It is characterized by its own characteristics, among which a significant dependence of the company's results on its own efforts and natural conditions, the presence of homogeneous demand on the market, the special (strategically important for the country) role of the sector's goods, the peculiarity of the employment of staff and price formation in the market, etc. should be singled out. Thus, a marketer in such an enterprise should consider these features before making his own marketing strategy. Separately, it is worth mentioning the pricing in the agricultural market. The fact is that farmers often use the futures contracts to ensure their own risks, this practice is widespread among the highly developed Western countries. However, in the conditions of a low level of development of the Ukrainian stock market, their use is quite difficult. This brings additional instability to the industry, makes it less attractive and increases the complexity of doing such a business. J. Olipra (2020) notes in his work on the study of existing trends in the liberalization of trade in prices in the agricultural sector that the setting of prices for goods in this sector is increasingly dependent on the trends in the world markets. It also indicates that the companies should rely less on possible financial assistance from the state, since the state is almost powerless in such conditions of globalization.

In general, scientists agree that the principles for creating marketing strategies should change with the improvement of technology levels. Thus, K. Storbacka and T. Moser (2020) in their work on the role of marketing in the modern business conditions, write about the need to integrate multifunctional methods of digital transformation into the marketing processes to improve efficiency of the company operation, increase economies of scale and increase its competitive advantages. It should be noted that an increase in the level of innovativeness of agricultural enterprises is important to reduce the risks inherent in the industry, for example, the seasonality. As it was shown in the work based on the company "Myronivsky Hliboproduct", the maintaining of a high level of technology in the conditions of the modern business management for enterprises of the agricultural sector is one of the main goals. Although enterprises in the sector can maintain a high level of competitiveness in the market for some time due to the low production costs (including the low labor costs), they will eventually be forced to leave the market with such an approach.

Modern scientists inextricably associate the development of technology with the achievement of goals of the sustainable development. Indeed, S. Beder (2000) in his work on the interaction of technological development and goals of sustainable development, wrote about the huge role of innovation in achieving these goals. However, the goals of enterprise and sustainable development do not have to coincide, because the company most often conducts its activities to maximize profits (unless it is a start-up, the main goal of which is to capture as much market share as possible, or unless it is a state-owned enterprise interested in achieving a high social effect for citizens). At the same time, the implementation of such technologies leads to additional short-term and long-term costs. P. Ekins and D. Zenghelis (2021) describe this is in their work on the costs and benefits of introducing technologies for environmental protection. However, in today's era of fast information transfer, the companies should listen to the consumers' opinions and their moods to build a marketing strategy. According to D. Morrone (2012), this is the reason why enterprises independently begin to introduce technologies that help achieve the goals of sustainable development: a modern consumer most often sincerely worries about the environment, and it becomes profitable for companies to achieve the goals of sustainable development in order to attract customers. Thus, the goals of sustainable development have become an urgent aim for companies in the agricultural sector, which has been shown by the example of the "Myronivsky Hliboproduct" company and its production of biogas.

O.V. Mityay (2014) mentions in one of his works that companies in the agricultural sector in Ukraine and the world do not use the full functionality of opportunities for marketing activities at the macro and micro levels. This is probably due to the above-described features of functioning of the agricultural sector, which is characterized by the fairly stable demand for its products. However, this also means that at this stage, the start of active implementation of such methods would probably allow such a company to gain a temporary comparative advantage in the market associated with an increase in demand for the company's product. In the above-mentioned work, it was determined that the course towards achieving the goals of sustainable development and the maximum level of innovation were the main features of modern marketing strategies of companies in the agricultural sector. C. Huang and Y. Chen, Y. (2021) in their work on the analysis of the features of doing agricultural business come to similar conclusions. However, they pay much more attention to innovation and technological development. The scientists argue that companies in the agricultural sector actively implement intellectual and information technologies in order to increase the efficiency of marketing of agricultural products and promote the agricultural business, since such technologies contribute to an increase in the product quality and thereby increase the demand for the company's products. In addition, the introduction of innovative technologies makes it possible to reduce the long-term production costs, which also increases the company's competitive advantages (Kurvinen *et al.*, 2020).

On the example of the "Myronivsky Hliboproduct" company, it was shown how the approach of Ukrainian companies in the formation of marketing strategy differed from the foreign companies. Therefore, the MHP technologies are partially outdated, but the company

manages to achieve competitive advantages due to the cheaper labor. In any case, in order to be able to continue doing business abroad, this company should devote more time and money to technological development. Other scientists, who have been studying and evaluating the features of marketing strategies for the agricultural sector in Ukraine, come to different conclusions. For example, L. Byvsheva *et al*. (2019) do not single out innovative development and achievement of goals of the sustainable development as the characteristic and main features of the development of a marketing strategy in the agricultural sector. They only remind that every company should pay special attention to its strengths and weaknesses in order to form a marketing strategy that will be able to effectively function as a holistic optimized mechanism. At the same time, I. Gogol (2013) in his work on studying the features of the approach to creating marketing strategies in companies in the agricultural sector states that a single model for creation of marketing strategies has not been formed in Ukraine yet. In general, it is possible to agree with this idea, since Ukraine with its companies try to adhere to the European-style methods of economic development. However, in the example of the "Myronivsky Hliboproduct" company, it was shown that Ukrainian producers of agricultural products had some peculiarities in marketing strategies compared to the European ones: they were characterized by a high, albeit relatively lower, level of using the innovative technologies in production, wide expansion into foreign markets, the maximum possible reduction in the price of products (even by complicating the processes of information transfer between the production lines) and some other features. Thus, despite the fact that the Ukrainian model has differences from the European one, it tries to inherit it. Probably, the level of technological backwardness of the Ukrainian companies will gradually become minimal in the future, and they will become even more competitive in the international arena.

CONCLUSIONS

In this study, the features of functioning of the marketing strategy of the agricultural enterprise "Myronivsky Hliboproduct" were analyzed. It was shown that the company's main goal was an expansion into other markets: the Middle East and the countries of Western and Eastern Europe. This reorientation led to the fact that the number of products sold for export gradually increased than in the domestic market. An important issue for the enterprise is also the issues of innovation and achievement of goals of sustainable development. However, in terms of manufacturability, the company still has significant problems, since not all mechanisms at enterprises have the latest designs; many of them are obsolete long ago. With regard to sustainable development, such activities for the MHP on the part of the company allow not only increasing the efficiency of enterprise through the waste-free production, but also attracting the attention of investors.

Based on the analysis of the company's policy, the main features of its marketing campaign among the enterprises of the agricultural sector of Ukraine were established. It is worth highlighting the desire for innovation and the achievement of goals of sustainable development. It should be noted that the problem with technology is leveled due to the cheaper labor and resources inherent in Ukraine, which allow reducing the cost of production. Although the European companies have similar principles for running a marketing campaign, they are still different. This is due to their greater accessibility to cash, technology and hedging methods. The last point is especially important: due to the instability in the agricultural business, companies have significant needs for insurance against the price fluctuations and yields. However, due to insufficiently developed financial institutions in Ukraine, the local companies are forced to find a way out of this problem through the other methods. This may explain their particular aggressiveness, riskiness and autonomy in matters of development. However, even within the same country, the marketing strategies of different enterprises differ significantly, since each company builds this policy according to its own specifics of doing business. Consideration of the development of marketing strategies for other sectors in Ukraine is relevant for further research: for example, in the field of information technology.

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Розробка маркетингової стратегії вдосконалення ринкової діяльності сільськогосподарських та переробних підприємств на прикладі політики підприємства

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Анотація. Маркетингова стратегія відіграє величезну роль у якісному функціонуванні та розвитку будь-якого підприємства. Тому пошук нових методів розробки маркетингових стратегій завжди залишається актуальним моментом як для підприємців, так і для науковців. Оскільки для України найбільшу роль відіграють сільськогосподарські та переробні підприємства, було вирішено приділити увагу створенню маркетингової стратегії саме для цих підприємств. Таким чином, метою роботи є аналіз прикладу розробки маркетингової стратегії підприємства у вищезазначених галузях, опис її переваг та недоліків, а також формулювання висновків щодо специфіки створення маркетингової стратегії в Україні. Основоположним методом для написання даної роботи став аналіз, враховуючи значну кількість даних, що потребували інтерпретації, які були використані при написанні даної статті. Проаналізовано особливості створення та реалізації маркетингової стратегії компанії «Миронівський хлібопродукт». Показано, що компанія орієнтується на масштабування (експансію на зовнішні ринки), розвиток інноваційності компанії та досягнення цілей сталого розвитку. Її особливістю вважаються особливі підходи до формування структури управління, що характеризується її складністю та автономністю, а також бізнес-модель, заснована на максимально можливій незалежності від зовнішніх постачальників товарів і послуг (замкнутий виробничий цикл). Показано, що український підхід до створення маркетингової стратегії все ще має певні відмінності від європейського, оскільки характеризується вищим рівнем агресивності в захопленні ринків та нижчим рівнем інноваційності підприємств, що компенсується нижчими цінами на робочу силу та сировину. Робота привносить нові знання щодо специфіки проведення маркетингових кампаній та створення маркетингових стратегій серед українських компаній, зокрема в аграрному секторі

Ключові слова: маркетинг, сільське господарство, економіка підприємства, економіка України, управління, бізнес-процеси

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