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Agroclimatic substantiation of common fennel cultivation in the Western Forest-Steppe

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Abstract. Common fennel, as a plant with a wide range of uses and a highly profitable crop, is of great interest to researchers and agricultural producers and determines the relevance of the study on the adaptation of the crop in the Western Forest-Steppe zone and the complex of technological factors in its cultivation. The purpose of the study was to identify the influence of active and effective temperatures, sowing time, row spacing width, and seeding rate on the productivity of common fennel. In the course of the study, general scientific, mathematical and statistical methods were used. In the conditions of the Western Forest-Steppe, the authors investigated the sums of active and effective temperatures in dynamics in the context of different weather conditions of the years of research and vegetation phases of common fennel plants. As a result of the conducted studies, the indicators of integral photosynthetic active radiation in the growing, generative, and

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vegetative periods of plant growth and development were analysed. The yield level of common fennel seeds, when grown on deep low-humus chernozems, was determined, depending on the sowing period and the seeding rate for row spacing under different weather conditions during the years of research. A correlation analysis was performed according to the indicators of the yield of common fennel seeds and total temperatures, which can be attributed to the main uncontrolled factors affecting the yield of agricultural crops in a particular growing zone. The expediency of growing common fennel in the conditions of the Western Forest-Steppe of Ukraine was proved in terms of the sum of active and effective temperatures during the growing season of fennel, which contributed to the generation of a sufficiently high seed yield, and the optimal sowing time, seeding rate, and row spacing for growing crops in specific soil and climatic conditions of the zone were established. The practical value of the study is conditioned by the development of recommendations for production for agricultural enterprises in the conditions of the Western Forest-Steppe on optimising the complex of technological factors in the cultivation of common fennel

Keywords: common fennel; active and effective temperatures; yield, sowing time; row spacing width; seed application rate

INTRODUCTION

The range of crop choices for cultivation depends on many factors: weather and climatic conditions, pharmaceutical production, the needs of the food and cosmetics industries, and prices for certain raw materials. One of the most valuable essential oil, medicinal, and spice crops is common fennel, the biological and technological aspects of which are practically not investigated in the Western Forest-Steppe, which indicates the relevance of choosing a research topic. Particularly relevant issues are the study of temperature compliance and improvement of such components of cultivation technology as sowing time, row spacing, seeding rate, top dressing, investigation of their impact on plant growth, development, yield, and quality indicators of seeds and their chemical composition.

In world agriculture and in European countries, common fennel is considered a crop with a wide range of uses. Common fennel plants are used completely, starting from the roots and ending with seeds, since the whole plant contains valuable biologically active substances that can serve as a component for medicines, seasoning for various dishes, flavouring, or oil for perfumes and cosmetics. The value of essential oils, in particular common fennel, as a seasoning is indicated by researchers from other countries (Xie & Finley, 2018; Sharangi & Acharya, 2018). Fennel inflorescences are a traditional culinary spice in Italy (Ferioli *et al.*, 2017). An important area of use of essential oil crops is the processing of essential oils to obtain natural food flavourings (Frolova & Ukrainets, 2010; Badgujar *et al.*, 2014). Due to the content of biologically active substances in plants, raw materials are used for medical needs as bactericidal, antiviral, anti-inflammatory, antispasmodic, sedative, and tonic agents (Zrira, 2017; Najjaa *et al.*, 2017). In addition, the plant is also characterised by carminative, secretolytic, and diuretic properties, helps to slow down the growth of tumour cells (Sarla, 2019; Granata *et al.*, 2022). The antibacterial properties of medicinal raw materials of such essential oils as coriander seed and common fennel are indicated (Lo Cantore *et al.*, 2004; Miguel *et al.*, 2010). The extract obtained on the basis of fennel is characterised by antioxidant and antimicrobial action (Mahdavi *et al.*, 2017).

Fennel essential oil consists of a number of substances, the ratio of which depends on many factors, both biological and technological. Global aspects of studying the chemical composition of common fennel are extremely relevant and substantial. The basis of research (Afifi *et al.*, 2021) is used to determine the chemical composition of essential oil in the context of substances by gas chromatography and mass spectrometry of 12 different types of fennel grown in different soil and climatic conditions. The anthelmintic effect of fennel oil (Wakabayashi *et al.*, 2015) and an extract of certain parts of the plant (Domínguez-Vigil *et al.*, 2022) have been established. Ukrainian researchers (Filipyuk & Vishnevska, 2022) have investigated the technological qualities of medicinal plant raw materials of common fennel fruits (extractives, degree of grinding, fractional composition, humidity, etc.).

Mirzoeva (2019) notes that the field of production of medicinal plants in general and essential oils in particular is very profitable and promising. At the same time, it is widely reported that medicinal crop production in Ukraine is a very narrow segment, in which demand now exceeds supply.

Issues of development and improvement of the technology of growing common fennel were studied in different zones of Ukraine. In the conditions of the Right-Bank Forest-Steppe (Vinnytsia Oblast), a study was carried out to determine the optimal timing of planting fennel seedlings, their influence on the formation of the green mass of the plant, and harvesting. Researchers (Knyaziuk *et al.*, 2019) found that increasing the width of row spacing up to 45 cm helps increase the individual productivity of common fennel. Regarding the timing of planting seedlings, the best was the early planting (April 20), which resulted in maximum seedling growth.

Studies conducted in Polissya are devoted to the investigation of the influence of sowing methods on

the yield of fennel. Researchers (Moisienko & Stotska, 2019; Stotska *et al.*, 2022) prove that in the conditions of the zone, it is advisable to sow common fennel with a row spacing of 60 cm, since this experiment option provided the optimal area of the leaf apparatus (24.2 to 25.5 thousand m^2/ha), photosynthetic potential of crops (1.512 to 1.685 mln m^2/ha*day), net photosynthetic productivity (3.39-3.65 g/m2 per day), seed yield (0.96 t/ha).

Early spring sowing with a row spacing of 45 cm is preferred by researchers in the South of Ukraine. According to (Makuha & Fedorchuk, 2016) for sowing common fennel in the third ten days of March against the background of $N_{60\text{-}90}$ were the most favourable conditions for the formation of sowing qualities and the accumulation of essential oil in seeds. Changing the row spacing width relative to 45 cm reduced seed yield by 0.08-0.17 t/ha, or by 7.3-15.5%.

Various terms of sowing common fennel have also been studied in the conditions of the Carpathian region. As a result of research (Dmytryk, 2019), the expediency of early sowing (the first ten days of April) was established, and the yield indicator for this period reached 1.58 t/ha. At medium and late sowing dates, the yield of fennel seeds decreased by 0.2 and 0.34 t/ha. In the conditions of the Western Forest-Steppe, this crop is poorly studied, so there was a need to improve technological measures for growing common fennel in the zone conditions.

The purpose of the study consisted in establishing the feasibility of growing common fennel in the conditions of the Western Forest-Steppe, considering active and effective temperatures and technological factors: the sowing period, the width of row spacing, and the seeding rate.

MATERIALS AND METHODS

The study uses general scientific methods for generalising research results, which are based on objectivity, evidence, reproduction, and mathematical and statistical methods for processing experimental data.

The research was conducted during 2015-2020 on the experimental field in the production conditions of the private enterprise "Prudivus S.M." in the Khmelnytska Oblast, Kamianets-Podilskyi district. According to the heat supply and degree of moisture during the growing season, the region belongs to a warm agroclimatic region. The main type of soil in the experimental field is deep low-humus chernozem on carbonate loessial loams, with a heavy loamy texture.

The experiment included the following factors: A – sowing period: 1st ten days of April (soil thermal regime – 6-8°C), 2nd ten days of April (soil thermal regime – 10-12°C); B – row spacing width: 15, 30, 45, and 60 cm, C – seeding rate: 1, 1.5, and 2 million germinated seeds/ha. The area of the accounting plot – 50 m^2. The repetition is fourfold. The sowing period was taken as the control – the first ten days of April, the seed application rate – 1.5 million germinated seeds/ha, and the row spacing – 60 cm.

In autumn, deep fall ploughing was carried out at 27 cm, under which $N_{45}P_{60}K_{60}$ was applied, and P_{10} was applied in the spring during sowing. When the plants were in the stemming phase, they were fertilised with $N_{30}P_{30}$. To establish the feasibility of growing common fennel in the conditions of the Western Forest-Steppe, the sums of active and effective temperatures in dynamics were determined by the phases of plant growth and development, and as the final result – the yield of the crop.

The sum of active temperatures was determined on an accrual basis by the growth and development phases of common fennel plants. The interval for sowing dates was one decade, but the generation of plant yields significantly depended on the sum of active and effective temperatures during the passage of plant growth and development phases.

To determine the yield of common fennel seeds, a Sampo-130 combine harvester was used to thresh each plot separately. Variance, correlation, and regression analyses using Excel 2003 and Statistica 6.0 programmes were used for mathematical processing of the obtained data.

RESULTS AND DISCUSSION

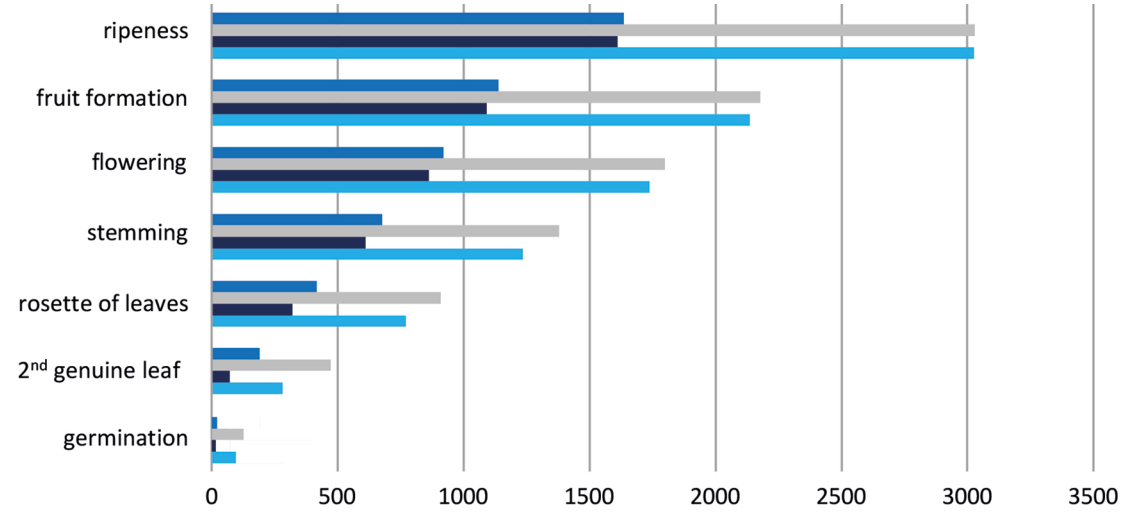
Active and effective temperatures during the growing season of common fennel were calculated in the context of years of research. The conditions in 2017 were the most favourable in terms of the accumulation of the sum of active and effective temperatures by the phases of growth and development of common fennel plants. In the ripeness phase, the sum of effective temperatures in the first sowing period was 1,611°C, in the second – 1,637°C, in the conditions of the year, optimal indicators of fennel seed yield were formed. The lowest total temperatures were characterised by 2018 and 2019. The sum of effective temperatures for the growing season and the sowing period was 1,516-1,518°C, for the second term – 1,527-1,529°C. With an increase in the sum of active and effective temperatures, the growing season of common fennel was shortened and the seed yield increased.

Under the conditions of 2017, the highest indicators of the sum of active and effective temperatures above 10°C (cumulative total) of the onset of the developmental stages of common fennel depending on the sowing dates were noted (Fig. 1).

In the context of the remaining five years of research, the following trend was observed:

In the conditions of 2015, the germination phase took place at the sum of active temperatures in the first period – 94°C, in the second – 115°C, effective respectively: 15 and 18°C. During the passage of subsequent phases of plant growth and development from the formation of the 2nd true leaf to fruit formation, the increase in both active and effective temperatures occurred quite quickly, especially during the passage of the stemming and flowering phases,

and the fruit formation and ripeness of fennel plants. The total amount of active and effective temperatures was higher in the second sowing period, active was 3,018°C, and effective – 1,629°C.



	germination	2nd genuine leaf	rosette of leaves	stemming	flowering	fruit formation	ripeness
2nd sowing period. Sum of effective temperatures		191	417	677	921	1138	1637
2nd sowing period. Sum of active temperatures		472	909	1380	1799	2179	3029
1st sowing period. Sum of effective temperatures		71	321	610	862	1092	1611
1st sowing period. Sum of active temperatures		282	772	1235	1739	2137	3025

***Figure 1**. Sums of active and effective temperatures above 10°C (cumulative total) of the onset of phases of development of common fennel depending on the time of sowing in 2017, °C*

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

In 2016, a similar trend was observed, but with slightly higher amounts of active and effective temperatures. Thus, in the growing season during the first sowing period, the sum of active temperatures was 3,015°C, effective – 1,606°C, for the second term, respectively: 3,021 and 1,632°C.

The sums of active and effective temperatures during the growth and development phases of fennel plants in 2018 and 2019 were the lowest in all the years of research. Notably, during the growing season of plants in the context of phases, the analysed indicators were very similar as well as the duration of interphase and growing seasons during these two years. A similar pattern was observed for the yield, which was the lowest in the conditions of 2018 and 2019. Thus, the growing season in the conditions of these years was the longest, if the difference in comparison with other years of research for the first period was 1-2 days, then for the second – 1-4 days, which turned out to have an impact on yield. According to the accumulation of the sum of active and effective temperatures for the growth and development phases of ordinary fennel plants, the conditions of 2020 were close to the conditions of 2016, the difference in values for the growing season was only 1-2°C. The maximum increase in temperatures was observed during the leaf rosette formation – fruit formation. In the fennel ripeness phase, the sum of active temperatures during the first sowing period was 3,013°C, second – 3,019°C, while the effective level was at the level of 1,605 and 1,630°C, respectively.

Correlation analysis performed on indicators of yield and total temperatures, which can be attributed to the main uncontrolled factors affecting the yield of agricultural crops in a particular growing zone, showed the dependence of the yield of common fennel on the sum of active temperatures ($R=0.89$, $F=8.39$, $p=0.03$). The equation obtained as a result of statistical analysis is as follows: $Yc=-199{,}059+0.218\ Sat-0{,}000\ Sat^2$. The dynamics of integral photosynthetic active radiation indicators in the cultivation of common fennel have changed over the years of research in a wide range (Table 1).

***Table 1**. Integral photosynthetic active radiation indicators ΣQ_f when growing common fennel*

Years of research	Plant vegetation periods					
	vegetative		generative		growing	
	million kcal/ha for the period	GJ for the period	million kcal/ha for the period	GJ for the period	million kcal/ha for the period	GJ for the period
2015	778.7	3,252.8	936.7	3,912.6	1,715.4	7,165.4
2016	845.4	3,531.1	887.2	3,706.1	1,732.6	7,237.2
2017	867.5	3,623.5	1,005.9	4,201.7	1,873.4	7,825.2
2018	772.4	3,226.7	934.0	3,901.3	1,706.4	7,128.0
2019	769.5	3,214.1	938.3	3,919.6	1,707.8	7,133.7
2020	845.4	3,531.3	872.6	3,644.8	1,718.0	7,176.1
V, %	10.9		6.2		7.6	

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

From the analysis of the obtained data, it can be concluded that with the values of the integral PAR indicator in the range of 1,715.4-1,873.4 million kcal/ha in the conditions of the Western Forest-Steppe, it is possible to obtain a yield of fennel seeds at the level of about 1.74-1.77 tonnes per hectare. Variational analysis proved that the lowest variability (V=6.2%) of the integral headlight indicators ΣQ_f when growing common fennel was during the generative period, and during the growing and vegetative period, an increase in variation in the years of research was recorded up to 7.6-10.9%.

Thus, the sums of active and effective temperatures during the passage of the phases of growth and development of common fennel in the conditions of the Western Forest-Steppe during the years of research were satisfactory for the full development of plants and the formation of a high yield of seeds of the crop. These indicators correlated with the duration of vegetative, generative, and growing periods of fennel and its yield. With a larger amount of active and effective temperatures, the duration of the growing season of plants decreased and seed yield increased.

The yield of fennel seeds in the experiments was very diverse, it varied depending on the conditions of the year, the sowing period of the crop, the width of row spacing, and the seeding rate. Considering all the factors of influence, the yield ranged from 0.4-1.77 t/ha (Table 2).

***Table 2**. Yield of common fennel seeds depending on the sowing period, row spacing, and seeding rate, t/ha (2015-2020)*

Row spacing width, cm (B)	Seeding rate, million germ. seeds/ha (C)	Year of research					
		2015	2016	2017	2018	2019	2020
1st sowing period (A)							
15	1	0.68	0.71	0.72	0.55	0.5	0.69
	1.5	0.87	0.9	0.91	0.66	0.6	0.89
	2	0.98	1.0	1.1	0.66	0.62	1.0
30	1	1.66	1.69	1.69	1.14	0.92	1.67
	1.5	1.38	1.42	1.44	0.97	0.94	1.12
	2	1.01	1.04	1.06	0.67	0.69	1.04
45	1	1.74	1.76	1.77	1.19	1.16	1.75
	1.5	1.28	1.32	1.36	0.9	0.88	1.77
	2	0.95	0.98	1.01	0.53	0.65	0.98
60	1	1.63	1.65	1.67	1.16	1.14	1.63
	1.5	1.09	1.12	1.14	0.86	0.83	1.1
	2	0.77	0.79	0.83	0.69	0.64	0.81
2nd sowing period (A)							
15	1	0.65	0.67	0.68	0.5	0.48	0.66
	1.5	0.81	0.85	0.9	0.4	0.56	0.84
	2	0.91	0.95	0.96	0.63	0.59	0.93

Table 2, Continued

Row spacing width, cm (B)	Seeding rate, million germ. seeds/ha (C)	Year of research					
		2015	2016	2017	2018	2019	2020
30	1	1.59	1.62	1.63	1.09	1.07	1.62
	1.5	1.32	1.36	1.38	0.92	0.9	1.35
	2	0.93	0.91	0.99	0.67	0.63	0.94
45	1	1.64	1.62	1.68	1.12	1.1	1.65
	1.5	1.17	1.18	1.22	0.82	0.78	0.78
	2	0.86	0.87	0.9	0.59	0.58	0.84
60	1	1.55	1.57	1.58	1.1	1.08	1.55
	1.5	1.04	1.05	1.08	0.83	0.79	1.05
	2	0.71	0.72	0.77	0.62	0.58	0.71
	LSD_{05}	*A-0.04* *B-0.06* *C-0.05*	*A-0.06* *B-0.09* *C-0.08*	*A-0.08* *B-0.12* *C-0.10*	*A-0.05* *B-0.06* *C-0.07*	*A-0.05* *B-0.07* *C-0.06*	*A-0.05* *B-0.07* *C-0.06*

Source: *compiled by the authors*

The lowest seed yield was in 2018 and 2019, the sum of active temperatures in these years was the lowest – in the range of 2,940-2,986°C, and effective – in the range of 1,516-1,529°C, and the growing season lasted several days longer compared to other years. The maximum yield values of 1.14-1.16 t/ha were formed by crops of the first sowing period with a row spacing of 45 cm with a seeding rate of 1 million germ. seeds/ha, the minimum – in the range of 0.4-0.5 t/ha when sowing in a continuous row for both periods.

Optimal yield indicators (on the best variants of 1.76-1.77 t/ha) were obtained in 2016 and 2017, which most corresponded to the biological characteristics of the crop by hydrothermal coefficient, the presence of sufficient precipitation for the sowing period and during flowering, the uniformity of precipitation distribution and temperature regime in the context of months. At the best variants of 2015 and 2020, the yield of fennel was 1.74 and 1.75, respectively, these are variants of the first sowing period with a row spacing of 45 cm and a seeding rate of 1 million germ. seeds/ha. Relative to the width of row spacing, the lowest yield in the context of all years of research (in the range of 0.4-1.1 t/ha) was obtained by sowing in a continuous row method, as well as wide-row methods with a seed application rate of 2 million germ. seeds/ha. That is, the yield decreased on more thickened crops. Fennel plants can form a significant aboveground part, and with a small feeding area, fewer productive shoots are formed, shading of plants occurs, i.e., the photosynthetic potential of such crops decreases and, as a result, the yield is not enough.

Based on the correlation and regression analysis of the yield data of common fennel and the data of the sum of active and effective temperatures for the growing season of the crop, the tightness of statistical relationships was determined through the indicators of multiple and paired correlation coefficients, total and partial determination coefficients, and regression coefficients were calculated (Fig. 2).

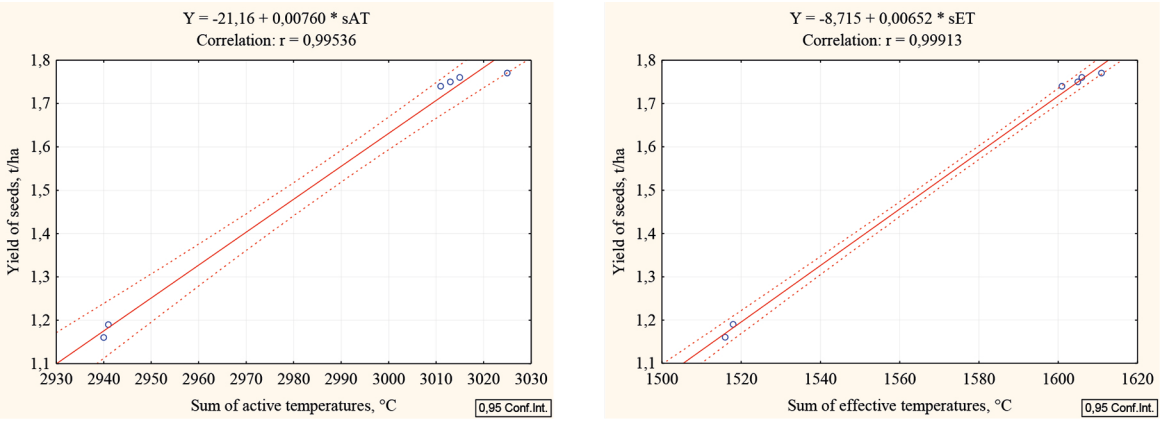


Figure 2*. Correlation and regression dependence of the yield of common fennel seeds on the sum of active and effective temperatures during the first sowing period (soil thermal regime – 6-8°C)*

Source: *compiled by the authors*

The sum of effective temperatures during the growing season of common fennel significantly affected the yield of seeds of the crop, as evidenced by the multiple correlation coefficient (R), which was equal to 0.9991. The coefficient of determination changed in the context of the studied factors in the same way as the correlation coefficient. To predict the seed productivity of fennel based on the results of statistical modelling, regression equations were developed for different sums of effective temperatures: Y=-8.71506+0.00652 sET.

Correlation and regression analysis of statistical relationships between the dependence of fennel yield on the sum of active and effective temperatures during the second sowing period (soil thermal regime – 10-8°C) showed that a similar trend was observed with the first term (Fig. 3).

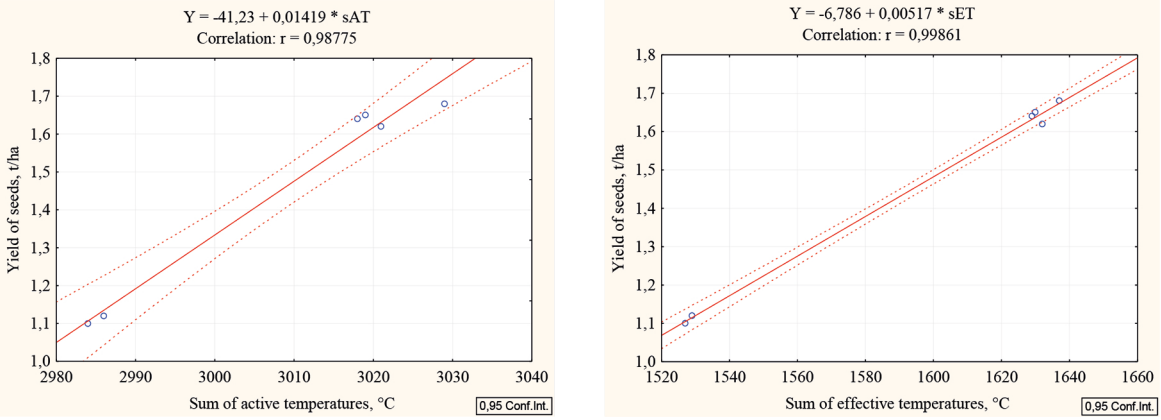


***Figure 3**. Correlation and regression dependence of the yield of common fennel seeds on the sum of active and effective temperatures during the first sowing period (soil thermal regime – 10-12°C)*

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

Thus, fennel by its biological characteristics needs early sowing dates, which range from the third decade of March to the second decade of April (depending on the growing region). Based on the conducted observations and analyses, (Kostenko, 2012) indicates the fastidiousness of common fennel to heat, moisture, and soil fertility.

Researchers in India prove the feasibility of early sowing of common fennel (Parashar & Lodha, 2012), since early spring crops are characterised by a lower incidence of crops with such a common disease as ramulariosis.

For the formation of optimal linear parameters of plants, high photosynthetic potential of agrocenoses, the formation of a high level of yield and accumulation of essential oil in seeds, the best row spacing width for most growing regions is 45 cm, as shown by the results of studies performed in the conditions of the Carpathian region. The researcher (Dmytryk, 2018) proves that with such agrotechnical parameters, the soil and climatic conditions of the zone allow obtaining a stable yield of fennel seeds at the level of 1.6 t/ha. In the conditions of the Western Forest-Steppe, fennel is able to form a yield of 1.56 t/ha under the conditions of sowing in the first decade of April with a row spacing of 45 cm and a seeding rate of 1 million germ. seeds/ha. The soil and climatic conditions of Polissya are somewhat less consistent with the biological characteristics of fennel and the yield is within 0.96 t/ha according to data (Stotska *et al.*, 2022) was obtained when sowing with a row spacing of 60 cm, that is, in these conditions, plants need a larger feeding area. With the specified width of row spacing and sowing at an early stage, plants increase such indicators as the raw mass of the plant, leaf surface area, photosynthetic potential, net photosynthesis productivity, and dry matter yield. Conclusions drawn by (Makuha, 2019) indicate that the maximum yield of common fennel seeds was obtained in the variant of the interaction of the early sowing period, row spacing width of 45 cm, nitrogen fertiliser doses of 60 and 90 kg a.s./ha, the indicators were 1.35 and 1.38 t/ha, respectively.

The largest areas of essential oil crops are concentrated in the Southern Steppe (Svidenko & Yezhov, 2015). Notably, the heat supply of the Southern Steppe zone of Ukraine allows growing common fennel as an annual crop with a growing season duration of 132-135 days, while in the conditions of the Western Forest-Steppe, 15-18 days more are needed to complete the generative period of plant development. Common fennel is among the most promising crops for the South of Ukraine, and a number of studies have confirmed the economic efficiency of its production in this growing area (Vozhegova *et al.*, 2021).

Such agrotechnical measures as increasing the width of row spacing and the number of plants per metre of linear row lengthen the duration of the generative period of development of fennel plants (Babii, 2015), this is conditioned by the formation of more umbrellas on plants with a larger feeding area. The author received the optimal yield due to the row spacing width of 45 cm and the seeding rate of 10 germinating seeds per running metre.

Thus, the feasibility of growing common fennel in different regions should be considered not only by technological factors, but also by biological ones (Stroyanovskyi & Khomina, 2021). In order to obtain a stable yield, determining the sum of active and effective temperatures when growing common fennel is an important aspect. Unfortunately, there is practically no research on this issue, with the exception of data obtained in the conditions of the Southern Steppe (Makuha & Fedorchuk, 2016; Makuha, 2020), which indicate a significant adaptive potential of the culture. According to researchers, the sum of active temperatures above 10ºC required for the formation of fennel seeds is on average 3,055ºC over the years of research, and the sum of the effective temperatures is 1,634ºC.

In recent years, there has been a redistribution of precipitation and heat regime in all zones of Ukraine, in the conditions of 2020 in the Western Forest-Steppe, when growing common fennel, the sum of temperatures was close to the data obtained in the steppe zone ten years prior, namely: active – 3,019ºC, and effective – 1630ºC, which indicates the prospects for growing common fennel in the climatic conditions of this zone.

CONCLUSIONS

The expediency of growing common fennel in the conditions of the Western Forest-Steppe of Ukraine in terms of the sum of active and effective temperatures during the growing season of common fennel was established, which contributed to the formation of a fairly high crop yield.

In the context of years of research, a similar trend was observed in the accumulation of the sum of active and effective temperatures during the growing season of common fennel, but the dynamics of plant development phases had their own characteristics and influence on the yield of seeds of the crop. In all the years of research, the total amount of active and effective temperatures was higher in the second period of fennel sowing. In the conditions of 2015, the sum of active temperatures was 3,018ºC, effective – 1,629ºC. The growing season of 2016 was characterised by slightly higher total temperatures: during the first sowing period, the sum of effective temperatures was 1,606ºC, during the second – 1,632ºC. The sums of active and effective temperatures during the growth and development phases of fennel plants in 2017-2019 were the lowest and amounted to 2,940-2,986 and 1,516-1,529ºC, respectively. The growing season in these years was the longest, and the yield was the lowest in all the years of research, but high enough for the conditions of the growing zone.

According to the accumulation of the sum of active and effective temperatures in the phases of growth and development of fennel plants, the conditions of 2020 were close to the conditions of 2016, the difference in values during the growing season was only 1-2°C. In the fennel ripening phase, the sum of active temperatures during the first sowing period was 3,013°C and 3019°C during the second sowing period, while the effective temperatures were at the level of 1,605°C and 1,630°C, respectively. Based on the results of the study, it was concluded that at the values of the integral net photosynthetic productivity in the range of 1,715.4-1,873.4 million kcal/ha in the conditions of the Western Forest-Steppe, it is possible to obtain a yield of common fennel seeds of about 1.74-1.77 t/ha.

The correlation analysis of yield indicators and the sum of temperatures, which can be attributed to the main uncontrolled factors affecting crop yield in a particular growing zone, showed the dependence of fennel yield on the sum of active temperatures (R=0.98-0.99; F=160.3-428.3). Prospects for further study are to investigate the effectiveness of growing common fennel as a two- and three-year crop, considering the sum of temperatures in the Western Forest-Steppe.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Агрокліматичне обгрунтування вирощування фенхелю звичайного в умовах Західного Лісостепу

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Анотація. Фенхель звичайний як рослина широкого спектру використання та високорентабельна культура, викликає значний інтерес у науковців та сільгосптоваровиробників і визначає актуальність досліджень з питань адаптації культури в умовах зони Західного Лісостепу та комплексу технологічних факторів при її вирощуванні. Метою досліджень було виявити вплив активних і ефективних температур, а також строку сівби, ширини міжрядь і норми висіву насіння на формування продуктивності фенхелю звичайного. В ході дослідження було використано загальнонаукові та математично-статистичні методи. В умовах Західного Лісостепу авторами було досліджено суми активних та ефективних температур в динаміці у розрізі різних за погодними умовами років досліджень та фаз вегетації рослин фенхелю звичайного. В результаті виконаних досліджень було проаналізовано показники інтегральної фотосинтетичнї активної радіації у вегетативний, генеративний та вегетаційний періоди росту і розвитку рослин. Було визначено рівень урожайності насіння фенхелю звичайного при вирощуванні на чорноземах глибоких малогумусних залежно від строку сівби, норми висіву насіння на ширини міжрядь за різних погодних умов років досліджень. Проведено кореляційний аналіз, який виконано за показниками урожайності насіння фенхелю звичайного і сумарних температур, які можна віднести до основних некерованих факторів, що впливають на урожайність сільськогосподарських культур в конкретній зоні вирощування. Було доведено доцільність вирощування фенхелю звичайного в умовах Західного Лісостепу України за показниками суми активних і ефективних температур впродовж вегетаційного періоду фенхелю, що сприяло формуванню достатньо високої урожайності насіння, а також встановлено оптимальний строк сівби, норму висіву насіння і ширину міжрядь за вирощування культури в конкретних ґрунтово-кліматичних умовах зони. Практична цінність роботи полягає в розробленні рекомендацій виробництву для аграрних підприємств умов Західного Лісостепу з питань оптимізації комплексу технологічних факторів при вирощуванні фенхелю звичайного

Ключові слова: фенхель звичайний; активні та ефективні температури; урожайність; строк сівби; ширина міжрядь; норма висіву насіння

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Efficiency of organic technologies of winter rye cultivation in Ukraine's Polissya in the context of climate change adaptation

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Abstract. In the conditions of the Polissya region of Ukraine, the cultivation of winter rye in organic farming is promising, but it is constrained by low crop yields. Therefore, the urgent task is to find ways to improve the efficiency of the fertilisation system of this traditional Polissya crop. The purpose of the study was to analyse the feasibility of using liquid complex fertilisers against the background of three fertilisation systems for organic and convection cultivation of winter rye in the conditions of Ukrainian Polissya. Field, laboratory and analytical, mathematical and statistical research methods were used. The results of a stationary experiment on light grey forest soil were analysed. It was found that the highest yield of winter rye was when grown using convection technology with a mineral fertilisation system – 4.2 t/ha, which provided an increase in grain yield of 1.07 t/ha or 34.4% compared to the control option. The use of organic

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technology based on organic and organo-mineral fertilisation systems provided a significantly smaller increase – 0.6 and 0.75 t/ha or 19.3 and 24.0%, respectively. However, the level of profitability for the mineral system decreased by 0.54 thousand UAH/tonne or 39.1%, net operating profit – by 1.6 thousand UAH/tonne or 26.0% compared to the organic fertilisation system. The latter was also better from the standpoint of energy efficiency. It is proved that double foliar top dressing with liquid organo-mineral fertilisers significantly increases the efficiency of the fertilisation system. In the conditions of the experiment, this was expressed in an additional increase in productivity by 0.47-1.16 t/ha, a reduction in the cost of production by 0.14-0.36 thousand UAH/ha, an increase in profitability by 19.3-48.3%, energy efficiency – by 0.14-0.71, and the plasticity of the crop to dry conditions during the growing season. The findings can become the basis for improving the fertilisation system for organic cultivation of winter rye, which would ensure the formation of sustainable yields by minimising the impact of stress factors (dry periods during the growing season) and increase the economic efficiency of grain production in agricultural enterprises of various forms of ownership

Keywords: corganic farming; short-term crop rotation; fertilisation systems; liquid organo-mineral fertilisers; plasticity of winter rye; profitability level; energy efficiency coefficient

INTRODUCTION

The dominant soil types in Ukraine's Polissya region are those of light particle size distribution, characterised by unfavourable agrophysical and physicochemical parameters, very low nutrient supply, and low energy potential. This is a serious obstacle to the development of organic farming in Polissya. This situation forces agricultural producers to saturate crop rotations with low-margin crops that are not demanding to soil fertility. Therefore, it is important to maximise the potential of winter rye in organic farming of this agricultural soil zone, primarily by increasing the efficiency of the fertilisation system for this crop.

Rye is more tolerant to growing conditions compared to other winter cereals, which allows effectively cultivating it in the Polissya region. Research by Avramenko *et al*. (2022) found that rye is able to absorb nutrients from poorly available forms and can be successfully grown on soils with low natural fertility. Due to its high resistance to agrocenosis and plasticity to environmental conditions, this crop is often placed on poor soils due to unsuccessful predecessors, optimal sowing times are neglected, and fertilisers are not used. However, as noted by Nelson *et al*. (2011) and Hayden *et al*. (2012), the crop, even at late sowing dates, has time to accumulate enough plastic substances, is able to form a shrub well in early spring, effectively use spring moisture reserves, and develop a sufficient productive stem. One of the ways to solve the problem of increasing the yield and economic efficiency in the cultivation of winter rye is the mandatory inclusion in the technological process of foliar top dressing with complex fertilisers containing the main macro- and microelements. Goenadi *et al*. (2018) note that the requirements for the economic efficiency of the use of complex fertilisers are increasing every year. Wilier *et al*. (2020) also emphasise economic priorities when applying biological factors to the intensification of agricultural production. At the same time, studies by Karasiuk & Khomchak (2005), Martinez-Alcantara *et al*. (2016) proved that the more complex the soil and climate, and weather conditions, the more important the role of biologisation in crop cultivation technologies. According to Didiek *et al*. (2018), Bargaz *et al*. (2018), Stamenković *et al*. (2018), biological preparations are able to activate the viability of beneficial epiphytic and, especially, saprophytic microflora, which inhibit the development of pathogenic organisms by 25-30% and contribute to better assimilation of mobile phosphorus and nitrogen by plants. Mc Guire (2017) notes that liquid complex microfertilisers and biologics contribute to improving the quality of agricultural products obtained, primarily by improving the root nutrition of plants. As stated by Kysil (2005) and Gunes *et al*. (2015), there is a close correlation between plant growth and the intensity of biophilic element uptake. Therefore, it is of great importance to establish patterns of influence of various types of fertilisers and preparations on this process. The value of such research increases in the organic farming system. As noted by Jezierska-Thöle *et al*. (2017), Reganold *et al*. (2016), Muller *et al*. (2017), efficient organic production should be based on energy-efficient soil protection technologies, intensifying the circulation of substances, improving the quality of food and living conditions of people. Equally important, according to Stovolos (2014), Klonsky (2012), is the introduction of sustainable crop rotations, the widespread use of plant residues, manure and compost, perennial legumes and green manure crops. However, Seufert *et al*. (2012), Freyer *et al*. (2019) suggest that a serious deterrent to the expansion of areas under organic farming is, first of all, the widespread belief that the rejection of mineral fertilisers and chemical protection products would lead to a rapid decline in yields.

The purpose of the study was to evaluate the influence of foliar top dressing with liquid complex fertilisers on organic and convection cultivation of winter rye in Ukraine's Polissya on the formation of high and stable yields, which is relevant in the context of climate change.

MATERIALS AND METHODS

The stationary experiment "Development and evaluation of biologisation elements in the farming system in Polissya", in which the research was carried out, started in 2010 (experimental field of Polissya National University, Chernyakhivskyi district, Zhytomyr Oblast). The period of 2014-2016 was analysed. It included a 5-field crop rotation, which was deployed on light grey forest soil, characterised by a low supply of macronutrients and general humus, and a slightly acidic reaction (pH_{KCl}=4.8). The area of the sown plot was 130 m^2, and the accounting area – 110 m^2. The repetition of the experiment was threefold. Field, laboratory and analytical, mathematical and statistical research methods were used. Statistical processing of the results was performed according to Dospekhov (1985) using *Statistica* 10.0 software suite, the collection and accounting of the main and by-products was carried out in sections at full grain ripeness.

Sowing was carried out with high-yield seeds of the Khlibne variety. The technology of growing winter rye was up to the principles of organic production and was adapted for the Polissya zone. The main tillage was carried out with disk tools. The predecessor was potatoes. To assess the effectiveness of liquid organo-mineral fertilisers against the background of the use of various fertilisation systems for winter rye, the results of a two-factor stationary experiment were analysed:

Factor A Fertilisation system: 1. Biological control (without fertilisers); 2. Organic system (aftereffect of manure applied to potatoes at a rate of 50 t/ha); 3. Organo-mineral system (50% organic fertilisers and 50% fertilisers of mineral origin); 4. Mineral fertilisation system ($N_{50}P_{40}K_{70}$ directly under the crop). In the biological control variant, fertilisers were not applied, however, post-harvest residues remained in the field to simulate an agroecosystem with minimal human intervention. In the organic system, no fertilisers were applied directly to winter rye, but the aftereffect of the 1st year of applying litter manure under the predecessor was used. Notably, the fertilisation systems are balanced in terms of nutrition elements and according to the organo-mineral system, part of organic fertilisers (50% of the need for biophilic elements) was replaced with minerals of natural origin ($N_{20}P_{10}K_{30}$ directly under the crop), which are used in organic farming: nitrogen in the form of urea, phosphorous – phosphorite, and potash – kainite. Straw after harvesting grain crops remained in the field and was subsequently incorporated into the soil. The mineral fertilisation system provided for the application of fertilisers of chemical origin: simple granular superphosphate (20% a.s.), potassium chloride (51% a.s.), ammonium nitrate (34% a.s., for pre-sowing cultivation). The total need for fertilisers was determined when developing a stationary experiment scheme, considering the agrochemical characteristics of light grey forest soil, its absorption capacity, and biological features of crop rotation crops. To optimise the *C:N* ratio in the soil, nitrogen fertilisers were additionally applied at the rate of 10 kg/t of straw to accelerate the process of straw degradation.

Factor B. Liquid complex fertilisers (LCF): 1. Control; 2. Mochevyn-K No. 1 (1 l/ha); 3. Mochevyn K No. 2 (1 l/ha); 4. Organik D-2M (1 l/ha); 5. Potassium humate (2 l/ha).

Foliar top dressing of winter rye crops with liquid complex fertilisers was performed twice during the growing season (according to the experiment scheme and recommendations for their use): the first application was carried out in the phase of entering the tube, the second – after 14 days. In the control, water spraying was carried out in parallel. The studied preparations are listed in the relevant state registers (State register of pesticides..., 2022; Havran *et al.*, 2022). Mochevyn-K No. 1 (1 l/ha) is recommended by the manufacturer to improve the development of the root system, plant biomass, and improvement of the immune system. Fertiliser contains 11-13% N, 0.1-0.3% P_2O_5, 0.05-0.15% K_2O, trace elements (0.1%), and succinic acid (0.1%). Mochevyn-K No. 2 (1 l/ha) contains 9-11% N, 0.5-0.7% P_2O_5, 0.05-0.15% K_2O, 3 g/l of sodium humate, 1 g/l of potassium humate, 1 g/l of a complex of trace elements. This fertiliser is recommended to increase the resistance of plants to drought, the development of additional shoots and accelerate maturation. Organik D-2M (1 l/ha) contains 2.0-3.0% N, 1.7-2.8% P_2O_5, 1.3-2.0% K_2O, 2.0-6.0% total calcium, 65-70% organic substances (in terms of carbon) and is recommended for strengthening plant immunity to various diseases, increasing seed germination energy, reducing the conversion rate of nitrates, heavy metals and radionuclides in plants, enhancing soil microbiological activity. Potassium humate (2 l/ha) contains macronutrients (*NPK*), a complex of trace elements (0.3-2.5 g/l) and is recommended for enhancing plant resistance to frost, drought, their better growth and development (State register of pesticides..., 2022; Havran *et al.*, 2022).

RESULTS AND DISCUSSION

The analysis of crop yield in 2014 showed that the highest result was provided by the conventional mineral fertilisation system, where, on the variant without the use of preparations, the increase was 1.71 t/ha or 72.5% compared to the indicator that was achieved on biological control (2.36 t/ha). On this version of the fertilisation system, Mochevyn-K2 and Organik D-2M preparations worked best, which provided the highest yield in the experiment – 5.00 and 4.94 t/ha, respectively.

Under the conditions of the organic fertilisation system, where the crop used only the aftereffect of manure, which was applied under the predecessor, the yield on the version without the use of preparations was 3.00 t/ha. The introduction of preparations provided an increase in the yield at the level of 3.67-3.83 t/ha. The lowest rates were recorded when using the Mochevyn-K1 preparation. The organo-mineral fertilisation

system on the variant without the use of preparations provided an increase in yield of 1.42 t/ha or 60.2% compared to the biological control. The use of liquid organo-mineral fertilisers significantly improved the indicator. The highest yield on this agricultural background was recorded when using Organik D-2M and Mochevyn-K2 – 4.70 and 4.98 t/ha, respectively.

The highest cost of the obtained products in the experimental conditions in 2014 was recorded for the mineral fertilisation system and the use of liquid organo-mineral fertilisers Mochevyn-K2 and Organik D-2M – 15.00 and 14.82 thousand UAH/ha, respectively. This trend was also observed in the organo-mineral system. The lowest production costs for growing winter rye were recorded on biological control and organic system (5.12 and 5.04 thousand UAH/ha, respectively), and the highest – on mineral system (8.16 thousand UAH/ha). The highest level of profitability in the cultivation of winter rye in the first year of research was with the use of the organic system. This is conditioned by the fact that the culture used the aftereffect of manure, which was introduced under the potatoes. Treatment of crops with liquid complex fertilisers has increased the efficiency of this fertilisation system. The highest level of profitability was obtained with the use of Mochevyn-K2 – 123%, Organik D-2M – 120%. Moreover, a high level of profitability of these preparations was achieved in the organo-mineral system – 124 and 111%, respectively.

In 2015, the yield level was significantly higher. On biological control, the increase was 1.23 t/ha or 52.1%. This is primarily conditioned by more favourable weather conditions during the formation of the winter rye crop. In the experiment, the highest yield was obtained under the mineral fertilisation system – 4.39 t/ha, which is 0.8 t/ha or 22.3% more than under biological control. With the use of preparations, the advantage of the fertilisation system has increased. At the same time, the best result was provided by Mochevyn-K2 and potassium humate – 5.59 t/ha and 5.67 t/ha, respectively. The organo-mineral system also provided a high yield increase relative to biological control – 0.44 t/ha or 12.3%. When using Mochevyn-K2 and Organik D-2M against the background of the organo-mineral system, the increments were 1.14 and 1.47 t/ha, respectively, or 28.3 and 36.5% relative to the control.

Analysis of the results of the economic efficiency of fertilisation systems showed that the highest cost of the products was recorded on the variants where crops were treated with Mochevyn-K2 and potassium humate against the background of the mineral system – 16.77 and 17.01 thousand UAH/ha, respectively. However, the cost of cultivation here was also the largest – 8.19 thousand UAH/ha, which is 3 thousand UAH/ha or 58.7-59.0% more than on the organic system variant. Slightly lower indicators were recorded under the conditions of the organo-mineral system with the treatment of crops by Organik D-2M and Mochevyn-K2. Net operating profit was the largest under the organic system – an increase in biological control amounted to 1.54 thousand UAH/ha, or 26.7%. Preparations also provided an improvement in the indicator. Thus, under the organic system, liquid organo-mineral fertilisers Organik D-2M and Mochevyn-K2 provided the net operating profit at the level of 9.72 and 9.81 thousand UAH/ha, which is 33.2 and 34.4% more than in the control. Under the influence of the organo-mineral system, these preparations provided an increase in net operating profit by UAH 3.28 and 4.26 thousand, or 59.1 and 76.8%, respectively. The highest level of profitability under the organic system is conditioned by the fact that rye used the aftereffect of manure to form the crop, and the cost of its application was attributed to the technological costs of the previous crop (potatoes). For the same reason, rather high profitability indicators are characteristic of the organo-mineral fertilisation system.

In 2016, the yield was lower compared to the previous year. Thus, in biological control, the indicator decreased by 0.17 t/ha or 4.7%. This is conditioned by the difficult weather conditions during the critical period of crop development, since according to the hydrothermal coefficient (HTC) in the phases of entering the tube, flowering, formation and maturation of grain, they were characterised as arid. According to the organic system, the yield increase in the control was 0.65 t/ha or 19.0%, organo-mineral – 0.39 t/ha (11.4%), and mineral – 0.71 t/ha (20.8%). The effectiveness of the preparations under different fertilisation systems was not clear. According to the organic system, foliar top dressing with Mochevyn-K No. 2 and Organik D-2M preparations was the most effective – the increase in the indicator was 0.52 t/ha (12.8%) and 0.68 t/ha (16.7%), respectively. According to the organo-mineral system, the advantage of these preparations remained – an increase relative to the control – 0.79 t/ha (20.7%) and 1.09 t/ha (28.6%), respectively. Under the mineral fertilisation system, the highest yield increase relative to the control was recorded for treatment with Mochevyn-K2 and potassium humate preparations – 1.07 t/ha (25.9%) and 1.24 t/ha (30.0%), respectively.

The highest net operating profit without the use of preparations was obtained under the organic fertilisation system – 7.18 thousand UAH/ha, which is 36.8% more than with biological control. Under foliar top dressing with Organik D-2M and Mochevyn-K2 preparations, the indicator increased by 1.43 thousand UAH/ha or 19.9% and 1.91 thousand UAH/ha or 26.6% relative to the control, respectively. For the organo-mineral system, the advantage of these preparations remained – for treatment with Organik D-2M, the increase relative to the control of the system was 3.12 thousand UAH/ha or 63.8%, and Mochevyn-K2 – 2.23 thousand UAH/ha or 45.6%. In the third year of the study, the profitability level was highest for the organic system – from 143% for the control to 176% with the use of preparations.

In general, for three years of research, the advantage of Mochevyn-K2 and Organik D-2M preparations in terms of yield was indisputable against the background of all fertilisation systems studied in the experiment (Table 1). Thus, against the background of various fertilisation systems for foliar top dressing with liquid complex fertilisers (LCF) Mochevyn-K2, the increase was 21.1-26.9%, and Organik D-2M – 19.5-29.9%.

***Table 1**. The yield of winter rye depending on fertilisation systems and preparations (average for 3 years) in the short-term crop rotation in Polissya*

Fertilisation system	Preparation	Yield, t/ha	Deviations				Variation coefficient
			by fertilisation systems		by preparations		
			±	%	±	%	
1. Biological control	Control	3.12±0.75*	–	–	–	–	21.34
2. Organic system	Control	3.73±0.71	0.60	19.3	–	–	16.90
	Mochevyn-K1	4.20±0.58	–	–	0.47	12.6	12.28
	Mochevyn-K2	4.51±0.68	–	–	0.79	21.1	13.32
	Organik D-2M	4.46±0.69	–	–	0.73	19.6	13.71
	Potassium humate	4.40±0.65	–	–	0.68	18.2	13.04
3. Organo-mineral system	Control	3.87±0.70	0.75	24.0	–	–	15.89
	Mochevyn-K1	4.54±0.70	–	–	0.67	17.2	13.70
	Mochevyn-K2	4.92±0.66	–	–	1.04	26.9	11.95
	Organik D-2M	5.03±0.75	–	–	1.16	29.9	13.23
	Potassium humate	4.62±0.54	–	–	0.74	19.2	10.41
4. Mineral system	Control	4.20±0.72	1.07	34.4	–	–	15.24
	Mochevyn-K1	4.80±0.66	–	–	0.60	14.4	12.14
	Mochevyn-K2	5.26±0.68	–	–	1.07	25.4	11.35
	Organik D-2M	5.02±0.66	–	–	0.82	19.5	11.66
	Potassium humate	5.22±0.58	–	–	1.03	24.5	9.77

***Note:** *M±m – confidence interval*
***Source:** compiled by the authors*

On average, over 3 years of research, the organic system without the use of LCF provided an increase in yield at the level of 0.6 t/ha or 19.3%, organo-mineral – 0.75 t/ha or 24.0%, and mineral – 1.07 t/ha or 34.4% relative to biological control. Foliar top dressing with Mochevyn-K2 and Organik D-2M against the background of various fertilisation systems provided an increase in yield by 0.73-1.16 t/ha or 19.5-29.9% relative to the corresponding control variants. The highest productivity was provided by agricultural technologies based on the mineral fertilisation system and foliar top dressing with Mochevyn-K2 and potassium humate – 5.27±0.68 t/ha and 5.23±0.58 t/ha, respectively.

A significant level of variation in yield in the context of years of research is conditioned by the influence of weather conditions, the share of influence of which on the indicator reached 23% (Fig. 1). For comparison, the share of exposure to fertilisation systems was 41%, and top dressing with liquid complex fertilisers was 19%. As the statistical analysis of crop yield results showed, the degree of influence of the weather factor on agricultural technologies was not the same. However, an interesting pattern can be traced. Thus, biological control recorded a strong level of variation in the yield of winter rye over the years of research (21.3%). The use of fertilisation systems with the treatment of crops with LCF significantly reduced the level of variability of the indicator. It can be assumed that improving the level of nutrition of the crop and, especially, the use of LCFs contributed to increasing the resistance of the variety to arid conditions in 2016. Although this comparison is somewhat conditional, it confirms the conclusions of researchers about the positive effect of liquid and mineral fertilisers on protecting crops from adverse weather conditions during the growing season (Semenjuk, 2017; Drobek *et al.*, 2019).

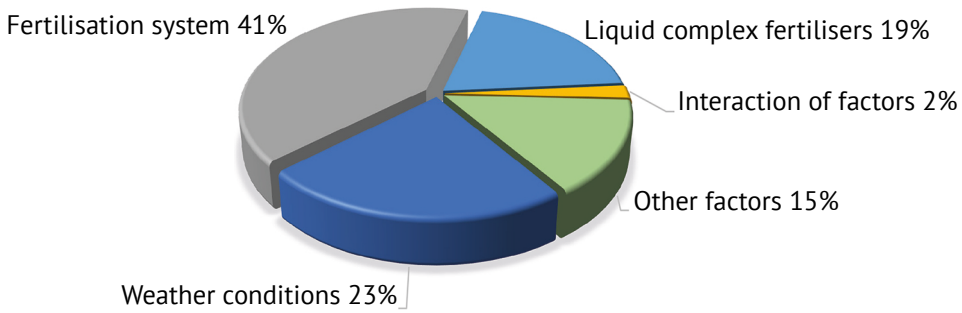

***Figure 1**. Share of influence of factors on the yield of winter rye during the observation period*
***Source:** compiled by the authors*

In general, for 3 years of research, the lowest technological costs for growing winter rye on control variants were observed for organic and organo-mineral fertilisation systems – 5.03 and 6.54 thousand UAH/ha. For the mineral system without the use of preparations, costs increased by UAH 3.03 thousand/ha, or 60.5% relative to biological control. The highest net operating profit was obtained for the organo-mineral system with the use of Organik D-2M – 8.41 thousand UAH/ha (Fig. 2).

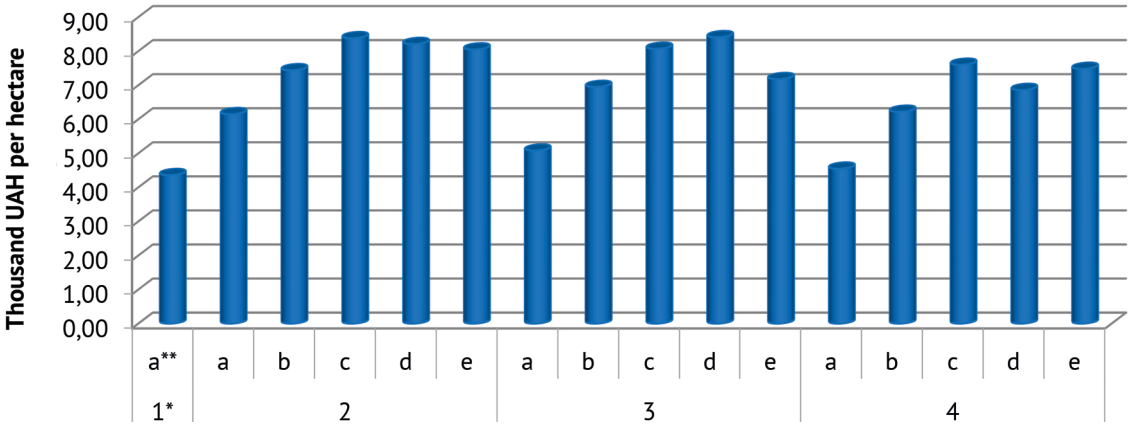

***Figure 2**. Net operating profit for growing winter rye depending on fertilisation systems and preparations (average for 3 years)*
***Note:** *Fertilisation systems: 1 – Biological control; 2 – Organic system; 3 – Organo-mineral system; 4 – Mineral system. **Liquid complex fertilisers: a – control; b – Mochevyn-K1; c – Mochevyn-K2; d – Organik D-2M; e – potassium humate*
***Source:** compiled by the authors*

The mineral fertilisation system, although it provided high productivity of the crop, but the increase in the cost of its cultivation compared to alternative organic systems significantly reduced the economic attractiveness of agricultural technologies based on it, which was manifested in a decrease in net operating profit and profitability. Thus, on the option without the use of preparations for the mineral system, the lowest level of net operating profit was recorded (4.55 thousand UAH/ha), which is 26% lower than for the organic system.

On average, for three years of research, the lowest cost of winter rye was recorded for the organic fertilisation system – 1.38 thousand UAH/t, which is 0.28 thousand UAH/t or 17% less than for biological control (Fig. 3). For the mineral system, the prime cost increased by 0.26 thousand UAH/t, or 15.5%, compared to absolute control. In general, under the organic system, the cost of winter rye grain was 0.54 thousand UAH/t, or 39.1% lower than under the mineral fertilisation system. With the foliar application of liquid organo-mineral fertilisers Mochevyn K1 and Organik D-2M, the indicator decreased, respectively, by 16.0-19.4% and 14.8-21%, depending on the system.

The use of an organic system contributed to an increase in the profitability of growing crops by 35.3% compared to the control (Fig. 4). For convection cultivation, there was a significant decrease in the indicator for all variants of the mineral fertilisation system. Without the use of liquid complex fertilisers, the profitability of grain production on this system was 65.7% lower than on the organic system. Liquid organo-mineral fertilisers significantly improved the economic efficiency of growing crops in all fertilisation systems. Thus, in particular, the use of Mochevyn-K2 and Organik D-2M provided an increase in net operating profit by 2.06-3.33 thousand UAH/ha or 33.5-67.0% relative to the control options with water treatment.

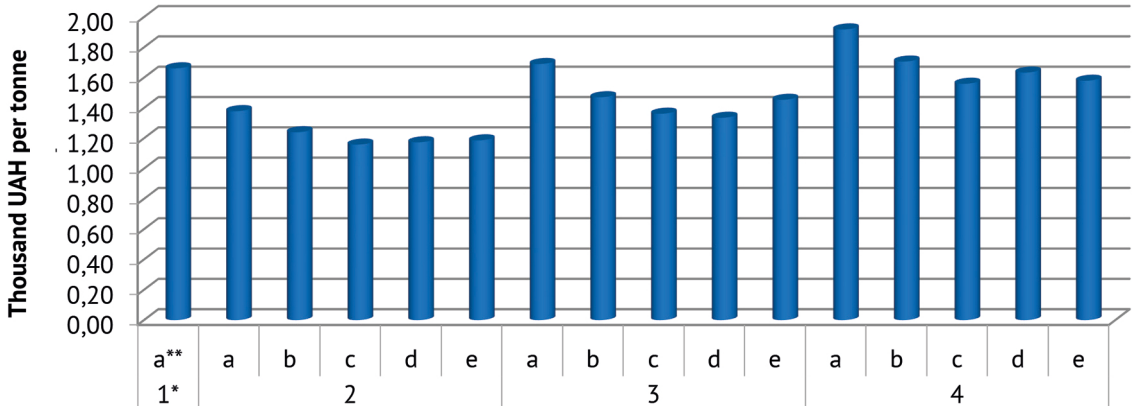

Figure 3. *Cost of winter rye depending on fertilisation systems and preparations (average for 3 years), thousand UAH/t*
Note: **Fertilisation systems: 1 – Biological control; 2 – Organic system; 3 – Organo-mineral system; 4 – Mineral system. **Liquid complex fertilisers: a – control; b – Mochevyn-K1; c – Mochevyn-K2; d – Organik D-2M; e – potassium humate*
Source: *compiled by the authors*

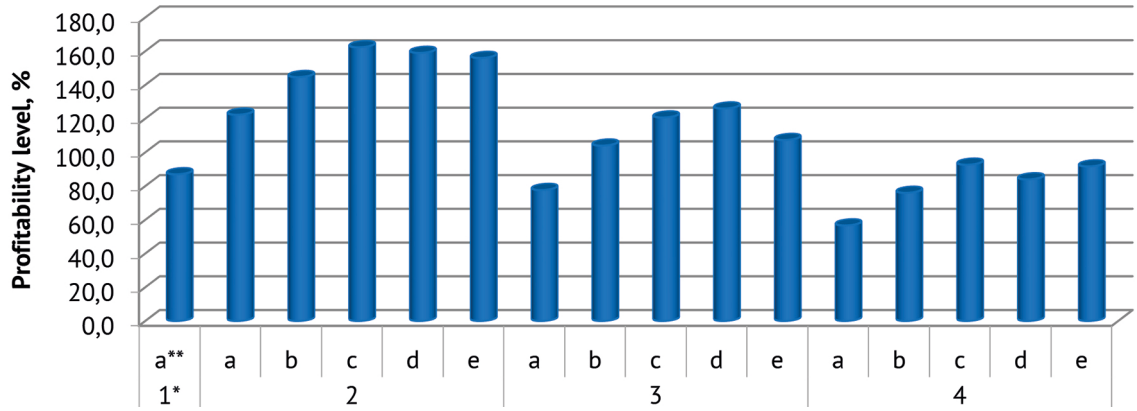

Figure 4. *Profitability level of growing winter rye depending on fertilisation systems and liquid complex fertilisers (average for 3 years), %*
Note: **Fertilisation systems: 1 – Biological control; 2 – Organic system; 3 – Organo-mineral system; 4 – Mineral system. **Liquid complex fertilisers: a – control; b – Mochevyn-K1; c – Mochevyn-K2; d – Organik D-2M; e – potassium humate*
Source: *compiled by the authors*

Along with the economic one, the energy analysis of cultivation technologies is no less important. It was found that during the research period, agricultural technologies provided a high level of energy efficiency, since the accumulation of total energy in the crop significantly exceeded the total energy costs for production (Table 2). Thus, even on biological control, the energy efficiency coefficient was 3.74±0.91. For the mineral fertilisation system in the control, the indicator improved by only 6.6%, and for the organo-mineral system – by 11.8% compared to the biological control. The organic system was the best from the standpoint of energy, providing an increase in the energy efficiency coefficient by 19.3%. Top dressing with complex preparations contributed to an increase in the indicator by 3.5-13.5% for the mineral system, 4.8-16.1% for the organo-mineral system, and 7.8-15.9% for the organic system.

Table 2. *Indicators of energy efficiency of winter rye cultivation in short-term crop rotation of Polissya*

Fertiliser variant	Liquid complex fertiliser	Energy output, GJ	Energy efficiency ratio
1. Biological control	Control	52.19±12.6	3.73±0.9
2. Organic system	Control	62.27±11.91	4.45±0.85
	Mochevyn-K1	70.13±5.97	4.8±0.41
	Mochevyn-K2	75.42±11.36	5.16±0.78
	Organik D-2M	74.47±11.55	5.09±0.79
	Potassium humate	73.58±10.86	5.03±0.74

Table 2, Continued

Fertiliser variant	Liquid complex fertiliser	Energy output, GJ	Energy efficiency ratio
3. Organo-mineral system	Control	64.72±2.58	4.17±0.17
	Mochevyn-K1	75.86±3.1	4.37±0.18
	Mochevyn-K2	82.16±5.49	4.73±0.32
	Organik D-2M	84.11±7.87	4.84±0.45
	Potassium humate	77.14±7.34	4.44±0.42
4. Mineral system	Control	70.13±3.22	3.98±0.18
	Mochevyn-K1	80.21±3.62	4.12±0.19
	Mochevyn-K2	87.95±5.67	4.52±0.29
	Organik D-2M	83.83±1.89	4.3±0.1
	Potassium humate	87.28±10.12	4.48±0.52

Source: *compiled by the authors*

The highest energy efficiency in the experiment was provided by agricultural technologies that provided for the use of an organic system and foliar top dressing of LCF Mochevyn-K No. 1 (*Kee*=5.16) and Organik D-2M (*Kee*=5.09).

Considering the characteristics of zonal and other soils common in Polissya and the recommendations of Solovei *et al.* (2018) regarding the ecological and genetic suitability of Ukrainian soils for organic production, it was found that the land fund of Polissya (except for massifs of light loamy granulometric composition) is not suitable for organic farming. Based on the study by Solovei *et al.* (2018), 50.4% of Polissya's soil cover was classified as poorly suitable, 45.5% as conditionally suitable, and only 4.1% as suitable for organic farming. The authors note that the zonal soils of Polissya are characterised by a high return on mineral fertilisers, which sharply reduces the organic coefficient. However, the approach to assessing fitness proposed by Solovei *et al.* (2018) is rather conditional. Thus, according to Grycenko (2020), the development of organic farming in the zone has significant potential, especially when growing winter rye and introducing an effective organic fertilisation system. This is confirmed by the authors of this study (Kravchuk *et al.*, 2021).

Research by Yavorskaya *et al.* (2006) substantiated the need for foliar leaf feeding of plants with microelements in the phases of intensive growth and development and, especially, in stressful situations (low temperatures, drought). Januskaitiene *et al.* (2021), Karasiuk & Khomchak (2005) note that microlements, which are part of liquid organo-mineral fertilisers, activate the course of many physiological and biochemical processes, in particular, increase the intensity of photosynthesis, activate the action of enzymes, enhance hydrocarbon metabolism, which determines the resistance of the crop to stressful situations during dry periods during the growing season. According to Bargaz *et al.* (2018), an important condition for improving the effectiveness of such fertilisers is to consider the biological characteristics of the crop, the method of their application, and the timing. Popko *et al.* (2018), Gunes *et al.* (2015), Antille *et al.* (2013) emphasise that the effectiveness of liquid complex fertilisers significantly depends on the temperature regime and moisture regime during the growing season and the state of the soil ecosystem. During the research period, it was found that the hydrothermal conditions of the growing season had a significant impact on the course of biochemical processes occurring in plants. This is confirmed by the relevant biochemical studies by Januskaitiene *et al.* (2021). Similar results were obtained by Kalenska (2004). The researcher notes that fluctuations in crop yield by year can reach 40-60%, depending on weather conditions (Kalenska, 2004).

The positive effect of organic fertilisation on increasing the resistance of cereals in critical years of moisture supply, which was recorded during the research period, was also noted by Januskaitiene *et al.* (2021). The researchers point to a significant increase in the production of enzymatic antioxidants by spring barley plants, as well as a decrease in the rate of photosynthesis in dry years with organic fertiliser than with the mineral system. In addition, as noted by Sivojiene *et al.* (2021), Zikeli & Gruber (2017) long-term mineral fertilisation significantly impoverishes the species biodiversity of soil microorganisms. This leads to the establishment of niches for the acclimatisation of pathogenic organisms and a decrease in the resistance of cultivated plants to stressful factors.

Notably, the study was carried out under a soil-saving tillage system. The expediency of using such a processing system is substantiated in the studies by Galich & Strelchenko (2004), Veremeienko & Semenko (2019), Kadžienė *et al.* (2011). This was confirmed by previous research (Kravchuk *et al.*, 2021). Moreover, previous studies (Kravchuk *et al.*, 2021) found that winter rye can be effectively grown without the use of herbicides, since it is characterised by a high tillering coefficient and an intensive increase in biomass, which causes weed suppression. The same conclusions were obtained by Reddy (2003) and Cavigelli *et al.* (2008).

Kravchuk *et al*. (2021) have found that with the long-term use of soil-protective agricultural technologies, positive changes in the agroecological state of the root layer of light grey forest soil occurred. This was manifested in a significant improvement in certain biological (humus content and biological activity of the soil), agrophysical (structure), and water and physical (supply of productive moisture) indicators. However, in terms of the impact on crop yields of crop rotation, the advantage of long-term use of no-till methods of basic cultivation in the experiment was manifested only if a fertilisation system was used.

CONCLUSIONS

For 3 years of research in short-term crop rotation, the highest productivity of winter rye was observed when growing crops using convection technology with a mineral fertilisation system – 4.2 t/ha. This fertilisation system provided a grain increase of 1.07 t/ha or 34.4% relative to the control option. When using organic cultivation technology based on an organic fertilisation system in crop rotation, the yield increase was 0.6 t/ha or 19.3%, and organo-mineral – 0.75 t/ha or 24.0%. Foliar top dressing with liquid complex fertilisers significantly increased the efficiency of these fertilisation systems, providing an additional yield increase of 0.47-1.16 t/ha or 12.6-29.9%. The highest yield gains were provided by the use of Mochevyn-K2 and Organik D-2M fertilisers.

The share of influence of weather conditions on crop yield during the research period was 23%. The variation of yields in different years of water supply significantly decreased when using fertilisation systems with treatment of crops with liquid complex fertilisers, which is especially relevant in the context of adaptation to climate change.

The most economically and energetically expedient method in the experiment was to grow crops using organic technologies based on organic (aftereffect of manure) and organo-mineral fertilisation systems (with the introduction of 5 t/ha of manure per 1 ha of crop rotation area and $N_{12}P_{10}K_{25}$, incl. $N_{20}P_{10}K_{30}$ directly under the crop) and foliar top dressing with Organik D-2M. These technologies provided net operating profit at the level of 8.21 and 8.41 thousand UAH/ha, profitability – 159 and 126%, energy efficiency coefficient – 5.09 and 4.84, respectively, which significantly exceeded the corresponding indicators for convection cultivation of winter rye.

The prospects for further research are related to the search for new effective liquid complex fertilisers and, especially, biologics for organic cultivation of winter rye, which would reduce the impact of stress factors in dry periods during the growing season, ensure stable yields, and contribute to increasing the economic efficiency of grain production in economic and production facilities of various forms of ownership.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Ефективність органічних технологій вирощування жита озимого в умовах Полісся України у контексті адаптації до змін клімату

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Анотація. В умовах Полісся України вирощування жита озимого у органічному землеробстві є перспективним, проте стримується низькими врожаями культури. Тому актуальним завданням є пошук шляхів підвищення ефективності системи удобрення цієї традиційної поліської культури. Метою досліджень було проаналізувати доцільність застосування рідких комплексних добрив на фоні трьох систем удобрення за органічного та конвекційного вирощування жита озимого в умовах Полісся України. Було використано польові, лабораторно-аналітичні, математико-статистичні методи досліджень. Було проаналізовано результати стаціонарного досліду на ясно-сірому лісовому ґрунті. Встановлено, що найвища урожайність жита озимого була за вирощування за конвекційною технологією з мінеральною системою удобрення – 4,2 т/га, яка забезпечила приріст зерна 1,07 т/га або 34,4% до контролю по досліду. Застосування органічної технології на основі органічної і органо-мінеральної систем удобрення забезпечило значно менший приріст – 0,6 і 0,75 т/га або 19,3 і 24,0%, відповідно. Однак, рівень рентабельності за мінеральної системи скоротився на 0,54 тис. грн/т або 39,1%, умовно чистий прибуток – на 1,6 тис. грн/т або 26,0% порівняно з органічною системою удобрення. Остання була кращою і з енергетичної точки зору. Доведено, що двократне позакореневе підживлення рідкими органо-мінеральними добривами суттєво підвищує ефективність системи удобрення. В умовах досліду це виражалось у додатковому прирості продуктивності на 0,47–1,16 т/га, зниженні собівартості на 0,14–0,36 тис.грн/га, підвищенні рентабельності на 19,3–48,3%, енергетичної ефективності – на 0,14–0,71 та пластичності культури до посушливих умов протягом вегетації. Наукові результати можуть стати основою для вдосконалення системи удобрення за органічного вирощування жита озимого, що забезпечить формування сталих врожаїв за рахунок мінімізації впливу стресових чинників (посушливі періоди протягом вегетації) та підвищити економічну ефективність виробництва зерна у агроформуваннях різних форм власності

Ключові слова: органічне землеробство; короткоротаційна сівозміна; системи удобрення; рідкі органо-мінеральні добрива; пластичність жита озимого; рівень рентабельності; коефіцієнт енергетичної ефективності

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Formation of narrow-leaved lupine productivity depending on seed inoculation and fertilization

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Abstract. Narrow-leaved lupine is characterised by valuable economic features, so it is an important source of balanced and easily digestible vegetable protein. The purpose of the study was to substantiate the effect of seed inoculation and fertiliser on the growth and development of narrow-leaved lupine plants in order to maximise the genetic potential of the variety in Polissya conditions. The following research methods were used: general scientific (induction and deduction, generalisation), special (field, measurement and weight, physiological, laboratory), and statistical (correlation and regression). Field studies were conducted during 2019-2021. The features of growth and development of narrow-leaved lupine plants of the Olimp variety in Polissya conditions were investigated. The positive effect of seed inoculation with bacterial preparations and foliar fertilization with complex fertiliser on the productivity of narrow-leaved

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lupine, which plays an important role in solving the problem of plant protein, was established. The optimal area of the leaf surface of plants was determined by optimising the elements of agricultural technology of narrow-leaved lupine. The photosynthetic potential of lupine was determined depending on seed inoculation with biological preparations and fertiliser. The studied factors increase stem density, plant survival, and improve the indicators of individual crop productivity. Inoculation of seeds with biologics and foliar application ensures the formation of the highest (2.43 t/ha) grain productivity of narrow-leaved lupine. Seed inoculation increases the yield of narrow-leaved lupine grain by 10.8-11.4%, depending on nutritional background. Foliar application of plants with complex fertiliser in phases BBCH 21-23 and BBCH 51 on a mineral background for seed inoculation provides a 2.8% increase in grain yield compared to the control. The findings can be used to improve the elements of the technology of growing narrow-leaved lupine, which will ensure high and stable grain yields

Keywords: grain yield; bacterial preparations; foliar application; BBCH scale; linear indicators; leaf surface area; photosynthetic potential

INTRODUCTION

Vegetable protein is an important component of food and feed resources. The search for reserves to increase the production of vegetable protein to ensure proper nutrition of the population is of strategic importance in economic and social aspects. Increasing the production of vegetable protein is a key area of the agricultural sector. Among the agricultural crops that are a reserve for increasing the volume of vegetable protein, legumes are the most important. The most valuable protein crops of world crop production include narrow-leaved lupine (*Lupinus angustifolius* L.), which is promising for growing on low-fertile soils. To implement the genetic potential of narrow-leaved lupine varieties, it is necessary to review the agricultural technology of the crop. Thus, the study of the effects of seed inoculation and fertiliser on field germination, plant growth and development during the growing season, and the formation of productivity elements on low-fertile Polissya soils is relevant.

Narrow-leaved lupine is unpretentious to growing conditions and is able to form a grain yield of up to 2.58-2.61 t/ha (Holodna, 2022). However, the newly created varieties of narrow-leaved lupine are not fully able to meet the maximum genetic potential due to the impact of climate change (Kotelnytska *et al.*, 2021).

The yield of narrow-leaved lupine grain significantly depends not only on weather conditions but also on elements of cultivation technology, in particular, varieties, fertilisers, seed treatment before sowing, and other factors (Szymańska *et al.*, 2017; Mazur *et al.*, 2019; Panasiewicz *et al.*, 2020). An important factor in increasing the level of grain yield of agricultural crops is the application of mineral fertilisers (Punchyshyn *et al.*, 2019; Shevnikov *et al.*, 2022). Many researchers have studied the effectiveness of applying mineral fertilisers in the cultivation technologies of narrow-leaved lupine (Tkachuk *et al.*, 2019; Holodna, 2019).

The study by H. Kotelnytska *et al.* (2021) found that the maximum yield of grain of the narrow-leaved lupine variety Peremozhets (2.26 t/ha) was obtained by complex foliar application with a mixture of fertilisers in the budding phase and applying mineral fertilisers to the soil ($N_{30}P_{60}K_{60}$). The study by Lithuanian researchers (Tripolskaja & Asakaviciute, 2019) found a 22.8% decrease in the yield of narrow-leaved lupine grain when applying nitrogen fertilisers on acidic soils. Inoculation of seeds with biologics based on nitrogen-fixing bacteria and antagonist microbes in agricultural technologies improves plant nutrition, accumulates physiologically active substances in the rhizosphere, increases plant resistance to stress factors, increases yield, and improves the quality of crop products (Nyoki & Ndakidemi, 2018; Adesemoye *et al.*, 2021; Mirriam *et al.*, 2022).

According to A.V. Holodna (2022) treatment of narrow-leaved lupine seeds with a bioinoculant (based on a strain of nitrogen-fixing bacteria of the genus *Bradirhizobium lupini* 359a) in combination with the growth stimulator Nano-Gro increases grain yield by 4.5%. Seed treatment before sowing with BTU-R and MikoHelp biologics for applying mineral fertilisers to the soil ($N_{68}P_{48}K_{66}$) and double foliar application of plants at the 2nd and 4th stages of organogenesis with Tropicel provides grain yields up to 2.58-2.61 t/ha (Holodna, 2021).

Thus, *the purpose of the study* was to substantiate the regularities of the formation of productivity of narrow-leaved lupine depending on seed inoculation and fertiliser on sod-podzolic sandy loamy soils of Polissya. The objectives of the study were to find out the influence of fertiliser, foliar application with complex fertiliser during critical periods of plant development, inoculation of seeds with bacterial preparations on linear indicators, individual productivity and yield of narrow-leaved lupine grain.

MATERIALS AND METHODS

Studies of the effect of fertiliser and seed inoculation on the productivity of narrow-leaved lupine were conducted during 2019-2021 on sod-medium-podzolic sandy loamy soils of Polissya. The soil of the experimental plots was characterised by the following indicators: pHsalt – 5.9, content in the arable layer of humus (according to Tyurin and Kononov) – 1.2%, easily hydro-

lysed nitrogen (according to Kornfield) – 63.8 mg/kg of dry soil, mobile forms of phosphorus (according to Kirsanov) – 22.7 mg/kg of dry soil, exchange potassium (according to Kirsanov) – 13.6 mg/kg of dry soil.

The field experiment scheme includes factors:

Factor A – seed treatment: 1. Control (without inoculation); 2. Rhizoactive legumes, KL, 2 l/t (seed inoculation);

Factor B – fertilization: 1. Control (without fertilisers); 2. $N_{35}P_{60}K_{16}$ – background 3. N35P60K16 (background) + YaraVita BRASSITREL PRO, KL, 3 l/ha (double foliar application).

Foliar application was carried out with microfertiliser YaraVita BRASSITREL PRO in the rosette phase at a rate of 3 l/ha and at the beginning of budding at a rate of 3 l/ha. Granular mineral fertiliser YaraMila, GR (NPK 16-27-7) at a rate of 220 kg/ha was used. The composition of the fertiliser includes: nitrogen, total (N) – 16%, nitrate (NO_3) – 11.8%, ammonium (NH_4 – 4.2%, phosphorus (P_2O_5 – 27%, potassium (K_2O) – 7%, sulphur (S) – 2% (SO_3 – 5 %), zinc (Zn) – 0.1 %. Mineral fertilisers were applied before early spring harrowing ($N_{24}P_{41}K_{11}$) and before pre-sowing cultivation ($N_{11}P_{19}K_5$). The working fluid rate – 200 l/ha. Inoculation of seeds with biologics was carried out on the day of sowing.

The narrow-leaved lupine variety Olimp was grown using the technology generally accepted for the Polissya zone. Weight of 1,000 seeds – 172 g, laboratory germination rate – 93%. The seeding rate of narrow-leaved lupine in the experiment was 1.1 million germinated seeds per 1 ha.

The area of the accounting plot in the experiment was 26 m^2. The placement of the variants in the experiment is systematic, repeated four times.

Phenological observations of plant growth and development were carried out in the following phases of plant development of narrow-leaved lupine: BBCH 11-51 (germination – budding), BBCH 51-65 (budding – flowering); BBCH 65-81 (flowering – green beans); BBCH 81-93 (green beans – full ripeness). The density of lupine grass was determined twice during the growing season: in the phase of full germination and before grain harvesting. Plant safety was determined by equation 1:

$$P = \frac{H \times 100}{S}, \quad (1)$$

where: P – plant safety, %; H – number of plants before harvesting, units/m^2; S – number of plants at the time of full shoots, units/m^2; 100 – a number to convert to percentages (Yeshchenko *et al.*, 2005).

The assessment of photosynthetic activity of lupine plants was carried out according to the following indicators: the leaf surface area was determined by the contour method, when the leaves from the test plants laid out on paper were circled with a pencil, and then the contours were measured with a planimeter to determine the total area of the accounting leaves; photosynthetic potential (PP) was calculated according to equation 2:

$$ФП = t \times (S_1 + S_2) \div 2, \quad (2)$$

where: t – period from germination (BBCH 11) to the green bean phase (BBCH 81), days; S_1 – leaf surface area of plants in the phase BBCH 11, thous. m2/ha; S_2 – leaf surface area of plants in the phase BBCH 81, thous. m^2/ha (Didora *et al.*, 2013).

Accounting of the yield of narrow-leaved lupine was carried out in the phase of full ripeness by harvesting each site separately and weighing the grain. Mathematical processing of the obtained results was carried out by the method of variance analysis using applied computer programmes Excel and Statistica 6.0.

RESEARCH RESULTS

Normal growth and development of lupine plants during ontogenesis is largely ensured by favourable abiotic factors and nutritional conditions. The growing season of narrow-leaved lupine is a complex dynamic process with specific critical periods defined for this crop and a well-defined morphotype for each phase of vegetation. As a result of the conducted phenological observations, indicators of the passage of the main interphase periods by plants of narrow-leaved lupine were established. Notably, over the years of research, shoots (BBCH 11) in lupine occurred on days 13-15 after sowing (Fig. 1). There is a tendency to increase the passage of interphase periods in plants during fertilization. However, the difference in phase passage in fertilised and non-fertilised areas in the germination – budding phase (BBCH 11-51) was 3-5 days (without inoculation) and 3-4 days with inoculation. The budding – flowering period (BBCH 51-65) for all variants ranged from 10-11 days, and the flowering period – green beans (BBCH 65-81) was 17-22 days. A slightly larger time difference between fertilised and non-fertilised areas was observed during the green bean – full ripeness period (BBCH 81-93). Thus, in areas without fertilization, this period was 33-34 days, with the application of $N_{35}P_{60}K_{16}$ – 35-36 days, and 38-40 days – in the option with $N_{35}P_{60}K_{16}$+ YaraVita BRASSITREL PRO, KL, which is 5-6 days longer compared to the control. In general, the growing season of narrow-leaved lupine in the control areas was 97-101 days, in areas with only mineral fertilisers – 103-108 days, and 109-115 days – with additional foliar application with YaraVita Brassitrel. Seed inoculation increased the growing season of plants by 4-6 days.

Determination of plant growth dynamics indicates the peculiarities of grass stand development and its dependence on the studied factors. Admittedly, there was a steady tendency to increase the height of narrow-leaved lupine plants as the growing season progresses and decrease it during the development and maturation of generative organs on plants

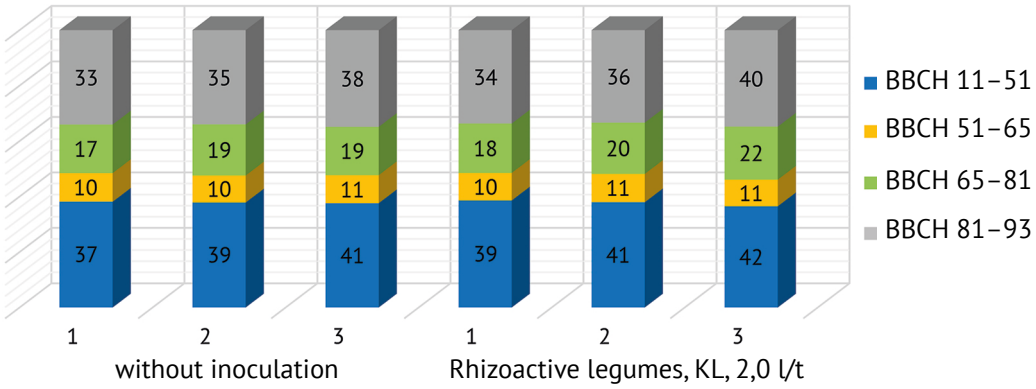

***Figure 1**. Duration of interphase periods in narrow-leaved lupine plants of the Olimp variety, depending on fertilization and inoculation of seeds, average for 2019-2021, days*
***Note:** 1 – without fertilisers (control); 2 – $N_{35}P_{60}K_{16}$; 3 – $N_{35}P_{60}K_{16}$+YaraVita BRASSITREL PRO*
***Source:** compiled by the authors*

This is conditioned by the fact that starting from the green bean phase, the inflorescence of plants dries up and the main part of the nutrients begins to be spent on the development of beans and seeds. During the budding period, the height of narrow-leaved lupine plants in non-fertilised areas was 30.3-31.8 cm and 32.4-36.3 cm in fertilised areas. During plant flowering, the height at the control increased by 15.4-15.7%, while during fertiliser application – by 16.3-16.9%, which indicates the effective use of nutrients from fertilisers. In the green bean phase, the increase in plant height was 13.7-13.9% and 12.9-13.4%, respectively. That is, the rate of increase in linear plant growth has decreased in all variants, since during this period the use of nutrients by plants for the development of generative organs and future seed yield begins. The highest height indicators of narrow-leaved lupine plants (80.0 cm) were noted during processing seeds before sowing with bioinoculant Rhizoactive legumes, KL, 2 l/t, double foliar application of crops with YaraVita BRASSITREL PRO, KL microfertiliser in the green bean phase with the background application of mineral fertilisers ($N_{35}P_{60}K_{16}$) (Table 1).

***Table 1**. Dynamics of the height of narrow-leaved lupine plants of the Olimp variety depending on fertilization and inoculation of seeds (2019-2021), M±m, cm*

Seed treatment	Fertiliser	Phases of plant growth and development			
		budding	flowering	green beans	full ripeness
without inoculation	without fertilisers (control)	30.3±3.3	46.8±3.6	64.1±4.0	58.6±4.7
	$N_{35}P_{60}K_{16}$	32.4±2.7	52.8±5.9	70.7±3.9	63.0±4.9
	$N_{35}P_{60}K_{16}$ + YaraVita BRASSITREL PRO	33.8±3.9	54.4±3.3	72.2±2.9	69.8±4.3
Rhizoactive legumes, KL, 2 l/t	without fertilisers (control)	31.8±3.0	49.9±5.0	69.2±4.4	63.3±5.0
	$N_{35}P_{60}K_{16}$	34.6±3.1	58.4±5.1	75.5±4.8	70.2±5.6
	$N_{35}P_{60}K_{16}$ + YaraVita BRASSITREL PRO	36.3±3.6	61.2±2.6	80.0±5.0	74.2±5.8

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

The intensity of the initial processes of plant growth and development plays a significant role in the formation of high productivity of narrow-leaved lupine.It was established that the density of narrow-leaved lupine plants varied depending on pre-sowing seed treatment with a bacterial preparation and double foliar application. Notably, the studied factors did not significantly affect the germination rates of narrow-leaved lupine seeds. Thus, in the control, this indicator ranged from 87.7 to 89.0%, while in fertilised areas it was 88.4-89.4%, respectively, that is, the difference was only 0.4-0.7% (Table 2). A significantly greater dependence on fertiliser was observed in plant survival rates. In areas without fertilisers, the density of plants before harvesting was 75.4-76.3 units/m^2 (the survival rate was 75.4-76.3%). The application of only mineral fertilisers increased the density indicators to 79.8-82.5 units/m^2 with a plant survival rate of 90.3-92.3%. Additional foliar application of

plants with microfertilisers YaraVita BRASSITREL PRO, KL on the background of $N_{35}P_{60}K_{16}$ provided an increase in density and survival rates by another 1.1-1.6 units/m^2 and 1.3-1.8%, respectively, and by 6.0-7.3 units/m^2 (6.2-7.9%) compared to the control. Seed inoculation contributed to an increase in field germination by 1.0-1.27%.

***Table 2**. Indicators of plant density of narrow-leaved lupine of Olimp variety depending on fertilization and inoculation of seeds, average for 2019-2021*

Seed treatment	Fertiliser	Number of plants per 1 m^2, units	Field germination, %	Plant density before harvesting, units/m^2	Survival rate, %
without inoculation	without fertilisers (control)	96.5	87.7	75.4	85.9
	$N_{35}P_{60}K_{16}$	97.2	88.4	79.8	90.3
	$N_{35}P_{60}K_{16}$ + YaraVita BRASSITREL PRO			81.4	92.1
Rhizoactive legumes, KL, 2 l/t	without fertilisers (control)	97.9	89.0	76.3	85.7
	$N_{35}P_{60}K_{16}$	98.3	89.4	82.5	92.3
	$N_{35}P_{60}K_{16}$ + YaraVita BRASSITREL PRO			83.6	93.6

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

According to the results of multiple linear regression analysis, there is a strong positive dependence of grain weight per plant on the number of beans per plant and the number of grains per bean (Table 3).

***Table 3**. Results of regression analysis of the dependence of grain weight from one plant on the number of beans on the plant and the number of grains in the bean, average for 2019-2021*

	Beta	Std. Err. of Beta*	B	Std.Err. of Beta	t(3)	p-level
Intercept			-2.09804	0.350663	-5.98308	0.009347
Number of beans per plant, units (X_1)	0.987428	0.028251	0.80904	0.023147	34.95253	0.000051
Number of grains per bean, units (X_2)	0.098733	0.028251	0.32695	0.093551	3.49490	0.039627

***Note:** *Std. Err. of Beta – Standart error of Beta*
***Source:** compiled by the authors*

Regression results for the dependent variable: grain weight from 1 plant (Y) R= 0.99880735,

R^2=0,99761612, Adjusted R^2=0.99602687, $F(2,3)$= =627.73, p<0.00012. The coefficient of determination is calculated based on the constructed model (R^2=0,996), which showed a significant impact of the number of beans on the plant and the number of grains in the bean on the indicator under study. Regression model for the dependence of the indicator ($\hat{Y}$) – weight of grain per plant depends on the number of beans in the plant and the number of grains in the bean is (3):

$$\hat{Y}=-2.1+0.81x_1+0.33x_2 \quad (3)$$

where $\hat{Y}$ – predicted value of grain weight per plant of narrow-leaved lupine;
X_1 – number of beans per plant, units;
X_2 – number of grains in a bean, units.

All coefficients of the equation are significant at the 5% level (p-level<0.05).

According to the findings, indicators of individual productivity of narrow-leaved lupine plants were established. The number of beans on one plant, regardless of the studied factors, ranged from 4.1-4.6 units. In general, it can be noted that with an increase in fertiliser application doses and pre-sowing seed inoculation, the indicators of individual productivity of narrow-leaved lupine increased (Table 4). In non-fertilised areas, the weight of 1,000 seeds was 161-162 g, and with the application of $N_{35}P_{60}K_{16}$ it increased to 165-166 g. Additional application of YaraVita BRASSITREL PRO, KL provided an increase in the weight of 1,000 seeds by another 2-3 g, which certainly affects the commercial quality of seeds. The largest weight of seeds from a single narrow-leaved lupine plant was observed on variant $N_{35}P_{60}K_{16}$+YaraVita BRASSITREL PRO, KL – 2.91 g.

***Table 4**. Individual productivity of narrow-leaved lupine depending on fertilization and seed inoculation, average for 2019-2021*

Seed treatment	Fertiliser	Quantity, units			Weight, g	
		beans on a plant	grains on a plant	seeds in a bean	1,000 seeds	seeds from the plant
without inoculation	without fertilisers (control)	4.1	15.1	3.7	161	2.43
	$N_{35}P_{60}K_{16}$	4.3	15.6	3.6	165	2.57
	$N_{35}P_{60}K_{16}$ + YaraVita BRASSITREL PRO	4.4	15.7	3.6	167	2.62
Rhizoactive legumes, KL, 2 l/t	without fertilisers (control)	4.3	15.9	3.7	162	2.58
	$N_{35}P_{60}K_{16}$	4.6	17.1	3.7	166	2.84
	$N_{35}P_{60}K_{16}$ + YaraVita BRASSITREL PRO	4.7	17.2	3.7	169	2.91

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

A fairly important indicator of the productivity of any crop is the leaf surface area, which directly affects the process of photosynthesis in the plant. The results of the conducted studies indicate that in the germination phase, the area of narrow-leaved lupine leaves amounted to 6.3-6.8 thousand m²/ha on plots without fertilization. With the application of mineral fertilisers at a rate of $N_{35}P_{60}K_{16}$ this figure was 6.9-7.1 thousand m²/ha, which is 4.5-7.9% more compared to the control, that is, starting from the germination phase of the narrow-leaved lupine plant on fertilised areas, the leaf apparatus begins to form more intensively (Fig. 2).

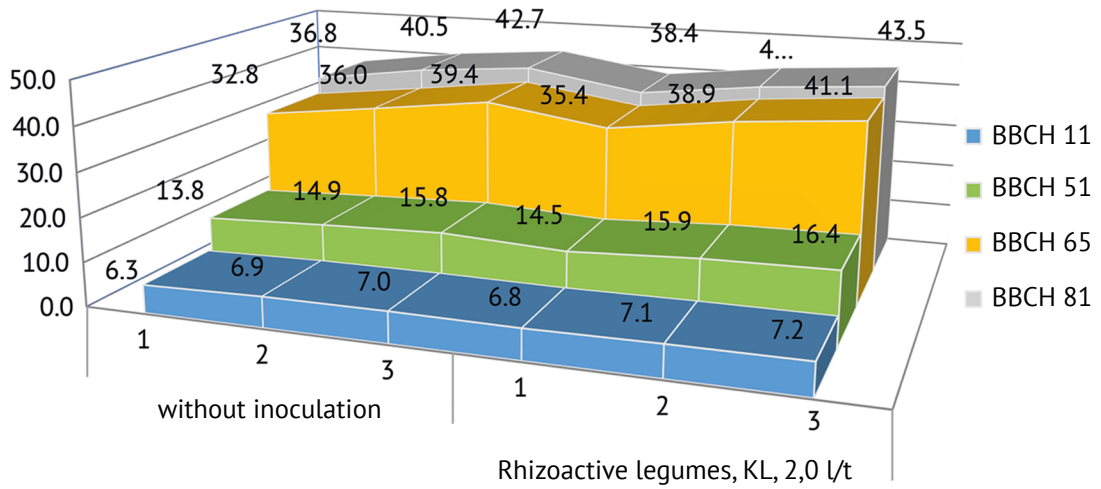

***Figure 1**. Leaf surface area of narrow-leaved lupine depending on fertiliser and seed inoculation, average for 2019-2021, thous. m²/ha*
***Note:** 1 – without fertilisers (control); 2 – $N_{35}P_{60}K_{16}$; 3 – $N_{35}P_{60}K_{16}$+YaraVita BRASSITREL PRO, KL*
***Source:** compiled by the authors*

The tendency to increase the difference in leaf surface areas between fertilised and non-fertilised variants was also observed in later phases of vegetation of narrow-leaved lupine plants. Thus, in the green bean phase, the area of leaves in the control was 36.8-38.4 thousand m2/ha, whereas on variant $N_{35}P_{60}K_{16}$+YaraVita BRASSITREL PRO, KL – 42.7-43.5 thousand m²/ha. Seed inoculation provided an increase in the leaf area by 0.8-1.6 thousand m²/ha (10.2-10.4%) compared to non-inoculated plots.

Calculation of photosynthetic potential (PP) indicators of narrow-leaved lupine plants during the phases of active growth indicate that in non-fertilised areas, the PP was 1.3-1.51 million m²/ha×day, and given the duration of the growing season (64-67 days), this is a fairly good indicator (Fig. 3).

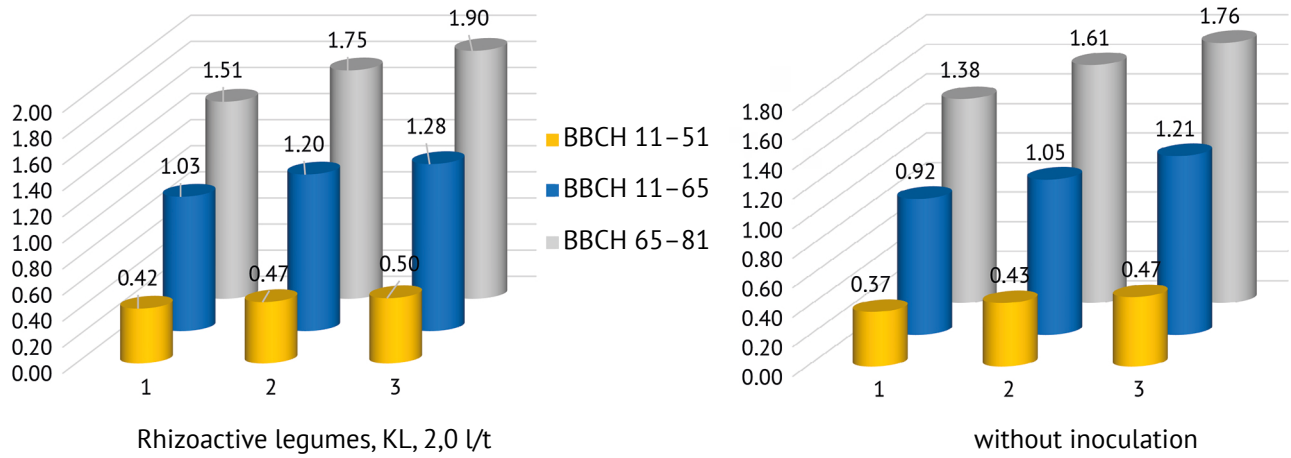

***Figure 3**. Photosynthetic potential of narrow-leaved lupine depending on the fertilization and inoculation of seeds, the average for 2019-2021, mln. m²/ha×day*
***Note:** 1 – without fertilisers (control); 2 – $N_{35}P_{60}K_{16}$; 3 – $N_{35}P_{60}K_{16}$+YaraVita BRASSITREL PRO, KL*
***Source:** compiled by the authors*

There was a tendency to increase PP in interphase periods of active growth. During the germination – budding phase, the PP was 0.37-0.50 million m²/ha×day, and in the germination – flowering phase – 0.92-1.20 million m²/ha × day, that is, the increase in PP was 25.4-25.8%. Photosynthetic potential during the germination – green beans phase amounted to 1.38-1.90 million m²/ha×day , which is 14.6-15.3% more than the germination – flowering phase, that is, the rate of photosynthetic activity after the flowering phase began to decrease slightly. In general, in all fertilised areas, high indicators of lupine leaf activity were observed. According to the findings, high grain productivity of narrow-leaved lupine was established. Inoculation provided a yield increase of 0.14 t/ha on plots without fertilisers and 0.29-0.30 t/ha on fertilised ones, which in percentage terms was 10.8% and 11.4%, respectively (Fig. 4). In the control cariant, the yield was 1.83-1.97 t/ha. With the application of only mineral fertilisers in the norm $N_{35}P_{60}K_{16}$, the yield increased to 2.05-2.34 t/ha (the increase was 0.22-0.37 t/ha). Additional top dressing of plants with YaraVita BRASSITREL PRO, KL on the background of $N_{35}P_{60}K_{16}$ together with pre-sowing inoculation of seeds with bioinoculant Rhizoactive legumes, KL provided a yield of narrow-leaved lupine grain at the level of 2.43 t/ha, which is 0.60 t/ha more compared to the control.

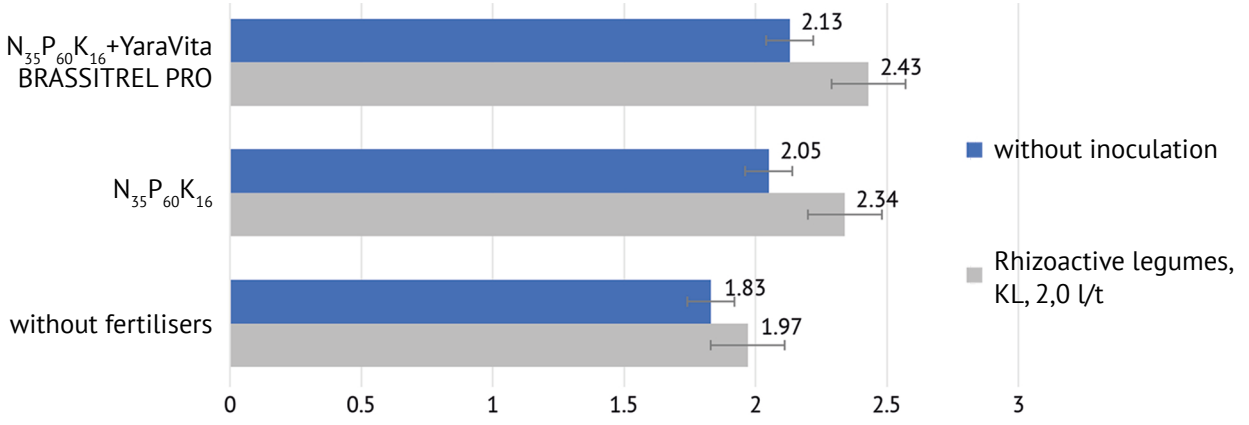

***Figure 4**. Yield of narrow-leaved lupine grain depending on fertiliser and seed inoculation, average for 2019-2021, t/ha*
***Note:** LSD=0.18 (least significant difference) to estimate the significance of the difference in partial averages; LSD=0.11 to estimate the significance of the difference in the average values for factor A; LSD=0.13 to estimate the significance of the difference in the average for the factor B and AB*
***Source:** compiled by the authors*

Based on the results of statistical analysis, indicators of the share of influence of the studied factors on the yield of narrow-leaved lupine grain were established (Fig. 5).

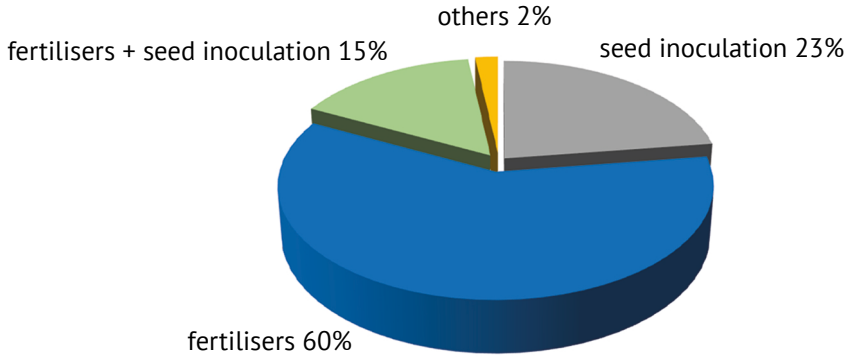

Figure 5. *The share of influence of factors on the yield of narrow-leaved lupine grain, average for 2019-2021, %*
Source: *compiled by the authors*

The "fertiliser" factor had the greatest impact on grain yield – 60%, followed by "inoculation" – 23%. The share of influence of other factors not studied was 2%. Based on the results of correlation analysis, the dependence of the yield of narrow-leaved lupine grain on the leaf surface area in the green bean phase was established (Fig. 6).

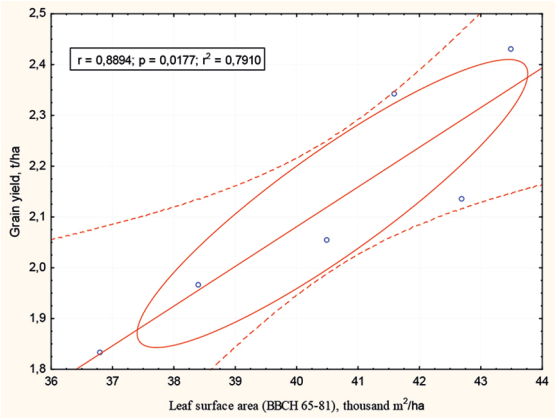

Figure 6. *Correlation between the yield of narrow-leaved lupine grain and the leaf surface area*
Source: *compiled by the authors*

Regression model of indicator dependence ($\hat{z}$) – grain yield from the leaf surface area of narrow-leaved lupine plants has the form (4):

$$\hat{Z}=-1.0469+0.0782x, \quad (4)$$

where $\hat{Z}$ – grain yield, t/ha; X – leaf surface area, thousand m^2/ha.

Therefore, it can be stated that there is a strong relationship between the grain yield of narrow-leaved lupine and the leaf area in the green bean phase (r=0.8894). The significance level did not exceed 5% (p-level=0.0177), which confirms statistical reliability. This equation applies to 79.1% of the sample.

The formation of yield and quality of narrow-leaved lupine seeds in the conditions of medium podzolic sandy loamy soils of Polissya is influenced by the duration of interphase periods by plants, the dynamics of grass stand growth, features of the use of photosynthetic active radiation (PAR), seed inoculation, and fertiliser. The study by V. Ratoshniuk and M. Havryliuk (2020) established an increase in the duration of the growing season of narrow-leaved lupine by 6-9 days with double foliar application with water-soluble complex fertilisers in the budding phase and the beginning of seed filling on a mineral background ($N_{60}R_{60}K_{60}$) compared to options without fertiliser. The obtained results of phenological observations regarding the passage of phenological phases of plants can be explained by the biological features of the Olimp variety and its reaction to the factors under study, which is consistent with the conclusions of other researchers (Pidpaly *et al.*, 2013). The dependence of lupine yield on the characteristics of a particular variety has also been noted (Mazumder *et al.*, 2021).

Optimisation of fertilization of narrow-leaved lupine contributed to the formation of maximum plant height indicators in the budding (BBCH 51), flowering (BBCH 65), and green bean (BBCH 81) phases. The studies also established the formation of the maximum height indicators of narrow-leaved lupine plants with double top dressing in the budding phase and at the

beginning of seed filling with Kristallon Brown fertiliser against the background of mineral fertilization at a rate $N_{90}R_{60}K_{90}$ (Pidpaly *et al.*, 2013). A distinctive feature of lupine is the weak possibility of developing a number of side branches, which limits the formation of plant productivity (Holodna, 2021). Therefore, for the optimal supply of plants in critical periods of their development with nutrients during the growing season of narrow-leaved lupine, not only the main fertiliser, but also foliar application with liquid fertilisers have a significant impact (Holodna, 2019). The obtained experimental data are consistent with the conclusions of other researchers regarding the effectiveness of inoculation of leguminous seeds with bacterial preparations using trace elements and foliar application during the growing season. Thus, inoculation of chickpea seeds with Biomag bioinoculant and two-time foliar application of plants with microfertilisers increases stem density and plant survival (Didur & Temchenko, 2017). The positive effect of applying mineral fertilisers in combination with double foliar application on the individual productivity of narrow-leaved lupine is also confirmed by the findings of other researchers (Pidpaly *et al.*, 2013). The data obtained confirm the conclusions of other researchers (Sulas *et al.*, 2016; Tkachuk *et al.*, 2019; Bouray *et al.*, 2021) regarding the effect of inoculation of leguminous seeds with bacterial preparations and foliar application during the growing season on the indicators of individual plant productivity. Thus, inoculation of chickpea seeds with Biomag bioinoculant and two-time foliar application of plants with microfertilisers significantly improves such elements of the crop structure as the total number of beans and seeds per plant, the weight of seeds per plant and the weight of 1,000 seeds (Didur & Mordvaniuk, 2018). According to A.V. Holodna (2022), the maximum number of beans (20.2 units/plant) was obtained by treating narrow-leaved lupine seeds with a bioinoculant in combination with a Nano-Gro growth stimulator and applying mineral fertilisers ($N_{38}P_{48}K_{66}+N_{30}$).

The effect of foliar application with water-soluble complex fertilisers on increasing the leaf surface area of narrow-leaved lupine is consistent with other studies (Ratoshniuk & Havryliuk, 2020). Similar studies were conducted on other leguminous crops. Inoculation of soybean seeds with BTU bioinoculant and foliar application of plants with Helprost organo-mineral fertiliser contributed to an increase in the leaf surface area by 35.3% compared to the control (Didur, 2022). The establishment of the maximum leaf surface of soybeans under the influence of seed inoculation with bacterial preparations and foliar application with complex microfertiliser Rostok bobovi was also observed in studies by S.M. Kalenska *et al.* (2016). The indicator in the experiment, depending on the variety, increased by 17.8-29.8% compared to the control (Kalenska *et al.*, 2016). The results obtained are consistent with data from A.V. Holodna (2019) on the formation of the maximum yield of narrow-leaved lupine (2.79 and 2.80 and t/ha) with the application of mineral fertilisers ($N_{68}R_{48}K_{66}$), complex seed treatment with BTU-r and MikoHelp biologics, foliar application at the 2nd and 4th stages of plant organogenesis with Tropikel fertiliser. The study by O. Milenko (2022) found that the maximum yield of soybeans (3.11 t/ha) was formed with the combined application of mineral fertilisers ($N_{15}P_{30}K_{40}$) and double top dressing with Vuksal Microplant complex fertiliser. The formation of high grain productivity of narrow-leaved lupine can be explained by the ability of lupine to fix atmospheric nitrogen and the use of phosphorus and potassium from hard-to-reach compounds of arable and deeper horizons.

CONCLUSIONS

The productivity of narrow-leaved lupine in Polissya conditions is formed due to a number of factors. Thus, when applying only mineral fertilisers, the duration of the growing season of plants was 103-108 days, additional foliar application helped to increase it to 109-115 days, which is 6-7 and 12-14 days more compared to the control.

Plant density of narrow-leaved lupine for the harvesting period, regardless of fertiliser and seed inoculation, accounted for 75.4-83.6%. In fertilised areas without inoculation, this indicator was 2.2-2.7% lower compared to inoculation. The survival rate of lupine plants with fertilization ranged from 90.3 to 93.6%. The greatest individual productivity of lupine plants was recorded on the variant of combined fertilization and inoculation with the following indicators: the number of beans per plant is 4.7 units; the number of grains per plant is 17.2 units; the number of seeds in a bean – 3.7; weight of 1,000 grains – 169.0 g; weight of grain per plant – 2.91 g.

Multiple linear regression analysis showed a high positive dependence of the grain mass from one plant on the number of beans on the plant and the number of grains in the bean (R=0.99), as a result of which a regression model was constructed, and probability of the null hypothesis for the coefficients of the regression equation for all variants was less than 0.05. The best indicator of photosynthetic potential was observed in fertilised areas of narrow-leaved lupine, which in the period from germination (BBCH 11) to green bean phase (BBCH 81) with seed inoculation amounted to 1.75-1.90 million m^2/ha×days.

When applying mineral fertilisers at a rate $N_{35}P_{60}K_{16}$, the yield of narrow-leaved lupine grain was obtained at the level of 2.34 t/ha. Double fertilization of plants with YaraVita BRASSITREL PRO, KL on the background of $N_{35}P_{60}K_{16}$ together with pre-sowing treatment of narrow-leaved lupine seeds with bioinoculant Rhizoactive legumes, KL contributed to the maximum yield of the Olimp variety (2.43 t/ha). A close positive correlation

was established between the leaf surface area during the flowering phase (BBCH 65-81) and the grain yield indicators of narrow-leaved lupine (r=0.89). Based on the obtained data, a regression equation was constructed, which is valid in 79.1% of the sample.

Crop production in modern climatic conditions requires adaptive agricultural technologies for growing field crops, which are aimed at maximising the protective reactions of the plant body to adverse environmental conditions. Further study of narrow-leaved lupine involves the selection of adaptive varieties, improvement of tillage methods, and identification of optimal sowing dates and seeding rates in order to adapt plants to abiotic environmental factors.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Формування продуктивності люпину вузьколистого залежно від інокуляції насіння та удобрення

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Анотація. Люпин вузьколистий характеризується цінними господарськими особливостями, тому є важливим джерелом збалансованого і легкозасвоюваного рослинного білка. Метою досліджень було обґрунтувати вплив інокуляції насіння та удобрення на ріст і розвиток рослин люпину вузьколистого для максимальної реалізації генетичного потенціалу сорту в умовах Полісся. Використані такі методи досліджень: загальнонаукові (гіпотеза, індукція і дедукція, узагальнення), спеціальні (польовий, вимірювальний та ваговий, фізіологічний, лабораторний), статистичний (кореляційно-регресійний). Польові дослідження проводили протягом 2019-2021 рр. Досліджено особливості росту і розвитку рослин люпину вузьколистого сорту Олімп в умовах Полісся. З'ясовано позитивний вплив інокуляції насіння бактеріальними препаратами та позакореневого підживлення комплексним добривом на продуктивність люпину вузьколистого, що відіграє важливе значення у вирішенні проблеми рослинного білка. Визначено оптимальну площу листкової поверхні рослин за рахунок оптимізації елементів агротехнології люпину вузьколистого. Встановлено фотосинтетичний потенціал люпину залежно від інокуляції насіння біопрепаратами та удобрення. Досліджувані фактори підвищують густоту стеблостою, виживаність рослин і поліпшують показники індивідуальної продуктивності культури. Інокуляція насіння біопрепаратами та позакореневе підживлення забезпечує формування найвищої (2,43 т/га) зернової продуктивності люпину вузьколистого. Інокуляція насіння підвищує на 10,8-11,4 % урожайність зерна люпину вузьколистого залежно від фону живлення. Позакореневе підживлення рослин комплексним добривом у фазах ВВСН 21-23 і ВВСН 51 на мінеральному фоні за інокуляції насіння забезпечує збільшення на 2,8 % урожайності зерна порівняно з контролем. Результати досліджень можуть бути використані для удосконалення елементів технології вирощування люпину вузьколистого, що забезпечить формування високих і сталих врожаїв зерна

Ключові слова: урожайність зерна; бактеріальні препарати; позакореневе підживлення; шкала ВВСН; лінійні показники; площа листкової поверхні; фотосинтетичний потенціал

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Comparative analysis of the content of salicylic acid in biotechnological cotton genotypes under some kinds of abiotic stress

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Abstract. The relevance of this study is conditioned by the current findings on salicylic acid (SA) synthesis in plants, which suggest that the presence of some transient factors in cotton is a signal that the stress-protective functions of the plant are being activated. An increase in the content of key mediators of the defence signalling system in cotton cells triggers the activation of stress factors, triggering the defence mechanisms of the living organism. Thus, the resistance of plants to certain types of abiotic stress is achieved by activating the protective reactions of the signalling system. This process allows for the targeted use of biologically active substances such as salicylic acid. Therefore, the purpose of this study is to investigate the combined properties of the protective signalling system of some genetic types of cotton plants, when phenolic acids are synthesised in them. The leading approach to the study of this issue is a laboratory

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experiment, which allowed comprehensively considering cotton lines containing RNA sensitive to certain types of abiotic stress. Additional biological and chemical techniques were used as auxiliary methods in the field to test the specific effects of saline soils on cotton RNA salicylic acid concentration. This study presents data on the resistance of the RNA interference (RNAi) genotype ESKIMO1 to salinity and limited irrigation. The content of salicylic acid in cotton tissues under the influence of various concentrations of NaCl was studied. The formation of reactive oxygen species in the process of activation of plant defence reactions to certain types of abiotic stress is substantiated. The study materials are of practical value to microbiologists, geneticists, and agronomists. The investigation of the biotechnological features of the plant genotype plays an important role in understanding plant adaptation to natural conditions caused by certain types of abiotic stress. The affordability of salicylic acid allows its widespread application as a commercial reagent in crop production practices

Keywords: salicylic acid; resistance; salinity; liquid chromatography; metabolomics

INTRODUCTION

Cotton is the leading crop in the Central Asian regions, ranking second in the export of technical products. Sharp temperature fluctuations, drought, soil salinity, and heavy metal pollution reduce cotton yields. To address this issue, biotech cotton varieties resistant to abiotic stressors are being developed. Although firmly anchored in the soil, plants are known to be able to respond to abiotic stresses by being able to activate several metabolic pathways, leading to the generation of a huge number of secondary products, in particular, those that perform a protective function. One of these metabolites is salicylic acid (SA). There is a large body of evidence in the available scientific data on the involvement of salicylic acid in the development of resistance to abiotic stressors. Analysis of literary sources by N. Abdi *et al.* (2022), J. Liu *et al.* (2022) and F. Zhang *et al.* (2022), who have investigated this problem, showed that salicylic acid has a wide range of physiological effects on plants, in particular, an anti-stress effect.

M. Omidi *et al.* (2022) in their research refute the fact that the accumulation of salicylic acid is an indicator of the plant's response to stress. The researchers suggest that the first indicator to be considered when examining the signalling responses of plants to abiotic stress is an increase in the generation of the active form of oxygen. Throughout the study, authors have accumulated data indicating that the amount of salicylic acid increases more slowly and is involved in the multiplication of oxygen-inducing signals. Salicylic acid acts as a plant regulator involved in many processes, including seed germination, root formation, stomatal closure, flowering induction, thermogenesis, and response to abiotic and biotic stresses. Numerous studies prove the protective effect of salicylic acid against various types of abiotic stress (ultraviolet, ozone, heat stress). For example, it acts as a cell stimulator to resist stressful environmental conditions such as salinity, drought, and temperature stress.

The damages presented by the effects of abiotic stresses require the exploration of approaches that reduce their negative impacts on plants. Investigating the role of salicylic acid as a plant signalling molecule, A. Dubey *et al.* (2021) and Kamburova *et al.* (2022) proved that both external and internal sources of salicylic acid influence the expression of core genes encoding polypeptides and increasing the thermogenesis process in plant tissues. Also the study examined the effect of salicylic acid on the expression of the plant mitochondrial genome by encoding their electron-transport chain complex. As a phytohormone that provides plant resistance to damage by various pathogens, salicylic acid induces the production process of PR proteins. For example, a study by N. Esmaeili *et al.* (2021) proved that the manifestation of PR-1 class proteins indicates the resistance of the plant against contact with the pathogen; PR-2 class proteins cleave the plant cell wall glucans into shorter fragments. Insufficient amount of proteins of the PR-3 class led to chitin deficiency and, as a result, pathogens affected plants. When salicylic acid interacts with catalase, the efficiency of the latter decreases and the oxygen concentration increases.

The salicylic acid content in biotech cotton under abiotic stress is studied less than the response of this plant to pathogen infestation. P. Singh *et al.* (2022) noted an increase in endogenous salicylic acid with the accumulation of excess heat in mustard plants, grapes, and soybean plants during drought, and rice on saline soils. Based on the analysed studies, *the purpose of the present study* is to investigate the salicylic acid content in cotton tissues with RNA interference (RNAi) of the ESKIMO1 gene under the influence of different concentrations of NaCl.

MATERIALS AND METHODS

The object of the study was cotton biotechnological lines containing the calling RNA construct to the ESKIMO1 gene: RNA and genotype Eskimo1, and hybrids of the Eskimo1 genotype with varieties Porloq-1 and Ravnaq-1. The original genotype Cocker-312 (C-312) was used as control samples. The experiments were carried out on plants grown under phytotron conditions to investigate the response of the Eskimo1 RNA and cotton genotype to the impact of saline solutions. The concentration of SA was observed when plants were irrigated during the growing season with a NaCl salt

solution in a concentration of 50 to 200 mM. For this, pre-soaked seeds of selected samples are sown in ordinary soil, pre-washed and kept in a thermostat at a high temperature in a cabinet, poured into pots with a volume of 250 g with drainage, so that the seedlings do not rot and the soil composition is waterlogged. Cultivation was carried out under artificial lighting, by analogy with the change of seasons in the summer period of the year for 21 days. At first, watering was done with 50 ml of distilled water daily until the cotyledon leaves appeared. Then the control variant was irrigated with distilled water, the experimental variant with the corresponding NaCl solutions.

After the appearance and deployment of cotyledon leaves and exposure to saline solutions, SA was extracted from the tissues of cotton leaves at the vegetation stage, which reached 3-4 leaves. Before extraction, the leaves were dried and already 1 ml of extractant was added to 200 mg of ground powder of dried cotton leaves, with the composition methanol: water: acetic acid (80:19:1 v/v). Then the mixture was stirred on a rocking chair for 3 hours, after which centrifugation was carried out in the mode of 10,000 samples for 5 minutes. From the centrifuged samples, the liquid fraction was separated into another, clean test tube, and a portion of fresh extractant was once again added to the sediment. This extraction was carried out for a longer period of time (for 12 hours), and after centrifugation, the supernatants were pooled and dried on a vacuum rotary unit. Further, 0.5 ml of 15% aqueous acetonitrile containing 0.05% acetic acid was added to the dry residue, shaking was carried out on a vibratory mixer and centrifuged again. The supernatant obtained and selected at this stage was analysed on a high-pressure liquid chromatograph LC20.

To simulate salt stress, plants were divided into 2 groups: control and experimental. For 21 days, the control plants were treated with ordinary water, and the experimental plants were treated with a salt solution (NaCl) at concentrations of 50, 100, 150, and 200 mM. Drought was modelled by limiting the flow of water due to irrigation in the amount of 40, 60, 80 ml on the soil with plants. Extraction of free salicylic acid was performed according to the method of J.K. Zhu (2002). The supernatant was analysed by HPLC using a Shimadzu Prominence LC20 chromatograph, which included an LC20AD 4-gradient pump with a 5-channel DGU-20A5R degasser, an SPD-M20A diode array detector, a CTO-20A column thermostat, and a manual injector Rheodyne 7725i with 20 µl sample loop. Chromatography conditions: column – Zorbax Eclipse XDB C18 (3.0x100 mm), particle size 3.5 µm, pre-column Zorbax Eclipse XDB C18 2.1x12.5 mm, elution mode – isocratic, mobile phase 25% acetonitrile in 0.05% phosphoric acid pH 2.5, flow rate 0.5 ml/min, detection photometric at 235 nm. Thermostat temperature – 40°C. Inlet pressure – 9.5 MPa (95 bar). Sample volume – 20 µl.

The content of salicylic acid was determined according to a pre-built calibration line, for which 5 solutions of the salicylic acid standard were analysed, in the concentration range of 0.3125-5 µg/ml. The correlation coefficient between peak areas and salicylic acid concentrations was not less than 0.9999. The amount of salicylic acid was given to 1 g of the initial weight of dry leaves. Data processing, plotting of a calibration curve, and output of results were performed using Shimadzu Lab Solutions software suite.

RESULTS

SA is involved in the regulation of such important plant physiological processes as photosynthesis, nitrogen metabolism, proline metabolism, glycine betaine production, and the antioxidant defence system under stress conditions, and thus, ensures plant resistance to abiotic stresses (Munns & James, 2003). In addition to being involved in the induction of defence-related genes and stress tolerance in plants exposed to biotic stresses, SA has been shown to improve plant tolerance to major abiotic stresses. According to the results of the experiment, it turned out that in the control sample C-312 and in the Eskimo1 line, when watered with distilled water, the SA content did not exceed 5 µg/g of dry leaf tissue. At the same time, the content in seedlings of the Eskimo1 line was slightly less than in the control genotype (C-312). However, even when these two genotypes were irrigated with a salt solution at a concentration of 50 mM, the SA content increased to 6 µg/g of dry leaf tissue, and a slight excess was observed in Eskimo1 plants (Fig. 1).

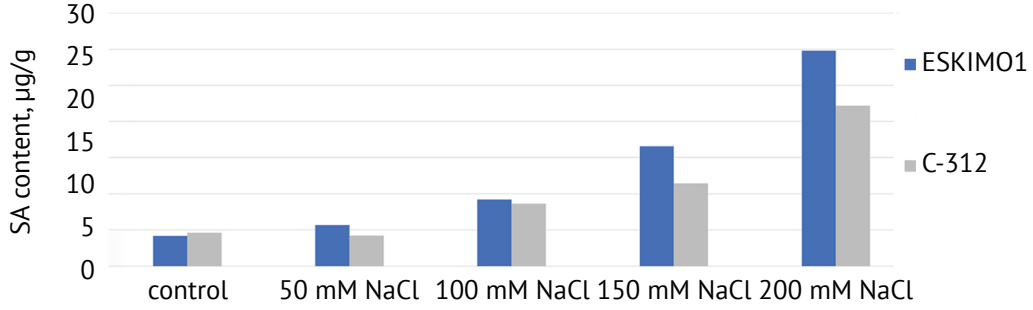

Figure 1. *Dynamics of SA accumulation in ESKIMO1 and C-312*

Source: *compiled by the authors*

Thus, as shown in the diagram, with an increase in the concentration of the stress component, the content of the phytohormone increases. And the maximum concentration of NaCl solution in this experiment, as a stress factor, led to the synthesis and accumulation of SA up to 29.8 μg/g of dry leaf tissue in plants of the Eskimo1 line against 22.19 μg/g, detected in the control parental cotton genotype – C-312. When seedlings were irrigated with NaCl solutions at a concentration of 100 and 150 mM, an increased content of SA was also observed in leaf tissues near the biotechnological line. Therefore, the study results showed that the content of SA, taken as an indicator of resistance to stress, when plants are treated with NaCl solutions, significantly increases in biotechnological genotypes.

M. Ashraf (2005) considered various strategies to maximise cotton growth and productivity under salt stress conditions. In the course of analysing the process of adaptation to environmental stress at the stage of germination and early stages of vegetation through a change in the composition of secondary metabolites in plants, they also note that when growing cotton, with the addition of NaCl solutions at concentrations of 50, 100, 150, and 200 mM, a noticeable an increase in the concentration of tannic acid (15.1-24.3%), flavonoids (22.5-37.6%), and gossypol (26.8-51.4%). The salinisation behaviour of hybrid genotypes, in which the Eskimo1 line participated in the crossbreeding combination, aroused interest. That is, Ravnaq-1×ESKIMO1 and Porloq-1×ESKIMO1 hybrids were included in the analysis. Notably, the Ravnaq-1 cotton variety was created by the technology of marker-associated breeding and the Porloq-1 variety was created by RNA interference of the phytochrome gene (Abdurakhmonov, 2016; Darmanov *et al.*, 2015). The pattern of SA content in Ravnaq-1×ESKIMO1 Porloq-1×ESKIMO1 hybrids against the background of parental samples is shown in Figure 2.

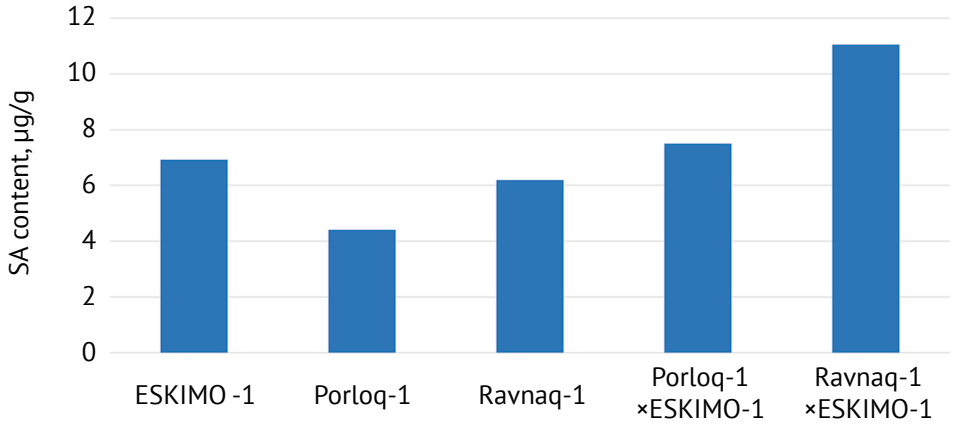

***Figure 2**. Indicators of SA values in Porloq-1 and Ravnaq-1 hybrids with RNA and genotype Eskimo1 when watering plants with 150 mM (in greenhouse conditions)*

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

The level of SA in plants of the hybrid combination Ravnaq-1×ESKIMO1 was 1.6 times higher than in the Eskimo1 genotype (6.92 μg/g, dry weight) and 1.8 times higher than in the original parental varieties Ravnaq-1. In the hybrid Porloq-1×ESKIMO1, the SA content is approximately 10% higher than in the Eskimo1 genotype and 1.7 times higher than in the original parental variety Porloq-1. Such studies have not been carried out before, as well as the fact that obtaining biotechnological RNA and genotypes for the phytochrome gene and the ESKIMO1 gene (an ortholog of the Arabidopsis gene) for cotton has not been observed in the world literature until today. In this regard, an indirect comparison with the literature data can be made.

As a glycophyte, cotton is considered to exhibit higher resistance to abiotic stresses than other major agricultural crops. As a rule, salinity can also be caused by increased evaporation during hot periods of the year. And there is a need to observe the impact of moisture limitation on biotechnological cotton genotypes. Extreme environmental conditions such as drought are known to significantly affect the growth, productivity, and quality of cotton fibre. Drought stress causes a wide range of morpho-physiological and biochemical changes that adversely affect the development and productivity of cotton. Under such conditions of limited water access (drought stress), the growth and development of cotton is significantly reduced, for example, which affects the height of the plant, dry leaf weight, dry weight of the stem, leaf area index, and accordingly the number of fruit elements, fibre quality, development of crown and root system (Loka *et al.*, 2011). Admittedly, like other plants, cotton has acquired a wide range of morpho-physiological, biochemical, and molecular mechanisms in response to multiple stresses that allow them to avoid and/or tolerate these stressors and survive in harsh environments.

S.E. Shermatov *et al.* (2017) investigated how extreme environmental conditions, such as drought, significantly affect cotton fibre growth, productivity, and quality. Of these, drought tolerance mechanisms were classified by Y. Fang and L. Xiong (2015) into four strategies: drought avoidance, drought rescue, drought tolerance, and drought recovery. Drought avoidance and drought tolerance are the two main plant strategies against drought stress. Drought avoidance is the maintenance of key physiological processes, such as stomatal regulation, root development, etc., in moderate drought conditions. Drought tolerance is the ability of plants to withstand severe dehydration through certain physiological actions, such as osmotic adaptation with osmoprotectors (Luo, 2010). Drought rescue may depend on the ability of plants to regulate their growth period or life cycle, for example, cotton varieties with a short life cycle to avoid the stress of seasonal drought (Manavalan *et al.*, 2009). Restoration of plants after drought leads to the resumption of growth and, as a consequence of physiology, to yields after exposure to severe drought. The ability of cotton to resist dehydration by regulating SA synthesis and accumulation was examined.

When setting up the experiment, as mentioned above, the plants were grown in small pots for 21 days under lighting conditions simulating the diurnal regime, and watering was limited both in volume and time. The variant of the limited irrigation volume includes conditions when watering was carried out in a volume smaller than in the control (100 ml). And the second option – watering was not done daily, but at intervals of one, two, and three days (Fig. 3).

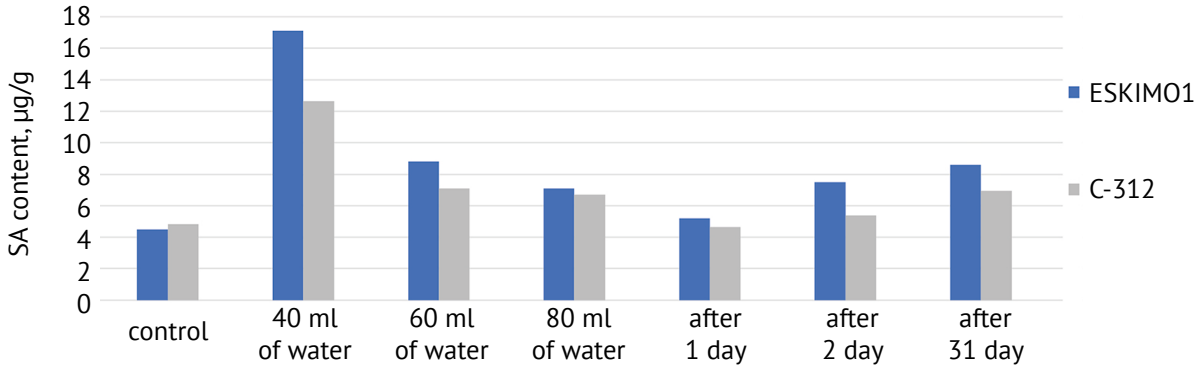

Figure 3. *Dynamics of SA content in dry tissue of seedlings of line ESKIMO1 and control line C-312 under limited watering (in volume and time)*

Source: *compiled by the authors*

In the course of studying the response of the RNA and cotton genotype Eskimo1 to limited irrigation, it was found that the content of SA differed and correlated with their resistance to water deficit. At the same time, the least amount of SA was observed in the control variant and the irrigation variant every other day. Whereas the highest content of SA was found in the variants when the plants were watered in insufficient volume – 40 ml of water (17.1 µg/g dry weight) versus 60 and 80 ml (8.8 µg/g and 7.1 µg/g.). Increased content of SA was also observed with a long interval between watering, both after 2 days (7.5 µg/g dry weight) and after 3 days (8.9 µg/g). For the parental genotype (C-312), there is a reduced accumulation of SA under stress conditions. The responses of hybrid genotypes to the conditions of limited water access were similar to the responses to an increase in the level of salinity concentration in the above experiment. The pattern of SA content in Ravnaq-1×ESKIMO1 Porloq-1×ESKIMO1 hybrids against the background of parental accessions is shown in Figure 4.

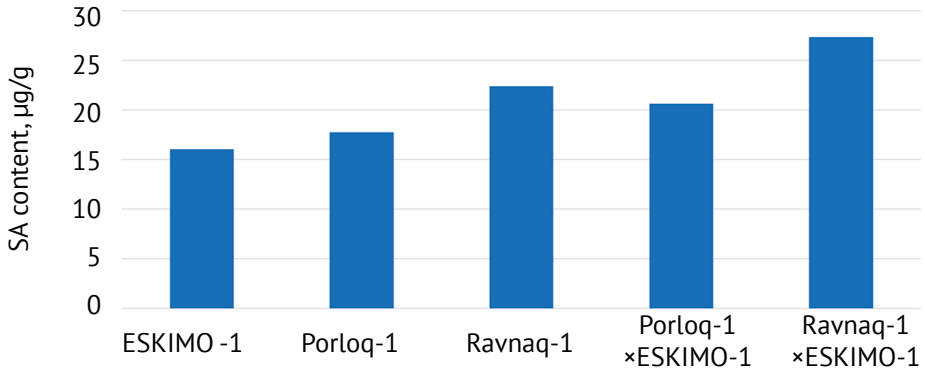

Figure 4. *Indicators of SA values in Porloq-1 and Ravnaq-1 hybrids with RNA and genotype Eskimo1 when watering plants with 150 mM (in greenhouse conditions)*

Source: *compiled by the authors*

According to the results of analytical investigation, the content of SA of the Eskimo1 genotype in field growing conditions with limited irrigation (in the control, watering was done 3 times during the growing season before flowering) was 16.05 μg/g dry weight. In comparison with it, the varieties Porloq-1 and Ravnaq-1 showed a slightly increased accumulation of SA (17.76 and 22.42 μg/g, respectively). An interesting fact was the increase in the amount of SA in the Porloq-1×ESKIMO1 and Ravnaq-1×ESKIMO1 hybrids up to 27.35 μg/g for the last crossing combination. The level of SA in the plants of the hybrid combination was 1.6 times higher than in the plants (6.92 μg/g, dry weight) and 1.8 times higher than in the original parent variety. In the hybrid, the SA content is approximately 10% higher than in the Eskimo1 genotype and 1.7 times higher than in the original parent variety. Thus, the obtained results indicate that the studied genotypes, carrying in the genome the RNA and construct to the ESKIMO1 gene, have an increased content of SA under conditions of salt and osmotic stress, which suggests their higher resistance to these types of stress.

DISCUSSION

According to the findings obtained in this study, salicylic acid levels in the tissues of biotech genotypes of cultivated plants indicate the presence of some kind of abiotic stress. Under various external unfavourable conditions, the genes that carry out the transcriptional signal of the plant's inability to convert energy into biomass are activated, and proteins are then synthesised to protect the plant against stressful conditions. Under stress factors, the cultivated plant is unable to realise its full productivity potential, causing the quantity of harvested crops to drop.

S. Syeed *et al*. (2021) examined the effect of salicylic acid on the production of protective enzymes of the antioxidant system of grain under the influence of sulphuric acid. Wheat sprouts were soaked for 6 hours in a salicylic acid solution with a concentration of 0.1 mM. Next, the experimental material was introduced into soils previously treated with sulphurous acid and grown with a gradual increase in its concentration. The study revealed that growth intensity, the activity of oxidative degradation of lipids, and the content of amino acids that promote photosynthesis depend CdSO_4 on the level concentration. Salicylic acid stimulates the antioxidant system while keeping it at a high level and at all concentrations $CdSO_4$ contributes to increased oxidative stress.

The ability of plants to retain their antioxidant status was also mentioned by the researcher. The balance between pro-oxidant and antioxidant reactions occurring in the cells of the control and experimental cotton groups were determined. The study of the functioning of the antioxidant system was also carried out by M. Rakszegi *et al*. (2019) in the context where a plant adapts to altered environmental conditions caused by stressors. The researchers compared the antioxidant systems of two cotton varieties: those resistant to saline solution and those not resistant to saline solution. Similar to the present study, the stability of components of antioxidant defence system in the study by J. Guo *et al*. (2015) investigated the adaptation of both cotton species to chloride salinity. Salt-resistant and non-salt-resistant seeds were exposed to 1% and 4% NaCl solution, respectively. After 24 hours, the malondialdehyde index increased slightly in the stable variety, while the unstable variety showed a significant increase. The authors suggest that in seedling leaves of salt-tolerant cotton cultivars, the accumulation of oxidative degradation of lipids and malondialdehyde was controlled at the same level under the action of NaCl. This was facilitated by the increased action of antioxidant enzymes. A high level of lipid peroxidation in Gulistan (salt-resistant) varieties after 24 hours indicates a more effective protective reaction that limits the spread of the superoxide radical. In the non-salt-resistant cotton variety, the increase in lipid peroxidation was insignificant. A high constitutive level of ascorbate peroxidase was detected in the Gulistan cotton variety. When exposed to saline solution, the ascorbate peroxidase index was significantly activated in both experimental specimens, reaching a maximum value.

M. Pessarakli (2002) analysed the correlation of two cotton varieties in terms of insensitivity to salt solutions and the ability to produce antioxidant enzymes. The study shows that differences in the response to salt stress are associated with the activity of enzymes of the antioxidant system. The resistance of the test material to saline solutions is highly correlated with the efficiency of antioxidant enzymes to reduce the production of reactive oxygen species, which enhances the ability of living organisms to maintain physiological constancy.

S. Saud and L. Wang (2022) investigated the effect of heavy metals as one of the types of abiotic stress inducing salicylic acid content. Wheat seedlings were treated with a solution high in copper and zinc. Under this type of abiotic stress, the development of the plant body is reduced by almost half. When seeds were treated exogenously with salicylic acid at high concentrations of heavy metals, the increase in root weight was 20.6% and in shoot weight 22.4. Thus, as can be seen from the results of this study, the introduction of a high concentration of copper and zinc into a nutrient solution can lead to disruption of metabolic processes in plants at the cellular level.

Salicylic acid plays an important role in activating the defence system under abiotic stress in the structure of the photosynthetic apparatus. Thus, in an experiment on cucumber seedlings by T. Yadav *et al*. (2020), it was shown that pre-treatment with salicylic acid caused a decrease in oxidative damage when exposed to low temperatures by enhancing the expression of the alternative oxidase gene. An increase in the activity of antioxidant enzymes under the action of salicylic acid has

thus been detected. The author of the study suggests that an important precursor that occurs when endogenous salicylic acid is produced are reactive oxygen species. Thus, studies by M. Omidi *et al*. (2022) showed the levelling of the protective effects of exogenous salicylic acid as one of the antioxidants produced under the influence of certain types of abiotic stress. N. Esmaeili *et al*. (2021) confirms this hypothesis, as the study of the effects of salicylic acid on the main energy-transforming processes of plants are the main producers of reactive oxygen species in the plant cell and are of great interest to the scientific community.

These findings address the biotechnological challenge of developing a cotton variety that will increase crop productivity through its antioxidant status. In recent years, genetic engineering research has developed techniques, methods, techniques and technologies for the inter-system transport of genes. Recently, scientists have been able to clone the genes of living organisms and use special techniques to conduct experiments to produce enzymes that induce the protective properties of plants. For example, in the present study, the author targeted a DNA regulatory region recognised by RNA polymerase as the start of gene transcription to select a suitable gene. Of great interest are repressed RNA polymerases, which, under the influence of inducing factors such as light, thermogenesis, and the influence of a parasitic microorganism, activate the transcription of the introduced gene. To monitor the process of gene transport, marker genes are introduced, which track the process of embedding a foreign gene into the recipient's genome. Such genes are selectively picked out on media of high concentration, as the marker genes are resistant to various antibiotics and herbicides. Also of great importance in the study of cross-system gene interaction are reporter genes – attachment proteins that have unique features or unique enzymatic activities. Such genes do not degrade the selective advantages of the cell and result in transgenic phenotypic transformations. Therefore, the main task that agricultural industry specialists, microbiologists, and breeders are trying to solve is to increase the survival rate of cultivated plants under abiotic stress and the creation of overproducing biologically active substances.

CONCLUSIONS

Based on the above, the cultivation of new salt-tolerant and tolerant to limited irrigation valuable cotton crops is relevant and efficient using biotechnology and genetic engineering methods, as revealed by the method of salicylic acid content diagnostics. A comparative analysis of biotechnological cotton lines containing the ESKIMO1 gene and a control sample of the C-312 genotype showed that at high concentrations of saline solution, the level of salicylic acid rapidly increased to 29.8% in the ESKIMO1 variety, while the level of salicylic acid in the C-312 variety was 22.19%. However, with a water deficit (40 ml) the amount of salicylic acid in ESKIMO1 was 17.1%, which is 4.5% higher than in C-312 (12.64%). The salicylic acid level began to decrease with the gradual addition of water. Thus, the study proved that the activation of the properties of the protective signalling system of some genetic types of cotton is activated during the synthesis of salicylic acid in plants under the influence of some abiotic factors.

A comparison of the responses of biotech cotton genotypes to the above abiotic factors involves the investigation and interpretation of their mechanisms at the plant cell level. Thus, the study suggests that salicylic acid acts as a plant response to stresses of various nature, and its activation in the genome with the participation of inducing signals such as reactive oxygen species. The nature and method of response at plant developmental stages along with organs and tissues is also a matter of great interest, but such phenomena are largely overlooked and require further investigation. Although abiotic stresses have been addressed extensively in the international scientific community, the prospect for further research will be to develop a complete picture of plant responses to certain types of abiotic stress. Analyses of the behaviour of biotech genotypes are expected to reflect some of the behaviour of plants.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Порівняльний аналіз вмісту саліцилової кислоти у біотехнологічних генотипів бавовнику за різних видів абіотичного стресу

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Анотація. Актуальність питання, представленого в даній роботі, визначається сучасними даними про синтез саліцилової кислоти (СК) в рослинах, які свідчать про те, що наявність деяких транзиторних факторів у бавовнику є сигналом про активацію стрес-протекторних функцій рослини. Збільшення вмісту ключових медіаторів захисної сигнальної системи в клітинах бавовнику спричиняє активацію стресових факторів, запускаючи захисні механізми живого організму. Таким чином, стійкість рослин до певних видів абіотичного стресу досягається за рахунок активації захисних реакцій сигнальної системи. Цей процес дозволяє цілеспрямовано використовувати біологічно активні речовини, такі як саліцилова кислота. Тому метою даної роботи є дослідження комбінованих властивостей захисної сигнальної системи деяких генетичних типів рослин бавовнику за умов синтезу в них фенольних кислот. Провідним підходом до вивчення цього питання є лабораторний експеримент, який дозволив комплексно розглянути лінії бавовнику, що містять РНК, чутливі до певних видів абіотичного стресу. Додаткові біологічні та хімічні методи були використані як допоміжні в польових умовах для перевірки специфічного впливу засолених ґрунтів на концентрацію саліцилової кислоти в РНК бавовнику. У цьому дослідженні представлені дані про стійкість генотипу ESKIMO1 з РНК-інтерференцією (RNAi) до засолення та обмеженого зрошення. Досліджено вміст саліцилової кислоти в тканинах бавовнику за дії різних концентрацій NaCl. Обґрунтовано утворення активних форм кисню в процесі активації захисних реакцій рослин на окремі види абіотичного стресу. Матеріали дослідження мають практичне значення для мікробіологів, генетиків та агрономів. Дослідження біотехнологічних особливостей генотипу рослин відіграє важливу роль у розумінні адаптації рослин до природних умов, спричинених певними типами абіотичного стресу. Доступність саліцилової кислоти дозволяє широко застосовувати її як комерційний реагент у практиці рослинництва

Ключові слова: саліцилова кислота; стійкість; засолення; рідинна хроматографія; метаболізм

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Comparative characteristics of plant protection against copper and sulphur influence

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Abstract. Efficient agriculture provides not only food security but also improves the economy of the country. Despite the existence of different types of agricultural production (traditional or organic), plant protection is currently a necessary component. Copper and sulphur are effective against pests and improve the quality and quantity of crops, but are toxic and harm the environment, biodiversity, and human health. The purpose of the study is to investigate the current situation regarding the use of copper and sulphur in plant protection in the Republic of Albania and other countries of the Balkan Peninsula and Europe. Theoretical and empirical research methods were used in the study. As a result, it was determined that the studied elements were actively used in different European countries, both in traditional and organic agriculture. There is a tendency to reduce the norms of use, and in some countries – the removal of these chemical elements

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from plant protection programmes. The paper includes a comparative characteristic of the use of copper and sulphur and a survey among Albanian agricultural producers on the use of preparations based on these elements. It is established that in the republic, copper and sulphur are actively used mainly in the form of herbicides and fungicides. They are used on vegetable and fruit crops, as well as grapes and olives. There is a problem of informing producers about the negative impact of copper and sulphur on the environment and human safety, as well as control by the state. The practical significance of the study lies in the analysis of the current situation of copper and sulphur use in Albania and in the identification of ways to change it for the better

Keywords: inorganic pesticides; nanofertilisers; efficiency; crop production; organic production

INTRODUCTION

Agriculture is an integral part of the well-being of any country, as it provides food security, which is especially important considering recent events. Thus, the COVID-19 pandemic and Russia's war with Ukraine have led to an economic crisis around the world, especially in Europe and Central Asia (The World Bank, 2022). The constant and rapid growth of the world population, as predicted by many researchers, is also an issue that needs to be addressed (Shahini *et al.*, 2022). All this requires paying more attention to the agricultural sector. Gaps in the research on the use of copper and sulphur in plant protection in several Balkan countries determine the relevance of the study.

Following M.A. Horvat *et al.* (2019) and D. Dokic *et al.* (2022), the agricultural sector of the Balkan countries has undergone significant changes that occurred several decades ago because of the transition from a planned to a market economy. The desire of these countries to integrate into the European Union (EU) is caused not only by geographical but also by political reasons. F.Z. Zupanic *et al.* (2021) report that agriculture in the Western Balkan countries accounts for an average of about 10% of gross domestic product (GDP), and according to the World Bank (2020), the agricultural sector in Albania accounted for more than 18% of GDP and provided 36% of employment in 2019. Wahab *et al.* (2022) argue that it is possible to increase agricultural production using pesticides, which allows increasing gross yields and improving the quality of products, but the use of chemicals also harms the environment and human health, especially their uncontrolled use. This requires a re-evaluation of agriculture, and the introduction of modern, environmentally friendly technologies, including plant protection.

According to M. Ranjith and S. Sridevi (2021), it is necessary to increase agricultural production while minimising the harmful impact on the environment for sustainable development. World experience shows that this can be achieved through integrated plant protection, modern fertilisation technologies using smart fertilisers with slow or controlled release of elements, biological control agents, and genetic breeding. Copper and sulphur have been used for a long time in plant protection and are well studied, but modern requirements of environmental friendliness and safety for human life require limiting their use or complete removal from the system of agricultural pest and pathogen control. Despite the high efficacy of inorganic pesticides, studies show that they pose ecotoxicological problems for the biodiversity of agricultural landscapes and aquatic ecosystems, and copper and its compounds are among the most prominent soil pollutants (Global assessment of the impact..., 2017).

A. Kir *et al.* (2022) investigated the use of copper oxychloride against olive leaf spots and found that copper accumulated in the soil and in the fruits and leaves of olive trees, which posed a risk to human health. A. La Torre *et al.* (2018) argue that copper cannot penetrate plant tissues and is washed away by rain, accumulating in the soil. However, copper and sulphur are allowed for use not only in traditional but also in organic agricultural production regardless. Notably, in recent years, the EU countries have been actively searching for alternative substitutes for copper, while less attention is currently paid to sulphur, although it has been proven to be toxic to pollinators and other beneficial arthropods (Gesraha & Ebeid, 2019).

The purpose of the study is to investigate the use of copper and sulphur in agriculture in the Republic of Albania and other countries of the Balkan Peninsula and Europe. The main objectives were to analyse scientific literature on the subject; to compare the characteristics of copper and sulphur, which are actively used in the form of inorganic pesticides and fertilisers; to conduct a survey of agricultural producers on the use of copper and sulphur in plant protection.

MATERIALS AND METHODS

The study applied theoretical and empirical research methods. The theoretical basis was the main provisions and results of research by many scholars of European countries and the Balkan Peninsula, dedicated to the use of copper and sulphur in the production of agricultural products. To search for scientific literature, the following web resources and databases were used: Google Scholar, World Wide Science, Directory of Open Access Journals (DOAJ) and AGRIS. Scientific literary sources were selected by the topic, using a series of searches by key words, by the type of journals, and the year of publication. First, the articles were identified, then the review and selection of only those publications that

were relevant to the topic of the current study was carried out. Literary sources were analysed on the following issues: the use of the investigated microelements in traditional and organic agriculture, their effectiveness, effects on plants, pathogens and pests, biodiversity, ecology, and human health. Moreover, an important aspect was the study of the use of alternative copper and sulphur plant protection products. In addition to the analysis of literary sources, the abstract logical method and the method of analogy were also applied to investigate the use of copper and sulphur-based pesticides and their alternatives; comparative method was used during the study of the main characteristics of these elements; grouping, abstraction, and generalisation of the received information was also conducted.

A survey was conducted to investigate the issue of the use of copper and sulphur in plant protection and the attitude of agricultural producers towards these micronutrients in the Republic of Albania in 2022. The questionnaires were distributed through the online testing software Google Forms, as well as among representatives of agricultural enterprises in Tirana, Elbasan, Berat, and Gjirokastra. The number of respondents was 216, of which 179 were Google Forms participants. The survey included 8 questions and three specific answer options for each item (Table 1).

***Table 1**. Questionnaire content*

No.	Question	Answers
1	What system of crop production do you consider appropriate?	a) traditional; b) integrated; c) organic.
2	How do you regard chemical plant protection?	a) positive, I use it in full; b) negative, I try to use alternative means of protection; c) tolerant, I use it only when necessary.
3	What are your concerns when deciding on protective measures with pesticides?	a) cost and effectiveness of chemicals; b) necessity; c) price, safety, effectiveness, and environmental friendliness.
4	How often do you use pesticides and fertilisers based on copper and sulphur?	a) constantly; b) if necessary, occasionally; c) do not use.
5	Do you use alternatives to copper and sulphur?	a) yes; b) no; c) if possible.
6	What sulphur-based products do you use the most?	a) herbicides; b) fungicides; c) fertilisers.
7	On which crops do you use inorganic copper- and sulphur-containing preparations?	a) on all crops grown on the farm; b) do not use on any crops; c) only on vegetables, fruits, olives, and grapes.
8	Do you support the ban on copper and sulphur in plant protection?	a) yes; b) no; c) I support only partial limitation of the norms of use.

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

In a survey with the participation of producers of agricultural products regarding the use of copper and sulphur in plant protection, the following ethical principles were used: legality; respect for human rights and freedoms, prevention of discrimination; objectivity and impartiality; voluntariness; competence and professionalism; honesty and confidentiality.

RESULTS

A survey on the use of copper and sulphur by crop producers in the Republic of Albania by questionnaire method showed that most of them were oriented towards integrated (50.5%) and traditional (30.1%) farming systems, and only 19.4% of respondents were interested in organic production (Table 2).

***Table 2**. Results of the survey on the use of copper and sulphur in plant protection, Republic of Albania, 2022*

Question number	Respondent answers					
	a		b		c	
	quantity	share, %	quantity	share, %	quantity	share, %
1	65	30.1	109	50.5	42	19.4
2	106	49.1	11	5.1	99	45.8
3	78	36.1	16	7.4	122	56.5
4	151	69.9	62	28.7	3	1.4
5	28	13.0	104	48.1	84	38.9
6	123	56.9	77	35.6	16	7.4
7	39	18.1	3	1.4	174	80.6
8	6	2.8	106	49.1	104	48.1

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

It was also determined that crop producers had different opinions on chemical plant protection: almost half of the respondents expressed a positive assessment of the use of inorganic fertilisers and pesticides, about 5% gave a negative answer, others were tolerant in this matter. When choosing protective measures, more than 56% of Albanian producers consider not only the cost and effectiveness of such measures but also their environmental friendliness and safety. This figure indicates an incomplete understanding of the respondents about the impact of chemicals on the environment and human health, which requires clarification and control by the state authorities. Most agricultural producers (about 99%) use copper and sulphur-based products. Among them, sulphur-containing herbicides take the first place, fungicides (mainly copper-based) take the second place, and fertilisers take a small share. It was established that copper and sulphur-based fertilisers in the Republic of Albania were used on vegetable (mostly solanaceous) and fruit crops, grapes, and olives. Regarding alternative plant protection products to copper and sulphur, it was determined that almost half of the producers did not use them at all. The ban on copper and sulphur-containing products was supported by only 2.8% of respondents, while other producers were divided almost in half into those who do not support such an initiative and those who support the introduction of certain restrictions on the use of such products. As such, the survey shows that Albanian crop producers actively use copper and sulphur in plant protection; and a low level of awareness of the negative impact of these chemical elements on the environment and human health.

It has been established that today the elements under study are allowed for use in most countries of the world (Andrivon, 2018; Hykas *et al.*, 2022), but due to the ability to accumulate in the environment and food, and due to toxicity, copper-based preparations are gradually abandoned, especially in European countries (Katsoulas *et al.*, 2020). Despite this worldwide trend, copper-based fungicides are still actively used, even in organic agriculture. Eurostat data (2022) on the volume of pesticide sales in European countries in 2020 indicate that fungicides and bactericides accounted for the largest share (43%) of their total volume, followed by herbicides (35%), insecticides and acaricides (14%). It was noted that inorganic fungicides containing copper and inorganic sulphur accounted for almost 57% of the fungicides and bactericides sold during this year (Fig. 1).

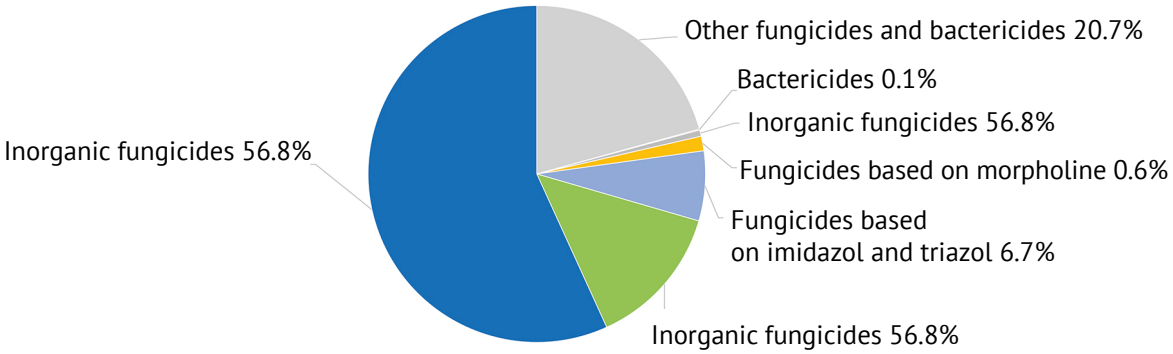

***Figure 1**. Share of fungicides and bactericides sales by active ingredients in European countries in 2020, %*
***Source:** Eurostat (2022)*

Eurostat data (2022) show that the leaders in sales of fungicides and bactericides in 2020 were Spain, Italy, France, and Turkey. The volume of these sales ranged from 20.5 to 37.9 thousand tonnes. The lowest level of sales of these goods was recorded in Iceland, Malta, and Norway. It was at the level of 0.2-93.6 tonnes. Such figures are related to the level of development of agricultural production in these countries.

The European Commission data on the intensity of pesticide use indicate that the most active substances are used in the production of agricultural products by the most economically developed countries. For example, the Netherlands – 8.8 kg/ha, Ireland – 6.9 kg/ha, and Belgium – 6.7 kg/ha of active substance. The lowest level of pesticide application (1.5 kg/ha) is typical for Slovakia, Lithuania, Latvia, Denmark, and Bulgaria (EU Pesticides Database, 2022), that is for countries with a less developed economy. In Spain, Italy, Germany, France, and Poland are seeking to reduce or even ban the use of copper compounds in agriculture. This is conditioned by the development of organic production and increased demand for ecological and safe food products. It was also clarified that copper is not registered as a means of plant protection in five European countries: Denmark, Estonia, the Netherlands, Finland, and Sweden (Tamm *et al.*, 2022).

Under the European Commission (EU Pesticides Database, 2022), the following active substances containing copper are allowed for use in agriculture in the EU countries: copper compounds, copper hydroxide, copper oxide, copper oxychloride, copper tri-basic sulphate, and the prohibited ones are 8-hydroxyquinoline with salicylic acid and dithiocarbamic acid derivatives. Among sulphur-containing pesticides allowed for use in plant protection are preparations with the following active ingredients: amidosulfuron, bensulfuron, flazasulfuron, foramsulfuron, halosulfuron-methyl, iodosulfuron, mesosulfuron, metsulfuron-methyl, nicosulfuron, prosulfuron, rimsulfuron (or renriduron), sulfosulfuron, sulfuryl fluoride, tifensulfuron-methyl, triflusulfuron and tritosulfuron.

Copper group fungicides are characterised by contact-prophylactic and protective action. Their fungicidal action is more effective against the spores of the pathogens than against the development of the mycelium of the fungus. Preparations of the copper group are characterised by the fact that the active substance is adsorbed by the cytoplasm of the cells of fungi. Fungal spores gradually adsorb copper from solutions up to lethal doses. The solubility of copper preparations is facilitated by the excretion of plants, fungi, carbon dioxide from the air, precipitation, etc. The intense transition to the soluble state helps to increase the fungicidal activity of drugs of the copper group, but at the same time increases their phytotoxic effect. The biological effectiveness of fungicides of the copper group depends on the correctly defined period of application and the uniformity of coverage of vegetative organs with working mixtures.

Copper compounds are most effective in protecting against pathogens of mildew, apple and pear scab, and some spots of fruit, berry, and vegetable crops. The biological features of the development of mushrooms are characterised by the fact that their mycelium lives and harms inside the cells of plants. On the surface of vegetative organs, fungi form only asexual sporulation. The mechanism of action of copper compounds has only a preventive protective nature. Therefore, copper fungicides should be used in accordance with the forecast of the spread and development of phytopathogens. Plants must be sprayed with working mixtures of preparations from the beginning of the spore flight until the possible infection of the tissues of the host plant. When a pathogen enters plant cells, drugs of this group are not able to destroy it. The duration of the protective effect of drugs of the copper group is 10-20 days. Therefore, the subsequent use of drugs is determined by weather conditions, the intensity of disease development, and the duration of the protective effect of the fungicide. One of the serious disadvantages of fungicides of the copper group is their phytotoxicity, which is manifested in long-term and significant humidity. Plants are especially sensitive during the period of active growth. Therefore, it is necessary to remember that not only different types of plants, but also their varieties react differently to the phytotoxicity of copper-based preparations. Due to such circumstances, it is necessary to consider all the factors that determine the sensitivity of plants to the preparations of this group.

Sulphur, along with copper, is also an important microelement for plants and is involved in various physiological processes. In plant protection, sulphur-containing preparations are used to destroy weeds, pathogens, and pests (mites, insects). Previously, sulphur was actively used for the fumigation of warehouses and greenhouses to control pests and mould fungi, but now there are more effective and safer means. Recently, the main use of sulphur is in herbicides and fungicides. Table 3 illustrates the comparative characteristics of copper and sulphur by the main indicators.

The fungicidal and acaricidal properties of sulphur-based preparations are revealed at high air temperature, but they must be applied in the morning or evening. Gooseberries and black currants are very susceptible to sulphur fungicides, therefore, before applying on large areas, it is advisable to check their effect on several bushes of certain varieties. Sulphur preparations can be used not only for processing vegetative plants, they can be applied to the soil to limit damage to cabbage by clubroot and root rot (*Pythium*). Sulphur suppresses the development of powdery mildew pathogens, and also restrains the spread of apple and pear scab.

Thus, the study results showed that those elements differed in terms of action and objects of use, but their

relatively low cost and the absence of alternative means contributed to their wide application for plant protection in the research region under both traditional and organic agriculture.

***Table 3**. Comparative characteristics of copper and sulphur application in plant protection*

Attribute	Copper	Sulphur
Plant protection means	fungicides, fertilisers	herbicides, fungicides, insecticides, acaricides, fertilisers
Biochemical functions in plants	participation in photosynthesis and transpiration, synthesis of chlorophyll, anthocyanins, etc., increase of stress resistance to drought, improvement of pollen fertility	participation in protein metabolism, involvement in photosynthesis, improvement of root nutrition, increase immunity to diseases
Harmful element	oomycetes, peronospore fungi, bacteria	weeds, powdery mildew fungi, mites, and insect pests of storage products
Effect on harmful organisms	copper ions cause the denaturation of proteins in pathogen cells and accelerate intracellular oxidative processes	blocks the synthesis of amino acids in the growth points in weeds, disrupts the processes of hydrogenation and dehydration in fungi, effect on insects and ticks has not been studied
Advantages of usage	wide range of effects, formation of a low level of resistance to pathogens, relatively low acute toxicity to mammals, high efficiency in rainy weather, low cost, permit in organic crop production	low level of resistance to harmful organisms, wide range of effects, low cost, permission for use in organic production
Disadvantages	toxicity to invertebrates (worms, pollinators, entomophages), phytotoxicity, formation in the soil of compounds inaccessible to plants, can accumulate in the environment	phytotoxicity, narrow temperature range of application (18-28°C)

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

DISCUSSION

The use of copper and sulphur in plant protection is important in the current context. Their accumulation in agricultural landscapes may hurt the environment in the future. According to D. Andrivon (2018), the large volumes and widespread use of copper in agriculture are subject to increased regulation. Since the invention of Bordeaux mixture in the late 19th century, copper has been a key element in methods of combating fungal and bacterial diseases, especially in viticulture, fruit, and vegetable growing. According to N. Katsoulas *et al.* (2020), this remedy is still used in several European countries: France, Greece, Germany, Turkey, etc.

Following Wahab *et al.* (2022), the volume of pesticide use in the Republic of Albania is 350-400 tonnes per year, with a steady increase in this figure. Currently, chemicals are actively used on vegetables both in the field and in greenhouses, as well as in vineyards and intensive orchards. The survey determined that the use of copper and sulphur-based pesticides in the country is widespread. Albanian agricultural producers use them on almost all crops against weeds (sulphur-containing herbicides), and on potatoes, tomatoes, cucumbers, grapes, olives, and in orchards against diseases and pests.

Notably, the countries of the Balkan Peninsula (Albania, Bosnia and Herzegovina, Serbia, North Macedonia, Montenegro) are heading towards the EU, and due to the lack of domestic production of pesticides and fertilisers in this region, imports of these products prevail. According to T. Brankov and B. Matkovski (2022), the same pesticides and fertilisers are used in the Western Balkan countries as those allowed for use in the EU, but according to the World Health Organization (2008), there are risks of using unregistered and obsolete chemicals that remain in large quantities from the past.

Copper is allowed on perennial crops against fungal and bacterial diseases affecting vines, bunches, and leaves of grapes, fruits and leaves of stone fruits and pome fruits, and nuts. The authors note that copper is also used, contrary to recommendations, against brown rot on apricots and black rot on grapes (Kullaj *et al.*, 2017). Copper-based fungicides are also approved for use on vegetable crops of various botanical groups (in the field and greenhouses), on cereals against some seed diseases, aromatic, essential oil, and ornamental and medicinal plants. Copper and sulphur can be used in organic agricultural production, but with certain restrictions.

The main characteristics of these chemical elements will be considered in more detail. Copper (Cu) is of great importance for living systems and is involved in energy metabolism and has biocidal properties that are used to manage human, animal, and plant health. L. Tamm *et al.* (2022) admit that copper has a broad spectrum of action against several harmful objects of agricultural plants (oomycetes, ascomycetes, basidiomycetes, and bacteria), which is especially important for the control of widespread and harmful diseases: tomato late blight and grape mildew, and diseases of other crops.

According to G. Borkow, J. Gabbay (2005) and D. Andrivon (2018), the exact mechanisms of action on pathogens are not fully understood. The authors argue that there are several hypotheses in this regard. For example, the biocidal effect of copper ions is manifested through the loss of electrolytes from the cell through its membrane, by blocking the normal functioning of proteins in microbial cells, or by disturbing the ionic balance of cells, etc. Copper compounds are used in chemical protection in the form of fertilisers, which contributes to the enhancement of natural plant immunity, but most often in the form of fungicides. They are used against the following diseases: cucumber peronosporosis, grape mildew leaf spot of olives, and phytophthora infestans.

Despite the widespread use and high efficiency of copper and sulphur in plant protection, these elements, depending on the concentration dose, have a toxic effect. L. Kiaune and N. Singhasemanon (2011) state that copper- and sulphur-containing inorganic fungicides can run off and reach surface waters and accumulate in the soil. For example, recent studies conducted by G.D. Gikas *et al*. (2022) in vineyards showed that long-term use of copper-based fungicides led to the accumulation of high concentrations of copper in the soil, which affected pesticide biodegradation, soil structure, availability of nutrients to plants and their resistance to pathogens. According to the authors, sulphur also has toxic properties towards beneficial fungi and bacteria. In addition, their studies show that sulphur is phytotoxic to pumpkins, apricots, and raspberries.

It was established that the repeated use of copper and sulphur-based products was the main source of soil and water pollution. A. Kir *et al*. (2022), while studying the use of copper on olive plantations, concluded that copper accumulated not only in the soil layer, but also in the leaves and branches of trees, which negatively affected biodiversity and human health.

A. La Torre *et al*. (2018) state that high copper concentrations in the soil layer can reduce the population of earthworms and carabids, which is a cause of ecological imbalance, as these animals play an important role in maintaining healthy ecosystems and soil formation processes. K.J. Rader *et al*. (2019) also noted that these elements could have a detrimental effect on aquatic biota when released into water bodies. Thus, according to their data, the toxicity of copper was influenced by pH and the amount of organic carbon in dissolved water. M. Ranjith and S. Sridevi (2021) report the negative effects of chemical pesticides on soil microorganisms and animals. They also note that to reduce the harmful effects of copper and sulphur on beneficial organisms, it is necessary to use the achievements of nanotechnology in agriculture: sulphur nanoparticles (SNPs) and copper nanoparticles (CuNPs), which have low cytotoxicity. A. Karthik and M.U. Maheswari (2021) argue that nanofertilisers retain a large number of nutrients with a particle size of 30-40 nm, slowly releasing them according to the planned yield.

E. Angeleska *et al*. (2011) note the harmful effects of elevated copper concentrations in the soil on the condition of cultivated plants. It is known that excessive amounts of copper compounds negatively affect the growth and development of aboveground and underground plant organs, which leads to a decrease in their total biomass and yield. Legumes, grapes, hops, and cereals are particularly sensitive to copper. The toxicity of this element is related to the bioavailability of copper ions. It has been established that copper concentrations above 2 μM can be phytotoxic. This situation requires the search for new alternative means against diseases.

As a result of the analysis, it was determined that there were no effective and affordable alternatives to the use of copper and sulphur. According to M.E. Sadek *et al*. (2022), various plant extracts with fungicidal effects, chitosan, seaweed, etc., are currently among the proposed alternatives to copper. It is also stated that no copper substitutes for plant protection are effective, and research on this issue is ongoing. The study by N. Katsoulas *et al*. (2020) included a survey of organic producers on alternative plant protection products to copper and sulphur. They determined that in ten European countries, resistant varieties, biological control agents, plant extracts, etc., were used as substitutes for the chemical elements under study. The research showed that in European countries, copper is still used quite often in plant protection, while sulphur and mineral oils are used less often. As the authors admit, this indicates a limited use of alternatives to chemical elements, or such products do not have the necessary effect compared to inorganic substances. Similar conclusions were obtained after a survey of Albanian agricultural producers, which revealed the total use of sulphur-containing herbicides on almost all crops and copper fungicides mainly on vegetables and fruit crops, olives, and grapes.

The studies by A. Karthik and M.U. Maheswari (2021) describe in detail the protective measures alternative to inorganic chemicals. As such, alternatives to copper include combinations of substances with a reduced copper content of up to 2-6%, which reduces the amount of this chemical element per hectare of crops; potassium compounds (e.g., K_2SiO_3 and potassium bicarbonate), sulphur lime, zeolite, and kaolin; natural alternative formulas that allow replacing or reducing the copper usage rate; plant extracts with biocidal properties; biological control agents that have different mechanisms of action against bacterial and fungal pathogens of crops; chitosan, a natural polymer derived from chitin; seaweed extracts (*Ascophyllum nodosum* and *Laminaria digitata*) that can enhance the natural immunity of plants; pest-resistant plant varieties.

G.D. Gikas *et al*. (2022) argue that sulphur alternatives are not currently used, mainly for economic reasons, as sulphur is cheaper and more readily available than other substances. In addition, sulphur is considered a substitute for mineral oil, which is used against

harmful mites and insects on citrus, olives, and tomatoes. Aside from pesticides, fertilisers containing copper or sulphur are also used in agriculture. An analysis of the situation with the use of copper and sulphur in Europe and the Balkans has shown a tendency to limit, and in some countries – to completely ban, the use of copper in plant protection. Thus, according to L. Tamm *et al*. (2022), over the past ten years in Europe, there was a gradual restriction on the use of copper in plant protection, and in 2021, the maximum amount of copper allowed for use was 28 kg. The authors note that the goal is to phase out copper from production, and this element is already on the EU's list of replacement candidates.

Thus, copper and sulphur are widely used in Europe and the Balkans, although there is a gradual tendency to reduce it in plant protection. It was established that it was impossible to abandon their use for objective reasons at the moment. Moreover, active searches for alternatives to these substances have been ongoing recently.

CONCLUSIONS

The survey of Albanian agricultural producers showed the total use of copper (fungicides) and sulphur (herbicides, fungicides, acaricides) in plant protection. The majority of respondents adhere to integrated and traditional farming, and less than 20% practice organic farming. In the Republic of Albania, copper and sulphur are used on vegetables, fruits, grapes, and olives. Alternative plant protection products are rarely used. The positive and tolerant attitude of producers to these chemicals was revealed, which indicates problems with awareness of the negative impact of chemicals on the environment and human health, or the lack of other options to protect the crop.

In Europe, the volume of sales of fungicides and bactericides in 2020 among all types of pesticides was 43%, of which 57% were based on copper and sulphur. Economically developed countries used the largest amount of copper and sulphur in plant production.

A comparison of the main characteristics of copper and sulphur in plant protection showed that those two chemical elements had several common features related to their participation in plant physiological processes (photosynthesis, protein metabolism, etc.), development of natural plant immunity to stressors, phytotoxicity, and negative effects on the environment and human health (in certain concentrations). Otherwise, copper and sulphur are very different: in terms of objects and methods of use, mechanism of action, etc. For example, copper has a biocidal effect in the presence of droplet moisture, its ions penetrate pathogen cells and cause protein degradation, while sulphur has a fumigant effect due to the formation of hydrogen sulphide, which causes the death of fungal spores.

This research showed that in further studies, it is necessary to conduct an additional analysis of global developments in the use of copper and sulphur in plant protection, and to continue research to find substitutes for these elements that would be highly effective in combating harmful crop pests and minimise the burden on the environment. This would allow any country, including Albania, to ensure food security in a constantly changing world.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Порівняльна характеристика засобів захисту рослин від впливу міді та сірки

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Анотація. Актуальність питання, представленого в даній роботі, визначається сучасними даними про синтез саліцилової кислоти (СК) в рослинах, які свідчать про те, що наявність деяких транзиторних факторів у бавовнику є сигналом про активацію стрес-протекторних функцій рослини. Збільшення вмісту ключових медіаторів захисної сигнальної системи в клітинах бавовнику спричиняє активацію стресових факторів, запускаючи захисні механізми живого організму. Таким чином, стійкість рослин до певних видів абіотичного стресу досягається за рахунок активації захисних реакцій сигнальної системи. Цей процес дозволяє цілеспрямовано використовувати біологічно активні речовини, такі як саліцилова кислота. Тому метою даної роботи є дослідження комбінованих властивостей захисної сигнальної системи деяких генетичних типів рослин бавовнику за умов синтезу в них фенольних кислот. Провідним підходом до вивчення цього питання є лабораторний експеримент, який дозволив комплексно розглянути лінії бавовнику, що містять РНК, чутливі до певних видів абіотичного стресу. Додаткові біологічні та хімічні методи були використані як допоміжні в польових умовах для перевірки специфічного впливу засолених ґрунтів на концентрацію саліцилової кислоти в РНК бавовнику. У цьому дослідженні представлені дані про стійкість генотипу ESKIMO1 з РНК-інтерференцією (RNAi) до засолення та обмеженого зрошення. Досліджено вміст саліцилової кислоти в тканинах бавовнику за дії різних концентрацій NaCl. Обґрунтовано утворення активних форм кисню в процесі активації захисних реакцій рослин на окремі види абіотичного стресу. Матеріали дослідження мають практичне значення для мікробіологів, генетиків та агрономів. Дослідження біотехнологічних особливостей генотипу рослин відіграє важливу роль у розумінні адаптації рослин до природних умов, спричинених певними типами абіотичного стресу. Доступність саліцилової кислоти дозволяє широко застосовувати її як комерційний реагент у практиці рослинництва

Ключові слова: саліцилова кислота; стійкість; засолення; рідинна хроматографія; метаболізм

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Life forms of plants of natural and anthropogenic landscapes

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Abstract. The relevance of the study is conditioned by the solution of environmental issues to preserve the natural biological diversity of plant life forms in Central Asia and the Balkan Peninsula. The most important task of Uzbek botanists is to investigate all aspects of the structural and dynamic organisation of vegetation cover and changes in plant communities in areas affected by the intense impact of anthropogenic factors. In this regard, the purpose of this study is to conduct a comparative characterisation of plant life forms of natural and anthropogenic landscapes of Central Asia and the Balkan Peninsula. The leading approach to the examination of this problem is spatial-comparative, which allows comprehensively investigating the elements of the system of plant life forms of natural and anthropogenic landscapes. In addition, during the empirical study, the collected field material was analysed by generally

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accepted geobotanical and forestry methods, which consist in describing the topographic position of woody, semi-woody, polycarpic, and monocarpic terrestrial grasses, aquatic plants. The authors used both herbarium and live material from expedition surveys on the Biosphere Reserve and the protected area of the Uvac river gorge by Kazakh, Uzbek, Greek, and Turkish researchers. As a result, a comparative characteristic of the state of modern plant communities of Central Asia and the Balkan Peninsula by the nature and degree of anthropogenic impact was presented. The main life forms of plants of the regions under study were covered; the interrelation of environmental conditions with the process of flora formation was identified and substantiated. The materials of the study are of practical value for ecologists, landscape researchers, geographers, and biologists to use the findings in creating long-term plans for the development of natural landscapes for nature reserves, ecological centres, and nature protection zones. The developed method of comparative characteristics can be used to investigate natural and anthropogenic landscapes of other territories

Keywords: vegetation; transformation; species composition; ecological system; human factor; comparison

INTRODUCTION

With the development of civilisation, the special relationship between nature and society became the impetus for the emergence of landscape studies. As a scientific discipline, landscape science began its existence at the end of the 19th century in the process of complex research on agricultural lands. In the future, the development of landscape ideas in scientific natural science has been transformed and over the past 10 years, the object of research has been man-made landscapes created on a natural basis.

Uzbek researchers G. Abdiniyazova and O. Khozhimatov (Abdiniyazova & Khozhimatov, 2019) investigated anthropogenic landscapes as man-modified nature, which became the basis for the development of terrestrial civilisation. That is, in this case, while preserving its natural version in a slightly edited form, nature was of little interest to the researcher. Landscapes untouched by human activity and their preservation have been the subject of study by environmental organisations over the past few years.

D. Ishankulova *et al*. (2021) based on their studies, concluded that the modern landscape shell consists of natural and anthropogenic components. Natural landscapes, according to D. Ishankulova *et al*. (2021) are not affected by human economic activity. Anthropogenic landscapes – are subject to human exploitation to the extent which allowed them to be restored even after the cessation of economic activity. This happens because, by being included in the natural environment, human makes changes not only in the biota but also in the geological, geomorphological, and hydro-climatic components.

As stated by E. Bryanskaya and D. Sandanov (2021), each specific plant species adapts to the ecological conditions in which it grows. Therefore, the typical life form inherent in a plant in most of its range can be transformed. E. Bryanskaya and D. Sandanov (2021) noted that these changes do not occur in one season. Changing plant life form is a long evolutionary process of the natural adaptability of plants to external factors. This process manifests itself in appearance, that is, the vegetation of alpine meadows near the glacier will differ from the life form of vegetation of Alpine meadows near rock scree.

N. Kulha *et al*. (2020) investigated the types and spatial scales of forest structure changes in different landscapes. Findings of their study support the idea that the structure of boreal old-growth forests changes at discernible spatial scales. Instead of being driven by gap dynamics, the old-growth forests in the studied regions are currently responding to large-scale drivers by an increase in canopy cover.

V. Cheremushkina *et al*. (2020) proved in their study that the diversity of the aerial parts of the axes reflects the adaptation of plants to specific ecological conditions, while maintaining a genetically fixed, general development programme. Their results expand the understanding of the main areas in the evolution of morphs, which has practically not been studied in plants of the Central Asian flora. Using an architectural approach to describing plants, the authors showed that various ecotopic and ecological-coenotic conditions do not affect the nature of the development of life forms of related taxa.

M. Rufino *et al*. (2023) drew attention to such a phenomenon as the seed dispersal syndrome. In the study, the authors evaluate the influence of environmental factors on floristic composition, seed dispersal syndrome and potential for wild fauna refuge. The study emphasises the importance of creating and protecting private conservation areas, such as the RPPN Fazenda Macedônia and corridors among all forest private areas belonging to the CENIBRA company in that landscape.

J. Plue *et al*. (2022) suggested that species may benefit from green infrastructure, i.e., the network of natural and anthropogenic habitat remnants in human-dominated landscapes, if it helps isolated populations in remaining habitat patches to be functionally connected. Inferred functional connectivity explained genetic variation better than structural connectivity, yielding positive effects on genetic variation. The authors' study proposes that green infrastructure can promote functional connectivity, providing that a plant species can survive outside of core habitat patches. As this often excludes habitat specialist species, conservation practice and policy should primarily focus on ancient, managed semi-natural grasslands.

According to F. Liccari *et al.* (2022), fragmentation and isolation of plant species can be reversed by restoring landscape connectivity through effective Ecological Network planning. Interestingly, the study aims at parsing the interacting effect of landscape structure, surrounding habitats and nodes, and structural connectivity on EN plant diversity at two specific scales of investigation i.e., the habitat and the node scale. In general, landscape composition of semi-natural land cover (i.e., hedgerows, watercourses) showed a positive effect on species diversity as opposed to that of the configuration of anthropogenic elements on both scales.

The purpose of the study is to determine the adaptive capabilities of some plant species in complicated climatic conditions developed during evolution by comparing and analysing their development in different ecosystems. The geomorphological zones investigated during the study contain various plant communities that differ in appearance and species composition.

MATERIALS AND METHODS

The method of source analysis was used in the research process to investigate the geographical, biological, landscape, historical, philosophical literature on the chosen topic. With the help of the generalisation method, the authors recorded common features and properties of research by Uzbek, Kazakh, Chinese, American, British, and other researchers. According to the method of analogies, comparative characteristics of plant life forms of natural and anthropogenic landscapes of Central Asia and the Balkan Peninsula were conducted. Having modelled the classification of the main plant life forms of the territories under study, it was possible to identify similarities and differences in indicators of floral richness. The classification of plant life forms of the investigated regions was depicted using the graphical representation of the results method, and Latin and English taxon species were presented according to the summary of plants of the biosphere reserve and the protected area of the Uvac river using method of mathematical statistics.

Among the diagnostic methods, observation, analysis of herbarium materials, and the results of field photography were applied. The samples of areas with natural and anthropogenic landscapes were conducted. For this purpose, the semi-desert and mountainous zones of Central Asia, and the plains and mountainous territories of the Balkan Peninsula were considered. Classification of plant life forms was conducted according to the following forms: woody plants, shrubs, lianas, grasses, succulents. For classification, a description of the topographic position of communities, soil characteristics, and a description of the stand, undergrowth, and grass tier were used. The study of the structural features of the species was conducted both at the live material and at the National Herbarium of Uzbekistan Institute of Botany of the Academy of Sciences of the Republic of Uzbekistan, and at the Herbarium of History Museum of Bosnia and Herzegovina in Sarajevo. The experimental base of the study was the National University of Uzbekistan named after Mirzo Ulugbek.

In the course of the empirical research, the results of long-term studies of structural and dynamic organisations of plant communities formed in territories with a scarce natural irrigation system, and normative and methodological documentation of the physical and geographical conditions of the biosphere reserve and the protected area of the Uvac river gorge were investigated (Ovchinnikova *et al.*, 2020). The biological and biomorphological diversity of plants of the two territories and the degree of resistance of natural landscapes to anthropogenic factors were empirically analysed. Plant life forms were investigated according to the following criteria: appearance of the plant (height, width of foliage), level of lignification of the stem, survival rate of ground shoots, root system. Each of these morphological features was rated 1 point, which was converted into percentages in further processing. One life form can consist of a variety of species and genera. Therewith, one species can form several life forms. In accordance with the above criteria, the plants were determined based on the Centre for Advanced Technologies under the Ministry of Innovative Development of the Republic of Uzbekistan.

RESULTS

Plant life forms are closely related to the rhythm of the development of the ecological situation in the region. The desert and steppe natural zones of Central Asia account for 20 to 25 thousand plant species. Located between China in the northwest and Turkey in the east; Kazakhstan in the north, and the Arabian Peninsula in the south – Central Asia is rich in bluegrass, cabbage, legumes, saxifrage, stonecrop, borage, and lily families in the steppe zone. Mountain vegetation is represented by pine, deciduous-pine forests in combination with herbaceous and shrubby vegetation (Halilaj *et al.*, 2021).

The vegetation of the Balkan Peninsula is represented by a large number of endemic plant species. The coastal zone is mountainous, represented by Mediterranean-type vegetation, and has several levels. The lowest storey – pine and oak forests, shrubs, the middle storey – deciduous forests, deciduous shrubs. The upper border of the mountains at an altitude of 180-2,300 metres – beech, fir, pine. In the central and northeastern parts of the peninsula, the plants are mainly represented by steppe vegetation and agricultural products: wheat, corn, tobacco, grapes (Noroozi *et al.*, 2019).

As a classification of plant life forms, the authors of the study identified the following groups: woody, semi-woody, and herbaceous plants. A group of woody plants is characterised by a crown with branches, on which, as a rule, there is no tillering. Throughout life, aboveground shoots are perennial, the buds are located on all parts of the plant and easily tolerate the winter period.

Semi-woody plants have two parts: the lower perennial woody, aboveground – annuals with elongated shoots. The buds are located relatively low above the soil surface, so, during severe spring and summer frosts, their death is possible. In addition, the authors of the study attributed shrubs to this group: creeping shrubs and climbing shrubs. The bush zone can be both underground and surface. The creeping shrubs have the shape of a tree with perennial lignified shoots that creep along the ground. Due to the fact that the shoots of shrubs have an underground and surface location, the buds can also be located both underground and above it. Stimulation of bud growth occurs as a result of forcible suppression of the growth of the main trunk.

Herbaceous plants – depending on the time of germination of the seed to the adult plant, annual and perennial plants are distinguished. The life span of shoots of annual plants is less than a year, there are no wintering buds in the body. In perennial plants, all aboveground parts of shoots are annuals, and underground ones can last for several years, wintering buds are located on them.

In the course of an empirical study of the life forms of natural landscapes in Central Asia, the species diversity of plants is presented in Figure 1.

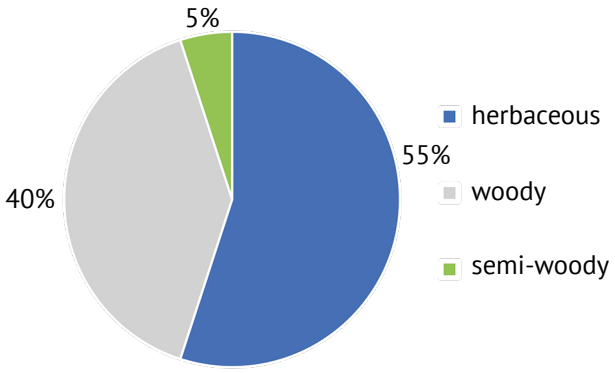

Figure 1. *Classification of plant life forms of natural landscapes of Central Asia*
Source: *compiled by the authors*

The analysis of life forms indicates that the phytocenosis of herbaceous flora is 15 plant species (55%), of which 14 species are short-lived: annuals – 10 species; and biennials – 4 species. The latter have a rod root system. The following representatives are most common: *Fallopia convolvulus (L.) A. L¨ove, Polygonum aviculare L., Berteroa incana (L.) DC., Capsella bursa-pastoris (L.) Medik., Chorispora tenella (Pall.) DC., Sisymbrium loeselii L., Thlaspi arvense L., Viola arvensis Murray, Solanum nigrum L., Carduus crispus L., Conyza canadensis (L.) Cronqist*. Woody plants include 11 species (40%): trees – 6 species, shrubs – 4 species, and semi-shrubs – 1 species. The smallest number of species is semi-woody plants (lianas, perennial herbaceous plants, succulents) – there is 1 species of these representatives (5%).

The life form affects not only the ability of the plant to tolerate unfavourable climate and weather conditions, it determines the place of the plant (its species coenopopulation) in the morphological and functional structure of the phytocenosis. Vegetation analysis of anthropogenic landscapes of Central Asia is presented in Figure 2.

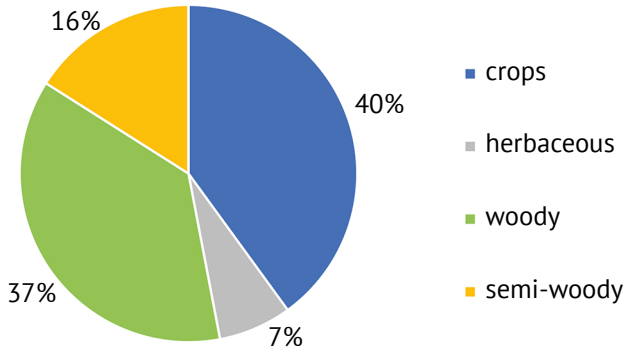

Figure 2. *Classification of plant life forms of anthropogenic landscapes of Central Asia*
Source: *compiled by the authors*

Crops of semi-desert and steppe regions are among the leaders of anthropogenically formed plant groups (40%) (*Acer negundo L., Elaeagnus angustifolia L., Haloxylon ammodendron (C.A.Mey.) Bunge ex Fenzl, Salsola richteri (Moq.) Karel ex Litv., Poa bulbosa L., Salsola gemmascens Pall., Kochia prostrata (L.) Schrad., Salsola Sogdiana Bunge, Kraschennikovia ewersmanniana (Stschegl. ex Lonsinsk.) Grub., Salsola dendroides Pall., Ephedra distachia L. Kraschennikovia ceratoides (L.) Gueldenst., Limonium otolepis (Schrenk) Kuntze, Capparis spinosa L., Glycyrrhiza glabra L., Nitraria sibirica Pall., Peganum harmala L., Heliotropium arguzioides Kar.et Kir., Licium ruthenicum Murr., Artemisia scoparia Waldst. & Kit. Salicornia europea L., Halostachys belangeriana (Moq.) Botsch.*). Herbaceous plants make up a much smaller volume, given the aridity of the earth, they die immediately after flowering even before the onset of summer (7%). Such plants are most vulnerable in the climatic conditions of the forest-steppe zone and mountainous terrain. Woody plants of forest species are preserved in the volume of 37% of the total flora of the anthropogenic landscape, and semi-woody plants make up 16% of its vegetation. Being at a slight distance from the soil surface, their buds are more vulnerable during spring-summer frosts, and the leaves are exposed to a dry period in July–August, so the plants are forced to retain moisture in the stem, while actively shedding foliage.

The classification of plant life forms of the natural landscapes of the Balkan Peninsula is presented in Figure 3.

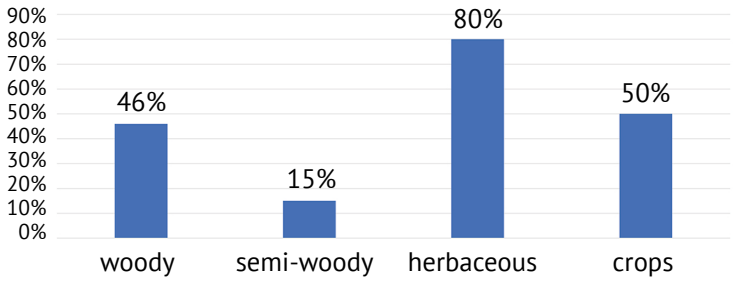

***Figure 3**. Analysis of plant life forms of natural landscapes of the Balkan Peninsula*
***Source:** compiled by the authors*

The mountainous terrain of the peninsula is least susceptible to human intervention. Woody plants are represented by various plants (12 species), which make up 46% of all vegetation on the peninsula. The following species are represented: *Ulmus pumila L., Armeniaca vulgaris Lam., Malus domestica Borkh., Prunus divaricata Ledeb., Robinia pseudoacacia L., Aesculus hippocastanum L., Grossularia uva-crispa (L.) Mill., Ribes aureum Pursh, Parthenocissus quinquefolia (L.) Planch., Symphoricarpos rivularis Suksd.* Semi-woody plants are scattered over the entire area of natural landscapes, and do not form a common canopy. Lianas and vines are located singly and in groups at the level of shrubs, make up 15% of the vegetation. The most common herbaceous plants (64 species, 80%) are herbaceous lianas, ferns, large grasses. Herbaceous plants are mostly perennials. The abundant grasses are explained by the inaccessibility of the Uvac river gorge due to the mountain ranges around and the moderate flow of the riverbed, which allows herbaceous plants to preserve foliage for a long time. Unlike the herbaceous vegetation of Central Asia, which has to shed leaves to conserve moisture. The main representatives are *Allium pervestitum, Rumia crithmifolia, Centaurea taliewii, Dianthus lanceolatus, Astragalus henningii, Astragalus pallescens, Bellevalia lipskyi, Salvia scabiosifolia, Agropyron cimmericum, Agropyron dasyanthum, Elytrigia stipifolia, Crataegus taurica.*

The anthropogenic landscapes of the Balkan Peninsula are represented by plains and lowlands in the northeastern part of the peninsula. It is these territories that are most susceptible to human intervention. The analysis of plant life forms in this region is presented in Figure 4.

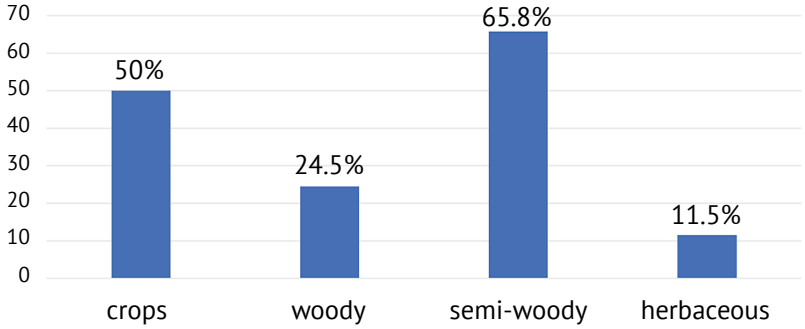

***Figure 4**. Analysis of plant life forms of natural landscapes of the Balkan Peninsula*
***Source:** compiled by the authors*

Woody plants (89 species) – 24.5% (*Pinaceae, Cupressaceae, Taxaceae, Ephedraceae, Robinia pseudoacacia L., Amorpha fruticosa L., Ailanthus altissima (Mill.) Swingle, Machonia aquifolium (Pursh) Nutt., Koelreuteria paniculata Laxm.*). Semi-woody plants: 237 shrubs species (65.8%), 35 semi-shrubs species (9.7%). Herbaceous plants: 42 evergreen species (11.5%), represented by such species as *Arenaria rhodopaea Delip., Astragalus alopecurus Pall., Astracantha aitosensis (Ivan.) Podl., Eranthis bulgaricus (Stef.) Stef., Gypsophila tekirae Stef., Tulipa splendens Delip., Viola parvula Tineo, Pinus brutia Ten., Quercus thracica Stef. et Nedjalkov, Spiraea salicifolia L., Ribes nigrum L., Potentilla fruticosa L., Salix rosmarinifolia L.* tree vines – 12 species (3.3%). A substantial part of the flora is developed by planting plant species in the lowlands and plains (50%). Main representatives: *Asteraceae, Poaceae, Fabaceae, Caryophyllaceae, Rosaceae, Brassicaceae, Scophulariaceae, Apiaceae, Lamiaceae, Liliaceae S. L., Ranunculaceae, Cyperaceae, Boraginaceae*.

After analysing the plant life forms of natural and anthropogenic landscapes of Central Asia and the Balkan Peninsula, the authors of the study conducted a comparative characterisation of the phytocenosis of the territories under study (Fig. 5).

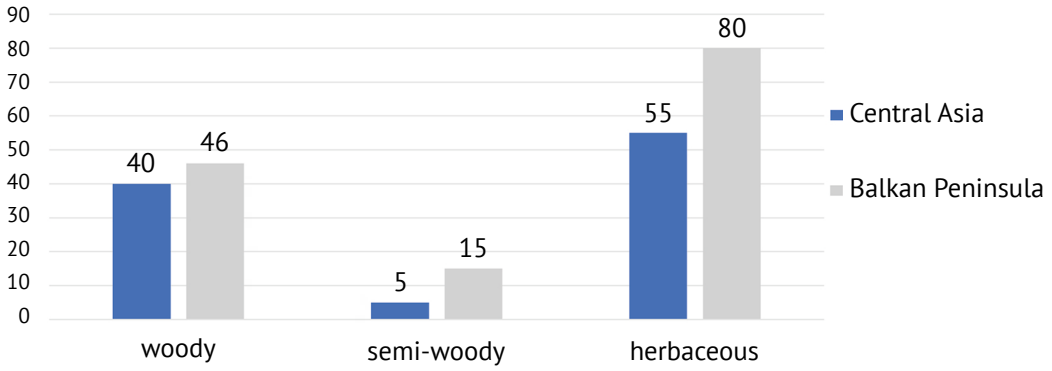

Figure 5. *Comparative characteristics of plant life forms of natural landscapes of Central Asia and the Balkan Peninsula*
Source: *compiled by the authors*

A comparative analysis of plant life forms by the number of species diversity has shown that the largest number of them is recorded on the Balkan Peninsula, especially woody and herbaceous plants. The results of the analysis of the similarity of plant life forms of anthropogenic landscapes of Central Asia and the Balkan Peninsula are presented in Figure 6.

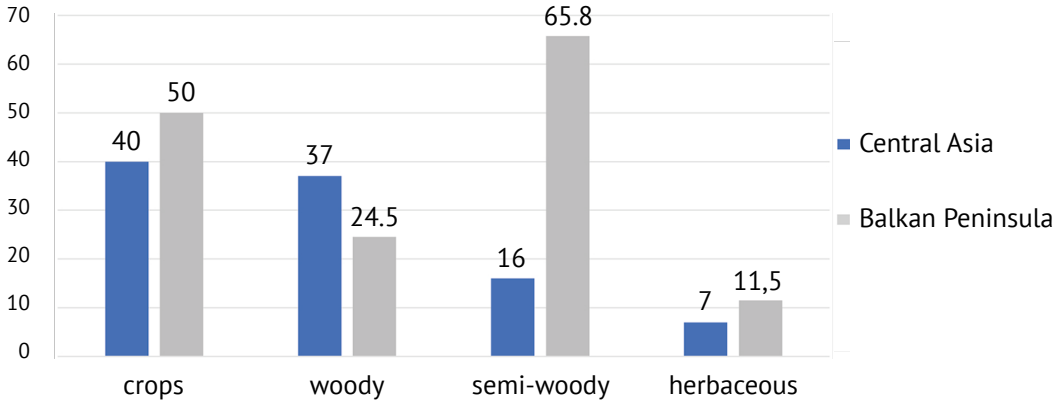

Figure 6. *Comparative characteristics of plant life forms of anthropogenic landscapes of Central Asia and the Balkan Peninsula*

Source: *compiled by the authors*

The number of plant life forms of the Balkan Peninsula prevails over the similar plant communities of Central Asia. However, the species diversity of woody plants is 10% greater in Central Asia. In both landscape zones, perennials predominate in terms of life expectancy, an increase in annual plants is observed from the middle mountain belt and is completely absent in the highlands. Seasonal development on the Balkan Peninsula is dominated by summer-green plants, which is generally understandable since the climate of the peninsula is heterogeneous and changes from west to east from the Mediterranean to the continental climate. For Central Asia, seasonal development is limited to tree stands, lianas, and succulents. Trees and shrubs predominate among the planting plants: olives and citrus fruits (Balkan Peninsula) and cotton (Uzbekistan).

The largest number of variants of plant life forms was observed in the middle band of the mountains in both territories under study. In Central Asia, the upper parts of the mountains are favourable for plants that retain moisture; the flora of the Balkan Islands is devoid of such a need, since the mountains are able to retain moisture coming from the seas.

The following biological properties play an extremely important role for plants: the ability to tolerate unfavourable climate and weather conditions (frosts, heat, drought), the ability to vegetative reproduction and growth, the duration of vegetation, the method of pollination, and the spread of diasporas. They give an idea of the degree of compliance of the species with the conditions of the place of growth and ultimately allow predicting the stability of its existence as part of the flora and vegetation of the investigated territory.

The climate of Central Asia is sharply continental, winters are cold and dry, and summers are very hot. The irrational use of water resources and poor management of industrial enterprises led to the fact that the regions located downstream of the main rivers of Central Asia are in a critical situation with the irrigation system, which can lead to a humanitarian catastrophe. Since plants are dominant in the production of medicinal, feed, and technical industries, the transition to the orderly use of water resources is a nationwide problem. The waters of the rivers used for the irrigation system of plant plantations in some cases do not reach them: they either evaporate or seep into the sands. In this regard, farmers have to reduce agricultural areas, as once fertile fields turn into a poisonous salty desert. The same thing happens with the vegetation of the southern part of the Balkan Peninsula, which is exposed to the salty breeze from the seas, and the mountainous terrain does not allow for sufficient irrigation. However, a large number of rivers on the territory of the Balkan Peninsula allows creating of irrigation systems, which ultimately leads to even greater human intervention in the natural environment. Thus, the natural resources of the regions under study directly depend on natural and ecological, and anthropogenic factors, therefore, the effectiveness of the use of plant resources directly depends on the careful attitude of mankind towards them.

DISCUSSION

Considering that all anthropogenic landscapes are created on a natural basis – in any anthropogenic landscape, even the most man-made, there is necessarily a natural component (subsystem) (Erdős *et al.*, 2019). They are referred to as natural-anthropogenic, such as fires, deforestation, and land ploughed for agricultural land transform ecotones of natural conditions into anthropogenic landscapes.

In Uzbekistan, landscape studies originated and developed mainly based on the investigation of anthropogenic, not natural landscapes. Currently, only those anthropogenic landscapes are recognised that optimally perform the specified socio-economic functions and are environmentally favourable for human life. Geoecological studies were indicative in this regard, which were aimed at identifying valuable resources, their practical use, and a measure of protection and reproduction (Eriksson, 2021). Water has become one such resource for Central Asia and the Balkan Peninsula. Canals to provide the inhabitants of the desert of Central Asia and the plains of the Balkan Peninsula from which irrigation of agricultural plantations directly takes place are being developed. However, due to the imperfection of the irrigation system (most of the canals are not isolated) about 40% of the water evaporates on the way to residential areas (Bengtsson *et al.*, 2019). The flora suffers from this and the vegetation strip may shift to zones with a more optimal temperature for some species. Thus, the deserts of Central Asia will take the place of meadow areas, and those, in turn, will move up to higher parts of the mountains, and forests may disappear completely. The same will happen with the plains and lowlands of the Balkan Peninsula.

Thus, N. Berisha and V. Bytyqi (2021) examined the transition zone between the plain and forest-steppe regions of the central and southern parts of the Balkan Peninsula, focusing on the current state of plant communities. Anthropogenic factors always enhance the differentiation of plant communities of contact environments. The interzonal ecotone diagnoses afforestation of steppe territories within the forest-steppe, and the forest's advance into the steppe zone. Due to the increase in average annual temperatures and the shift of the main part of precipitation to the last stages of vegetation, it is possible to slow down the degradation of forests within the boundaries of the forest-steppe with the activation of the processes of their slow recovery. The development of forest plant communities surrounded by steppe spaces in conditions of removal of anthropogenic influences is also likely. As a result, the process of changing the border of the forest-steppe in the latitudinal direction is possible, which is confirmed by the permanent state of the contact zone of the forest-steppe and the zonal steppe for a specific period of time in the south. As mentioned above, the optimal use of anthropogenic landscapes has a positive effect on the ecological situation in the region. Thus, W. Eide *et al.* (2020) observed a decrease in pasture loads in the area under study over the past ten years. As a result of the emergence of farmlands, steppe plant communities are gradually restored: their storeys are forming, and the projective coverage and species diversity in communities increase.

As noted in the study, some plant life forms have already adapted to survive without water, while in the dry period, semi-woody plants of anthropogenic landscapes of Central Asia are forced to shed foliage to retain moisture in the trunk.

L. Garibaldi *et al.* (2020) also highlight the relationship between water, temperature, and vegetation.

This triad is of great importance for life and economic activity. In regions with hot summers, plants and trees play an important role in cooling the air and providing shade. According to L. Garibaldi *et al*. (2020), the lack of sufficient water supply will lead to an increase in temperature and put pressure on the plants of natural and cultural landscapes. In this regard, the authors give the scientific and practical importance of a regular inventory of vegetation of natural and anthropogenic landscapes and compiling a list of the most adaptable species.

Thus, T. Campagnaro *et al*. (2019) identified economically valuable groups of plants as the object of the study. Having analysed the increase in the demand of the population for medicinal and other raw plants, T. Campagnaro *et al*. (2019) determined the species composition of medicinal plants in Central Asia and identified honey-bearing species. According to the study on the territory of Karakalpakstan, 40% of the wild flora consists of 444 species of medicinal plants, of which 95 species grow on the territory of the Southern Aralkum. In the near future, it is planned to increase such areas to 700,000 hectares. T. Campagnaro *et al*. (2019) drew conclusions that their introduction into production will contribute to meeting the needs of the population in medicinal and food products.

In the doctrine on natural landscapes, N. Kuzmanović *et al*. (2021) consider them as a natural, economic, and social complex. The researcher finds a genetic and functional relationship between climate, soils, vegetation, wildlife, on the one hand, and humans "in all manifestations of their life" – on the other: in their economic activities, methods of cultivation and ploughing of land. N. Kuzmanović *et al*. (2021) give a broad understanding of the landscape as a natural-historical, socio-ecological, and ethnocultural geosystem. The researcher considers the landscape an ethnic legacy of previous generations. With it, the material and spiritual wealth of the nation accumulated over centuries is transferred from epoch to epoch. Therefore, in the system of the most important national values, along with such concepts identifying each people as having a native language, history, culture, religion, the native land – the landscape created by the people is always one of the primaries.

The flora of any territory is a mobile, continuously developing natural system. The combination of species changes over time in its individual ecotopes, depending on the possibility of the existence of individual plant species and environmental factors affecting them in a given area. H. Halilaj *et al*. (2021) defined plant life forms as a floristic complex of species that geographically grow in a given area during evolution and dynamically develop under certain ecological and phytocenotic conditions. H. Halilaj *et al*. (2021) laid the socio-economic and socio-ecological principles of nature management as the basis for the classification of economically modified landscapes. Thus, the researchers determined the degree of anthropogenic transformation of natural landscapes according to the following criteria: the level of preservation or violation of the natural leaving areas; the ability of nature to regulate the deep human impacts (restoration); the functions performed by landscapes in the socio-economic field of human life. In this regard, H. Halilaj *et al*. (2021) classified natural landscapes as conditionally indigenous, not economically used; poorly exploited (successively restored); specially protected natural territories (nature reserves, national and natural parks).

V. Kalinkina *et al*. (2020) proved in their research that the distribution of species and the formation of a certain variant of life forms in them depend on environmental conditions, and on the adaptive potential of plants. V. Kalinkina *et al*. (2020) investigated phytocenosis in three trial areas of the forest area. An increase or decrease in humidity, a change in the degree of illumination and the density of the substrate on the first and third test areas led to a decrease in the total number of seed plant species. On each of the three test areas, rhizomatous species occupy a leading position, however, on the steep isolated slopes of the third test area, their number is noticeably smaller, but the share of involvement in coenosis is higher. Analysis of the shoot structure of herbaceous species showed that there is no consistent dependence of the type of shoot on the place of growth of the individual plant, in each sample area there are approximately equal proportions of all types of different types of shoots (elongated, rosette, and semi-rosette). Ferns are characteristic of undisturbed or slightly disturbed coniferous-deciduous forests, and their sufficient number indicates the stability and long-term development of the community. The presence of only one type of fern in the upper part of the slope indicates that, in general, the conditions here are not very favourable for forest plants in terms of soil moisture and light regime.

CONCLUSIONS

Comparative characteristics of plant life forms in natural and anthropogenic landscapes of Central Asia and the Balkan Peninsula were conducted based on important methodological principles: correct identification of species, determination of invasive plant groups in natural landscapes, and the level of environmental threat in anthropogenic landscapes. The study of the structural and dynamic organisation of plant communities formed on natural or anthropogenic landscapes fully characterises the phytocenosis of Central Asia and the Balkan Peninsula. In this regard, the authors of the study applied the following categories as a classification of plant life forms: woody plants, semi-woody plants (shrubs, lianas, succulents), herbaceous plants, and crops of anthropogenic landscapes.

As a result of the comparative analysis, it was identified that the plant life forms of the natural landscapes of the Balkan Peninsula predominate: woody plants by

6%, semi-woody plants by 10%, and herbaceous plants by 35%. Life forms of anthropogenic landscapes predominate by the criterion of semi-woody plants by 49.8%, herbaceous plants by 4.5%, and crops by 10%, but the species composition of woody plants prevails in Central Asia by 12.5%.

Notably, the flora of the Balkan Peninsula is much richer and more diverse throughout the territory. As already noted in this study, vegetation largely depends on the habitat, the climate in which it grows. The climate of the Balkan Peninsula changes from moderately continental in the north to subtropical-Mediterranean in the south and west, with a huge amount of precipitation and high altitude in the mountains. The climate of Central Asia is sharply continental with arid zones surrounded by mountain ranges that isolate the vegetation of the region from precipitation. Thus, the most destructive factor for the natural biota of Central Asia is drought, while isolation is for the natural landscapes of the Balkan Peninsula. The study of the protected area of the Uvac river led to the conclusion that the endangered plant species are the most vulnerable to alien biodiversity. The phytocenosis of anthropogenic landscapes of Central Asia and the Balkan Peninsula is under pressure from industrial enterprises.

Therefore, to record how the biodiversity of flora reacts to anthropogenic impacts, it is advisable to analyse data from long-term series of the number of plant communities living in territories affected by human activity as further studies.

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None.

CONFLICT OF INTEREST

The authors report no conflict of interest.

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Життєві форми рослин природних та антропогенних ландшафтів

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Анотація. Актуальність даного дослідження зумовлена вирішенням екологічних проблем збереження природного біологічного різноманіття життєвих форм рослин Центральної Азії та Балканського півострова. Найважливішим завданням узбецьких ботаніків є дослідження всіх аспектів структурно-динамічної організації рослинного покриву і змін рослинних угруповань на територіях, що зазнали інтенсивного впливу антропогенних факторів. У зв'язку з цим метою даного дослідження є проведення порівняльної характеристики життєвих форм рослин природних і антропогенних ландшафтів Середньої Азії та Балканського півострова. Провідним підходом до розгляду цієї проблеми є просторово-порівняльний, що дозволяє комплексно вивчити елементи системи життєвих форм рослин природних і антропогенних ландшафтів. Крім того, під час емпіричного дослідження зібраний польовий матеріал проаналізовано загальноприйнятими геоботанічними та лісівничими методами, які полягають в описі топографічного положення деревних, напівдеревних, полікарпічних та монокарпічних наземних трав, водних рослин. Автори використовували як гербарний, так і живий матеріал експедиційних обстежень біосферного заповідника та заповідної території ущелини річки Увац казахськими, узбецькими, грецькими та турецькими дослідниками. У результаті дано порівняльну характеристику стану сучасних рослинних угрупувань Центральної Азії та Балканського півострова за характером і ступенем антропогенного впливу. Висвітлено основні життєві форми рослин досліджуваних регіонів; виявлено та обґрунтовано взаємозв'язок умов середовища з процесом формування флори. Матеріали дослідження мають практичне значення для екологів, ландшафтознавців, географів, біологів і можуть бути використані при створенні перспективних планів розвитку природних ландшафтів заповідників, екологічних центрів, природоохоронних зон. Розроблений метод порівняльної характеристики може бути використаний для дослідження природних та антропогенних ландшафтів інших територій

Ключові слова: рослинність; перетворення; видовий склад; екологічна система; людський фактор; порівняння

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Methods for determining the critical deformations of wood with various moisture content

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Abstract. During construction of bridges, the possibility of flooding periods should be considered. Therefore, it is necessary to understand the degree of possible deformation of wooden structures and calculate the limit of their plasticity and elasticity at different values of moisture content. Thus, the purpose of study is to find the method for determining the relative critical deformations of wood with different moisture content and analyse the dynamics of their change. Problems of a deformable solid material were investigated by the analysis of a model of complete deformation diagram "stress σ_c – deformation u_c", methods of mathematical statistics, and systematic analysis of experimental results. This study allowed formulating the method for determining the relative critical deformations of solid wood at different moisture levels by axial compression along the fibres of experimental samples. Based on the experiment results, the

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formula for determining the relative critical deformations of solid wood with different moisture was proposed. The dynamics of changes in critical relative deformations at different moisture, and its elastic and plastic components were presented. It was found that in case of drying wood from 30 to 12%, the plastic component of relative critical deformations decreases and the elastic one, on the contrary, increases. The findings can be used in the deformation calculation methodology for wooden elements and structures of bridges, hydraulic structures, buildings, taking into account the changes in the moisture content of the material

Keywords: moisture content; "stress-strain" curve; compression along the fibres; modulus of elasticity; ultimate strength

INTRODUCTION

The load-bearing elements of bridge crossings, road and railway wooden bridges across rivers are affected by various influences, such as dynamic loads, seismic oscillations, and floods. Some load-bearing elements of such transport facilities are completely or partially in the water. Under such conditions, the elements and structures of bridges can reach stresses and strains that can be close to critical ones or exceed them. Thus, the study of hardwood and coniferous wood material under maximum stress, especially when the wood constantly changes its moisture content, for example, during floods, is of great interest.

Wood is one of the main raw materials in the world and will remain it for many years (Kulman *et al.*, 2019; Rudavska *et al.*, 2020; Pinchevska *et al.*, 2019). It is used in many sectors of the world economy, including the construction and renovation of bridges and overpasses (Kulman *et al.*, 2021; Gomon *et al.*, 2022, Sobczak-Piąstka *et al.*, 2022), transport facilities, railway, hydrotechnical and mining buildings, and in other sectors of the economy (Zhou *et al.*, 2018; Rudavska *et al.*, 2018; Bosak *et al.*, 2021).

Wood of deciduous and coniferous species of different moisture has been studied since the middle of the last century. Usually, researchers investigated the strength of wood with different moisture content (Kulman *et al.*,2020). Vasic & Stanzl-Tschegg (2007) revealed distinct changes in wood fracture behaviour as a function of moisture content. But these studies do not contain all important characteristics such as deformation parameters, which are also very important. The paper by Zhou *et al.* (2018) described deformation diagrams of bamboo wood and determined critical deformations at a standard moisture content of 12%. Da Silva & Kyriakides (2007) analysed the critical deformations of balsa wood in a similar way.

Since wood works in the elastic-plastic stage, it is necessary to consider not only the elastic stage, but in a complex with the plastic component. Chen Huang *et al.* (2020), Fothe (2021), Jin-Kyu Song *et al.* (2007) described characteristics of wood under compression and mathematical modelling of the stress-strain curve of wood. These studies in general showed method for determining yield point between elastic and plastic zone. The modulus of elasticity (MoE) decreased during increasing fixation time by applied compression level. Chen Huang *et al.* (2020) Báder and Németh (2018, 2019) also determined the relationship between compressive stress change during fixation, shortening and some mechanical properties. In addition, the researchers calculated the bending modulus of elasticity (MoE). For plastic characteristics, the main research is aimed only at determining the standard moisture content at which wood will retain the shape obtained during deformation. Thygesen *et al.* (2010), Báder and Németh (2017) analysed the influence of different moisture content on other physical and mechanical properties of wood. Huang *et al.* (2006) showed the influence of moisture content on the mechanical properties of wood-based composites. But these investigations were made for standard moisture content under standard conditions.

T*he purpose of the study* was to find the method for determining the relative critical deformations of wood with different moisture content experimentally and theoretically, including elastic and plastic components, and determine the dynamics of their change.

MATERIALS AND METHODS

Bridges and overpasses are usually made of hardwood and softwood material. Thus, such species were chosen for the experiment. A set of samples of 1 grade of solid wood with structural dimensions of different species in the form of rectangular prisms with a cross-section of 30x30x120 mm aged 60±5 years were taken (Fig. 1). These dimensions of the prisms allow considering the micro- and macrostructure of the wood and ensuring the absence of friction between the press plate and the end face of the sample. Therefore, the following wood species were selected for testing: birch, alder, ash, larch, pine, spruce. Samples of the trees such as pine and spruce were grown in the forests of Rivne Oblast (Ukraine); birch, alder, ash – in Volyn Oblast (Ukraine); larch was grown in the forests of Ivano-Frankivsk Oblast (Ukraine).

ASTM D 143-14 (2014), DSTU EN 380-2008 (2008), and DSTU 3129: 2015 (2015) suggest using a tree with a straight trunk and a small number of branches. This allowed reducing a number of samples with a lot of knots of wood and increasing the parallelism of the fibres. Trees were transported to carpentry shops by the trunks. There trees were cut into bars. The received elements were marked.

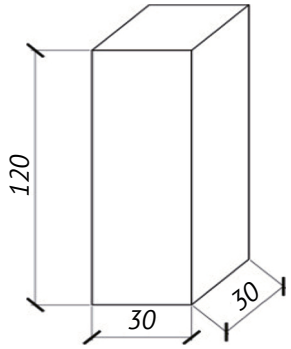


***Figure 1**. Geometric dimensions of solid wood samples*
***Source:** Yasniy et al. (2022), Varenik et al. (2019)*

The wood with moisture content of 30%, 21%, 12% was taken for experiment. DBN B.2.6-161:2017 (2017), Eurocode 5 (2004), DSTU EN 380-2008 (2018) suggest using wood samples that were pre-dried in the laboratory to an average moisture of 30±1% at the temperature of 20°C and moisture content of about 65% and in special drying chambers to moisture of 21±1% and 12±1. The moisture content was controlled using a moisture meter MD-814 (Fig. 2). Samples were cut from pre-prepared long bars. Each of the obtained samples, as required, was without visible defects. The prism samples were rejected if they not met this condition (Fig. 2).

A plan for conducting experimental research was developed in accordance with current regulatory documents. It is given in Table 1.

***Figure 2**. Moisture meter MD-814*

***Table 1**. The data of experimental studies of solid wood of hardwood and softwood*

No.	Wood species	Moisture content, %	Age, years	Deformation speed mm/min	Number of samples, pieces
1	Birch	30	60	1.5	6
2	Birch	21	60	1.5	6
3	Birch	12	60	1.5	9
4	Alder	30	60	1.5	6
5	Alder	21	60	1.5	6
6	Alder	12	60	1.5	9
7	Ash	30	60	1.5	6
8	Ash	21	60	1.5	6
9	Ash	12	60	1.5	9
10	Larch	30	60	1.5	6
11	Larch	21	60	1.5	6
12	Larch	12	60	1.5	9
13	Pine	30	60	1.5	6
14	Pine	21	60	1.5	6
15	Pine	12	60	1.5	9
16	Spruce	30	60	1.5	6
17	Spruce	21	60	1.5	6
18	Spruce	12	60	1.5	9

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

Total number of studied samples was 126 pieces. Yasniy *et al*. (2022); Dvorkin *et al*. (2021); Reiterer *et al*. (2002) performed the testing of wood samples and composite materials under the rigid regime of application with the single short-term load on a universal modern servo-hydraulic test machine STM-100 (Fig. 3). Such machine was used in this experimental study. The deformation rate for all investigated prisms was 1.5 mm/min (Nilsson & Johansson, 2019; Huč *et al*., 2018; Zakic, 1974). The samples were tested by axial compression along the fibres untill their complete destruction (Rabko *et al*., 2021; Pysarenko, 1988; Gomon *et al*., 2022). Figure 4 shows the character of the destruction of the samples.

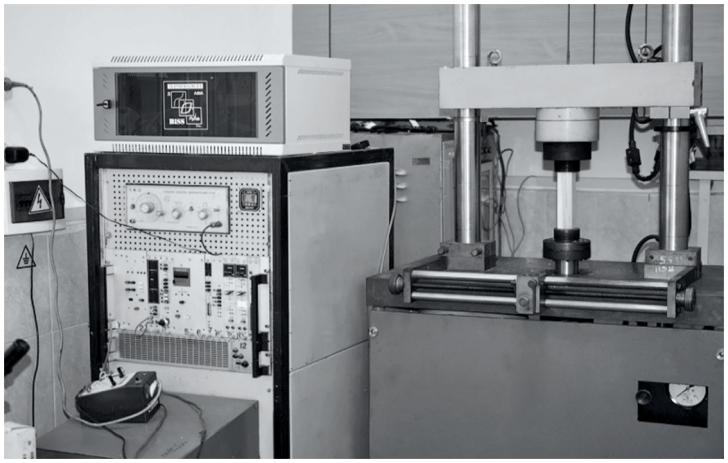


Figure 3. *Servo-hydraulic testing machine STM-100*

Figure 4. *Fracture of a pine wood sample at the moisture content of 21%*
Source: *compiled by the authors*

The given technique allows conducting out experimental studies of deformable properties at different moisture content levels with high accuracy of measurements.

RESULTS AND DISCUSSION

The average complete diagrams of hardwood and softwood fracture 'stress-strain' at moisture content of 30% (Fig. 5a, 6a), 21% (Fig. 5b, 6b) and 12% (Fig. 5c) were constructed based on the conducted experimental research.

The average relative critical deformations of wood (upper point of the diagrams) from the obtained diagrams (Fig. 5a, Fig. 5b, Fig. 5c, Fig. 6a, Fig. 6b, Fig. 6c) were determined. It corresponds to the maximum stresses. Therefore, the values of relative critical deformations uc,0,d,exp of all studied wood species were determined (Fig. 7).

It was found that deformable parameters were reduced by drying wood from 30 to 12%. The dynamics of changes the relative critical deformations were as follows (Fig. 7): for birch prisms it decreased by 19%, alder – by 21%, ash – by 16%; larch – by 18%; pine – by 19%; spruce – by 22%.

Yasniy *et al*. (2022) found that the determination of relative critical deformations of hardwood and softwood uc,0,d at different moisture levels corresponds to the maximum stresses fc,0,d of this material under short-term axial compression loading along the fibres. Such results were obtained in this experimental study and are shown in Figure 8.

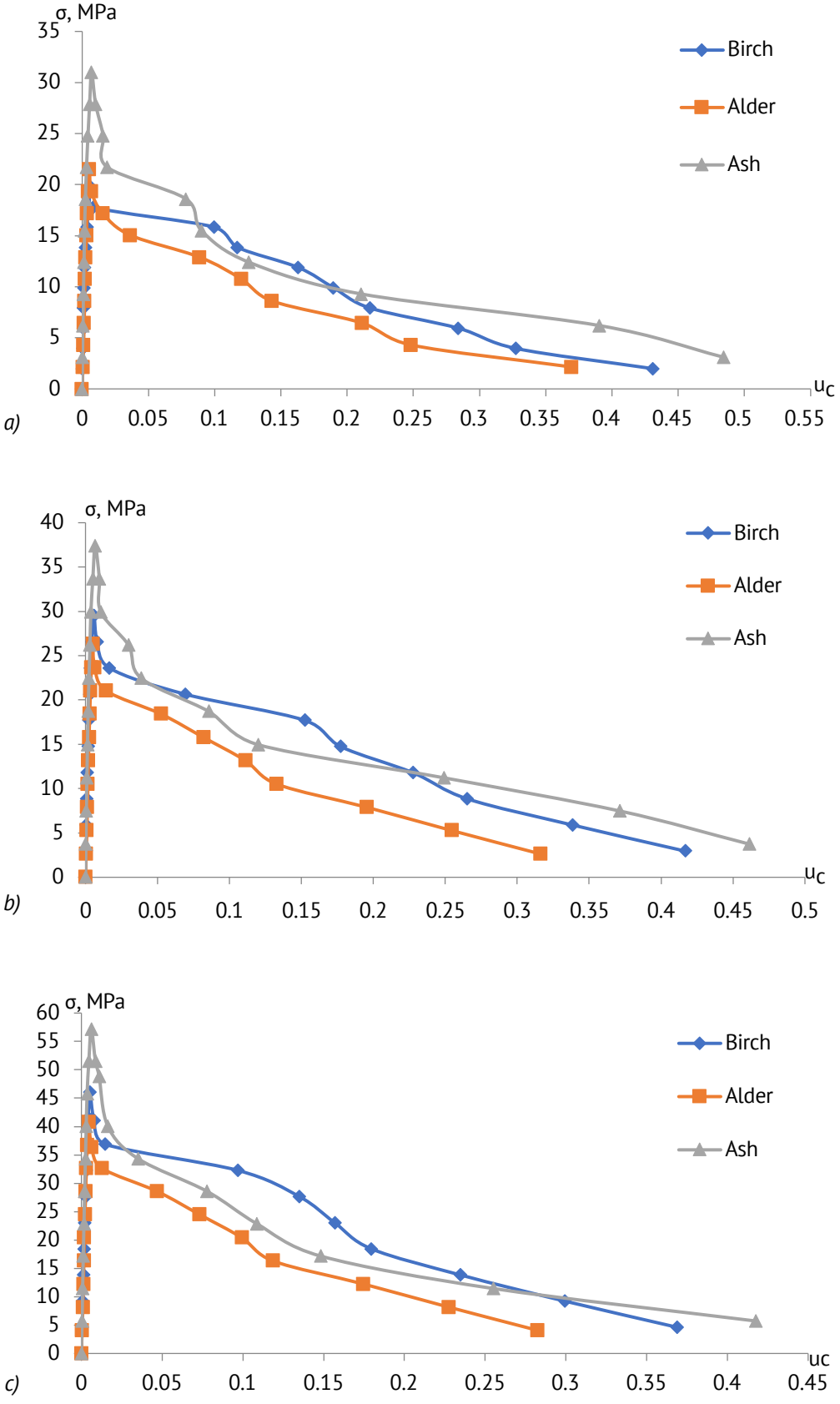


Figure 5. *Complete diagrams of deformation of 60-years-old aged solid hardwood at moisture content: a) 30%; b) 21%; c) 12%*

Source: *compiled by the authors*

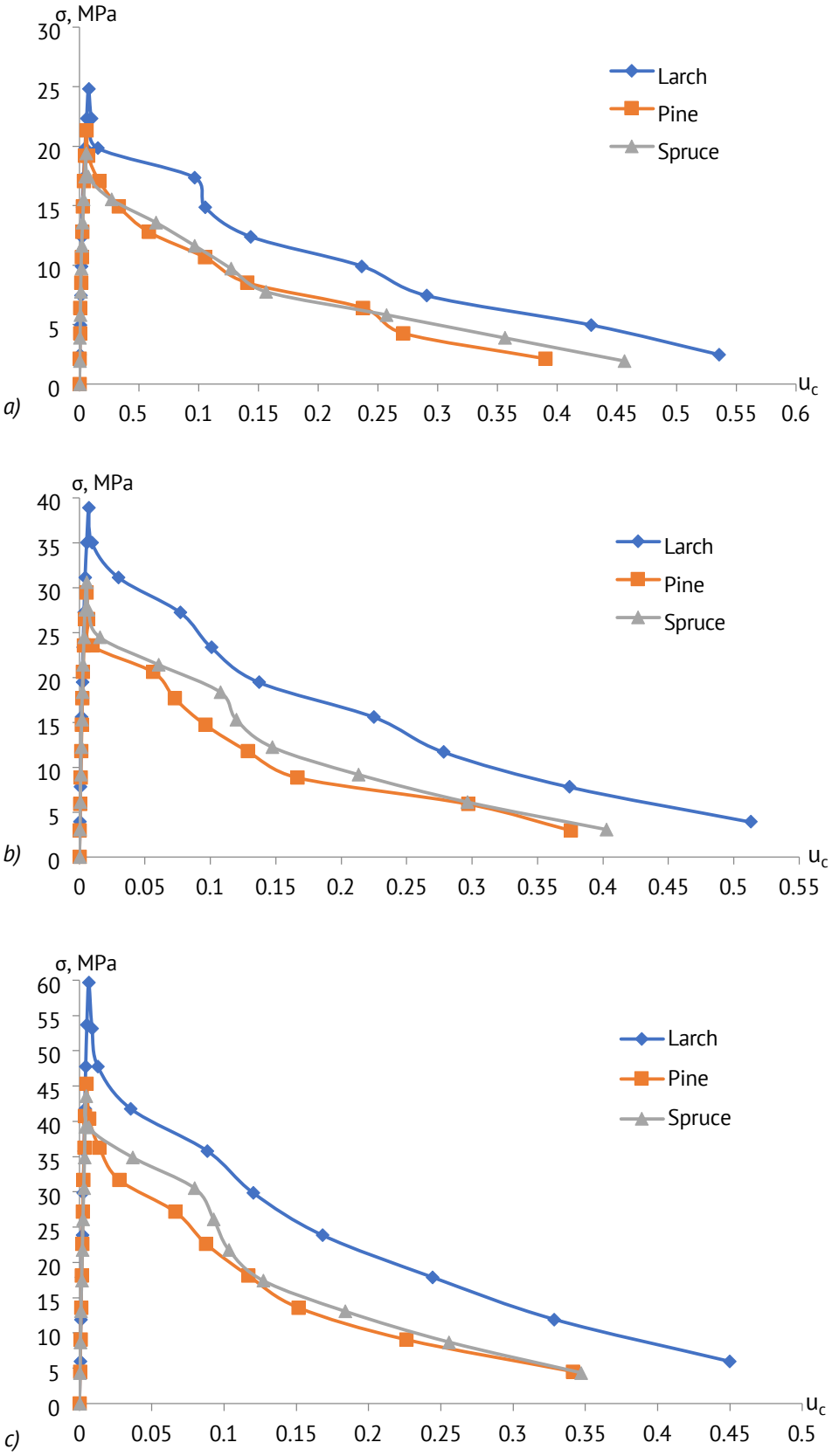
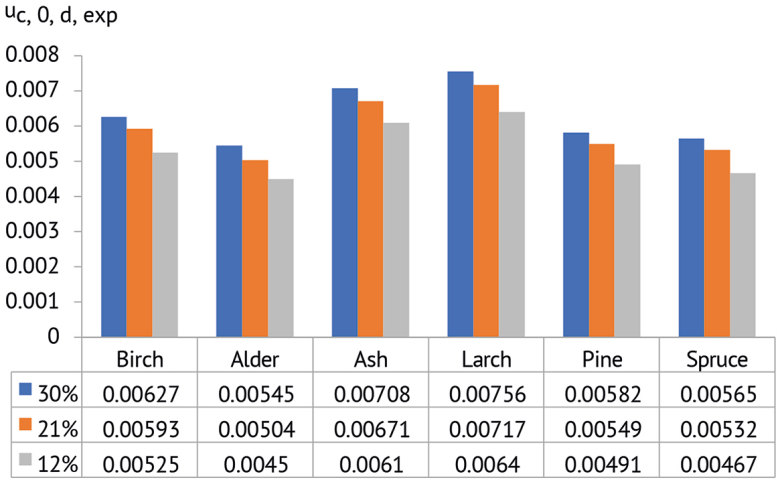


Figure 6. *Complete diagrams of deformation of 60-years-old aged softwood at moisture content: a) 0%; b) 21%; c) 12% (obtained from our experimental study by S. Homon et al.)*

Source: *compiled by the authors*



	Birch	Alder	Ash	Larch	Pine	Spruce
30%	0.00627	0.00545	0.00708	0.00756	0.00582	0.00565
21%	0.00593	0.00504	0.00671	0.00717	0.00549	0.00532
12%	0.00525	0.0045	0.0061	0.0064	0.00491	0.00467

***Figure 7**. Dynamics of changes the experimental relative critical deformations of hardwood and softwood at various moisture content (obtained from experimental study by S. Homon et al.)*
***Source:** compiled by the authors*

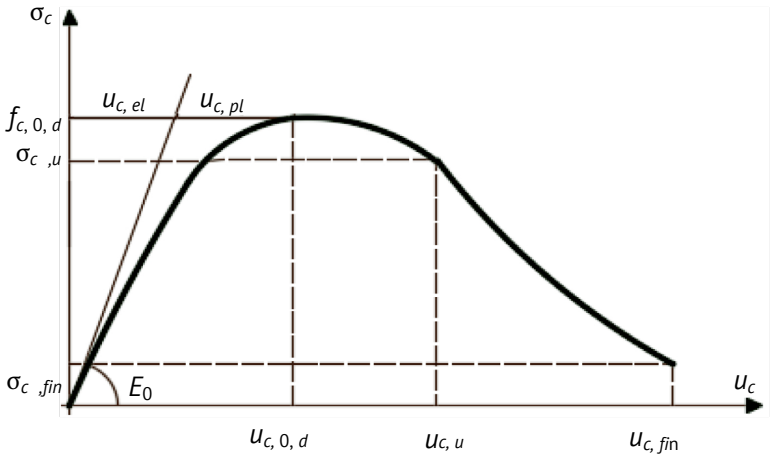


***Figure 8**. Complete diagram of deformation*
***Note:** 'stress σ_c – deformation u_c' of wood by axial compression along the fibres where: σ_c – stress of wood by axial compression along the fibres; u_c – relative deformations of wood by axial compression along the fibres; $f_{c,0,d}$ – maximum wood stresses; $u_{c,0,d}$ – relative critical deformations of wood corresponding to maximum stresses; $u_{c,el}$ – elastic component of relative critical deformations; $u_{c,pl}$ – plastic component of relative critical deformations; $u_{c,u}$ – relative limit deformations of wood; $\sigma_{c,u}$ – stresses corresponding to the limit deformations; $u_{c,fin}$ – relative residual deformations of wood; $\sigma_{c,u}$ – stresses corresponding to the relative residual deformations of wood; E_0 – initial modulus of elasticity of wood*
***Source:** compiled by the authors*

Zhou *et al.* (2018); Da Silva *et al.* (2007); Varenik *et al.* (2019) used a model of the complete deformation diagram 'stress σ_c – deformation u_c' for wood operation at standard moisture of 12%. Yasniy *et al.* (2022) modified this model. Moreover, complete deformation diagram 'stress σ_c – deformation uc' was obtained in this study (Fig. 8).

Then critical theoretical deformations were determined. The relative critical deformations were proposed to be determined by equation (1), distinguishing between elastic and plastic components

$$u_{c,0,d}=u_{c,el}+u_{c,pl}, \quad (1)$$

where $u_{c,el}$ – relative elastic deformation of solid wood; $u_{c,pl}$ – relative plastic deformation of solid wood.

By used experimental studies, equation (1) can be rewritten as

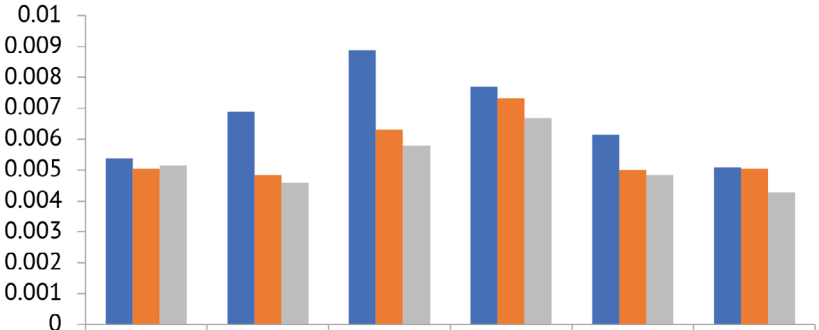
$$u_{c,0,d}=f_{c,0,d}/E_0+c_1 \cdot f^2_{c,0,d}, \quad (2)$$

where c_1 – coefficient which depends on the moisture and the age of solid wood.

The relative critical deformations of solid wood of all studied species were determined by equation (2) at a moisture content of 30, 21, and 12%, respectively (Fig. 9), and separately elastic (Fig. 10) and plastic

components (Fig. 11). The coefficient c_1 for any hardwood and softwood was: – 30% – c_1=8.70·10^{-6} (MPa)$^{-2}$;
– 21% – c_1=2.69·10^{-6} (MPa)$^{-2}$;
– 12% – c_1=6.55·10^{-6} (MPa)$^{-2}$;

The maximum wood stresses (ultimate strength) $f_{c,0,d}$ were set as in Fig. 5a, 5b, 5c, 6a, 6b, 6c (Table 2). Yasniy *et al.* (2022) determined the initial modulus of elasticity of wood E_0.



	Birch	Alder	Ash	Larch	Pine	Spruce
30%	0.00539	0.00689	0.00888	0.00769	0.00614	0.00509
21%	0.00505	0.00485	0.00631	0.00731	0.005	0.00505
12%	0.00514	0.00458	0.00579	0.00669	0.00485	0.00427

***Figure 9**. Dynamics of changes the plastic component of relative critical deformations of hardwood and softwood at various moisture content level determined by equation (2)*

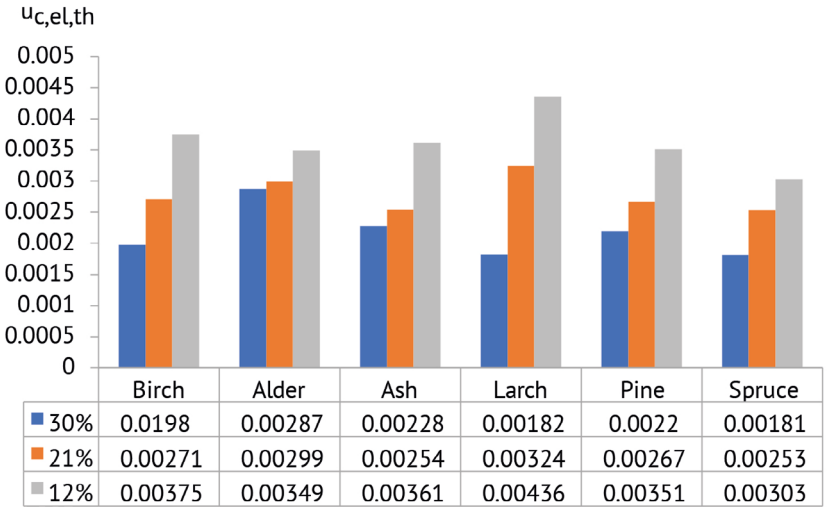
***Source:** compiled by the authors*

***Table 2**. Values of relative critical deformations of wood at different moisture content determined experimentally using equation (2) $u_{c,0,d,th}$*

No.	Wood species	$f_{c.0.d}$. MPa	E_0. MPa	$u_{c.0.d.exp}$	$u_{c.el.th}$	$u_{c.pl.th}$	$u_{c.0.d.th}$
			Moisture content 30 %				
1	Birch	19.8	10.000	0.00627	0.00198	0.00341	0.00539
2	Alder	21.5	7.500	0.00545	0.00287	0.00402	0.00689
3	Ash	31.0	13.600	0.00708	0.00228	0.00660	0.00888
4	Larch	24.8	10.600	0.00756	0.00182	0.00587	0.00769
5	Pine	21.3	9.700	0.00582	0.00220	0.00394	0.00614
6	Spruce	19.4	10.700	0.00565	0.00181	0.00328	0.00509
			Moisture content 21 %				
7	Birch	29.5	10.900	0.00593	0.00271	0.00234	0.00505
8	Alder	26.3	8.800	0.00504	0.00299	0.00186	0.00485
9	Ash	37.4	14.700	0.00671	0.00254	0.00377	0.00631
10	Larch	38.9	12.000	0.00717	0.00324	0.00407	0.00731
11	Pine	29.4	11.000	0.00549	0.00267	0.00233	0.00500
12	Spruce	30.6	12.100	0.00532	0.00253	0.00252	0.00505
			Moisture content 12 %				
13	Birch	46.1	12.300	0.00525	0.00375	0.00139	0.00514
14	Alder	40.8	11.700	0.00450	0.00349	0.00109	0.00458
15	Ash	57.7	16.000	0.00610	0.00361	0.00218	0.00579
16	Larch	59.7	13.700	0.00641	0.00436	0.00233	0.00669
17	Pine	45.3	12.900	0.00515	0.00351	0.00134	0.00485
18	Spruce	43.6	14.400	0.00467	0.00303	0.00124	0.00427

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

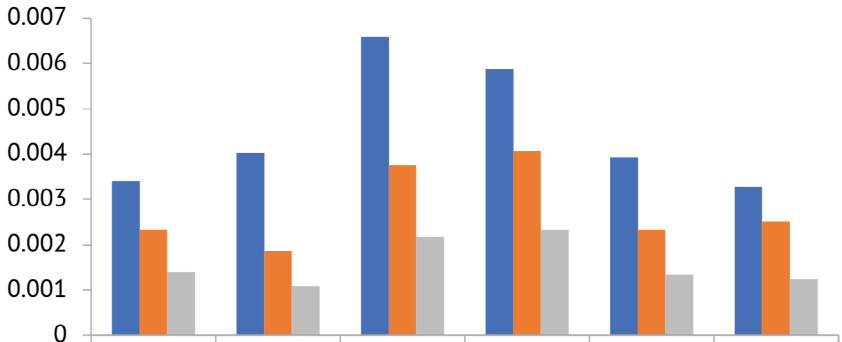
The critical deformations of solid wood of all studied species at the moisture content of 30 to 12% according to experimental studies is shown in Figure 9 and Table 2. This parameter was determined by equation (2). Results showed that critical deformations decreased only on a slightly different interval. Moreover, equation (2) determines the elastic and plastic components of critical relative deformations at different moisture content. According to it, values of these parameters presented in Figure 10 and Figure 11 were obtained.



	Birch	Alder	Ash	Larch	Pine	Spruce
30%	0.0198	0.00287	0.00228	0.00182	0.0022	0.00181
21%	0.00271	0.00299	0.00254	0.00324	0.00267	0.00253
12%	0.00375	0.00349	0.00361	0.00436	0.00351	0.00303

Figure 10. *Dynamics of changes the elastic component of relative critical deformations of hardwood and softwood at various moisture content level determined by equation (2)*

Source: *compiled by the authors*



	Birch	Alder	Ash	Larch	Pine	Spruce
30%	0.00341	0.00402	0.0066	0.00587	0.00394	0.00328
21%	0.00234	0.00186	0.00377	0.00407	0.00233	0.00252
12%	0.00139	0.00109	0.00218	0.00233	0.00134	0.00124

Figure 11. *Dynamics of changes the plastic component of relative critical deformations of hardwood and softwood at various moisture content level determined by equation (2)*

Source: *compiled by the authors*

The elastic component of relative critical deformations increases during decreasing moisture, and plastic one – vice versa, according to Figure 10, Figure 11, and Table 2. At the moisture content of 21%, they are very close in value.

Therefore, a methodology for determining critical deformations of wood with different moisture content, which includes elastic and plastic components, was proposed. It gives a good convergence with the experimental values (Table 2). Deviation of experimental values of critical deformations with theoretical ones according to the equation (3) for solid hardwood and softwood at moisture 30% is shown in Figure 12a and at moisture 21% is shown in Figure 12b.

Deviation of experimental values of critical deformations with calculated by equation (4) values for the same experiment data is shown in Figure 13.

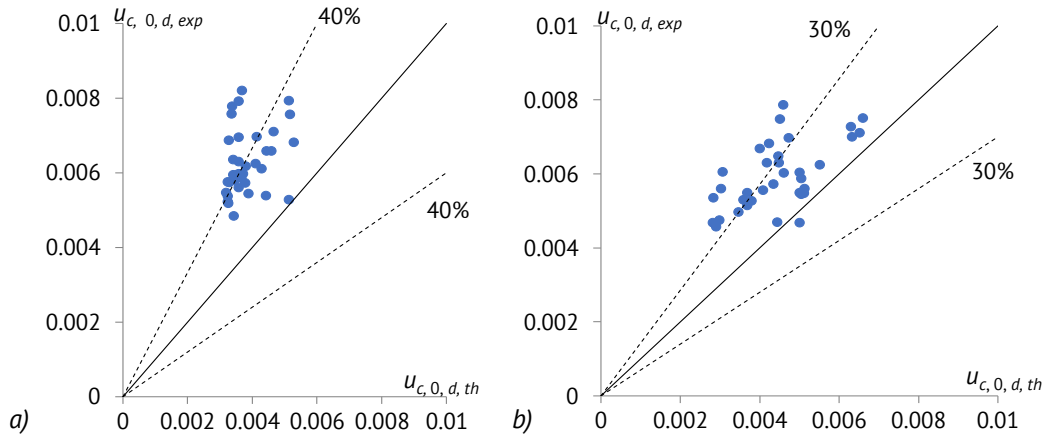


Figure 12. *Deviation of experimental values of critical deformations with theoretical ones according to the equation (3) for solid hardwood and softwood at moisture content: a) 30%; b) 21%*

Source: *compiled by the authors*

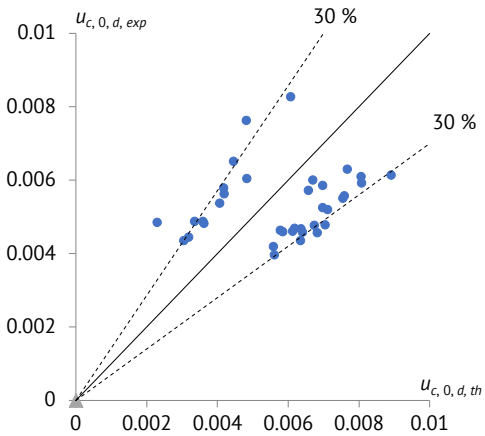


Figure 13. *Deviation of experimental values of critical deformations with theoretical ones according to the equation (4) for solid hardwood and softwood at moisture content of 21%*

Source: *compiled by the authors*

The convergence of experimental and theoretical relative critical deformations determined by equation (2), respectively, at the moisture of 30% is shown in Figure 14a and at the moisture of 21% – in Figure 14b. Convergence of results is achieved within 20%. Yasniy *et al.* (2022) obtained the results at standard moisture content.

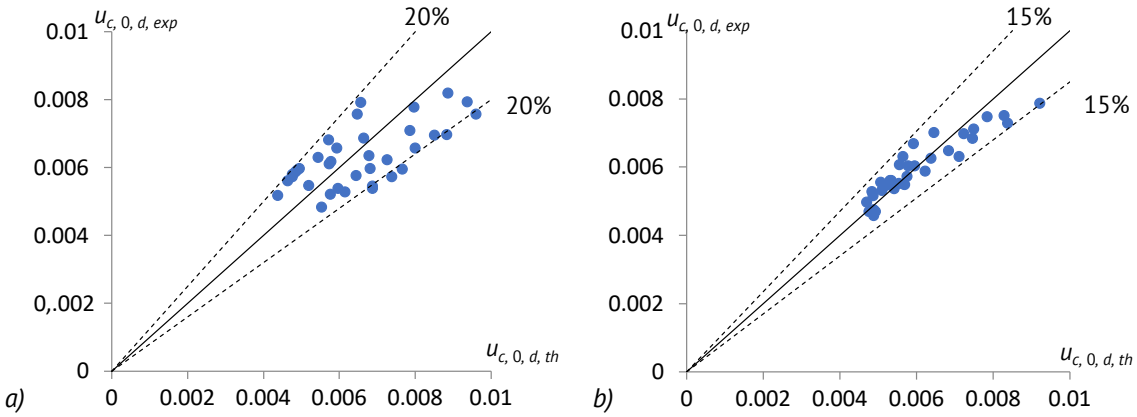


Figure 14. *Deviation of experimental values of critical deformations with theoretical ones according to the equation (2) for solid hardwood and softwood at moisture content: a) 30%; b) 21%*

Source: *compiled by the authors*

The calculation of critical deformation values for solid hardwood and softwood at 30% moisture content using equation (3) shows that it is almost 40%. But such the deviation with equation (2) that is proposed in this study is less than 20%. In addition, there is a huge range of deviation experimental values with theoretical obtained by equations (3) and (4) for some separate experiments that can be almost 50% and to be closed to experiment value with deviation less than 5%. Almost the same results were obtained for study wood at moisture content of 21%. Deviation of experimental values of critical deformations with obtained by equations (3) and (4) are still almost 30%, and using equation (2) – less than 15%. Therefore, the obtained theoretical equation (2) provides more accuracy of calculation of the critical deformations compared to equation (3) or equation (4).

Popescu *et al*. (2003) proposed the methodology for determining the critical deformations of wood of different moisture content. The researchers conducted experimental studies of pine wood with a section of 20x20x30 mm in axial compression along the fibres under various aggressive environments including water. The researchers obtained the results of the temporary ultimate strength and the initial modulus of elasticity of pine wood at different moisture levels. Popescu *et al*. (2003) proposed to describe the diagram "σ_c-u_c" (Fig. 8) by a second degree polynomial. The researchers also pointed out that this diagram had non-linear characteristic. A formula for determining the value of critical deformations of wood at different moisture levels was proposed based on their own experiments and numerous studies by other researchers:

$$u_{c,0,d} = \left(735.825 \cdot \sqrt{f_{c,0,d}} - 3.902\right) \cdot 10^{-6}. \quad (3)$$

The main drawback of the proposed formula is that it is empirical and is based on individual experimental studies. Another disadvantage is that experiments were carried out on outdated experimental facilities. Such experiments did not allow directly obtaining the critical deformations. Although the proposed equation (3) was the first formula that determined approximate value of critical deformations. Popescu *et al*. (2003) proposed a methodology for the calculation of compressed wooden elements and structures influenced by the aggressive environment based on the findings of the study. Such methodology considers the nonlinearity of the material.

Eurocode 5 (2004) also provides a methodology for determining critical deformations of wood at different moisture levels. It is based on the analysis of experimental studies of the temporary ultimate strength of wood at a standard moisture content of 12% for compression along the fibres. Critical deformations at different moisture content are determined by the coefficient K_{def}:

$$u_{c,0,d} = \frac{f_{c,0,d}}{E_0 \cdot K_{def}} \quad (4)$$

where K_{def} – coefficient of deformations that can be determined according to Eurocode 5. (2004)

This coefficient depends on the operating class of the environment. According to Eurocode 5 (2004) it can be applied to elements, materials and, constructors that have moisture content between 10 and 24%

The disadvantage of this method is that it considers only the elastic properties of wood and does not include the plastic ones. Thus, wood works according to the linear law of distribution. But this does not correspond to reality because wood at high moisture has quite significant value of plasticity. This is confirmed by the findings of this study. Another drawback is that critical deformations cannot be determined at a moisture content of more than 24%. Wood can be used only inside buildings.

S. Vasic & S. Stanzl-Tschegg, (2007) carried out experimental study with moisture content higher than 12%. The researchers constructed complete wood deformation diagrams "σ_c-u_c". The researchers showed a change in the structure as results of changing moisture content. The authors experimentally determined the critical deformations and other important mechanical characteristics of beech, oak, spruce, and pine wood at different moisture levels. The theoretical methodology of studying deformable parameters at different moisture content levels was not provided in the paper. The researchers determined only the values of the total relative deformations, but not the elastic and plastic components separately.

Varenik *et al*. (2019) proposed a methodology for determining the critical deformations of wood at different moisture content. The researchers conducted experimental studies on pine wood with a section of 30x30x120 mm by compression along the fibres under a strict test regime. Critical deformations of pine were determined experimentally. The authors also proposed to describe the "σ_c-u_c" diagram (Fig. 8) as a third degree polynomial. Moreover, they pointed out that wood works non-linearly at different moisture content levels. Critical deformations can be determined from the polynomial dependence describing the "σ_c-u_c" diagram (Fig. 8) by using the polynomial at maximum stresses coefficients. This methodology is quite complicated, because it is quite difficult to determine the coefficients of the polynomial. The study considered only pine wood. Thus, it is not clear if such methodology could be successful for another wood species.

The advantages of the proposed methodology over another analysed methodologies are the following: 1) allows determining elastic and plastic components, which is not observed in other methodologies; 2) works at moisture content from 12 to 30%; 3) critical deformations can be determined for any wood species; 4) allows determining the elastic and plastic components separately; 5) it is non-empirical and easy to calculate; 6) describes wood by a nonlinear characteristic.

CONCLUSIONS

New experimental data was obtained from the study of critical deformations of deciduous (birch, alder, ash) and coniferous (larch, pine, spruce) wood species by axial compression along the fibres. Based on it, the method of determination of relative critical deformations of solid hardwood and softwood at various moisture content levels by axial compression along fibres of bridge structures and bridge crossings was developed. The formula for determining the relative critical deformations of solid hardwood and softwood with various moisture content, which includes elastic and plastic components, was proposed.

It was found that value obtained by proposed formula had good correlation with the experimental values. The dynamics of change of critical relative deformations at different moisture content, and its components – elastic and plastic, were obtained. It was determined that drying of wood from 30 to 12% reduced its deformability: for birch prisms decreases by 1.19 times, alder – by 1.21 times, ash – by 1.16 times, larch by 1.18 times, pine – by 1.19 times, spruce – by 1.22 times. It was revealed that the plastic component of relative critical deformations decreases when drying wood from 30 to 12%, and elastic, on the contrary, increases.

It is necessary to develop methods for determination of relative limit deformations $u_{c,u}$ and relative residual deformations $u_{c,fin}$ considering the value of moisture content by axial compression along the fibres in further studies. Moreover, based on obtained experimental and theoretical data on critical deformations, a methodology for calculating wooden elements and structures that are operated under the influence of a water environment of varying intensity should be developed (elements and structures of bridges, overpasses, hydrotechnical structures, dams, structures of the mining industry and others).

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CONFLICT OF INTEREST

None.

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Методика визначення критичних деформацій деревини за різної вологості

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Анотація. Під час реконструкції та будівництва мостів слід враховувати можливість настання періодів паводків. Для цього необхідно розуміти ступінь можливих деформацій дерев'яних конструкцій, враховувати межу їх пластичності та пружності при різних значеннях вологості. Отже, метою статті є пошук методу визначення відносних критичних деформацій деревини за різного рівня вологості та аналіз динаміки їх зміни. В статті застосовувались методи дослідження проблем деформованого твердого тіла шляхом аналізу моделі повної діаграми деформування «напруження σ_c – деформація u_c», методи математичної статистики та системного аналізу експериментальних результатів. Проведені в роботі дослідження дозволили сформулювати методику визначення відносних критичних деформацій деревини листяних та хвойних порід при різному зволоженні шляхом осьового стиснення вздовж волокон експериментальних зразків. З урахуванням результатів експерименту запропоновано формулу для визначення відносних критичних деформацій суцільної деревини різної вологості. Було наведено динаміку зміни критичних відносних деформацій за різної вологості, а також її пружної та пластичної складових. З'ясовано, що запропонована формула дає хорошу збіжність з експериментальними значеннями. Встановлено, що пластична складова відносних критичних деформацій зменшується при висушуванні деревини від 30 до 12 %, а пружна, навпаки, збільшується. Результати досліджень можуть бути використані в деформаційній методиці розрахунку дерев'яних елементів і конструкцій мостів, гідротехнічних споруд, будівель з урахуванням зміни вологості матеріалу

Ключові слова: вміст вологи; діаграма «напруження-деформація»; стиснення вздовж волокон; модуль пружності; межа міцності

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Methodological foundations of information support for decision-making in the field of food, environmental, and socio-economic components of national security

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Abstract. The negative impact of strategic threats to the development of the state in the context of the development of its national security, in particular food, environmental, and socio-economic components, has intensified in the context of Ukraine's geopolitical challenges. This issue has become particularly acute as a result of open military aggression, which makes it necessary to develop and implement a system of information support for decision-making in the field of national security of Ukraine. Therefore, the purpose of the study is to substantiate methodological foundations of information support of decision-making in the field of national security of Ukraine and their implementation within the framework of the created system, which provides for the collection of information, in particular, using space and geographic information systems, and the use of mathematical modelling and situational analysis methods for data processing. In the course of the research, methods of econometric modelling, structural and functional modelling, and spatial analysis were used. A methodological framework has been developed for decision-making support to address the problems of food, environmental, and socio-economic components of national security. A functional model and algorithm of the decision-making

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process in the field of national security are constructed and, based on the results obtained, a decision-making system in the field of food, environmental, and socio-economic security is developed. In addition, the study formalises the conceptual provisions of the decision-making support process in the field of national security; a procedure for modelling the country's food security indicators is proposed. Based on the proposed methodological approach, it was determined how much the area of crops decreased due to the temporary occupation and military operations, and the post-war state of fields (minelaying, destruction of crops, equipment, etc.), which allowed forming input data for further projecting of indicators of the development of the agricultural sector and food security in Ukraine, the EU, and the world. The proposed methodological provisions, algorithms, models, and the developed system can be used by state authorities to make managerial decisions on the development of policy in the areas of ensuring food, environmental, and socio-economic security of the country

Keywords: information support; functional modelling; econometric model; information system; management solution; remote sensing of the Earth

INTRODUCTION

Modern threats to the sustainable development of Ukraine, which negatively affect the level of national security, are associated, in particular, with the deformation of the structure of the economy both in terms of optimal criteria for self-sufficiency and foreign economic specialisation, as well as with scientific and technological, social, and environmental positions; with the fact that the proposed world-class scientific results do not find application in the economy due to the low susceptibility of the business sector to innovation; low technical and technological level of production; the development of environmentally hazardous industries; the growth of negative impact on the environmental situation and public health of processes related to waste management; the outflow of qualified personnel; ageing and deterioration of the state public health, etc. The negative impact of these threats has intensified in the context of modern challenges to the national security of Ukraine as a result of the open aggression of the russian federation.

Most of the research papers that deal with decision-making processes in the field of ensuring national security are devoted to the organisational features of this process and the development of national security policies both in general and in individual countries (Bearne, 2005; Freilich, 2006). A separate issue in the context of studying the decision-making process is its information support, since the development of an effective solution is based on timely access to accurate adequate input information. According to the practical experience of some developed countries, specially created and authorised institutions, whose activities are clearly declared, are responsible for information support of the decision-making process in the field of national security (Routray, 2013; Heazle, 2010). According to S. Freilich (2006), one of the problems of the decision-making process in the field of national security in Israel was the need for decision-making actors to rely on their own experience, intuition, and recommendations of other, often interested, individuals. At the same time, since the 2000s, Israel has been actively developing the field of military and political planning (Freilich, 2006), which contributes to improving the effectiveness of policy-making.

But to substantiate specific actions and policies in the agricultural sector, scenario projections are built that take into account potential changes in factors through the adoption and implementation of relevant political decisions. It is this methodological approach that has proven its effectiveness in the process of developing the agricultural policy of EU countries and identifying threats in the medium term. In particular, R. Jongeneel and A.R. Gonzalez-Martinez (2022) investigated the impact of the abolition of the EU milk quota system on the development of the dairy industry. The studies by M. Haß (2022) and Mathenge *et al.* (2022) examine whether coupled support for sugar beet in the European Union would lead to market distortions. An important role in decision-making in the field of ensuring food security in the country is played by the development of scenario projections, considering potential threats to the development of the agricultural sector. In particular, R. Jongeneel *et al.* (2020) created a projection for the development of pig breeding in the EU, considering the potential impacts of the spread of African swine fever. Projections developed by O. Nykolyuk *et al.* (2021) and Gorbilin (2021) demonstrate potential changes in key indicators of the agricultural sector of Ukraine due to the consequences of the introduction of quarantine measures after the start of the COVID-19 pandemic.

Among the alternative types of data that are actively used in decision-making in the field of food, socio-economic, and environmental safety, there is spatial data that is accumulated and processed based on geographic information systems (GIS). According to the study by M. Mathenge *et al.* (2022), GIS-based data analysis methods can be used to make policy decisions in the area of sustainable agricultural development. The researchers note the lack of spatial data necessary for the development and implementation of agricultural policy. L. Beni *et al.* (2011) offer an information product that provides for the integration of ArcGis and Arena systems, for the purpose of modelling and monitoring the

spread of contamination in a food distribution network and information support for operational decision-making in the field of food quality control as one of the key elements of food security. Similar are the conclusions of E. Vandecandelaere *et al*. (2018), which prove the absolute importance of GIS for ensuring the development of sustainable food systems, considering the territorial characteristics of countries and their individual regions.

As for the field of ecology, K.T. Nemec and C. Raudsepp-Hearne (2012) suggest using GIS to evaluate the effectiveness of ecosystem services, which should be considered in the management decision-making process in ecology, and also provide a comparative analysis of existing software products. Lant *et al*. (2012) use GIS to model the effectiveness of policies that affect agricultural watersheds (Lant, 2005). The use of GIS in the process of land use regulation in the context of combating problems of environmental safety of land (in particular, soil degradation and erosion, land pollution) is reflected by (Xie, 2022). Integrated GIS and remote sensing work successfully for mapping nature reserve sites, especially fire area and scale analysis, fire research (Skydan, 2021; Fedoniuk, 2022), tracking the spread from multiple plant and animal individuals to species, ecosystems, landscapes, and identifying factors that contribute to local and global biodiversity changes, the spread of invasive species, etc. (Fedoniuk, 2022; Orlov, 2021).

The purpose of this study is to substantiate methodological aspects of information support for decision-making in the field of national security, which will involve the use of data from a wide range of information sources and the use of formalised methods and models.

MATERIALS AND METHODS

The experiment on information support for decision-making in the field of food security was conducted on the example of accumulating data on the acreage of agricultural crops, taking into account the impact of military operations on the territory of Ukraine. After the full-scale invasion of the russian federation, Ukraine was faced with the task of assessing the potential negative effects on food security at the regional, European, and global levels. The key problem was that a significant part of the country's agricultural land was under temporary occupation as of the beginning of the sowing campaign in 2022 and it was impossible to grow crops on the corresponding areas. As of March-April 2022, it was impossible to estimate potential crop losses in such areas using conventional methods and based on statistical data. In addition, a number of grain storage facilities are located in the temporarily occupied territories, where reserves should be defined as losses of the country's strategic food reserves.

Considering the above, the task was set to project the potential volume of gross harvest and export of strategic export-oriented agricultural crops in war conditions. Such crops primarily include wheat, corn, and oilseeds. The main task that was carried out in the course of the study since the beginning of the war was to develop a methodology for estimating the area of agricultural land in the temporarily occupied territories, in order to further projecting the potential volume of gross harvest and export of strategic export-oriented agricultural crops the production and export of agricultural crops, sunflower and other types of oils based on the AGMEMOD model (Salamon *et al.*, 2019). According to the developed methodology, it is determined how much the area of crops has decreased due to temporary occupation, military operations, and the post-war state of fields (minelaying, destruction of crops, equipment, etc.).

According to the proposed methodology for generating input data for further projecting indicators of the development of the agricultural sector and food security in Ukraine, the EU, and the world, satellite survey data processing is provided, which included the following stages:

1. Determination of the range of temporarily occupied territories, which was carried out based on information from the Centre for Environmental Initiatives "Ecoaction" (Almost, 2022).

2. Calculation of the area of agricultural land based on geodata obtained in 2019 using the TERRA and AQUA spacecraft using the Moderate Resolution Imaging Spectroradiometer (MODIS). Geoinformation is presented in the form of 17 classified types of land cover in Ukraine.

3. Selection from a classified image of an area located within the temporarily occupied territory of Ukraine.

4. Calculation of the geodetic area of plots whose class corresponds to agricultural land (Table 1). As a result of this operation in ArcGIS PRO, it was determined that the area of agricultural land within the temporarily occupied territories as of March 22, 2022, amounted to 33% of the area before the start of hostilities, or 12.8 million hectares.

5. To clarify the available food volumes of crop production stocks (primarily wheat, corn, and sunflower seeds), the task was set to determine possible grain losses due to temporary occupation and military operations in the territories where grain storage facilities are located.

Table 1. *Share of temporarily occupied territories of Ukraine (as of March 2022)*

Surface classes in Ukraine	Area. thous. ha	Temporarily occupied territories	%
Evergreen coniferous forests	716	256	36
Deciduous coniferous forests	2	0	23
Deciduous broad-leaved forests	2.684	448	17

Table 1, Continued

Surface classes in Ukraine	Area. thous. ha	Temporarily occupied territories	%
Mixed forests	2.668	727	27
Closed shrubs	0.04	0.02	60
Woody shrubs	2.395	814	34
Open woodlands	3.882	1.534	40
Pastures	4.730	2.793	59
Permanent wetlands	255	84	33
Agricultural land (cultivated)	39.056	12.749	33
Urban and built-up land	1.093	420	38
Seed plots / Natural plant mosaics	1.435	351	24
Barren lands	17	14	81
Water bodies	1.168	486	42
Total	60.101	20.677	34

Source: *authors' own research*

Geospatial data obtained according to the algorithm described above (Skydan, 2022) is used to calculate such areas:

1. Defining a range of temporarily occupied territories (Almost, 2022).
2. Collecting data on the location, characteristics, and occupancy rate of grain storage facilities.
3. Conducting a geolocation procedure for the data obtained above, to determine the geographical coordinates of grain storage facilities.
4. Identifying grain storage facilities located in the temporarily occupied territories and calculating the amount of stocks stored in them.

RESULTS

Use of GIS in assessing food security indicators. Food security, as an element of a country's national security, is based on the ability to meet domestic demand for food through current production and existing stocks. Consequently, the accumulation of data on the available volume of agricultural and processed products is of primary importance for an adequate assessment of food security. Based on the results of geospatial analysis conducted in accordance with the above methodology, the locations of grain storage facilities located in the temporarily occupied territories as of March 2022 were determined and the reserves stored in them were calculated (Table 2). Considering the riskiness of approaching the front line, a buffer zone of 50 km was built, where 17.5% of grain reserves or 3.86 million tonnes are concentrated (Fig. 1).

The information obtained is used as input data entered into the database and used for modelling food security.

Table 2*. Share of product stocks in grain storage facilities of Ukraine located in the temporarily occupied territories*

Indicator	thousand tonnes	%
Temporarily occupied territory	5.140	23.29
50 km buffer zone	3.859	17.49
Balance in Ukraine	13.068	59.22
Total	22.068	100.00

Source: *authors' own research*

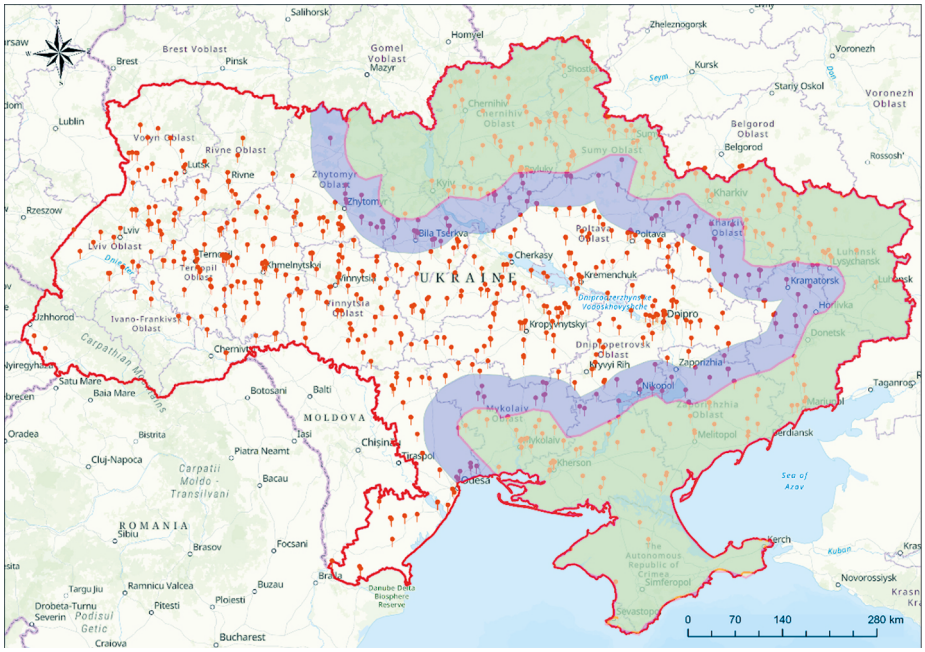

***Figure 1**. Grain storage facilities of Ukraine located in the temporarily occupied territories; * grey – temporarily occupied territories, blue – 50 km buffer zone (as of March 22, 2022)*

***Source:** authors' own research*

Functional modelling of the process of information support for decision-making in the field of food, environmental, and socio-economic security. The definition of methodological aspects of the decision-making support system (DMSS) in the process of developing national security should be based on the logic of business processes that are components of management activities. These business processes include the formation of data sets, the creation of products and/or the substantiation of a set of alternative solutions to problems in this area, and the collection and processing of data based on algorithms and techniques developed for specific types of requests within the framework of national security issues. In general, these business processes are a providing component of the decision-making process in the relevant area, which is responsible for the generation of input information necessary for the decision-makers (Fig. 2).

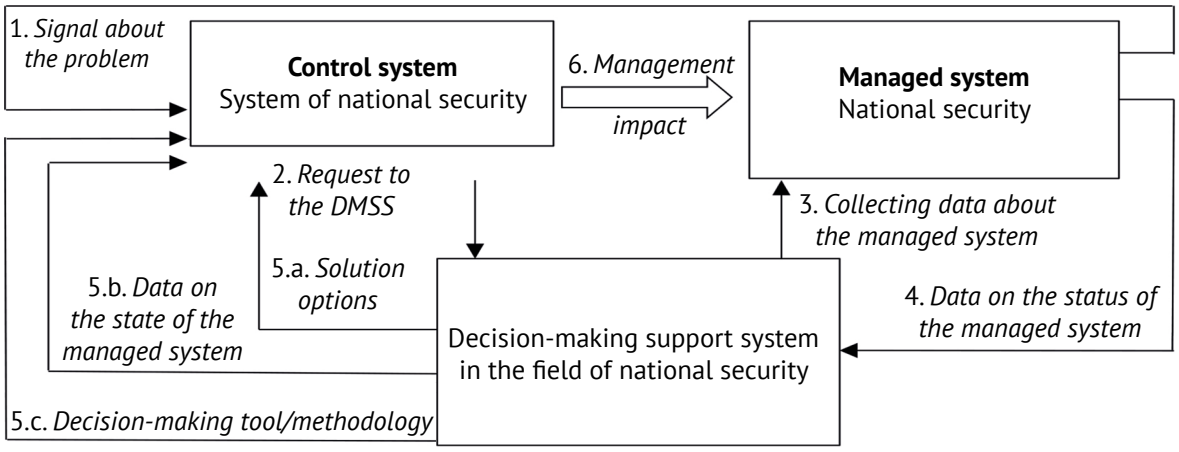

***Figure 2**. National security decision-making scheme*

***Source:** authors' own research*

The main functions that are performed within the framework of information support for decision-making in the field of national security include information collection (including substantiation of optimal sources, frequency of data collection, time interval, qualitative characteristics of data, etc.), processing the received data, creating a finished product or substantiating solutions to the problem (if necessary), transmitting a response to a request (Fig. 3).

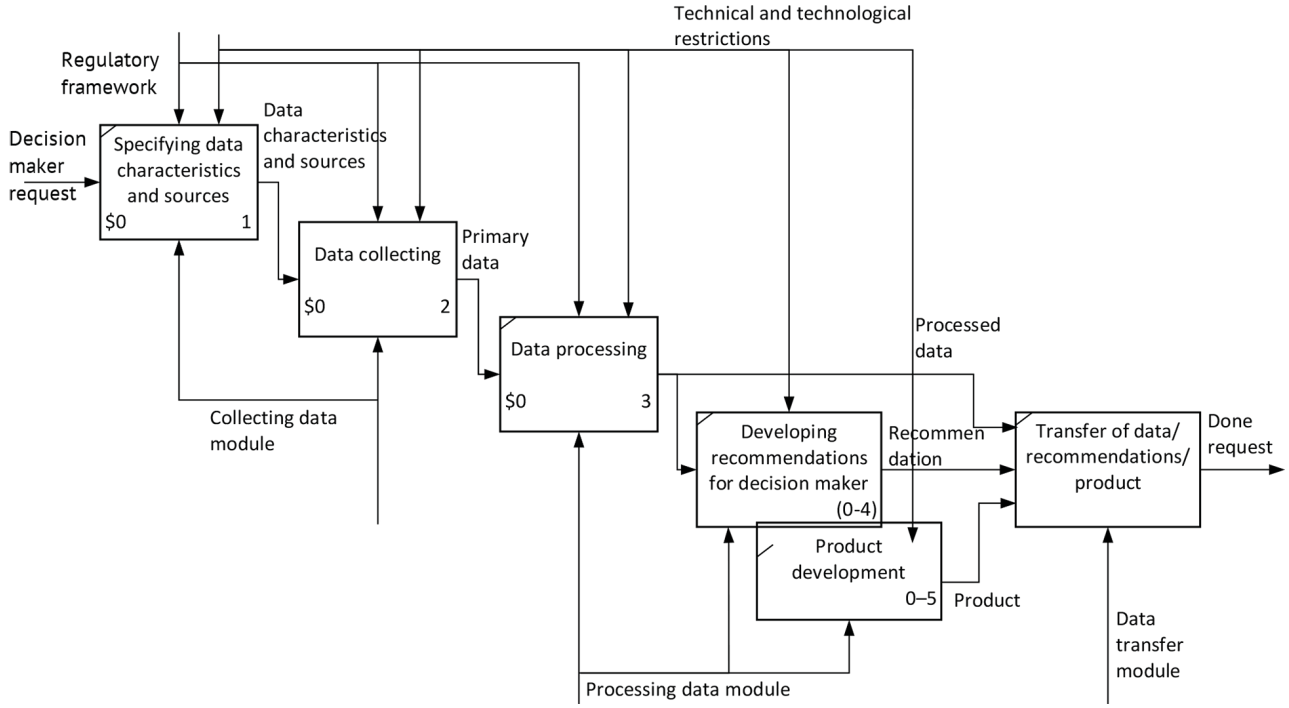

***Figure 3**. Functional model of the national security decision-making support system*
***Source:** authors' own research*

Requests for information required for decision-making involve the collection and processing of data necessary for solving a number of tasks within the framework of the establishment of food, socio-economic, and environmental safety (Fig. 4).

Considering the hierarchy of the system of state regulation and the development of national security, decision-making is based on the collection and processing of data within objects of various levels, in particular, the state, regional, and community levels. In addition, Ukraine is an actor of global space and, accordingly, an element of global security. That is why decision-making in the field of national security involves processing requests not only at the state (national, regional, community level), but also at the continental level (for example, at the European and global levels).

Methodological basis for information support of the process decision-making in the field of food, environmental and socio-economic components of national security. The national security decision-making support process is based on the following conceptual provisions:

1) at each point in time, there are two states of the object of management (i.e., the national security of the country at different levels of the hierarchy), namely: current/projected at a specific point in time $C(t)$ and target C^p states. Quantitatively, the state of the object takes the form of values of indicators of the country's security. Purposeful management influence on the control object becomes necessary if its current/predicted and target states do not coincide:

$$C(t) \neq C^p. \quad (1)$$

Usually, the situation (1) in the context of national security management of a country is caused by a radical change in external and/or internal conditions, accompanied by the emergence of additional threats to the country's security;

2) determination of the target state of the control object is based on a set of indicators of w_i national security $W(w_1, w_2, w_3, \ldots, w_n, \ldots, w_N)$ within the framework of food, socio-economic, and environmental security. The decision-making process involves finding a solution that would ensure the transition of the control object from the current state to the target (optimal) one by optimising factors $X(x_1, x_2, x_3, \ldots, x_m, \ldots, x_M)$ affecting the level of national security:

$$W(w_1, w_2, w_3, \ldots, w_n, \ldots, w_N, x_1, x_2, x_3, \ldots, x_m, \ldots, x_M) \underset{x}{\rightarrow} \max; \quad (2)$$

3) there are many limitations that should be considered in the process of substantiating optimal solutions. One of the main types of restrictions is resource restrictions:

$$R(r_1, r_2, r_3, \ldots, r_l, \ldots, r_L, x_1, x_2, x_3, \ldots, x_m, \ldots, x_M). \quad (3)$$

Hence, at a specific point in time t in the event of a mismatch of the current/predicted state $C(t)$ target C^p, the object of national security management should be transferred to the state of C_k^p ($C_k^p \in C^p$), which is optimal for a given time point t, subject to current restrictions R_k:

$$<C(t), C^p, C_k^p, R_k>; \quad (4)$$

4) within the framework of the decision-making support process in the field of national security, there are four basic stages of solving the decision-making problem.

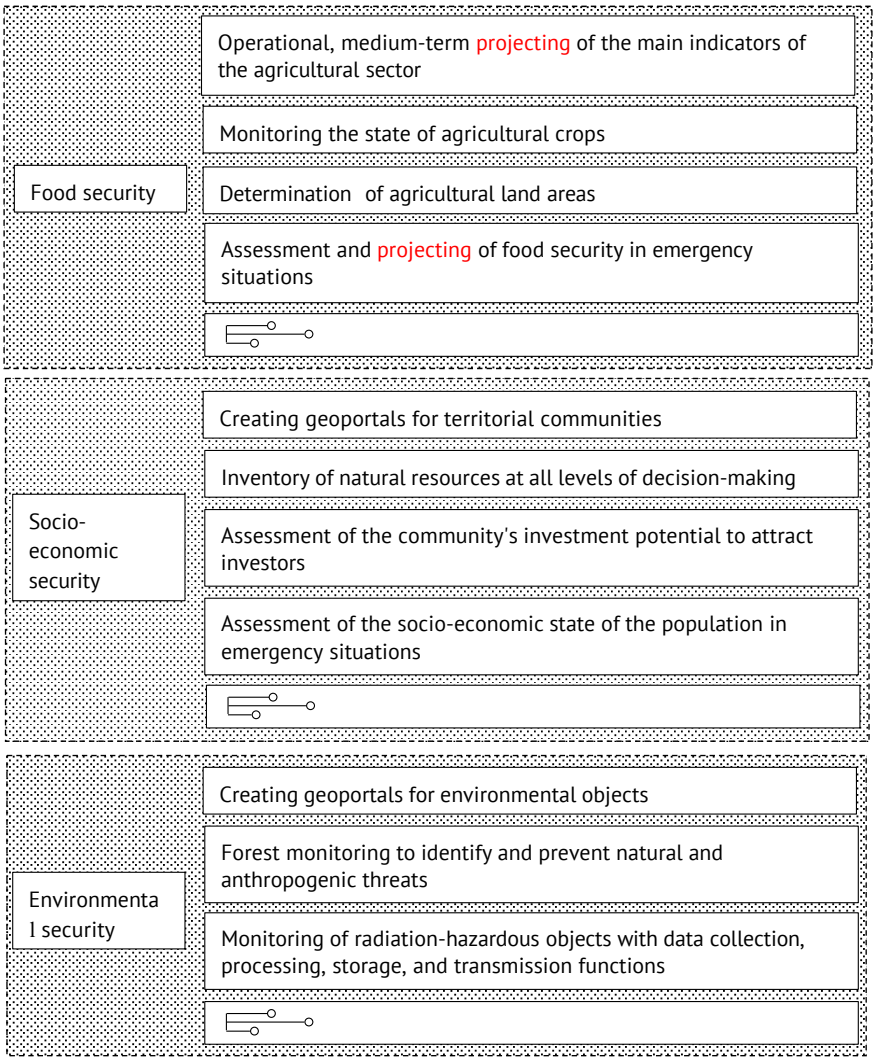

***Figure 4**. Functional model of the national security decision-making support system*
***Source:** authors' own research*

The first step is to identify the discrepancy between the current/predicted and target states of the control object. In other words, at this stage, it is necessary to compare the current/projected values of indicators of national security $W(w_1, w^2, w_3, \ldots, w_n, \ldots, w_N)$ with target users. In this case, the hypothesis $C(t) \subseteq C^p$ is tested.

The second stage involves determining the target state of the system C_k^p at a particular point in time t:

$$W_1(C_k^p)=\max W_1(C_i^p:\forall C_i^p \in C^p). \quad (5)$$

In a formalised form, the target state is displayed as an objective function (or a system of objective functions).

At the third stage, restrictions are defined $R_k \in R$, taking into account which measures will be taken to transfer the system from state $C(t)$ to state C_k^p:

$$W_2(R_k)=\max W_2(R_i:\forall R_i \in R). \quad (6)$$

At this stage, the system of restrictions is formalised.

The fourth stage involves determining the mechanisms for achieving the target state $M_k \in M$, the implementation of which would ensure the transition of the system from the current unsatisfactory state $C(t)$ to the target state C^p in the situation $<C(t), C^p, C_k^p, R_k>$:

$$W_3(M_k)=\max(M_i:\forall M_i \in M). \quad (7)$$

At the fifth stage, the subjects of decision-making substantiate and specify the methods, tools, and measures that need to be implemented to get out of the state of increased danger. In a formalised form, they take the form of values of unknown variables under previously defined objective functions and constraints.

Within the framework of information support for decision-making in the field of national security, first of all, tasks are solved within the first three stages. As for the fourth stage, it directly involves the decision-maker at the appropriate level of management.

The basis of the first stage of support for decision-making in the field of national security is the

collection of data for detection of discrepancies between the current/predicted and target states of the control object. To ensure that the input data is as complete and relevant as possible, it should be collected from a wide range of sources to ensure maximum accuracy of the output results and efficiency of decision-making. In the field of analytical data processing and decision-making at all levels of the hierarchy of food, socio-economic, and environmental spheres, it is advisable to use the following data:

– *statistical information*. The advantage of using statistical data is a stable frequency of collection, a significant number of indicators, and data collection both at the state and regional levels, which allows generating large amounts of panel data;

– *geospatial* data which are characterised by maximum accuracy and objectivity. It is advisable to use such data in support of agricultural policy decisions in two ways. Firstly, to clarify data obtained from other sources. It concerns assessments of the level of food and socio-economic security (for example, arable land, agricultural land, plantings in the context of agricultural crops, forest stands, and other geographical features). Secondly, the accumulation of geospatial data is indispensable when it comes to collecting data that cannot be accumulated from other sources. This is especially important during military operations, when it is impossible to collect information within the temporarily occupied territories and/or territories where active military operations are taking place (Gorbulin, 2021).

After the termination of the preparation of statistical reports at the level of districts of administrative regions of Ukraine, it became almost impossible to form an array of operational data on the area of crops/plantings, which are an integral part of assessing and projecting the level of food security. An alternative source of collecting such data is the processing of satellite images and the creation of algorithms for classifying territories by culture;

– *sociometric survey data*. The practice of carrying out economic activities in the context of the COVID-19 pandemic and martial law has shown the existence of a high level of risk that business entities may be outside the physical access zone. Since the source of some statistical information can only be the results of sociometric surveys, it is extremely important to find and use software that is maximally adapted to the conditions of remote surveys. In addition, when choosing software, it is necessary to consider the simplicity of its application and the ability to identify spatial reference to the received data, which would allow indicating the location of the survey subject or any other object;

– *data from global, international, and domestic organisations and institutions*.

The algorithm of information support for decision-making in the field of national security of the country is shown in Figure 5.

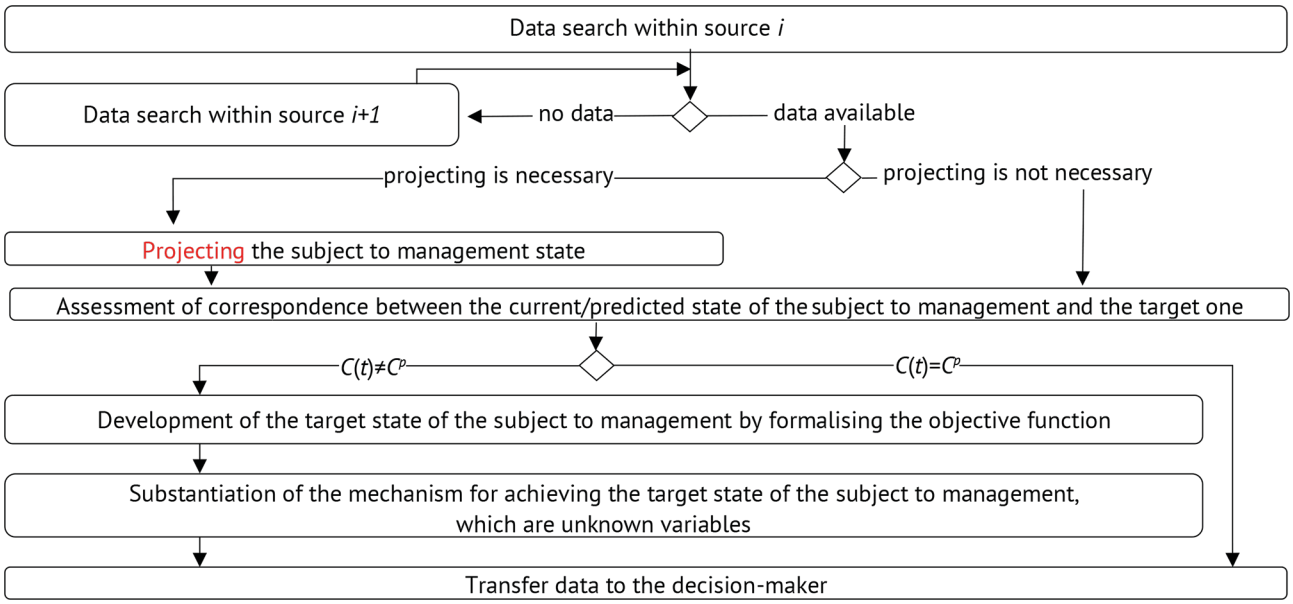

***Figure 5**. Algorithm of information support for decision-making in the field of ensuring national security*
***Source:** authors' own research*

Within the framework of the study of information support for decision-making in the field of national security of the country, the key role is played by the development and implementation of unified projecting methods, the use of which would allow identifying threats of crisis situations in advance and developing mechanisms for their prevention in advance. The relevant issues are investigated within the framework of the choice of methodological approaches to projecting indicators – indicators of the level of food security, for which the method of econometric modelling is used.

A system of information support for decision-making in the field of food, environmental, and socio-economic components of national security. The proposed methodological foundations of information decision-making support are implemented as part of the development of an information decision-making support system in the field of national security. The main principles of building and operating this system are as follows:

1) *openness*. The architecture and software part of the system are open, meaning that users can change them in accordance with external conditions. The implementation of this principle becomes more relevant in the face of new challenges, algorithms for responding to which were not previously developed. In 2020-2022, this principle of operation of the system ensured its prompt adaptation to meet requests for information support for decision-making in the context of a pandemic and war;

2) *flexibility*. The structure, functionality, methods, and tools of the system are adapted to the needs of decision-making entities in the field of national security and defence, restrictions, and environmental factors;

3) *efficiency*. The ability to meet requests for information for making operational decisions in the shortest possible time;

4) *cost-effectiveness*. The cost of creating, administering, and using the system cannot exceed the overall effects of using it. The effect should be understood as any positive effect from the application of the system (economic, environmental, social) in value terms. The effect can also be presented in the form of losses that were avoided as a result of the decision;

5) *purposefulness*. The purpose of the system is to form an information base for making adequate decisions in the field of national security. Any goal of the system should be based on a clearly formulated and quantifiable goal that will meet the request of decision-makers.

The decision-making support system in the field of national security consists of three modules, namely, modules for collecting, processing, and transmitting information that is necessary to substantiate decisions in the areas of food, socio-economic, and environmental security (Fig.6). The function of the data collection module is to create queries on obtaining information, accumulating and storing data that is responsible for a previously defined and restricted request of the decision-making subject.

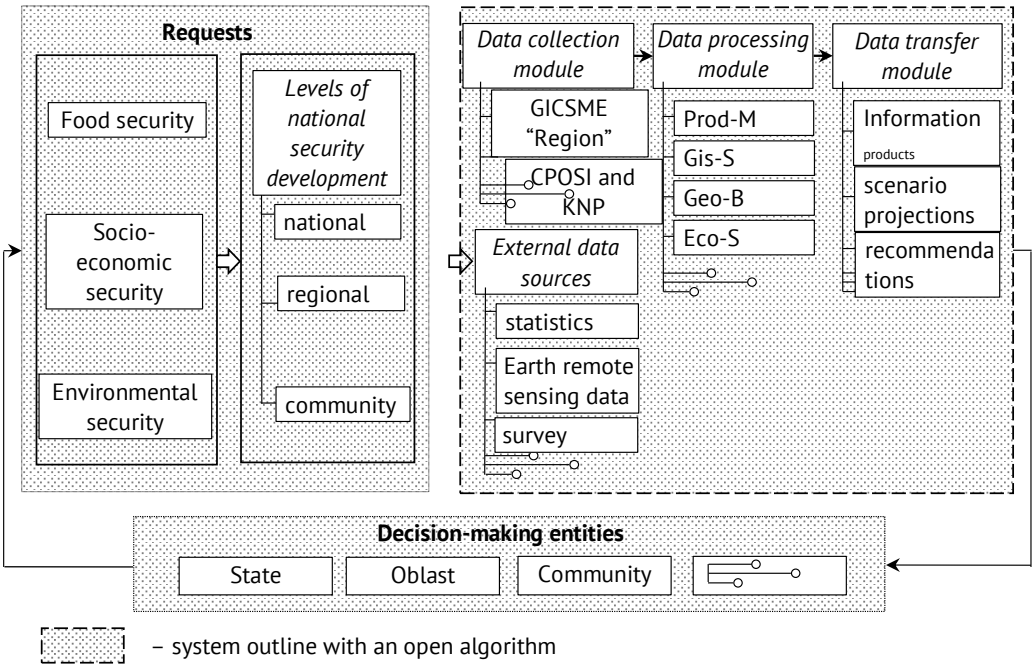

***Figure 6**. Scheme of the decision-making support system in the field of national security formation*
***Source:** authors' own research*

The main data sources from which the module accumulates information are the region subsystem (Ground Information Complex for Space Monitoring of the Earth, created by Polissya National University); Centre for receiving and processing special information and monitoring the navigation field, which is a branch of the National Centre for Vontrol and Testing of Space Assets of the State Space Agency of Ukraine (CPOSI and KNP); statistical data of Ukraine and international organisations; results of sociometric surveys collected with the involvement of automated information collection system Survey 123. At the same time, the list of sources is open. Figure 6 shows the functional model of the data collection module.

Subsystem GICSME "Region" and "CPOSI and KNP".

Analysis and modelling of the current security situation requires regular receipt and analysis of objective data on various components of the environment. Space-based remote sensing systems (remote sensing systems) are a source of up-to-date and reliable information that does not depend on possible distortions. The use of remote sensing data provides the following advantages: relevance of incoming information; high reliability of the information received; absence of restrictions related to state borders; high frequency of receiving information; coverage of large territories; obtaining information in a single standardised form; the ability to accumulate information and use it for projections and risk assessment.

Modern remote sensing systems have technical properties that allow solving a whole range of tasks – from mapping to analysing changes that have occurred in the study area. Using multi-time images allows tracking the dynamics of changes on the Earth's surface, identifying areas affected by human activity, predicting the consequences of emergencies, and many other tasks.

Obtaining remote sensing data in the system under consideration is provided by a complex consisting of a system of radio engineering, electronic computing, and software tools for receiving and processing data from remote sensing spacecraft in the L- and X- frequency bands. The use of the complex for its intended purpose is organised by preparing and conducting communication sessions with KA stations for receiving information. The information registered during the communication session is transmitted to the software and hardware complex of the remote sensing data archiving, display, and preprocessing system. For further use of remote sensing data, thematic data processing is carried out in accordance with the content of the problem being solved.

The main element of the region complex is the SNPI-8.2 ground information reception station, created by Polissya National University, which is the first Ukrainian university data reception station in the X-frequency range.

The data processing module operates on the basis of the subsystems "Prod-M", "Gis-S", "Geo-B", "Eco-S". Depending on requests for solution support, the system can be extended to other subsystems (Fig. 7). Similarly, the list of sources of data (now the main ones are satellite images, survey data, statistics) and ready-made results of the system's operation, which are transmitted to the subject of decision-making in the field of national security, remains open.

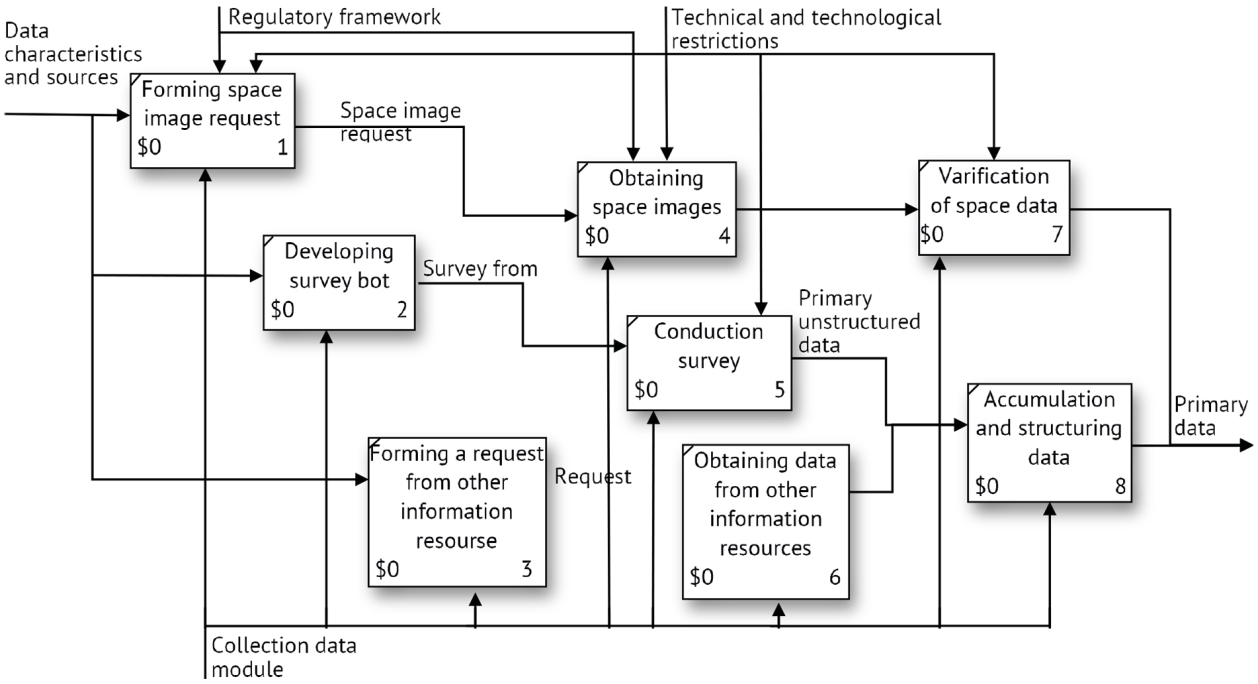

***Figure 7**. Functional model of the data obtaining module*

***Source:** authors' own research*

As of mid-2022, the subsystems of the data processing module are focused on providing users with satellite images, creating scenario projections, developing information systems based on geospatial data, and substantiating possible solutions (Fig. 8).

The "GIS-S" subsystem. The subsystem is designed to collect, transmit, process, analyse, and display spatial data in real time. It consists of hardware and software tools for geospatial support, in particular, geocoding of information (Survey 123, Insights, QuickCapture) –

accumulation of information on the server (ArcGIS Online) – processing, visualisation and transmission of information in a specialised software environment (ArcGIS Pro, ArcGIS Online).

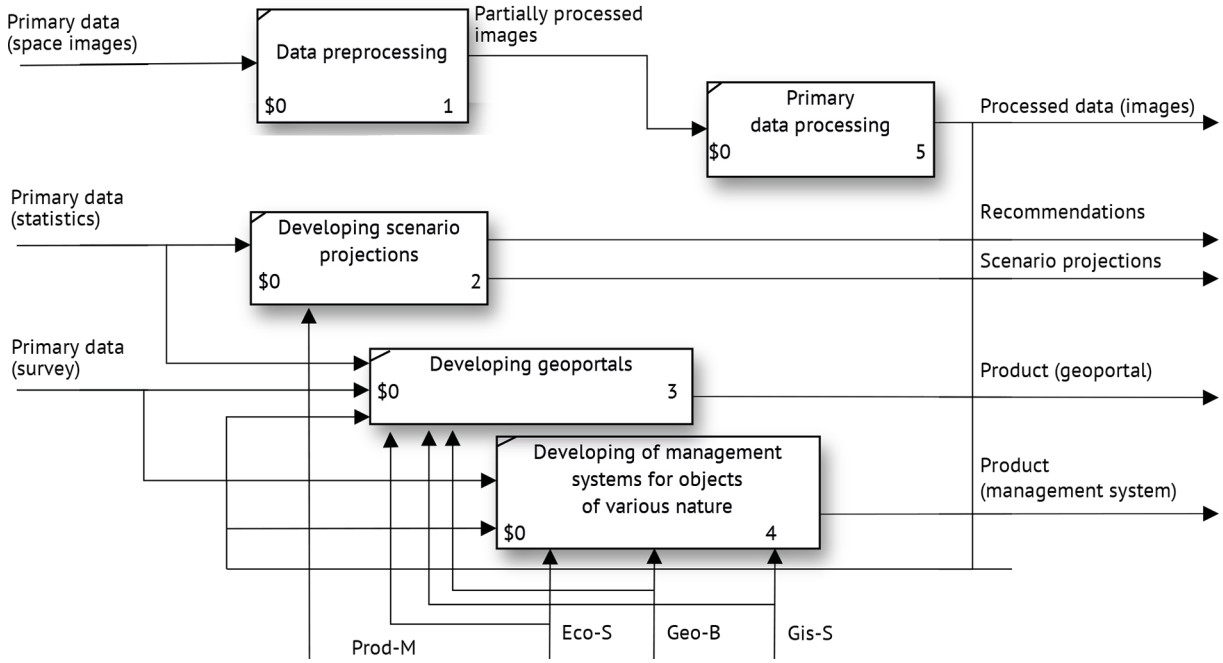

***Figure 8**. Functional model of the data processing module*

***Source:** authors' own research*

The "GEO-B" subsystem. The subsystem provides real time display of geospatial data about communities (in particular, the boundaries of communities and settlements, soil types, topographic basis, land structure, water bodies, roads, railways, power grids, gasification system, solid waste landfills, legal entities, individuals, population, medicine, gyms, and investment facilities). The main element of the subsystem is a geoportal, which is implemented using the ArcGIS Pro – Hub software environment application. Sources of filling in geospatial data databases at the level of the United territorial community can be: public cadastral map of Ukraine, Gosgeokadastr, OpenStreetMap, Natural Earth, UNEP Geodata, Global Administrative Areas, DIVA-GIS, Global Map, SEDAC, GeoNetwork, USGS Land Cover Institute.

The "ECO-S" subsystem. The subsystem is designed to collect, process, store and analyse information about the state of the natural environment, predict its changes and develop scientifically based recommendations for making effective management decisions at various levels. The software package of the subsystem provides the collection of in-kind data using the Survey 123 mobile application and satellite data, their accumulation on the ArcGIS Online server, processing, visualisation in the specialised ArcGIS Pro software environment and further transmission of information for making managerial decisions in environmental protection activities. The main types of information that circulate in the subsystem are remote sensing data, as well as data from field observations on the state of the main components of ecosystems and their changes under the influence of natural, biotic, and anthropogenic factors.

The "Prod-M" subsystem. The subsystem is designed to form an information base for supporting agricultural policy decision-making at the European, state, regional, and business entity levels. The initial parameters of the subsystem are short- and medium-term projections for the development of the agro-industrial sector of the country's economy. Software tools that provide input data processing by the "Prod-M" subsystem include information systems AGMEMOD and GAMS, R software environment, MS Excel.

Modelling of food security indicators of the country using the "Prod-M" module. One of the current problems of information support for making agricultural policy decisions in Ukraine is the lack of a unified methodology for scenario projecting of the development of the agricultural sector of the economy. Most of the relevant decisions are made based on the experience and intuition of officials. The key problem of this is that the agro-industrial sector of Ukraine is a complex open system, the components of which closely interact with each other and changes in one of them can lead to changes in all the others.

Therefore, when planning certain reforms in a particular sector of agriculture, it is necessary to be aware that they can lead to significant consequences in other sectors (including negative ones). This means that even if the changes affect only one sector, projections should be developed for all sectors. These needs are met by

the AGMEMOD information system (platform) (Salamon *et al.*, 2019), which is currently widely used to generate medium-term projections for EU member states and their key partners, as well as to support agri-policy decision-making in the EU and EU-members. Every year, AGMEMOD databases and mathematical models are updated in accordance with socio-economic and market changes at the country level and for the EU as a whole.

The procedure for modelling the country's food security indicators includes three stages:

1) development of a system of econometric models of the dependence of each result indicator of food security on each factor. For the individual outcome indicator *y*, hypotheses are first developed based on the provisions of microeconomic theory, interviews and discussions with experts on a number of factors that may affect food security. After that, simple regression models (which show the dependence of the outcome variable *y* on each factor *x*) are developed. The requirement for the list of factor attributes is the availability of data on their values in the database of the *Prod-M* subsystem:

$$y=f(x)\forall x\in S, \quad (8)$$

where *S* – set of numeric values of the indicator in the database of *Prod-M* subsystem.

Since the AGMEMOD model is linear, if a nonlinear relationship is detected between the food security indicator and its factor, the linearisation procedure is an additional stage of modelling. The time for each individual change is checked for an autocorrelation effect. Each individual regression model is checked for statistical significance using a criterion *p-value* (*p*), and to fulfil the condition of the logical nature of the relationship between variables in accordance with the laws of microeconomics:

$$\text{if } p\leqslant 0.1 \text{ and } a_x>0 \text{ (for } x\in\{K_{y_i}\}) \text{ or } a_x<0 \text{ (for } x\in\{L_{y_i}\}), y_i\in Y \text{ else } f''(x)\in\{F^1\}-\text{TRUE}, \quad (9)$$

where a_x – regression coefficient (*slope*), which corresponds to the variable *x*; $f''(x)$ – one-factor econometric model; $\{F^1\}$ – set of one-factor econometric models of effective indicators of food security *y*; $\{K_{y_i}\}$ – set of factor features that, according to the laws of microeconomics, must be directly related to i-th effective feature *y*; $\{L_{y_i}\}$ – set of factor features that, according to the laws of microeconomics, should be inversely related to *i*-th effective feature y; *Y* – multiple effective indicators of food security;

2) development of preliminary econometric models of each individual performance indicator. If, as a result of preliminary econometric analysis, several factors that affect the result indicators are identified, then a multiple regression model is developed. Multiple regression models, like the previous stage, must meet the condition of statistical significance ($p\leqslant 0.1$) and the logic of the nature of the relationship between variables:

$$\text{if } p\leqslant 0.1 \text{ and } a_{x_j}>0 \text{ (for } x_j\in\{K_{y_i}\}) \text{ or } a_{x_j}<0 \text{ (for } x_j\in\{L_{y_i}\}), y_i\in Y \text{ else } f'(x)\in\{F'\}-\text{TRUE}, \quad (10)$$

where a_{x_j} – regression coefficient (slope) for j-th factor *x*; $f'(x)$ – preliminary econometric model that will be used to develop scenario projections; $\{F'\}$ – set of previous econometric models of resulting indicators *y* which will be used to develop scenario projections;

3) analysis and adjustment of multi-factor multiple models of indicators of food security. First of all, intercept of the model is adjusted (a_0). To do this, the forecast projected values of each individual indicator are determined based on the equations developed at the previous stage. If the actual value of the intercept in the current year significantly deviates from the value in the first year of forecasting, the coefficient a_0 is readjusted:

$$\text{if } |y(t\text{-}1)\text{-}y(t)|\geqslant \Delta\_\max \text{ else } a_0=y(t\text{-}1)\pm\Delta \text{ and } f(x)\in\{F\}-\text{TRUE}, \quad (11)$$

where a_0 – intercept; *t* – first year of projecting; $f(x)$ – adjusted econometric model that will be used to develop scenario projections $\{F\}$ – set of adjusted econometric models of variable *y* which will be used to develop scenario projections; Δ – scientifically based/expert-determined possible increase/decrease in the result variable in the first year of projecting compared to its actual value in the last year of the time entered in the AGMEMOD database; Δ_{max} – the maximum deviation of the result variable in the first year of projecting compared to its actual value in the last year of the time series entered in the AGMEMOD database.

In general, tasks that are solved within the framework of the subsystem of information support for making agricultural policy decisions *"Prod-M"*, include:

1) development of medium-term projections of the main indicators of the agro-industrial sector of the Ukrainian economy under current conditions. To solve this problem, projections of balance sheets and prices of agro-industrial products for the next 10-30 years are developed at intervals of 1-2 years, reflecting the expected trends in their changes. As part of this task, the subsystem *"Prod-M"* identifies unfavourable trends, and the developed projections serve as an indicator of negative shifts and signal the need to form a new package of agricultural policy solutions;

2) projecting the consequences of each individual political decision. Results of the subsystem *"Prod-M"* within the framework of this task, have the form of projections for each type of agro-industrial products. If the goals of the relevant agricultural policy measure/reform are achieved, the subsystem determines the solution to be potentially effective;

3) operational short-term forecasting in conditions of turbulence and large-scale socio-economic and political shifts. Examples of situations where there was a need for the subsystem to perform *"Prod-M"* as part of

this task, there is a COVID-19 pandemic and the invasion of the russian federation on the territory of Ukraine. Both events have global implications not only for the country but also for the global economy and food security.

A distinctive feature of this study is that methodological approaches to information support are partially covered in research papers, for example, in (Liao, 2004; Lant, 2005; Xie, 2022) integrated into the unified national security decision-making support system with an open algorithm. The uniqueness of this study lies in the emphasis on procedures for collecting operational data in accordance with time-limited requests from decision-makers. It is proved that the timeliness and efficiency of incoming information for managing the country's food security requires the use of GIS. In particular, in contrast to the practice of using only official statistics (Haß, 2022; Jongeneel, 2022), in the process of creating unique scenarios for the development of the agricultural sector of the economy based on the AGMEMOD model (Salamon *et al.*, 2019) it is proposed to collect and process geospatial data (in particular, to determine the volume of crop stocks in grain storage facilities in Ukraine during the war). In the course of this study, it was found that the use of panel data, which was also successfully used in research, is quite reasonable for projecting the agricultural sector of Ukraine (Jongeneel, 2022; Corn, 2021).

Efficiency of information support of the decision-making process in the field of environmental safety is achieved by accessing the data of the software and hardware complex within the "Region" subsystem. In particular, the efficiency of obtaining and processing space survey data using the region subsystem allows quickly (45 min.) identifying the sources and location of forest fires, which is faster than in similar Chinese ones (Liiew, 2019) (100 min.) and open American (3 hours.) (Çolak & Sunar, 2020) systems.

Consequently, it was found that the efficiency of decision-making in the field of ensuring food, socio-economic, and environmental safety is based on the ability to provide timely decision-making entities with the necessary information.

CONCLUSIONS

The study has established that in this context, the determining factor is the development of an information support system that would minimise the time of transmitting a request for data and their accumulation and processing, and ensure maximum compliance of the transmitted data with the request. Along with statistical data, GIS plays a special role in providing information in a short time, which is actively used for rapid accumulation and thorough processing of geospatial data.

In addition, it is extremely important to formalise the decision-making process in the event of an urgent need to solve problems related to threats to national security. This would allow adhering to a clear algorithm of actions in case of an immediate response to danger. Considering the above, decision-making in the field of ensuring food, socio-economic, and environmental security should include the following stages: identifying discrepancies between the current/projected and target states of the management object; determining the target state of the system at a given time; formalising restrictions; determining mechanisms for achieving the target state; clarifying methods, tools, and measures that need to be implemented to get out of the state of increased danger.

Time constraints, lack of necessary data, and the need to form scenario projections of key safety indicators are characteristic features of information support in the field of ensuring food, socio-economic, and environmental security of the country. The development and implementation of the information decision-making support system proposed in the study would allow partially automating the processes of collection, processing, and transmission of information, considering these features, and forming and replenishing the information base for making adequate decisions in the field of national security. A separate element of the developed system is the data processing module, which integrates modern methods of modelling and projecting indicators of food, socio-economic, and environmental safety. In the future, it is promising to conduct research on automating data collection and improving their security within the proposed system

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CONFLICT OF INTEREST

No.

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Методичні засади інформаційної підтримки прийняття рішень у сфері продовольчої, екологічної та соціально-економічної складових національної безпеки

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Анотація. Негативний вплив стратегічних загроз розвитку держави в контексті формування її національної безпеки, зокрема продовольчої, екологічної та соціально-економічної складових, активізувався в умовах реалізації геополітичних викликів України. Особливо гостро це питання постало в результаті відкритої військової агресії, що зумовлює необхідність формування та імплементації системи інформаційної підтримки прийняття рішень у сфері національної безпеки України. Відтак, метою роботи є обґрунтування методичних засад інформаційної підтримки прийняття рішень у сфері національної безпеки України та їх реалізація у межах створеної системи, що передбачає збір інформації, зокрема, із використанням космічних та геоінформаційних систем, а також застосуванням методів математичного моделювання і ситуаційного аналізу для обробки даних. У процесі дослідження використано методи економетричного моделювання, структурно-функціонального моделювання та просторового аналізу. Було розроблено методологічні засади щодо підтримки прийняття рішень для вирішення проблем продовольчої, екологічної, соціально-економічної складових національної безпеки. Побудовано функціональну модель та алгоритм процесу прийняття рішень у сфері національної безпеки і, на основі отриманих результатів, розроблено систему прийняття рішень у сфері продовольчої, екологічної та соціально-економічної безпеки. Крім того, у дослідженні формалізовано концептуальні положення процесу підтримки прийняття рішень у сфері національної безпеки; запропоновано процедуру моделювання показників продовольчої безпеки країни. На основі запропоновано методичного підходу визначено, на скільки зменшилась площа посівів у зв'язку із тимчасовою окупацією, військовими діями та післявоєнним станом полів (мінування, знищення посівів, техніки тощо), що дало змогу сформувати вхідні дані для подальшого прогнозування показників розвитку аграрного сектора та продовольчої безпеки України, ЄС та світу. Запропоновані методологічні положення, алгоритми, моделі, а також розроблена система можуть бути використані органами державної влади для прийняття управлінських рішень щодо формування політики у сферах забезпечення продовольчої, екологічної, соціально-економічної безпеки країни

Ключові слова: інформаційне забезпечення; функціональне моделювання; економетрична модель; інформаційна система; управлінське рішення; дистанційне зондування Землі

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Performance management assessment in agriculture organisations (using factorial farameters case of Albania)

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Abstract. The relevance of the study is determined by the need to identify solutions to increase the productivity of agricultural and food enterprises in Albania and to improve their production. The purpose of the study is to analyse the production of agricultural and food products, the level of remuneration of agricultural workers, the impact of state financial assistance on production volumes, and to provide proposals for increasing productivity in the agricultural sector. The methodological approach is based on: statistical analysis, the analogy method, graphical method, method of logical generalisation. The key findings are the substantiation of the expediency of mechanisation in the production of agricultural products, and an increase in the budgetary financial support and the wages of employees to boost the productivity of agricultural enterprises, reducing the dependence on imported goods and increasing the export of Albanian agricultural products to the world markets. The authors confirmed that to enhance the productivity of agricultural and food enterprises, it is necessary to focus on raising the wages of workers, mechanising production, and expanding the area of irrigated land. This will raise the competitiveness of Albania's agricultural and food products to a new level and increase its exports to the world markets. The findings of the study and the conclusions formulated on their basis are of practical importance for the managers of agricultural and food enterprises in Albania when developing measures to increase the

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productivity of workers, as well as for the government of the country when approving the areas of financial support for economic activities

Keywords: remuneration rate; financial support; international trade; mechanisation; production efficiency

INTRODUCTION

Agriculture and the food industry are facing numerous challenges: the need to produce more food to feed a growing world population, the declining rural workforce and growing population in large cities, the search for more efficient production methods, and the adaptation of agriculture to climate change. The natural conditions of Albania are favourable for the development of agricultural production, in particular, the cultivation of fruit trees, vegetables, olive oil, and cereals. However, the country's agriculture and food sectors are affected by outdated agricultural equipment and low labour productivity. Therefore, it is important to find ways to increase the productivity of the agrarian sector with the purpose of improving its future growth and boosting the export of agricultural products from Albania to ensure food security in the world.

The labour productivity in the agriculture and food sectors in Albania was investigated by Albanian, American, Romanian, Lithuanian, Brazilian, and Indonesian researchers. The analysis of the forms of management of agricultural land in Albania, ownership, productivity per unit area and ways to properly manage them was carried out by the Albanian scientist S. Lushaj (2021), who investigated the obligations of law enforcement agencies and bodies for property management, property rights, and certification of ownership of agricultural land. The efficiency of labour productivity management depends on the success of labour resources management, in particular, meeting the needs of employees in terms of remuneration and other requirements for the organisation of production, and on mechanisation and innovation in production, which facilitates the work of employees and helps to increase production.

The impact of agricultural mechanisation on the income growth of farmers was studied by Chinese researchers Y.B. Zhou *et al*. (2019), who sought to provide suggestions on policies to promote the development of agricultural mechanisation and increase farmers' incomes. The authors argued that agricultural mechanisation contributes to the overall income of farmers and increases the wages of their employees. Important research into the impact of changes in soil cover and climate on labour productivity and agricultural production was carried out by Albanian scientist E. Lekaj (2019), who argued that these factors are important for soil and plant resources assessment and sustainable production management planning.

The profitability of agricultural production is also an indicator of labour productivity. That said, in the last 5 years, due to the rapid increase in prices for raw materials imported for production in Albania, there was a decrease in profitability, which negatively affected labour productivity. The impact of the 2021 high fertiliser prices, which added to the expenses for farmers, was studied by the American researcher S. Aaron (2022), who stressed that potential reasons for such an increase can be both supply and demand factors. That is, if farmers respond to high prices by using less fertiliser per acre, it would provide environmental benefits in the form of less nitrogen and phosphorus in rivers and lakes.

One of the negative phenomena in the development of agriculture in Albania is the high share of imports, which indicates the insufficiency of domestic products to meet the needs of the country's population. Indian scientist S. Simkhada (2019) has concluded that low productivity, growing population, the number of companies engaged in food and feed processing, high production costs, and the redirection of agricultural state aid to the non-productive sector are the main reasons that contribute to the large imports of agricultural products. The main risk groups of agricultural imports in foreign trade according to their relevance for such imports were identified by Lithuanian scientists L. Baranauskaite and D. Jureviciene (2021). The researchers identified eight risk groups: supply and demand risks, production risks, management and operational risks, logistics and infrastructure risks, political risks, regulatory risks, and financial risks.

However, despite the significant contribution of researchers to the study of this area, the issue of increasing labour productivity in the agricultural sector of Albania remains controversial and requires further investigation. *The main purpose of the stud*y is to analyse the state of labour productivity in the agricultural and food enterprises of Albania to propose solutions for its improvement, which would contribute to the sustainable development of the agricultural sector and increase the export of agricultural products.

MATERIALS AND METHODS

The methodological approach in this study is based on: statistical analysis, which is used to study the dynamics of employment and wages in the agricultural sector of Albania; the analogy method for comparing incomes and expenses between small and large agricultural producers in Albania; the graphical method – for the graphical display of the results obtained; logical generalisation for summarising information on the state of productivity of agricultural enterprises and the factors that affect it to identify areas for its improvement.

The scientific research involves assessing the state of labour productivity in agricultural and food production, identifying factors that can positively affect the increase in production and incentives for agricultural workers, and elaboration of proposals for increasing labour productivity in the agricultural sector of Albania. The presented study is carried out in three stages. The first stage involved the application of the statistical analysis. It allowed investigating the dynamics of labour productivity and the share of employees in the agricultural sector of Albania for 2018-2022.

To analyse the dynamics of the level of remuneration of agricultural workers for 2018-2022, data from the World Bank (Agriculture & Rural Development..., 2022) and the Institute of Statistics of Albania (Statistics by Agricultural sector..., 2022) were taken as a basis. Statistical analysis of the import-export activities of Albania, in particular, on trade in agricultural and food products, was carried out based on data from the International Trade Organization for 2019-2022 (Albania – Country Commercial Guide, 2021). In the second stage, using the analogy method and guided by data from the Food and Agriculture Organization (FAO, 2022) the income and expenses of small and large agricultural producers in Albania for 2022 are compared. Using the graphical method, the data obtained during the research on the breakdown of land in Albania by purpose and the dynamics of the employed population of Albania in the food and agriculture industry are displayed in the form of charts and graphs. At the final stage of the study, the approaches to the factors, the application of which would contribute to the increase of production and productivity in the agricultural sector of Albania, are summarised.

Based on the findings, the conclusions summarising these results are formed, namely: proposals for increasing the level of labour productivity are substantiated. The application of the method of logical generalisation of the results allowed determining further approaches to the investigation of labour productivity in the current conditions of development of the agricultural sector of Albania.

RESULTS

Given that Albania is in the process of acceding to the European Union (EU), support for food and agricultural development policies is crucial to prepare the country's agricultural sector to face the competitive pressures of the EU single market. To maximise its benefits in the EU single market, Albania is making efforts to reform its food and agricultural policy. For the last 17 years, the FAO, which has 195 members and is a specialised agency of the United Nations, has played an active role in supporting the development of the food and agricultural sector in Albania. FAO directs its efforts to ensure food security in the world by providing people with regular access to sufficient, high-quality food to enable them to lead active and healthy lives (FAO, 2022).

FAO's focus is on the transformation of Albanian agriculture to support smallholder farmers and the EU integration process. One of the main tasks is to increase labour productivity in this area. Notably, an increase in the agriculture productivity in Albania is a source of increasing production volumes. In turn, the improvement of production can lead to a reduction in human labour costs for the manufacturing of products and, as a result, to saving working time. This would create preconditions for reducing the working hours, working week, and the total number of working days per year, extending free hours of agricultural workers, and increasing their productivity. Productivity management in food and agricultural enterprises should be carried out considering the issues that exist in this sector and the factors that affect it. Food and agriculture are one of the largest and most important sectors for the Albanian economy and accounts for 21% of the country's gross domestic product, which is much higher than in the EU countries, where this sector mainly accounts for only 2% (Agriculture & Rural Development..., 2022). The total area of Albania is 28,750 square kilometres. Agricultural land is a significant part of the total area (Fig. 1) (FAO, 2022).

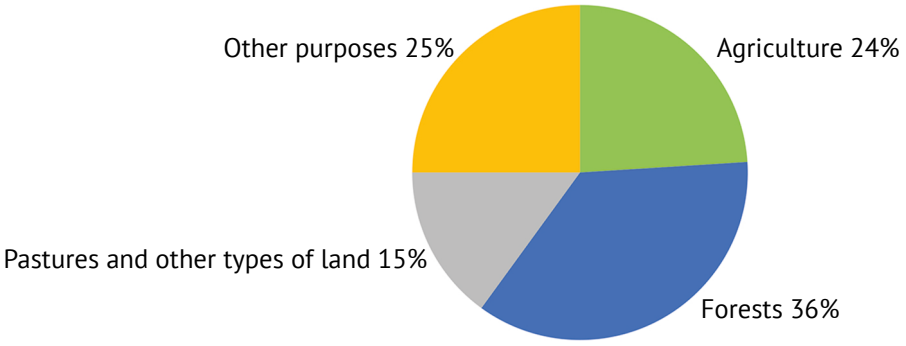

***Figure 1**. Distribution of land use in Albania for 2018-2022*

***Source:** compiled by authors*

Albania consumes more foreign agricultural products than it produces for export to other countries. Dependence on imported products has a negative impact on domestic production, in particular, due to rising

prices for imported products. Thus, during 2019-2021, there was an increase in raw material costs, as feed prices increased by 50% in 2022, which was conditioned by the shortage of grain and cereals caused by the armed aggression of the russian federation against Ukraine. This suggests the necessity to increase labour productivity to reduce the dependence of the agricultural sector of Albania on imported products and to increase domestic production and competitiveness in foreign markets. Labour productivity depends significantly on the number of people working in food and agriculture (Fig. 2) (Albania Employment, 2021).

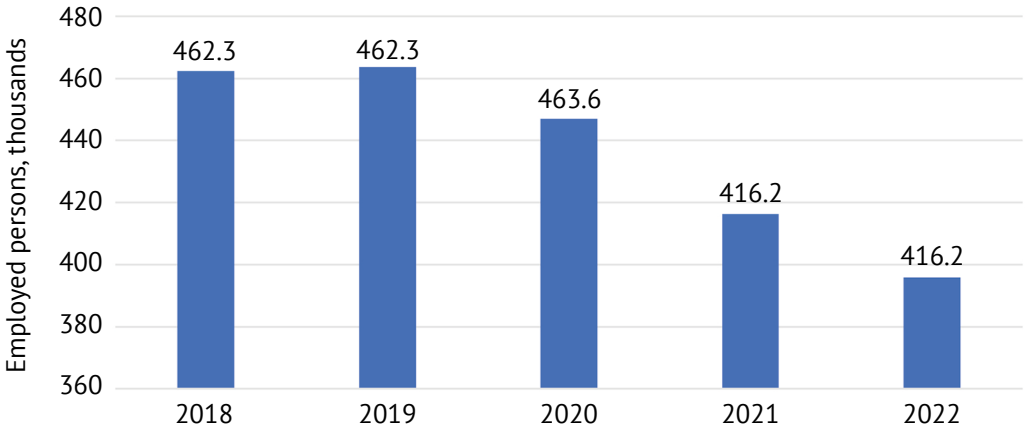

***Figure 1**. Dynamics of the employed population of Albania in food and agriculture for 2018-2022*
***Source:** compiled by authors*

The data in Figure 2 show that the number of people employed in agriculture during 2018-2022 has a gradual downward trend. Generally, employment in food and agriculture in the country in Albania in 2021 was 36.1% of the total number of employees, which is 9.9% less than in 2014 (Agriculture & Rural Development, 2022). Wages have a significant impact on the attractiveness of working in the agricultural sector. It is worth noting that the average gross monthly wage in the agro-industrial sector in 2022 is EUR 331, which is the lowest level of remuneration among other areas of activity and 47% less than the average wage in the country (EUR 509). However, during 2018-2022 there was a slight increase in wages in the agricultural sector, which had a positive impact on the volume of production. Labour productivity in the agricultural sector can be defined as an indicator of output per employee. To analyse the dynamics of labour productivity, the deviation of the indicators of the reporting and base periods should be found (Table 1) (Statistics by Agricultural sector..., 2022; Albania Employment, 2021).

***Table 1**. Dynamics of employment, wages and volumes of agricultural products produced in Albania in 2018-2022*

			Increment			Increment			Increment			Increment	
Indicator	**2018**	**2019**	**+/-**	**%**	**2020**	**+/-**	**%**	**2021**	**+/-**	**%**	**2022**	**+/-**	**%**
Annual salary. EUR	3.600	3.840	240	6.7	3.852	12	0.3	3.900	48	1.2	3.970	70	1.8
Annual production volume. thousand tonnes	9.221.4	9.376.7	155.3	1.7	9.480.9	104.2	1.1	9.413.9	-67	-0.7	9.452.2	38.3	0.4
Number of employed workers. thousands of people	462.3	463.6	1.3	0.3	447	-16.6	-3.6	416.2	-30.8	-6.9	435	18.8	4.3
Number of products produced by one employee (productivity). tonnes	19.9	20.2	0.3	1.4	21.2	1	4.9	22.6	1.4	6.6	23.5	0.9	3.8
Share of the change in the production volume		99.2			115.9			54			76		

***Source:** (Statistics by Agricultural sector..., 2022; Albania Employment, 2021)*

The data in Table 1 show that despite the decrease in the number of people employed in agriculture, the volume of products produced during 2018-2022 gradually increased. This had a positive effect on the labour productivity index, which increased by 13.6% over the entire period. The value of the share of the change in the volume of production shows that under the changes in labour productivity, the volume of agricultural production increased the most in 2020, but decreased in 2021, which was mainly conditioned by a decrease in the number of employed by 6.9%. In 2022, this number increased again, which is a positive trend. However, according to FAO, 72% of agricultural products are produced for domestic consumption, which indicates the need to modernise this production, in particular for small landowners (FAO, 2022). Small business entities engaged in the production of agricultural products in Albania prevail over large ones. This negatively affects production costs and overall productivity. Below, the authors compare the income and expenses of small and large agricultural producers in Albania for 2022 (Table 2).

***Table 2**. Comparison of income and expenses between small and large agricultural producers in Albania over the year 2022*

Indicators	Producers	
	small	large
The average size of the employed area. ha	0.4	1.7
Share of small farms in the total number. %.	74	24
Total income. USD	16.354	17.280
Cost of production per 1 ha. USD	4.978	1.945
Costs of production value. %	32	28

***Source:** (FAO, 2022)*

As is evident from Table 2, the share of small farms engaged in the production of agricultural products and food significantly prevails in their total number. At the same time, the cost of production for small producers is almost twice higher than for large ones, and production costs are 3% higher. This advantage of small producers over large ones is the main obstacle to increasing their productivity and competitiveness and investing in the modernisation of production. Thus, only 11% of small producers have access to motorised equipment, only 50% of small owners can apply fertilisers on their fields, and 48% of the area is irrigated, making agricultural production highly dependent on precipitation, especially during the summer growing season. To increase agricultural production and labour productivity, it is necessary to reorganise producers by merging them and creating larger enterprises to increase production and efficiency. It will also reduce costs and increase the competitiveness of Albanian agricultural products in foreign markets. Reducing labour and production costs will encourage an increase in product profitability. Among the existing challenges in the agriculture and food sector that have a negative impact on productivity are high rates of migration from rural areas, low technological levels of production, and insufficient financial support for small businesses. Only 0.2% of small farms receive loans for their development, while their investments in the development of production reach 32% of their value (FAO, 2022).

The government of Albania constantly provides financial support to the agricultural sector, which positively affects production. Thus, the financial support programme for 2017-2021 identified agriculture as one of the priority sectors. During this period, about EUR 193.2 million was invested in the regions of Albania to support agriculture and economic entities entering the markets. In 2018, the total budg*et* allocation for the agriculture and food sector reached EUR 43 million, which is significantly higher than the average expenditure over the previous 10 years (about EUR 25 million per year). The total amount of budget support for the agricultural sector in Albania is about 18% of the total amount of subsidies for all types of economic activity (Agriculture & Rural Development..., 2022). The impact of national support on the income of greenhouse and dairy farms is positive. The consequences of such impacts were analysed in three main areas: greenhouse vegetable cultivation, apple cultivation, and dairy production. According to studies conducted by the FAO, in 2019, revenues for greenhouses increased by 30%, apple cultivation – by 9.4%, and dairy products – by 69% (FAO, 2022).

It is necessary to expand support for the development of agriculture and food industry because it can solve the issue of providing production with the necessary technologies and improving the quality of land cultivation, which would improve fertility and productivity in this sphere. Along with these shortcomings in the development of the agricultural sector, the profitability of the sold products and the interest of workers in increasing productivity are negatively affected by the establishment of low prices for the sold products in Albania. For example, the export of tomatoes from the country is estimated at USD 0.5 (EUR 0.48) per kilogramme, while Italy exports the same product to the UK for USD 2.4 (EUR 2.3) per kilogramme, which is

4.8 times more expensive than Albania (Albania – Country Commercial Guide, 2021). The import figures for Italy are given for comparison since this country has a developed agricultural sector similar to the Albanian one.

Summarising the above, it is necessary to note that despite the fertility of Albania's lands and favourable natural and climatic conditions for the development of the agro-industrial sector, the productivity of agricultural and food enterprises faces such problems as: high dependence of production on imported products; a decrease in the level of the employed population, and low wages in the agro-industrial sector compared to other types of economic activity in Albania; the predominance of the number of small producers in their total number, the profitability of production of which is lower compared to large producers; and insufficient level of state financial support for the agro-industrial sector. The mentioned issues are the grounds for finding ways to improve the production of agricultural and food products with the aim of increasing labour productivity in this sphere and improving the competitiveness of agricultural products in foreign markets

DISCUSSION

The analysis of the state of labour productivity in agriculture and food in Albania showed that this sphere is promising in development and should become a priority for the government of the country, in particular, for the allocation of financial support, which can be directed to stimulate workers in the form of wages, providing production with the necessary equipment for land cultivation, improving irrigation, which will increase their productivity. The results obtained in the course of the study suggest that the proposals are aimed at increasing the production of the agro-industrial sector and improving the conditions for development in order to increase the participation of Albania, as a member of FAO, in ensuring food security in the world. Production efficiency management is a process that improves the productivity of employees of the enterprise, company, and other business entities, and also allows achieving better results in production (Qureshi *et al.*, 2012; The Effectiveness of Performance…, 2019).

The importance of increasing the efficiency of rice cultivation to ensure food security in the world was underlined by Indonesian researchers N. Nurliza *et al.* (2017). The results of the study proved that labour productivity depends to a greater extent on the desire and interest of employees to perform their work. A similar argument is expressed by Thai researchers J. Angsukanjanakul *et al.* (2019), who argue that to improve productivity in the agricultural sector, the professional development of employees or managers who are of high value to organisations is necessary. The authors conclude that obtaining the necessary knowledge in the agricultural sector and continuous training of employees is essential for increasing the productivity of the enterprise.

The paper reports on the low level of wages in the agricultural sector and the need to raise it. The same opinion is shared by the Indonesian researchers G.P. Pratama and N. Hermina (2022), whose study shows the impact of bonuses to the basic wage on the performance of employees of the agricultural training centre. Another factor, which affects the performance of employees is the work discipline factor. Workplace discipline requirements are established to improve employee ethics and productivity in the company. The analysis of agricultural production demonstrated that it is important to observe environmental friendliness in production, which will preserve the quality of the land on which the products are grown and increase their competitiveness in the EU markets. This conclusion is supported in the study by Romanian researchers V. Burja *et al.* (2009), which cite the characteristics of the two most commonly used environmental management systems promoted by EU legislation, and stresses the need for their adoption by Romanian agricultural enterprises to improve compatibility with EU environmental regulations.

Agreeing with the opinion of the Indian scientist S. Shevade (2022), it should be stressed that with the growth of the world's population, the struggle for natural resources is also growing, which will lead to pressure on agricultural production of food, energy, and other various high-value products. The author argues that with the increasing concern about the environmental impacts associated with the needs of a growing population, a life cycle assessment system in agriculture is rather important. However, the lack of a consistent approach to the impacts of some resources that are important for agriculture (e.g., land and water use) complicates this analysis. The role of environmental protection in the production of agricultural and food products was stressed by the Brazilian scientists E. Lopes *et al.* (2021), who argue that executives responsible for the technical and administrative management of productivity in agriculture are looking for solutions based on environmental efficiency. Such measures involve resource consumption and waste generation with minimal harm to the environment.

It is necessary to consider the results of the study by Brazilian scientist G.S. Medina (2019), who analysed: the degree to which the Brazilian government prioritises conservation in its agricultural policy budget; what existing agro-environmental measures effectively ensure environmental conservation; what are the opportunities for improving existing policies to address current environmental challenges.

The researcher argues that despite agri-environmental mechanisms having gained benefits, they make up only 5.8% of the American, 5.75% of the European, and 1.25% of the Brazilian agricultural policy budgets. Key resource conservation issues remain unresolved, such as water and nutrient management, landscape level management, soil quality and biodiversity loss in

Europe, where bird and farmland populations have declined by over 40%. It is therefore necessary to increase investment in environmental protection to ensure that agricultural production remains competitive.

The study has proved that the increase of labour productivity in agriculture and food is positively influenced by the financial support of this sector by the state. Such arguments were also expressed by Thai scientist T. Laiprakobsup (2019) regarding the impact of government support for rice cultivation aimed at increasing its production in the country and achieving self-sufficiency. The researcher argues that the less likely the government is to impose tax barriers on the rice sector and price controls in Southeast Asia, the greater the likelihood of rice production growth in the long term. The study concludes that increasing the level of mechanisation of production contributes to the growth of productivity in the agricultural sector. A similar opinion is supported by and the American researchers H. Takeshima *et al*. (2020), who points out that mechanical technologies can increase the production of crops grown in heterogeneous agro-ecological conditions.

Chinese scientists J.Q. Peng *et al*. (2022) underline the fact that the level of mechanisation has a significant positive impact on the cost of production, income, and profitability of all types of crops. For every 1% rise in the level of mechanisation, the yield of grain crops increases by 1.6%. Therefore, the author recommends increasing subsidies for the purchase of agricultural machinery and improving the capacities of farmers to use new tools to extend their service life. The study emphasises the negative impact of rising world prices on agricultural production and proposes to reduce dependence on imported raw materials used in this sector. The economic consequences of higher fertiliser prices for 64 representative crop farms are analysed by American scientists J Outlaw *et al*. (2022). At the same time, Serbian researchers N. Njegovan and M. Tomas-Simin (2020) analysed the impact of inflation and prices on agricultural and food products as a complex phenomenon and examine their causes and consequences. In particular, authors pointed out the importance of demand, which causes inflation in less developed countries and leads to higher food prices, further putting pressure on wage growth, which is usually not a consequence of productivity growth.

The presence of causal relationships between agricultural imports, agricultural productivity, and economic growth is evidenced by the findings of the African scientists E.N. Mwangi *et al*. (2020). The paper emphasises the need to reduce the number of small businesses by consolidating them to increase productivity. At the same time, Bulgarian researchers H. Harizanova and R. Terziyska (2021) note that small farms have an important place in the agricultural sector of Bulgaria. The impact of various factors brings out a variety of opportunities for the development of such farms, suggesting that some farms will make efforts to improve their economic viability. However, as noted by the Italian scientists C. Cidon *et al*. (2021), regardless of the size of production, consolidating the practices of various enterprises, public support and knowledge networking in the agricultural sector are crucial.

The analysis of the productivity management of agricultural enterprises revealed that productivity depends on many factors and indicators, in particular, the size of the enterprise, the qualification of employees, the use of innovative and advanced technologies, etc. Enterprise productivity management is crucial for boosting its competitiveness. According to the Chinese scientists Y. Huo *et al*. (2022), the balanced scorecard is commonly used in many areas due to the comprehensive and objective characteristics of performance management. The scientists analysed the problems faced by agricultural enterprises in productivity management and its application in innovations in productivity management of agricultural enterprises, which will contribute to long-term development.

The analysis of the above-mentioned studies confirms the conclusions and proposals presented in this paper regarding the improvement of labour productivity management in agricultural and food enterprises in Albania. To enhance the productivity of agricultural and food enterprises, it is necessary to focus on raising the wages of workers, mechanising production, and expanding the area of irrigated land. This will raise the competitiveness of Albania's agricultural and food products to a new level and increase its exports to the world markets.

CONCLUSIONS

According to the objective set in this paper and based on the analysis of the state of productivity in agricultural and food production in Albania, the following proposals are formulated. To encourage employees of agricultural enterprises, it is proposed to increase wages at least to the level of the average wage in the country, which will boost employment in this sector. The expediency of applying innovative technologies and mechanisation in the production of agricultural products has been substantiated, as it will simplify the process of land cultivation and harvesting, expand the area of irrigated land and increase their fertility, reduce production costs, and increase the volume of production. The study revealed the positive impact of budget financial support on the productivity of agricultural enterprises and proved the need to increase such assistance, which will contribute to the growth of production for export. The comparison of agricultural exports and imports highlighted the benefits of reduced imports and the negative pressure on production from higher commodity prices. The expediency of consolidation of small enterprises was emphasised, as it can reduce their production costs and increase the profitability of agricultural products.

In further studies, the authors suggest expanding the investigation of the relationship between the increase in wages and productivity in the agricultural and food production sector, as well as establishing factors that can increase the profitability of production in the face of rising prices.

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CONFLICT OF INTEREST

The authors report no conflict of interest.

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Оцінка управління ефективністю в сільськогосподарських організаціях (з використанням факторних параметрів на прикладі Албанії)

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Анотація. Актуальність дослідження зумовлена необхідністю пошуку шляхів підвищення продуктивності сільськогосподарських і харчових підприємств Албанії та вдосконалення їх виробництва. Метою роботи є аналіз виробництва сільськогосподарської та харчової продукції, рівня оплати праці працівників сільського господарства, впливу державної фінансової допомоги на обсяги виробництва та надання пропозицій щодо підвищення продуктивності в аграрному секторі. В основу методологічного підходу покладено: статистичний аналіз, метод аналогії, графічний метод, метод логічного узагальнення. Основними результатами дослідження є обґрунтування доцільності механізації виробництва сільськогосподарської продукції, а також збільшення бюджетної фінансової підтримки та заробітної плати працівників для підвищення продуктивності сільськогосподарських підприємств, зменшення залежності від імпортних товарів та збільшення експорту албанської сільськогосподарської продукції на світові ринки. Автори підтвердили, що для підвищення продуктивності сільськогосподарських і харчових підприємств необхідно зосередитися на підвищенні заробітної плати працівників, механізації виробництва та розширенні площ зрошуваних земель. Це дозволить підняти конкурентоспроможність сільськогосподарської та харчової продукції Албанії на новий рівень і збільшити її експорт на світові ринки. Результати дослідження та сформульовані на їх основі висновки мають практичне значення для керівників сільськогосподарських і харчових підприємств Албанії при розробці заходів щодо підвищення продуктивності праці працівників, а також для уряду країни при затвердженні напрямів фінансової підтримки господарської діяльності

Ключові слова: рівень оплати праці; фінансова підтримка; міжнародна торгівля; механізація; ефективність виробництва

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Various production planning models for manufacturing execution systems

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Abstract. Presently, many enterprises are automating all processes in their production, and the metallurgical industry is no exception. There are many software products for industrial automation on the market today. Such products allow bringing certain processes to a single management process, displaying all processes and automatically monitoring performance indicators, thereby assessing the effectiveness of the models implemented in the enterprise and the operation of the entire enterprise in general. The purpose of this study is to consider which production planning models are currently used for manufacturing execution system (MES) and highlight their features, specifically when implemented at metallurgical enterprises. The study employed the following methods: analysis, synthesis, comparison, graphical presentation of data. The information basis of this paper included the studies of Russian, European, American, Asian specialists investigating the implementation of an integrated management system (MES) in the metallurgical industry. The results of this study allowed highlighting the features of existing production planning models for manufacturing execution systems (MES) in the metallurgical industry. This study is of practical importance because it allows highlighting the major features of various production planning models for manufacturing execution systems (MES) in the metallurgical industry and based on a comparative analysis, choosing the best one to implement at the enterprise. The results of a comparative analysis of production planning models for manufacturing execution systems (MES) in the metallurgical industry can also lead to the fact that an enterprise may abandon one model that is already operating in the enterprise and switch to a new, more progressive model that meets all the requirements and development trends market in the steel industry

Keywords: metallurgical enterprise; digital transformation; IT infrastructure; big data analysis; business processes

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INTRODUCTION

The purposes of digitalisation and the introduction of information technology (IT) solutions at mining and metallurgical enterprises are aimed at reducing production costs, accelerating the introduction of new products and services to the market, simplifying and optimising interaction with participants in the value chain and, consequently, increasing business profitability. The purpose of automation is the need to set up the continuous functioning of production processes. According to researchers (Yang *et al.*, 2021), the level of digital maturity and activity of enterprises in the mining and metallurgical sector is growing every year.

Currently, due to the automation of production, it is possible to solve several problems at once: to set up and configure the optimal modes of operation of technological processes; to support the smooth functioning of the enterprise; to carry out activities aimed at improving the quality of products, etc. As a rule, automation of production is based on a systematic approach to all processes: heat engineering, environmental, metallurgical, and managerial. The introduction of integrated automation at enterprises running in the metallurgical industry allows subordinating all components of the enterprise's activities to the main management centre. According to Chehri *et al.* (2021), Gong *et al.* (2021), the problem of the performance of an enterprise related to the metallurgical industry is directly dependent on ensuring environmental safety for the environment.

To increase the service life of capacities and mechanisms, it is better to build them considering the possibility of collecting data on their state. In this regard, solutions using Big Data and IoT technologies are applied, with the later integration of data with ERP (Enterprise Resource Planning) or MES systems (Manufacturing Execution System) (Armellini *et al.*, 2018). The use of simulation modelling and end-to-end tracking allows controlling the technological process to maintain the specified product quality parameters and reduce costs. The study by Shinkevich & Malysheva (2020) suggests that online analysis of a large amount of data at each stage, the development of a dynamic management of reference information (RI) and mathematical modelling provides a synergistic effect, which reduces operating and technological costs. The level of automation of the largest metallurgical enterprises today can be described as quite high, although it cannot be said that it corresponds to the latest technological trends. For instance, MES, which links production resource planning, logistics processes, downtime monitoring, product quality management, and other links in the value chain in a single information space, is often built to satisfy the interests of one side of the technological process and does not consider the possibility of further integration and modernisation of systems.

When discussing the current demand for IT from steel companies, Li *et al.* (2018), Xiaoa *et al.* (2021) are oriented towards digital solutions and services. But digitalisation is impossible to implement without ensuring the proper level of automation. Thus, the introduction or modernisation of MES is one of the necessary and obvious requests. Steady demand for software solutions aimed at increasing the effectiveness of managing logistics processes, as well as the sales and purchases unit, is dictated by economic feasibility and industry specifics.

Liu *et al.* (2021) suggest that digital technologies allow the largest metallurgical producers to form their ecosystems, unite the client network and contractors. Metallurgical companies, traditionally considered B2B, currently can reach their end customers directly and, thereby, expand their business by entering new sales markets, where they were previously represented through intermediaries.

The studies by Verevka *et al.* (2021), Yanzhao *et al.* (2020) indicate that digitalisation enables an accelerated exchange of information and ensures the mutual enrichment of companies with ideas, technologies, and successful experience. In addition, they are multifaceted in their operation and can reduce costs in the production of products. Furthermore, when carrying out the digital transformation of an enterprise, it is important that all its tools, including artificial intelligence, predictive analytics, etc., can be distinguished, combined into a single information system. One should not forget about the security of network technologies during their installation.

Thus, the purpose of this study is to consider which production planning models are used today for manufacturing execution systems (MES) and highlight their features, specifically when implemented at metallurgical enterprises. Research goals: to investigate all the MES models available on the market and identify those that are used for the metallurgical industry; to characterise the selected MES models for the metallurgical industry; to offer recommendations for improving work related to production automation.

MATERIALS AND METHODS

The main approaches used in this study were theoretical (analysis, synthesis, comparison) and graphical methods of presenting data. The basis for this study was formed by the studies of European, American, and Asian researchers investigating the issues related to the digitalisation of industrial enterprises, namely in the metallurgical industry.

The first stage characterised the MES system, identified the number of customers, contractors, and projects currently available within the framework of the implementation of MES. Using the example of Interpipe, the practices of implementing major projects within the framework of the digitalisation of production was considered. Then the author of this study investigated the products available on the market, which are being intro-

duced at industrial enterprises to automate production, namely, at the enterprises of the metallurgical industry. At the second stage of the study, several MES models were selected for a comprehensive characterisation and evaluation. The following models were chosen: A'MES metal, K.U.P.O.L., Atlas MES, Symphony MES, 1C: MES, MES PHARIS, Zenith SPPS (Special Payroll Processing System).

The second stage of the study was to provide a complete description of each model: A'MES metal, K.U.P.O.L., Atlas MES, Symphony MES, 1C: MES, MES PHARIS, Zenith SPPS. For instance, Ausferr offers the implementation of the A'MES metal model in different workshops of a metallurgical enterprise, considering the specific features of each of them. When examining the A'MES metal model, the study considered its characteristics, the objectives of the task, the functions, principles, and advantages of working in an enterprise. The effectiveness of the implementation of this model and the platform on which it runs were also assessed. When describing the K.U.P.O.L. MES model, its characteristics were given, the possibilities, main components, and advantages were highlighted. The third model considered in this study was Atlas MES. When examining this model, its characteristics, elements, purpose, tasks, and opportunities were analysed. The next MES model under study was Symphony MES. When examining it, the author considered its features, capabilities, and advantages.

Next, the author singled out another model that is often implemented at metallurgical enterprises – 1C: MES. Its features of operation and the possibility of integration with different components were identified. Another model that was considered is MES PHARIS. Its features, functions, capabilities, structure, advantages, and sources of information and data were highlighted. The last model considered was the Zenith SPPS MES system for the metallurgical industry. The features of its functioning were highlighted, along with the reasons for choosing it and its possibilities. Based on the characteristics of these models, conclusions were drawn on how each model functions in production, with what processes it is associated.

At the third stage, recommendations were proposed aimed at improving the automation of production planning for production control systems (MES). These proposals can be implemented not only at metallurgical enterprises, but also at enterprises operating in other industries. Whatever model of production automation is chosen by the management of the enterprise, it allows reducing costs, ensuring an increase in labour productivity, and reducing the amount of manual labour, both when performing any operations in the production department and related to document flow.

RESULTS AND DISCUSSION

MES is an information and communication system of the enterprise environment where production processes take place (Clemons, 2021). MES, which is being implemented at the enterprises of the metallurgical industry, can be described as a system capable of supporting the implementation of the main ones in the production process and enabling the maximum economic effect; their functionality is related to the shop floor delivery process (Zheng *et al.*, 2021; Chen *et al.*, 2021).

According to official data, there are currently 298 customers ready to implement MES systems, 196 contractors, and 345 projects ("Interpipe", 2021). The study considers various production planning models for manufacturing execution systems (MES) and the practices of their implementation in enterprises. Using the example of Interpipe, the practices of implementing major projects within the framework of the digitalisation of production were considered. The main projects of Interpipe as part of the digitalisation of production are presented in Figure 1. The company is striving to move towards the digitalisation of delivery methods and routes and enable its customers to track the production of orders online ("Interpipe", 2021). Next, the study highlights several MES models for metallurgical enterprises.

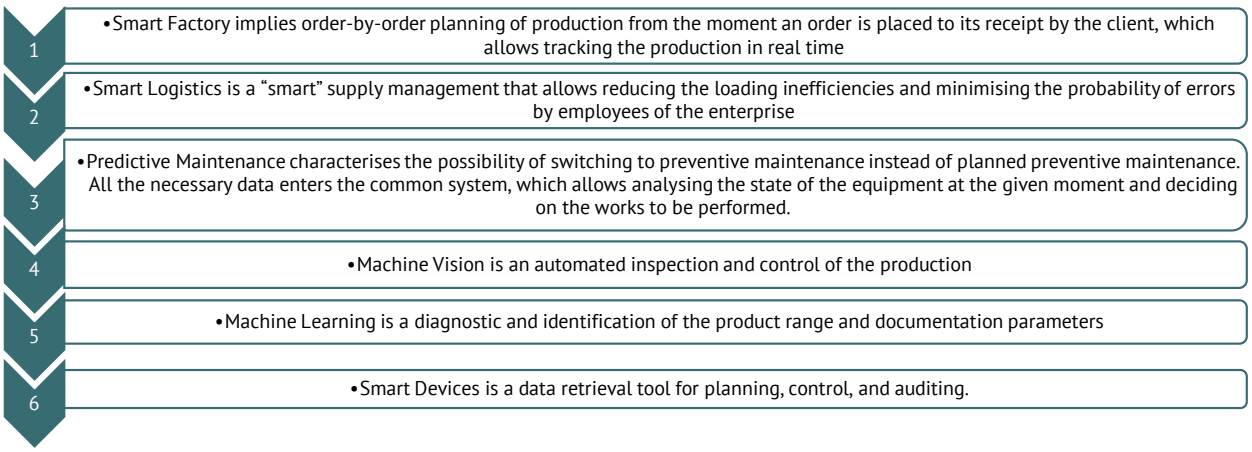

Figure 1. *The main projects of Interpipe as part of the digitalisation of production (Interpipe, 2021)*

A'MES metal is a full-featured production time management system that has been designed for use in enterprises running in the metallurgy industry. This model considers the specifics of all production business processes that occur at enterprises engaged in the metallurgical industry. Apart from the main tasks of production management, the system supports many other functions that can expand its use in the enterprise (Ausferr, 2021).

The composition and principles of the functioning of the system include: the implementation of enterprise resource planning (ERP), the implementation of business process management (Enterprise Asset Management: EAM; Customer Relationship Management: CRM; Supply Chain Management: SCM; Engine Control Module: ECM), the implementation of management technological processes (Distributed Control System: DCS; Supervisory Control and Data Acquisition: SCADA), monitoring the state of resources (Resource-aware Adaptive Scheduler: RAS), implementing production dispatching (Dispatching Production Units: DPU), collecting and storing data (Data Collection Agent: DCA), Implementation of Human Resource Management (HRM), Implementation of Quality Management (QM), Implementation of Process Management (PM), Implementation of Product Tracking and Genealogy (PTG), analysis and evaluation of effectiveness (Performance Appraisal: PA), implementation of the preparation of production orders (OpenDocument Spreadsheet: ODS), implementation of document management (DOC), and the implementation of information management of laboratories (Laboratory Information Management System: LIMS); people who work with these processes: administrators, staff, managers (Ausferr, 2021). The features of A'MES metal are presented in Figure 2.

1. •ensure the planning of manufacturing products at the enterprise with the implementation of the most effective programmes within the production cycle
2. •control the available flows of raw materials and components, from a material standpoint
3. •manage warehouses where the necessary materials and finished products are stored
4. •manage all processes directly related to production, operational accounting of production
5. •ensure the generation and transmission of tasks for automated process control systems of units
6. • ensure the implementation of the process aimed at collecting and storing information, processing this information, and transferring it to information systems
7. •ensure online production dispatching and timely detection of emergency situations
8. •provide product quality management, which would include the maintenance of protocols and data sheets of processes associated with technological operations, control to determine product quality
9. •implementat the automation of research centres by means of applying the methods of analysis of measurement system analysis (MSA) in the work
10. •monitor the production process, exercise control, which is aimed at determining the status of orders, and manage the processes associated with certification and shipment
11. •manage documentation, ensure its safety and the ability to quickly search for the necessary data
12. •analyse the level of production efficiency, create reports to determine its effectiveness, and find options for optimisation
13. •manage employees, ensure a high level of personnel involvement in the decision-making process and their personal responsibility
14. •provide the possibility of forming data samples for processing the relevant technological information to assess the state of the enterprise, technological processes, etc.
15. •manage the information that accompanies the processes associated with production
16. •ensure the monitoring of the condition and wear of equipment, manage its maintenance and repair work

***Figure 2**. A'MES metal features*

The main advantages of the A'MES metal system for enterprises in the metallurgical industry include the content of such components, tested in real production, which allow quickly and correctly adapting the solution to the conditions of a particular object (Ausferr, 2021).

Next, the study highlights the effectiveness of the use of A'MES metal. Its most clear components are as follows: the growth of productivity, the improvement of logistics processes, the optimisation of stocks, the reduction of work in progress. All this leads to an improvement in economic indicators and allows forming a positive image of the enterprise. This system allows reducing the number of deliveries that do not meet the requirements in terms of quality, by conducting a complete quality control using modern statistical methods in the work.

A'MES metal works with several platforms that ensure its productive functioning in the enterprise. The

A'Info system enables productive management of regulatory and reference information. A'Info holds guides and dictionaries specifically designed to help the industry function more efficiently, allowing for significant productivity. In turn, A'UniPlat (Universal Platform) ensures the development of a modern and efficient integration structure. A'Q cube represents an opportunity to ensure the implementation of additional capabilities in the management of the technological process of production and product quality that would correspond to the needs of a particular production. A'Material also provides similar opportunities. The systems described above have a lot of practical use and the best equipment for the quality management of certain projects (Ausferr, 2021).

The next MES model proposed for consideration is called K.U.P.O.L. (complex of production management and organisation of logistics). K.U.P.O.L. is a software environment that integrates engineering departments, supply, warehouse, workplaces, and technological equipment through the local area network of the enterprise and allows effectively managing the production cycle of product development (MES production management system, 2021). Capabilities of the K.U.P.O.L. system are presented in Figure 3. Its prominent level of integration is focused on ensuring seamless database maintenance. In addition, it allows efficiently managing production processes. The implemented technical support functionality allows sending reports online, and the availability of API (Application Programming Interface) allows interacting with external software environments. One of the many advantages of the system under study is its multifunctionality, which allows using only the currently required functionality, and using other features only as needed (Production process control..., 2021).

1. •ability to keep catalogues related to documentation on products, tools and equipment, in such areas as design and technological
2. •possibility of conducting preparation for the production of products for the electronic radio industry
3. •carry out the development of production routes between the constituent links of the production chain
4. •regulate access to work in the system, according to the roles and qualifications of the enterprise personnel
5. •ensure adherence to manufacturing routes and observe technological discipline at the enterprise
6. •approval of the calendar schedule for the product before its placement in production
7. •ensure the safety of data on each stage of production of products, as well as on the details and components created as part of this process, to be able to analyse the probable causes of failures
8. •maintaining inventory records of parts, components and finished products at the stages of manufacturing and preparing products
9. •keeping records of the number of substitutes used in the production of components, ensuring the preservation of contacts of their suppliers
10. •carry out the interaction of various types of technological equipment directly
11. •carry out integration with currently existing software environments

***Figure 3**. Abilities of the K.U.P.O.L. system*

The components that the K.U.P.O.L. system works with include production preparation, production management, and warehouse management. The ten key capabilities of this system (Fig. 4) make production more flexible and improve process control. The advantages that the system has are in its user-friendly interface, which allows increasing the possibilities in terms of penetration into the processes of enterprise operation even without subject knowledge. Furthermore, Dipol support allows customising the system to the needs of the buyer at any time of its use (Production process control ..., 2021).

1. •ability to draw up and comply with the technological route
2. •ability to provide traceability of processes, products, and suppliers
3. •ability to ensure the safe storage of products
4. •ability to carry out high-quality planning of future processes at the enterprise
5. •ability to provide data on production processes
6. •ability to keep track of the amount of inventory in warehouses
7. •ability to manage processes
8. •ability to automate workplaces and technological support
9. •ability to provide direct integration with process equipment
10. •ability to integrate with the software environment of production

***Figure 4**. Ten key abilities of the K.U.P.O.L. system*

The next model is Atlas MES, which characterises a system for automating production management (Atlas MES, 2017). Atlas MES can be used not only in large enterprises but is also focused on work in small and medium-sized enterprises, where a product, as a rule, goes through several units during its production. Thus, for example, if a product is manufactured on a single machine, then such a complex system is not required. However, if the products pass 10-15 units, along with different routes, then such a system can bring a tangible effect, both economic, social, and other types of effects. One of the key tasks of any production is to increase productivity and improve product quality without increasing the level of costs. Manual management of processes related to production and orders reduces quality, and therefore, it needs to be automated as much as possible. For instance, MES-systems can measure indicators, carry out planning, issuance, and distribution of tasks, analyse the received data, prepare reports, etc. Atlas MES includes five elements related to providing technology guidance, carrying out work on modelling technological processes, carrying out production planning, performing work with tasks from the contractor's perspective, performing work on collecting analytics related to production processes (Atlas MES, 2017).

As of the technical aspects of the model under consideration, Atlas MES is a cloud-based system, which makes it easy to deploy work and organise access to the system in factories of any size. Furthermore, it is possible to provide flexibility: any computer or Android-based device can act as a worker's terminal, due to which the system is cheaper and easier to implement, and therefore, the enterprise does not need to purchase an expensive boxed solution and immediately invest a lot of money in its implementation. The effect of the introduction of Atlas MES, from an economic standpoint, from the use of all the capabilities of this system is several times higher than its cost. As for the future of this system, the top priority for Atlas MES is, firstly, conducting analytics in terms of automating this process. Today, this system collects data, but the analysis of the received data is carried out by people who then decide based on their subjective assessment. The developers of this model strive to ensure that Atlas MES not only systematises information, but also can independently analyse it, signal problems, and offer ready-made solutions itself. In addition, the purpose of Atlas MES is to implement an increase in the level of planning, in terms of automating this process (Atlas MES, 2017).

The next model of the MES system is called Symphony MES (MES production management system, 2021). It is an enterprise process management system that can solve emerging problems related to synchronisation, coordination, analysis, and optimisation of output in real time. The system is very well-developed in its essence and is one of the most competitive among MES systems. The reason for this is its accounting features, the essence of which is to track each production element on the line online. In addition, it allows performing the necessary calculations to understand the process of manufacturing products at the moment. Its principle of operation is to provide capacity planning and continuous production support based on the received information about the processes on the line, the state of the equipment, the amount of remaining resources, etc. Symphony MES allows working more efficiently with scheduling and combining it with supervisory control (MES production management system, 2021). Furthermore, Symphony MES is a very versatile system in its own way, as it allows it to be adapted to different production capabilities and business processes.

Next, the study considers the 1C: MES model (1C: MES, 2021). The capabilities of this product are as follows: the implementation of production planning, production dispatching, volume-scheduling, data synchronisation, management of RI, factory orders, inventory management. The RI about the product is an initially available set of data that allows better planning the process of manufacturing future products. It consists of two main components: planning of material costs (a list of resources, materials, etc., used to manufacture a product) and the production process itself. All the necessary data is entered into the database and stored there, simplifying the process of managing and controlling production (1C: MES, 2021). One of the components of this database is resource specifications, which contain data, firstly, about the stages of production. In the description of this process, route maps are actively used, which is quite convenient both for understanding the data and their subsequent use. The product description methodology is identical to that used in 1C: ERP; therefore, when using it with 1C: MES, data systems are synchronised. It is possible to create RI and product compositions both using the interaction of Product Data Management (PDM) / Product Lifecycle Management (PLM) – systems with 1C: MES and using built-in products. The technological advantages of this model lie in the fact that it was developed on the latest version of the 1C:Enterprise 8.3 platform, which allows it to achieve a prominent level of security and efficiency both in terms of model generation and management, and when working in the system via the Internet (1C: MES, 2021).

The blocks that the 1C: MES system includes are provided below, in Figure 5.

One more model should be singled out – MES PHARIS (MES PHARIS, 2021). This MES PHARIS (C) model is a modular production process control system capable of solving all kinds of tasks that may face employees of production, workshops, and production sites, and can create and track the implementation of production orders. In this regard, it is important to determine some variables before the direct implementation of production, namely: who will be engaged in

its development, on what equipment and from what materials. This system is one of the most used in various industries, including metallurgy. The main functions of MES PHARIS are shown in Figure 6. MES PHARIS provides the implementation of all functions of the MESA MES model (MES PHARIS, 2021).

The modules that the MES PHARIS structure includes are shown in Figure 7 (MES PHARIS, 2021).

1. •production order portfolio management
2. •operational planning of production
3. •transportation matrix
4. •production schedule calculation
5. •production scheduling
6. •rescheduling of the production schedule
7. •production dispatching
8. •creation of production orders
9. •reflection of the fact of execution of the operation
10. •work with production terminals
11. •shift production report
12. •shift composition report
13. •generation of piecework orders
14. •quality assurance
15. •transfer of items to the warehouse
16. •role-based approach to workplace organisation

***Figure 5**. Blocks included in 1C: MES*

1. •ensuring production order management
2. •ensuring the nomenclature management
3. •providing equipment and tooling management
4. •ensuring the management of technical documentation and control programs
5. •ensuring personnel management
6. •implementation of production planning
7. •production visualisation
8. •implementation of maintenance and tracking of production
9. •information exchange with equipment that does not have built-in communication capabilities
10. •monitoring the properties of manufactured goods
11. •equipment health management
12. •analysis of the level of personnel training, as well as the serviceability of equipment
13. •accounting for the amount of energy used

***Figure 6**. Main functions of MES PHARIS*

1. •data collection
2. •control over orders
3. •control over production processes
4. •control over the keeping of documentation
5. •control of management programmes
6. •personnel control
7. •monitoring the maintenance of production facilities
8. •design assurance
9. •image provision

***Figure 7**. Main functions of MES PHARIS*

In practice, most often they start with the implementation of a basic system that can provide timely information, and conduct production visualisation with subsequent expansion to a full-fledged MES. MES PHARIS is focused on ensuring the creation and maintenance of a single base of reference data, which contains all the information necessary for the release of a product: product characteristics; operations within the technological process and their sequence; about materials for production, as well as the regulatory need for them; about the equipment that is used directly during production; about the time of equipment reconfiguration when creating a product; about the requirements for operators, etc. MES PHARIS can organise concentrated storage of programmes, which allows creating their new versions in the future, or return to the old ones, if necessary, at any time. MES PHARIS provides access for users from any place to the data they require from the documentation. MES PHARIS includes the creation of client process screens, which makes this system even more versatile and easy to use. These client process screens have all the capabilities to be displayed on almost any type of screen, even on ordinary personal computers or terminals (MES PHARIS, 2021).

Among the tasks of MES PHARIS, assistance to the operator at all stages of production also stands out. Assistance in this case will be in the form of issuing instructions on the implementation of the current stage of work, displaying data on the operation of a particular machine, and the above-mentioned submission of the necessary documents that are required at this stage of production. This is especially important given that the more information the operator receives, the fewer mistakes they will eventually make, and the less time they will spend on its implementation. One of the best ways to organise data exchange is to use the specialised EUROMAP63 protocol, which allows automatically obtaining the necessary information about the necessary parameters of the machine operation process (MES PHARIS, 2021).

Next, the study considers the Zenith SPPS MES system for the metallurgical industry (MES-system Zenith SPPS, 2021). The system provides guarantees regarding the continuity of the flow of information about all technological processes, while maintaining a constant high level of staff awareness. The key reasons to choose the Zenith SPPS MES system are the following: the need to optimise the use of enterprise capacities; the importance of maintaining consistent product quality; the need to ensure transparency of processes related to production; rapid implementation of the system into operation; the need to ensure the growth of the stability of the production process as a whole. The results of the operation of this system can be saved in several types of formats, as well as to be source codes for further analysis in other applications (MES-system Zenith SPPS, 2021). The features of the Zenith SPPS MES system are as follows: the presence of a high-performance core, the presence of an ergonomic user interface, networking (automation of the workplace of the shop manager, supervisor of the production site, technologist), ensuring openness and flexibility, accessibility to a wide range of enterprises. The use of the Zenith SPPS system at the enterprise allows significantly increasing the performance of the enterprise, namely, ensure the growth of labour productivity; ensure an increase in the equipment load factor; ensure a reduction in the volume of work in progress; ensure an increase in the level of "transparency"; improve the ability to control production processes; ensure an increase in the percentage of deliveries made on time (MES-system Zenith SPPS, 2021).

All the models considered in this study suggest that any software product related to production automation must consider the specifics of production, the quality of resources, the age of equipment, the readiness of personnel to switch to modern technologies, etc. Each of the models of production automation and individual production processes considered in this study has its specific features, its functions, advantages, relative to similar models. The market is constantly replenished with new companies that are developing IT solutions for automating production in a particular industry, considering the specifics of production, but also offering added support when implementing their product in an enterprise. As suggestions aimed at improving the automation of production planning for manufacturing execution systems (MES), the following can be proposed:

— before the implementation of automation in production, it is necessary to train all personnel to work within the framework of new technologies;

– introduce new equipment that allows implementing all the tasks in the framework of production automation;

– carry out constant monitoring and control of all electronic systems that transmit and process information;

– based on a comparative analysis of the characteristics of MES models, choose the one that is most suitable for the enterprise and considers the specifics of not only the industry where it operates, but also the production itself, its processes, and products manufactured by this enterprise;

– conduct a continuous audit of the effectiveness of the implemented model and, if efficiency decreases, be able to switch to another, more progressive model.

These proposals can be implemented not only at metallurgical enterprises, but also at enterprises operating in other industries. In any case, whatever model of production automation is chosen by the management of the enterprise, it allows reducing costs, increasing labour productivity, reducing the amount of manual labour, both when performing any operations in the shops and related to document flow. The introduction of MES systems is considered as a steppingstone towards the

creation of a high-tech manufacturing process. Due to the uniqueness, individuality, and diversity of MES-level systems, most companies developing software products for industrial automation offer various solutions, considering the characteristics of the production of an enterprise in a particular industry. As of the cases, when the MES system is indispensable in production, the following positions can be distinguished: synchronisation, analysis, and optimisation during production are required; it is required to obtain reliable information promptly about production; if the enterprise carries out many types of products, then, in this case, the processing of large amounts of data is required.

CONCLUSIONS

The study analysed many MES systems. In general, modern enterprises work with a large amount of data at various levels of management, and therefore, the introduction of automated systems is required. The efficiency of production in such a case is directly dependent on the well-coordinated work of many employees: personnel performing management functions, specialists who work in the laboratory, operators, as well as on the level of efficiency of the functioning of all means that carry out the production process. MES provide an opportunity not only to speed up the process of coordinating data flows between ERP levels and automated process control systems, but to help line operators optimise the production process and reduce the number of errors.

The integration of the MES system, as a rule, does not require large expenditures, and therefore, there are plenty of positive aspects from the introduction of the MES system, which include the acceleration of production activities by optimising various processes, the ability to improve product quality due to the possibility of introducing necessary amendments to the planning of the production process based on detailed information about the production load and what raw materials were used; increasing the productivity of technological equipment, personnel, materials; increase in data processing speed and many other indicators. As for what determines the choice of MES, it is not so much the choice of the system that plays a role, but the choice of functions used in it. The main criterion for choosing an MES model should be the focus on choosing a process with the most problems (or vice versa – with the greatest opportunities for improvement). Thereafter, it is worth selecting such functions within the framework of the system that allow influencing this particular process. Promising in subsequent research is to investigate the possibilities of increasing the efficiency of one or more MES systems, based on the disadvantages existing in them.

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CONFLICT OF INTEREST

The authors report no conflict of interest.

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Різні моделі планування для систем управління виробництвом

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Анотація. В даний час багато підприємств автоматизують всі процеси на своєму виробництві, металургійна галузь не є винятком. Сьогодні на ринку існує безліч програмних продуктів для автоматизації виробництва. Такі продукти дозволяють звести окремі процеси до єдиного процесу управління, відображати всі процеси та автоматично контролювати показники ефективності, тим самим оцінюючи ефективність впроваджених на підприємстві моделей та роботу всього підприємства в цілому. Метою даного дослідження є розгляд того, які моделі виробничого планування використовуються в даний час для систем управління виробництвом Manufacturing Execution System (MES) та висвітлення їх особливостей, зокрема при впровадженні на металургійних підприємствах. В ході дослідження були використані наступні методи: аналіз, синтез, порівняння, графічне представлення даних. Інформаційною базою даної роботи стали дослідження європейських, американських, азіатських фахівців, що досліджують питання впровадження інтегрованої системи менеджменту (ІСМ) в металургійній галузі. Результати даного дослідження дозволили виділити особливості існуючих моделей планування виробництва для систем управління виробництвом (MES) в металургійній галузі. Дане дослідження має практичне значення, оскільки дозволяє виділити основні особливості різних моделей виробничого планування для систем управління виробництвом (СУВ) в металургійній галузі та на основі порівняльного аналізу вибрати найкращу з них для впровадження на підприємстві. Результати порівняльного аналізу моделей виробничого планування для систем управління виробництвом (MES) в металургійній галузі також можуть призвести до того, що підприємство може відмовитися від однієї моделі, яка вже працює на підприємстві та перейти на нову, більш прогресивну модель, яка відповідає всім вимогам та тенденціям розвитку ринку в металургійній галузі

Ключові слова: металургійне підприємство; цифрова трансформація; IT-інфраструктура; аналіз великих даних; бізнес-процеси

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Specific features of using life quality assessment tools for geriatric horses: Literature review

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Abstract. With the change in the social role of horses and the development of veterinary medicine, their average life expectancy has increased, so the problem of the quality of life of geriatric horses has become relevant nowadays. The purpose of the study is to determine the main approaches to the assessment of the quality of life of horses in old age. The study employed the following methods: analysis, synthesis, comparison, graphical presentation of data. Five main ways to improve life expectancy and QoL indicators and reduce mortality of old horses were determined: full and sufficient feeding; ensuring optimal ADL performance; creation of comfortable housing conditions; conducting cryotherapy maintenance vibrotherapy, manual therapy, horseshoe therapy, therapeutic and preventive exercises, magnetotherapy, phototherapy, shock wave and ultrasound therapy; use of modern methods of early detection and treatment of oncological diseases. It was found that the most common causes of death were diseases of the gastrointestinal tract, followed by diseases of the musculoskeletal system and reproductive system, and oncological diseases. Among the latter, tumours of the pituitary and thyroid glands, melanoma, sarcoidosis, lymphoma, squamous cell carcinoma (SCC) prevailed – up to 60% of oncological sick horses. It was summarised that quality of life assessments, including evaluation of factors related to health, activities of daily living and mental well-being, are useful in informing decisions

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regarding management, health care and euthanasia. The results of this study can be used by equestrian professionals, farmers or veterinarians to help them choose the safest and most beneficial care for horses

Keywords: veterinary medicine; treatment; oncology; disease; euthanasia

INTRODUCTION

Over the last century, the role of horses in modern society has changed. Working-user horse breeding has lost its importance, while at the same time the demand for sports and prize horses has increased. There is a growing trend towards more applied roles, including intellectual horsemanship. In developed countries, the use of horses for recreational rather than commercial purposes is common. For example, according to C.M. McGowan, more than one-third of horses are used for recreational purposes, about one-third are used mainly for equestrian sports and shows, and the remaining 20% are used for hippotherapy and other purposes (McGowan, 2011). J.L. Ireland *et al.* (2011) characterise the relationship between people and animals as unique and strong, due to the long-term interaction between owners and athletes. Thus, the role of horses as recreational animals has been negligible for the past few decades. C.M. McGowan and J.L. Ireland (2016) in a research survey of 50,000 US households found that 38.4% of owners keep their horses for family and children, and more than half 56.5% – as pets, 5.1% – use only economic criteria.

R. Bushell and J. Murray (2016) claim that during a Dutch survey of horse owners, 47% of respondents named horses as their partners. In Great Britain, a 15-year survey of horse owners found that about 60% of the animals were used for recreation and sport, and 30-40% were kept as companions. About 25% of horse herds aged 15 and over kept their horses until old age or natural death, according to a survey of owners. M.K. Mueller *et al.* (2018) argue that most owners of elderly horses are concerned not only about their health and well-being, but also about the ability to maintain a high quality of life. Owners' interest in the health and well-being of their ageing animals is reflected in veterinary care, with the number of hospitalised horses steadily increasing. Thus, during the ten-year observation period, there was an almost six-fold increase in the total number of hospitalised horses from 2.2% to 12.5%.

S. Popescu *et al.* (2014) established that getting older, horses are more likely to suffer from chronic diseases. Given the above, when horses getting older, it is necessary to assess and maintain the quality of life of such animals. The state of health is often equated with the quality of life, therefore, the creation of a system of standards for its assessment is established in risk groups starting from 12-15 years of age.

Considering the increase in the average age of sports horses, for recreation, companions, the question arises of ensuring the quality of their life. Given the relevance of this issue, the goal of the research was to determine the main approaches to studying the quality of life of horses in old age in the process of analysing the results of fundamental research on this issue. According to the set goal, the following tasks have been established for the horses of the geriatric group: to analyse the role of owners and veterinarians in determining the quality of life (QoL); to investigate the factors of QoL assessment to determine the importance of daily activities; to determine the relationship between mortality and key factors of euthanasia in horses of the geriatric group according to QoL parameters.

PREPARATORY RESEARCH ANALYSIS

In world practice, a protocol Animal Welfare Indicators (AWIN) is used to assess the well-being of horses on farms, being aimed at improving animal welfare by developing practical protocols for assessing the well-being of horses (*Equus caballus*): selection of potential welfare indicators; elimination of gaps in knowledge; consultation of interested parties; testing the protocol prototype on the farm (Dalla Costa *et al.*, 2015). M. Long *et al.* (2022) in their research, focuses on comprehensive studies of the shortcomings of the welfare of horses, requiring the application of basic welfare criteria for evaluating animals in modern horse breeding.

The study by E. Dalla Costa *et al.* (2017) describes the created digital application AWIN Horse, it allows farmers, veterinarians, zoo technicians to determine indicators included in the AWIN protocol, which provides visual feedback on the well-being of horses, emphasises positive conditions and establishes comparisons with a reference population. According to M.M. Ratz *et al.* (2021), the well-being of horses of the geriatric group is assessed by the condition of the individual, the degree of satisfaction of needs, the absence of discomfort, physiological and biochemical indicators, animal behaviour, and the level of productivity.

Z. Raw *et al.* (2020) developed nine protocols consisting of 19 indicators of equine welfare based on Equid Assessment, Research, and Scoping (EARS). F.D. McMillan (2005) determined the indicator of the duration of hunger by weight, weight formula, visual assessment, and body condition score (BCS), this criterion is based on the monitoring of weight and hunger, since obesity is as much a welfare problem as underweight, and some animals can become obese when hungry. M.O. Zakharenko *et al.* (2021) consider the criterion of the absence of long-term thirst, which allows one to assess the level of dehydration based on the skin test, the dryness of the mucous membrane, and the "bucket of water" drinking test.

M.M. Brosnahan and M.R. Paradis (2003) describe the criteria for comfortable rest and thermal comfort, based on the duration and quality of sleep, the ability to lie on the side than in the supine position of the sternum, and the optimal temperature conditions of keeping, which affects their well-being and productivity in animals' geriatric group. M. Wisniewska *et al.* (2019) in their study, note an important criterion easy movement of horses in sufficient space, because locomotion plays a key role in the positive physical and mental health effects. A.B. Miller *et al.* (2021) emphasise the widespread one-box keeping of horses, finding that confinement endangers their well-being, especially in geriatric individuals.

N. Jarvis (2021) reports that more than 70% of horses over 20 years old have age-related diseases that require special care, reduction of respiratory and cardiovascular functions before intense exercise, problems with thermoregulation, including assessment of body weight, hydration status, and pain indicators. T. Doherty and A. Valverde (2008) provides an estimate of the quality of life of horses of the geriatric group under different conditions of keeping, especially when it is a question in making veterinary decisions regarding the euthanasia of chronically ill and old animals. The criterion for identifying injuries is characterised by the appearance of age-related changes in hair colour, hairless spots, skin lesions, swollen joints and tendons, a sensitive back, and lameness.

According to E. Boldt (2022), in horses of the geriatric group, it is mandatory to take care of the legs with the use of anti-inflammatory drugs for the joints, a thick layer of litter, installation of light horseshoes for comfortable movement. The criterion for the absence of diseases in horses is the absence of behavioural pain syndrome, the presence of ectoparasites, unhealthy hair, faecal contamination, cough, abnormal breathing, discharge from the eyes and nose, changes in the colour of the mucous membrane, and limb abnormalities. P.M. Dixon and I. Dacre (2005) point out the importance of dental health, horses' teeth continue to grow throughout their lives, but the rate of wear exceeds growth, wearing them down to the point of being unable to chew dry hay and straw, so geriatric animals are more often fed grass from pastures, grass pellets wheat flour, beet pulp, crushed grain, which are soaked in water and given in the form of thick or liquid porridge.

According to B.M. Hopka *et al.* (2011), the main problem for older horses is loss of condition, which is facilitated by dental conditions, parasite control, chronic diseases, reduced absorption of nutrients, and loss of appetite to the point of anorexia. F. Napolitano *et al.* (2008) reveal in his work the essence of the expression of social behaviour of horses, as highly social herd animals, considering the important role of being in a group. Moreover, with age, suppression of the emotional state of fear, suffering and apathy is possible in horses.

D. Bedenice and A.L. Johnson (2022) determined that the level of trust in people affects productivity and behaviour, strengthening the fear response, positive emotions of security and satisfaction. D. Butler *et al.* (2019) established that in the practice of veterinary care for ageing horses, the concept of integral indicators of QoL is used, borrowed from the medical practice of human geriatrics, where QoL includes special tools approved for monitoring the impact of pain, chronic diseases and age-related changes on the quality of life. QoL is also used to determine the success of treatment and other interventions. Despite the frequent use of this concept both in medicine and in veterinary medicine, a single consistent definition has not been developed in veterinary medicine.

S. Dyson (2002) characterises modern attitudes to the quality of life of horses QoL. There are objective and easily measurable indicators of physical health, as well as subjective indicators of psychological state (PS) and total enjoyment of life (TEL). They are defined as objective complex indicators of QoL, PS and TEL. The owner (caretaker) and a veterinarian who regularly treats horses over the age of 20 must participate in the assessment.

M.M. Pudgorotsky *et al.* (2019) reported that health-oriented quality of life assessment tools related to specific conditions and diseases were developed primarily for use in small animal medicine in dogs and productive farm animals. The requirements of horses are markedly different from those of small animals and livestock, so previously published tools for these species cannot be directly extrapolated to assess the quality of life of horses. Investigation of the problems of well-being, maintenance, and use of older horses for the preservation of high sports results in athletes of various levels is gaining relevance.

BASIC ASPECTS OF HORSE WELFARE

The analysis of literary sources indicates an increase in the life span and term of use of horses of all directions in most countries. Unsurpassed results are currently being observed in the US Equestrian Association. Ballynoe Castle RM horse, which is a mixture of Belgian Warmblood and Irish Thoroughbred, after reaching the age of 15, was included in the 4th place in the composition of the USA team at the World Equestrian Games (WEG) in 2010 and 2014. In 2015, "Reggie" continued to win many top-level competitions, but in 2016 he stopped competing. Thoroughbred Arabian endurance horse "Haji Karev Omar" covered 8,575 miles in 170 races at the American Endurance Ride Conference (AERC). "Smart Snap" won the National Show Horse Association and Equestrian Congress titles from members of the Galbraith family, and the 17-year-old bay gelding now competes in France, Italy, Germany and Canada, winning nearly 150 races (Dalla Costa *et al.*, 2014).

As a general rule, if having proper training and management, competition horses can continue to compete

at the highest level well into their older years, often in the range of 15-20 years. The same trend was observed in studies of horses of amateur equestrian organisations for 2014-2019. From the studied herd, 31.3% of horses belonged to the older group at the age of 15 years and older. The share of horses in the older group increased from 60% to 77.8% when the height of the obstacle was higher than 80-110 cm. Older horses had an advantage over younger horses on all routes. In the course of the study of the correlation between the age of the horse and the indicators of sports use, the value of older horses was also confirmed. This indicator increased from +0.192 to +0.694 correlating with an increase in the height of obstacles (Koskinen, 2014; Fenner *et al.*, 2019).

The loss of the importance of working-utility horse breeding, given an increase in the role of applied and intellectual, the predominance of the use of horses for non-commercial purposes and proper veterinary care – increases the average life expectancy of horses. There is some disagreement about which horses can be considered old. Not so long ago, a horse at the age of 8 was considered old, in some publications the maximum age of a horse was equal to 25 years, but today the perception of the age of horses has changed radically. At the 2012 London Olympics, of the 74 horses that competed in the triathlon, 23% were over 15 years old, with the oldest being 20; in dressage competitions, 24% of the 50 horses were over 15 years of age, including two of the three prize winners. In the USA, from 7 to 15% of sports horses are over 20 years old, while 63% of them still perform at various sports events, 10% participate in international competitions (Egenvall *et al.*, 2006).

A number of physiological changes are associated with ageing in horses: metabolism, insulin-like growth factor 1 (IGF-I), endocrine and immune and respiratory functions, aerobic capacity for exercise, cardiovascular tone decrease. Changes in the structure of muscle fibres are observed, animals become less hardy and tolerate intensive training worse. Control of cardiac activity is an important element of health control, especially for sports horses, in which the percentage of cardiovascular diseases is 61.5%, and when getting older, the efficiency of the heart muscle decreases and diseases of the cardiovascular system develop, therefore the heart rate increases and the animals sweat more actively. Young horses have a high physiological reserve, the ability to quickly recover, which is confirmed by their ability to adapt to loads. Horses of the geriatric group have problems with thermoregulation, so after training, the animal's normal body temperature is restored slowly (Briceno *et al.*, 2018).

The morbidity of cardiovascular system organs in horses older than 10 years for 2018-2020 is 55%, 6-7 years – 48%, 3-4 years – 20%, and in two-year-old animals only 5%. In sports horses, pathology of the organs of the cardiovascular system was noted much more often in 61.5%, less often in training horses – 15.4%, inseminators – 15.4%, and mares – 7.7% (Sobol *et al.*, 2020). Maintaining health and establishing high QoL indicators of horses is impossible without monitoring the state of the cardiovascular system in the geriatric group of animals, this parameter can provide some measure of health-related quality of life in horses. Assessment of individual or combined health indicators will not be sufficient for the geriatric group, so although weight loss or obesity may affect the risk of morbidity and mortality, the BCS assesses this problem partially. The problem of assessing the subjective parameters PS and TEL can also imperfectly give an adequate assessment of the horse's quality of life. Veterinarians are effective evaluators of equine health, although owners have more experience with individual animals and can significantly influence psycho-emotional well-being. Long-term ownership of geriatric horses tends to increase, and most owners are responsible for the day-to-day care of such an animal a long time. Thus, compared to veterinarians, owners have much more knowledge about their animal. As research has shown, they are familiar with the character, behaviour, and daily routine of their animal, have a heightened awareness of the importance of external factors from the standpoint of an individual animal.

QoL depends on the individual's perception and interpretation, leading to several forms of personal bias. The owner's perception of the quality of life and factors affecting the dependence of anthropomorphism or anthropocentrism, therefore, the owner, and the veterinarian must participate for a comprehensive QoL in geriatric horses. The vast majority of owners believe that their geriatric horses have a good or excellent quality of life; however, increasing age of the horse is associated with a decrease in QoL rating, from the owner's perspective. Welfare issues were named the fourth most important health issue affecting geriatric horses in a large survey of Australian owners. Among the largest horse owners in the Netherlands, 99.6% said that good health is an indicator of good well-being. Existing problems with health and increasing age of horses were negatively associated with quality of life because they were assessed by owners, not corresponding to QoL factors.

Mortality rates increased with age and varied greatly between breeds. Survival analysis showed that the average age of registered horses was 18.8 years. Joint problems are the most common cause of death or euthanasia (Hemsworth *et al.*, 2015). Research into the causes of death in thoroughbred horses, conducted between 2008 and 2012, showed that the most important causes of death were fractures due to skeletal muscle damage, abdominal crisis, intestinal torsion or stomach rupture, and respiratory pathology. For example, arthritis common in geriatric horses is found in many sport horses, in some cases the disease in the herd exceeds 70% (Hemsworth *et al.*, 2015). The aetiology of arthritis

varies, ranging from infections to complex fractures. In the event of pathology, animals are given preventive cryotherapy sessions, which are especially effective in the acute phase of the disease, trauma, or sudden relapse. Cryotherapy sessions are carried out in the first three to four days, the actions contribute to the removal of the pain effect in the affected area, reduction of swelling, cessation of inflammatory processes. For example, pneumonia in horses represents a significant number of cases of pulmonary bleeding caused by physical activity.

ASSESSMENT OF THE QUALITY OF LIFE OF HORSES AFTER SUCCESSFUL TREATMENT

The state of health after successful treatment of diseases with significant changes of about 18% in chronic forms is considered by owners to be a priority for the QoL of geriatric horses (Hotzel *et al.*, 2019). In addition, QoL is an important factor in the owner's decision-making regarding options for long-term treatment or euthanasia of the horse. In the assessment by the owner of the QoL of a geriatric horse, the main role is played by the state of health, therefore, a larger share of owners performs significant factors influencing the QoL: full balanced feeding according to age groups and health status; comfortable maintenance (especially stables, shelter in pastures, warmth, presence of rugs, etc.); the presence of other horses, because horses in nature live in small social groups; veterinary care (preventive health care, improvement of symptoms by providing effective analgesia. The owners focused no less attention on curative and preventive measures to support QoL: regular exercises, their intensity and variety, frequency of performance, gentle driving. Activities of daily life (ADL) is a key component in the assessment of QoL in geriatric individuals, lower scores for ADL were obtained in horse riding in association with increased risk of mortality, insist on the degree of restriction according to the effect of normal ageing (Hotzel *et al.*, 2019).

Considering the age factor, the mortality rate in geriatric horses increases with the transition to older groups of animals: among horses 10-12 years old, it is 4-6 cases per 100 animal units. At the age of 15-20, the rate is 9-11 people per 100 animal units; from 20 years old – 35-42 per 100 animal units. In many studies, the reported causes of death or euthanasia in geriatric horses are largely similar to some variation depending on the population. During the post-mortem pathological examination of breeding horses over 15 years of age, the most common causes of death were diseases of the gastrointestinal tract, musculoskeletal system, and reproductive system. For horses over the age of 20, various oncological diseases prevailed. The percentage of oncological diseases and tumours as causes of death was more than 16% in horses 15-20 years old, up to 22% in horses over 20 years old. Thus, subclinical signs of pituitary and thyroid tumours were observed in 70% of older horses, in grey horses older than 15 years, about 80% suffered from melanoma. The most common type of neoplasm is sarcoid – an oncological disease diagnosed in 39.9% of horses, compared to other cancers. According to the American statistics of neoplasms of horses, neoplasia, which is a common type of cancer, is diagnosed in the range of 45-80% compared to other cancers. SCC is a skin cancer with a prevalence of 60% (Taylor & Haldorson, 2013).

Serious injuries, incurable bone diseases are common causes of death in horses of various ages, thus fatal limb fractures have been recorded in animals older than 5 years and a small part of geriatric horses, which have non-traumatic diseases of the musculoskeletal system with fatal consequences. In horses of the geriatric group, important moments of QoL are preservation of ADL, PS, and TEL, but quite often the disease of the musculoskeletal system becomes a direct cause of death or euthanasia (De Sousa *et al.*, 2017).

Approving decisions regarding euthanasia, owners of geriatric animals take into account concomitant diseases, signs of ageing and exhaustion, noting specific diagnoses. The number of animals euthanised due to old age and concomitant disease for 2018-2022 was 26.8%, the number of horses with age-related problems was 8.4%, due to an accident or serious injury was 4.2%. In the US, old age is the most common cause of death or euthanasia, with 29% of deaths in animals older than 6 months and 2/3 in horses older than 20 years. Old age is the most common reason for horses to be unable to ambulate, stand on their own, climb unaided, or can stand but not walk. For horses over 30 years of age, the percentage unable to move is 10.4%, which is a serious welfare problem. Advanced age is not considered a specific cause of death, but a significant increase in age with massive signs of ageing affects the owner's decision regarding treatment options for geriatric horses (De Sousa *et al.*, 2017).

The economic factor is quite a strong reason, because the cost of keeping geriatric horses, with the costs of treating associated diseases, can make the owner likely to choose euthanasia, compared to expensive or long-term treatment. In cases where geriatric horses were found to have incurable concomitant oncological and musculoskeletal diseases with pronounced pain syndrome, 43% of the owners made decisions on euthanasia. For financial considerations, the decision to euthanise was influenced by insistence for only 2% of owners (Ireland, 2020).

Therefore, the state of health of the oldest horse will be an important determinant of its quality of life and health. The attention of veterinarians provides many opportunities to evaluate their patients using the Health-Related Quality of Life index (HRQoL). It is important to understand that the index includes more than a thorough clinical examination. Assessment of animal's health status will primarily involve assessing

the impact of specific clinical features or physical limitations caused by the disease, such as pain or fatigue, whereas HRQoL measures are broader, including mental and social well-being.

The most common causes of death or euthanasia were diseases of the oncological, gastrointestinal tract, musculoskeletal system, and reproductive system. Among the latter, oncological diseases of the pituitary gland and thyroid gland prevailed – 70%, melanoma – 80% of grey horses, sarcoidosis – 40%, lymphoma – 45-80%, squamous cell carcinoma – up to 60%. Quality of Life assessment includes health-related factors in daily life activity and mental well-being, useful for informing decision-making and management, health care and euthanasia, ensuring maximum longevity while preserving QoL. Equine welfare instruments are defined by environmental condition or health scores, BCS, hydration, lameness pain, and cardiopulmonary parameters. Parameters can be a measure of health-related quality of life, but assessment of individual or combined parameters may not be sufficient for geriatric horses. For example, weight loss and obesity are common in older horses and can affect mortality risk.

CONCLUSIONS

Given the conducted analysis, the issue of ensuring the quality of life of horses of the geriatric group, related to the change in the social role of horses, the loss of the value of working animals, the reproductive value and the increase in the role of intellectual horse breeding, for non-commercial purposes, was considered. Such changes led to an increase in the level of veterinary care and a corresponding increase in life expectancy, and an increase in the average age of horses, especially amateur animals.

If relatively recently, sports horses aged 8 years and older were considered age-matched, now horses over 15-18 years old are successfully performing, even at the international level. Older horses can have various health problems, but the factors affecting their well-being and quality of life are higher than in younger animals. Currently, there is no varied tool for assessing the quality of life of horses in animals of any age. However, in horse breeding, many medical resources borrowed from the preventive and therapeutic actions of humans or small animals are used, which should be included in detail in the assessment of QoL for horses of the geriatric group. Veterinary surgeons actively discuss quality of life with owners, conducting a comprehensive QoL assessment in older animals. The well-being of horses of the geriatric group is realised in the process of care, feeding and maintenance, as the owner and the veterinarian.

As a result of the study, five main factors of the most effective ways to improve life expectancy and QoL indicators and reduce mortality in the geriatric category were determined: full and sufficient feeding while maintaining the recommended BCS parameters; ensuring optimal ADL performance based on use, breed, and individual characteristics, including equine and human interactions, varied exercise, and economical riding; creation of comfortable housing conditions – shelters, dens, blankets, blankets, bedding; conducting cryotherapy maintenance therapy vibrotherapy, cryotherapy, manual therapy, horseshoe therapy, therapeutic and preventive exercises, magnetotherapy, phototherapy, shock wave and ultrasound therapy; use of modern methods of early detection and treatment of oncological diseases. In future studies, the analysis of the dependence of the life expectancy of horses on their nutrition and methods of treatment can be deepened

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CONFLICT OF INTEREST

The authors report no conflict of interest.

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Особливості використання засобів оцінки якості життя геріатричного коня

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Анотація. Зі зміною соціальної ролі коней і розвитком ветеринарної медицини середня тривалість їхнього життя зросла, тому проблема якості життя геріатричних коней набула актуальності в наш час. Метою статті було визначити основні підходи до вивчення якості життя коней у літньому віці. Основними методами роботи були аналіз і систематизація джерел. Визначено п'ять основних шляхів покращення показників тривалості та якості життя і зниження смертності старих коней: повноцінне та достатнє харчування; забезпечення оптимальної продуктивності повсякденних активностей; створення комфортних умов утримання; проведення кріотерапії підтримуючої вібротерапії, мануальної терапії, підковотерапії, лікувально-профілактичної фізкультури, магнітотерапії, фототерапії, ударно-хвильової та ультразвукової терапії; використання сучасних методів раннього виявлення та лікування онкологічних захворювань. Встановлено, що найпоширенішими причинами смерті коней були захворювання шлунково-кишкового тракту, на другому місці – захворювання опорно-рухового апарату та репродуктивної системи, а також онкологічні захворювання. Серед останніх переважали пухлини гіпофіза та щитовидної залози, меланома, саркоїдоз, лімфома, плоскоклітинний рак – до 60% онкохворих коней. Було підсумовано, що оцінка якості життя, включаючи оцінку факторів, пов'язаних зі здоров'ям, повсякденною активністю та психічним благополуччям, є корисною для прийняття рішень щодо лікування, охорони здоров'я та евтаназії коней. Результати цієї роботи можуть бути використані професіоналами кінного спорту, фермерами або ветеринарами, щоб допомогти їм обрати найбезпечніший і найефективніший догляд за кіньми

Ключові слова: ветеринарна медицина; лікування; онкологія; захворювання; евтаназія

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Category management: Industry vs trade

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Abstract. Identification of the peculiarities of category management in trade and industry enterprises, and development and testing of the method for category management evaluation in the light of global macro-trends that transform category management under the current conditions determined the relevance and purpose of the study. Nowadays, category management is perceived by most organisations as a continuous business process where category management activities are an integral part of the business. The theoretical and methodological basis of the study was the conceptual principles and methodological approaches to the management of product categories, which are highlighted by Ukrainian and foreign researchers, in the materials of periodicals, and in the Internet resources dedicated to the investigation of classical and modern concepts of category management. In the process of their development, such scientific and empirical methods as causal analysis and synthesis, deduction and induction, systematisation and generalisation, system and process approaches were used. The conducted research revealed the presence of significant reserves for the development of category management at industrial enterprises. According to the results of "The Future of Category Management" survey, such global macro trends of the transformation of category management were identified as the store

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of the future; digital supply system; the future of the food market; the growing role of environmental, social, and corporate responsibility. An approach to assessing the state of category management at a trade and industry enterprise is proposed, with the help of checklists for monitoring the state of provision of category management and monitoring the assessment of the organisational effect in the field of enterprise category management. The proposed approach to assessing the state of category management will contribute to the improvement of approaches to planning, information, and analytical support and control over the main management processes at the enterprise

Keywords: category management; management; industry; trade; retail; brand; social responsibility

INTRODUCTION

The COVID-19 pandemic has been replaced by martial law in Ukraine. Their consequences may be most tangible and durable in the long-term prospect for consumer-oriented companies that were affected by the pandemic and war crisis. Today enterprises are developing in the context of intensifying competition for target markets, the emergence of new information and communication technologies, new forms and distribution channels, and the introduction of innovative services. Therefore, they should work to anticipate the already rapidly changing consumer needs to convincingly win the consumer and create the necessary conditions to ensure their loyalty to the company. Such an advanced strategic maneuver can be considered the concept of category management, which is increasingly penetrating Ukrainian business now. Usually, category management is focused on obtaining effects from the product categories, first of all, in the form of reducing the cost of purchases, stocks, and, sometimes, optimising the logistics costs, and therefore, becomes relevant for implementation at enterprises of various fields of activity.

The first publications on category management belong to foreign authors, in particular J. O'Brien (2009), manager of the international procurement management consulting agency, published a book "Category Management in Purchasing". This was the first book about the application of category management to non-retailers.

A. Sinha *et al*. (2013) proposed model that allows solving strategic and tactical decisions of category management in the activities of the trading enterprise, but is not adapted to industrial management. Further research was devoted to organising category management functions within PSM, and integration between the purchasing department and other business functions in the process of purchasing category management. Four cases of application in manufacturing companies were considered (Heikkilä *et al.*, 2018).

Category management in e-commerce is mentioned by B. Mihalčová & M. Pružinský (2014), describing the preferences of stakeholders, summarising the results of the study of category management in e-commerce and presenting new categories that will increase the profitability of this business. The scheme of distribution of roles between participants of the 3D-system of category management was considered by N. Mykytenko (2020), as it can be implemented in the activities of an enterprise of any field of activity. In addition, models describing the forms of organisation of production activities in the conditions of probabilistic nature of demand were developed and their implementation by strategies of marketing interaction with consumers of products was determined by T. Kuvaieva & K. Pilova (2021).

I. Yashchyshyna *et al*. (2020), revealed the features of the social impact of corporate social responsibility of mining enterprises. Such approaches are important in the development of category management in the activities of an industrial enterprise. The monograph by V. Voronkova & N. Metelenko (2020) provided a complete, systematic, and concise coverage of a wide range of theoretical issues in the field of industrial management, based on digital technologies.

The study of a new key performance indicator, Category Conversion Power (CCP) is based on a unique data set obtained through a real-time location system (RTLS), which allowed the authors to collect behavioural data (Pascucci *et al.*, 2022). Despite the sufficient number of studies, this problem remains rather underinvestigated today.

*The purpose of the stud*y is to analyse specific features of category management at the trade and industrial enterprises, create and test the method of evaluation of category management in terms of global macro trends that transform this concept in modern conditions.

Based on this goal, the following tasks were formulated: 1) systematise the evolutionary path of category management, highlighting the stages of its development in trade and industry; 2) propose a system of indicators for monitoring the state of ensuring category management and evaluating the organisational effect in the sphere of category management; 3) monitor the state of security and evaluate the organisational effect in the field of category management at trade and industrial enterprises in Ukraine; 4) identify global macro trends in the transformation of the future of category management. They also assume different toolkits, which has been the focus of this study.

MATERIALS AND METHODS

The theoretical and methodological basis of this study is the conceptual principles and methodological

approaches to the management of product categories that are highlighted by Ukrainian and foreign researchers. Materials from periodicals and the Internet resources devoted to the study of classical and modern concepts of category management were also used. Scientific and empirical methods like causal analysis and synthesis, deduction and induction, systematisation and generalisation, and system and process approaches were also applied.

During the research, a complex of general scientific and special methods was used: analytical and logical generalisations – to systematise the evolutionary development of category management with the selection of stages of its development in trade and industry; methods of comparative analysis and synthesis – to clarify the specifics of category management in trade and industry with reference to the classical model by B. Harris; economic and statistical methods (sampling monitoring, comparative and technical and economic analysis, grouping) and the method of experimental evaluations – for the development and approval of a system of indicators for monitoring the state of ensuring category management and assessing the organisational effect in the field of category management at real enterprise operating in Ukraine; methods of marketing and sociological studies (surveys) and methods of generalisation – for conducting the survey "The Future of Category Management" and identifying global macro trends in the transformation of category management at modern enterprises.

To test the presented scientific developments, a survey was conducted, which included 163 respondents aged 20+, of various social statuses, professional skills, and positions from 64 enterprises of Ukraine, which have different sectoral groups, forms of ownership, number of employees, working conditions and technologies. The selected respondents gave voluntary consent to participate in the survey and completed the questionnaires. For the offline survey, adults were selected who voluntarily answered the questionnaire "The Future of Category Management" In each questionnaire, the respondent indicated consent to the processing of personal data and answers provided.

RESULTS AND DISCUSSION

The problem of development of category management. Category management is one of the concepts of management of a trade assortment based on the selection of product categories in it, which is aimed at increasing the business results of the enterprise, mutually beneficial integration, and cooperation between all participants of the goods movement system, the formation of consumer loyalty and optimal satisfaction of their needs. Initially, category management originated in grocery retailing. Owners have found that they can unusually group goods and evaluate the range not as a set of individual products, but as a product mix given the key consumer views. But today, the field of application of category management is no longer limited to retail trade (Table 1).

***Table 1**. Evolution of category management*

Period, participants, and stage	General characteristics of the stage and the main achievements of category management
1986, Apollo Space Management System	Following the instructions of the Apollo Space Management System, the Schnucks supermarket chain has set aside more space in baby food sections. As a result, sales in these sections increased by 20%. Schnucks soon began using the Apollo programme for all its categories, and in 1987 its main competitor left St. Louis. All this led to the creation of a revolutionary idea: the store can increase sales, approaching the range not as a combination of individual products, but as a set of certain categories or product groups.
1990, Procter & Gamble, Efficient Consumer Response	The stage is associated with Procter & Gamble, which in the early 1990s for the first time combined products in the category not by the principle of production, but by their common properties for the consumer.
2000, Super- and hypermarket chains, Modern retail	Mass use of technological innovations; introduction of unified approaches in the retail network to the introduction of automation of accounting, storage of goods, control of transactions, etc.; offering unique approaches to grouping the range of goods within the retailer; distribution of goods by groups, categories, and SKU; dynamic advertising of goods and services; use of multi-channel communication in customer service (television, e-mail, the Internet, mobile phones, etc.); the possibility of producing goods of its brand.
2013, Pharmacy chains, Pharmacy	Ability to meet the needs of end consumers, to invest with maximum efficiency in strategic categories of goods, and increase the loyalty of the end consumer to a particular brand of pharmacy chain or individual pharmacy.
2018, Industrial enterprises, Industry	Manufacturing companies need to respond quickly to changes in the market of a product and consider changes in market needs. The same range of products that have been produced at the company for years should be reviewed periodically. Tastes and needs change under the influence of scientific and technological progress, as a result of new fashion trends, new views on human safety and health, and environmental protection.

***Source:** authors' own research*

In 1995, the Category Management Subcommittee of the ECR Best Practices Operating Committee and the Partnering Group Inc. published an important study: Category Management Report: Enhancing Consumer Value in the Grocery Industry (Basuroy *et al.*, 2001). As a result of the study, a cycle of category management was developed, which consists of eight processes: category definition, category role, category assessment, category scorecard, category strategies, category tactics, plan implementation, category review. The proposed cycle became the basis for the development of category management. C. Holweg *et al*. (2009), based on an empirical study, demonstrated the application of adjustments to the aspects of customer service personnel, and how such employees significantly affect the development of customer value. An interesting approach to the study of category management was developed by J. Hall *et al*. (2010), which described a multi-brand ordering and pricing model. The authors proved that category management leads to significantly higher profits than brand or margin.

In 2018, the authors published a paper explaining the concept of category management, which is understood as the development and implementation of the technology management of the product range by using information and innovation support, strategy generation, and methodical use of management tools for making the key competence and ensuring the long-term competitiveness of the enterprise (Y. Romat *et al.*, 2018). O. Rusak & T. Palamarchuk (2020) described territorial marketing of agribusiness development in rural areas. The researchers noted that the modern development of agribusiness requires new approaches to solving the issue of creating favourable conditions necessary for independent and proactive work of various agrarian enterprises in rural areas, but did not describe any of the models of category management that can increase the efficiency of the industry. The study suggests that this may be the next stage in development of category management. V. Khurdei (2021) identified the need to develop and clarify the business process of category management of trade enterprises, emphasised the need to introduce into the business process of category management components related to the analysis, evaluation, and selection of suppliers; preparation for sale and direct sale; marketing communications and analysis of sales and customer satisfaction.

U. Motorniuk & I. Stelmakh (2021) suggest that the problems of introducing category management at domestic enterprises should be counteracted and solved, as this would help increase the competitiveness of enterprises. The results obtained by S. Strapchuk (2019) confirmed the fact that the few authors investigated the application of category management in the field of trade in medicines. The heterogeneity of customer behaviour in supermarkets depending on the use of means for carrying things investigated by N. Larsen *et al*. (2020) demonstrated the relationship between consumer segmentation and category management in retail. The volume of products sold depends on the available equipment, the area of the trading floor, and the location of product categories.

In the study by J. Cadeaux & L. Yee (2013), a structural equation model was developed, which was appropriate to interpret in the activities of an industrial or pharmaceutical enterprise because it showed how heterogeneity of category sales can affect both the category assortment and the distribution of inventory, and hence, in turn, the category performance. M. Goic *et al*. (2015) provided reports on how some category management exclusively from the standpoint of retail trade, and the proposed model for assessing the relative effectiveness of categories was aimed at achieving business processes and the mission of the enterprise.

The general scheme of the process of product category management at the trade enterprise is presented in Figure 1. The entire process was divided into three blocks of operations. The preparatory stage of defining product categories is the starting point of the activity of the category manager, which depends on the correctness and vector of movement of further actions related to the management of the product category. The most important is the second stage of implementation of category management – the definition of the list of roles that will be used within the assortment matrix adopted at the enterprise. The role of the product category is a very important stage for consumer cooperation with retailers. Depending on the relevance of the product and its popularity, stores allocate the necessary square meters, and shelves, apply different approaches to advertising, develop discount systems, and the consumer pays attention to the product in any case.

The process of determining the role of certain products can be divided into the following stages: clarification of the role of a particular product for the company, which will be used within the existing assortment matrix of the company; indication of roles for each category of goods; division of resources among the developed categories based on these roles. Thus, it can be concluded that the implementation of category management is reduced to two main steps: 1) development and application of a categorical strategy, namely a document that includes analysis of the supplier market, prime cost analysis, analysis of total costs, and development of strategic decisions on methods of procurement of materials and principles of selection of suppliers; 2) creation of a categorical team of an inter-functional project group that solves the problem of supply chain management to a certain product category.

The development of organisational and economic mechanism for ensuring the innovative development of retail trade requires a comprehensive consideration of internal and external factors of the system under study, the creation of strategies and programmes to increase

the innovative potential of its participants, their active interaction, the development of an organisational and economic mechanism for ensuring the innovative development of retail trade, increasing the use of innovative technologies, generating ideas and transformations (Hrynko *et al.*,2021).

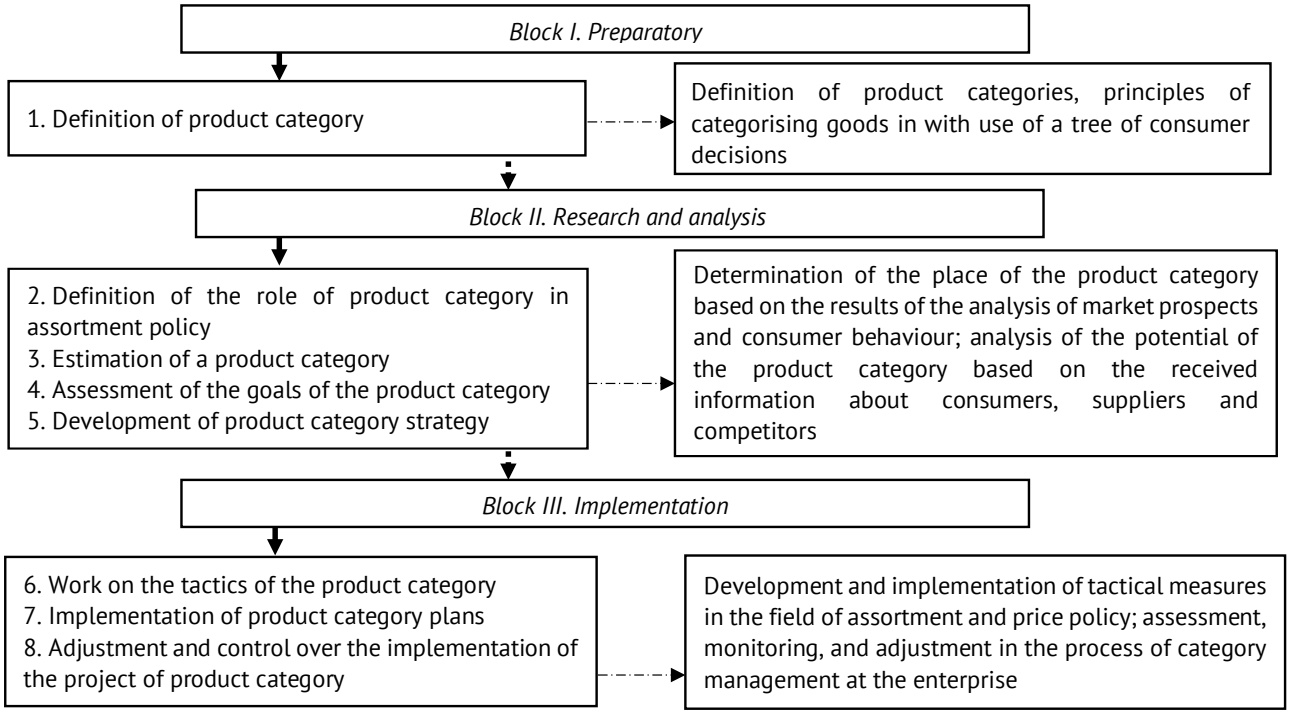

***Figure 1**. The scheme of the process of product category management at the enterprise*
***Source:** compiled by the authors*

The specific features of the pharmaceutical market are the subject of study by many researchers, but little attention is paid to the development of product categories of medicines. N. Prytulska *et al.* (2022) defining the modern pharmaceutical market Ukraine and the world includes the production of medicines, dietary supplements, medical cosmetics, hygiene products, and medical devices, including medical knitwear, children's goods, medical equipment, but not structured in detail by product categories.

In the paper by A. Vitiuk *et al.* (2018), the researchers asserted trends in the development of the pharmaceutical industry require innovative approaches, namely the principles and features of category management can be such an area in pharmacy. Table 2 presents a step-by-step comparison of category management in trade and industry. Notably, unlike in the field of trade, the separation of product categories in an industrial enterprise is based on the principle of common sources of supply or proximity of the characteristics of the purchased goods. While in retail, product categories are distinguished based on the study of expectations and their perception by consumers.

***Table 2**. Comparative characteristics of category management in trade and industry*

Elements of category management	Retail (wholesale) enterprise	Industrial enterprise
Category management purposes	Satisfying the consumer's final needs in product categories	Optimisation of costs related to purchasing and sale
Management approach	Category management as a value-oriented approach	Categorical approach to production
Focus of activity	Final consumer	Internal or external customer
Subject of management	Category manager	Category team
Selection of a class of goods	Food or non-food items	Basic and auxiliary materials
Selection of a group of goods (examples)	Groceries, bakery products, household chemicals	Components, materials, semi-finished products, fuel, raw materials

Table 2, Continued

Elements of category management	Retail (wholesale) enterprise	Industrial enterprise
Selection of a category of goods (examples)	Baking, milk, washing powder	Fabrics, knitwear, non-woven materials, natural and artificial leather, suede, artificial and natural fur, accessories, decorative materials
Balancing the assortment by width	The number of categories in the store is determined depending on gross profit and turnover	It is determined by the specifications of the finished product and the need for auxiliary materials or raw materials
Balancing the assortment by the depth	The number of products in the middle of the category, by brands, manufacturers, properties	Possible management by the procurement department with the participation in the category team of representatives of customer units
Balancing the assortment by height	Price offers	It is determined with the participation of customers and considering the company's policy on procurement
Roles of categories	Basic, priority, periodic, unique, convenient	None
Type of analysis	Analysis of product range, market, suppliers, logistics processes	Analysis of product range, market, suppliers
Merchandising	Sales promotion tool	None
Staff/sales training	Sales promotion tool	None
Advertising campaigns and promotions	Sales promotion tool	None
Tools for increasing the average check: up-sell, down-sell, cross-sell	Sales promotion tool	None
Determining the pricing policy of sales, pricing	Setting the selling price	None, because neither basic nor auxiliary materials are sold, and therefore have no selling price. The buyer manages only the purchase price of the materials
Turnover analysis	The most important key performance indicator (KPI) of trade, which reflects the speed of implementation, the number of frozen funds	Used for management analytics and illiquidity control
Development of supplier management strategy	Supply management system	Supply management system

Source: *developed by the authors based on Brubakken et al. (2020); Dandage et al. (2019); Landale et al. (2017); Sangka et al. (2019); Zuhaira & Ahmad (2021)*

Moreover, not all tools of category management can be fully applied in the work of industrial enterprises. Classic tools such as assortment analysis by role, depth, width, and height, marketing, merchandising, advertising campaign planning, and trade margin management are unacceptable in the industry. Due to the limitations in the application of management tools, it makes sense to talk about the use of the category approach in the industry, and not the entire set of management capabilities of category management. Moreover, at an industrial enterprise, the goal of category management in the procurement process is being reformatted to meet the needs of end consumers to optimise costs because procurement in such enterprises is not focused on external consumption, but on internal use.

In general, the use of a categorical approach in both trade and industry is very useful because it allows retailer so: personify approaches to the purchase of different categories of goods; overcome the problem of applying only cost analysis without considering other factors in the process of evaluation and selection of suppliers; formalise the approaches adopted by the company to the purchase of certain categories of goods, exclude the interpretation of the performers; involve representatives of other functional units in the development of strategies by category. In addition, if in trade the category manager bears full responsibility for the management of the product category, then in industry technological processes impose their nuances on the management of the assortment of the category, which is why it is advisable to form category teams of engineers, technologists, marketers, analysts, IT specialists, etc., who will provide consultations on specialised procurement, supplier management, and product category market analysis.

Algorithm for the development of category management. Nowadays, there are enough methods to

evaluate category management in retail, but none to evaluate it in an industrial enterprise. It is expedient to carry out the analysis and estimation of parameters of category management through control sheets of monitoring a maintenance condition of category management and monitoring the assessment of the organisational effect in the field of category management of the enterprise.

Each of the proposed indicators is assessed on a scale in points, where *3* – work is conducted in full and meets the requirements of the documentation; *2* – work is not conducted in full, there are remarks (remarks are made in the checklist); *1* – work is conducted in the minimum volume; *0* – work is not conducted. The significance coefficients are summarised based on an expert assessment by 42 employees who are involved in category management processes in 20 enterprises of both trade and industry. The state of the provision of category management can be assessed based on the Table. 3.

Gathering and aggregating information to assess the organisational effect, the experts, first of all, choose the factors of dominant influence. The study of their impact on category management provides a conclusion on the expediency of their grouping to more fully identify the existing reserves of economic growth, which may take the form of a single matrix (Table 4).

***Table 3**. Monitoring of the state of provision of category management*

No.	Indexes	Significance ratio, P_j	Estimate, T_j, point*	Significance of the factor, *Szab*
1	Status of completeness and quality of implementation of information management processes of category management (Siz)	0.25		
2	Status of completeness and quality of implementation of the processes of methodological support of category management (Smz)	0.20		
3	Status of completeness and effectiveness of the implementation of the processes of resource provision of category management (Srz)	0,15		
4	Status of completeness and quality of implementation of technical support processes of category management (Stz)	0.20		
5	Status of completeness, quality, and effectiveness of the implementation of the processes of organisational support of category management (Soz)	0.20		
	Provision of category management			Σ

***Note:** The proposed methodology involves filling out control sheets of monitoring of a condition of maintenance of category management of the enterprise by the method of expert assessments by specialists in the relevant field (trade, industry). Each of the proposed indicators is assessed on a scale in points*
***Source:** developed by the authors*

***Table 4**. Monitoring the assessment of organisational effectiveness in the field of category management*

No.	Indexes	Significance ratio, P_j	Estimate, T_j, point*	Significance of the factor, *Sef*
1	Status of assortment management (Sko)	0.15		
2	Status of defining the roles of categories (Skn)	0.20		
3	Status of inventory management (Stb)	0.25		
4	Status of management of work with suppliers (Std)	0.20		
5	Status of selection of categories and subcategories (Svd)	0.20		
	Organisational effect in the field of category management			Σ

***Note:** The proposed methodology involves filling out control sheets of monitoring the assessment of the organisational effect in the field of category management of the enterprise by the method of expert assessments by specialists in the relevant field (trade, industry). Each of the proposed indicators is assessed on a scale in points*
***Source:** developed by the authors*

As a result, a matrix for determining the state of category management in industrial and trade enterprises is proposed. Like all classical models of strategic planning, the matrix is a two-dimensional table, where axis X reflects the monitoring of the state of category management, and axis Y monitors the evaluation of organisational effectiveness in the field of category management. The authors propose to evaluate the specified criteria by calculating Szab (1) and Sef (2):

$$Szab=0.25*Siz+0.20*Smz+0.15*Srz+ \\ +0.20*Stz+0.20*Soz \quad (1)$$

where *Szab* – status of category management; *Siz* – status of completeness and quality of implementation of information support processes of category management; *Smz* – status of completeness and quality of implementation of the processes of methodological support of category management; *Srz* – status of completeness and effectiveness of the implementation of the processes of resource provision of category management; *Stz* – status of completeness and quality of implementation of the processes of technical support of category management; *Soz* – status of completeness, quality, and effectiveness of the implementation of the processes of organisational support of category management. 0.25; 0.20; 0.15; 0.20; 0.20 – corresponding coefficients of the weight of indicators.

$$Sef=0.15*Sko+0.20*Skn+0.25*Stb+0.20*Std+0.20*Svd \quad (2)$$

where, *Sef* – organisational effect in the field of personnel management; *Sko* – status of assortment management; *Skn* – status of defining the roles of categories; *Stb* – status of inventory management; *Std* – status of management of work with suppliers; *Svd* – status of selection of categories and subcategories. 0.25; 0.20; 0.15; 0.20; 0.20 – corresponding coefficients of the weight of indicators.

Thus, category management should be considered as a management technology aimed at supporting, substantiating, and improving the effectiveness of management decisions in the field of enterprise management, and ensuring its purposes. The proposed approach to assessing the state of category management will contribute to the improvement of approaches to planning, information, and analytical support and control over the main management processes in the enterprise. To assess the probability of support and development of strengths and eliminate weaknesses in category management, it is advisable to use the results of calculations of indicators of probability and the development of strengths and the elimination of weaknesses (Table 5).

***Table 5**. Matrix for determining the state of category management in enterprises*

	Monitoring the assessment of organisational effectiveness in the field of category management	**Criteria**		
		Monitoring the state of category management		
		Absence (0-1.5 points)	*Insufficiency (1.5-2.5 points)*	*Availability (2.5-3 points)*
Criteria	*Absence (0-1.5 points)*	Category management is absent, no attempts are being made to adjust it		The existing provision of category management in the absence of the organisational effect of category management
	Insufficiency (1.5-2.5 points)	Low level of provision of category management, adequate opportunities for the development of category management	Average level of category management at the enterprise	
	Availability (2.5-3 points)	Sufficient level of the management system of category management with its practically absent or low level	High level of category management	Ideal state of category management

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

The results of application of the algorithm. In the current conditions of operation, most enterprises of the country face problems in ensuring the efficiency of the use of resources. To investigate the practical aspects of implementing category management at trade and industry enterprises, the state of category management at Sika Ukraine LLC, Epicenter K LLC, Auchan Ukraine Hypermarket LLC, and Obolon JSC was analysed using the methodology proposed above (Table 6).

Considering Table 6, it is possible to ascertain the low level of organisation and provision of category management of the industrial enterprises (Sika Ukraine LLC and Obolon PJSC) compared to retail enterprises (Ashan Hypermarket Ukraine LLC and Epicenter K LLC). The most vulnerable aspects are the informational and methodological support, the state of selection of categories and subcategories, and the distribution of roles of product categories. Thus, from the standpoint of the product category management algorithm (Fig. 1), the block of research and analysis is less developed in terms of determining the role of the product category in the assortment policy of the enterprise, analysing the potential of the product category based on the received information about consumers, suppliers, competitors.

According to the matrix for determining the state of category management at the enterprise (Fig. 2), Auchan Hypermarket Ukraine LLC has an ideal state of category management development, Epicenter K LLC has an average level, and Sika Ukraine LLC and Obolon PJSC have an existing provision of category management

in the absence of the organisational effect of category management. This once again confirms the significant unused reserves for the development of category management at the specified industrial enterprises.

***Table 6**. Generalised results of monitoring the state of security and assessment of the organisational effect in the field of category management at trade and industrial enterprises in Ukraine*

No.	Indexes	Significance ratio, P_j	Auchan Ukraine Hypermarket LLC: Estimate, T_j, point	Auchan Ukraine Hypermarket LLC: Significance of the factor, *Sef*	Epicenter K LLC: Estimate, T_j, point	Epicenter K LLC: Significance of the factor, *Sef*	Sika Ukraine LLC: Estimate, T_j, point*	Sika Ukraine LLC: Significance of the factor, *Sef*	Obolon PJSC: Estimate, T_j, point	Obolon PJSC: Significance of the factor, *Sef*
			Auchan Ukraine Hypermarket LLC		Epicenter K LLC		Sika Ukraine LLC		Obolon PJSC	
	Monitoring of the provision of category management									
1	Status of completeness and quality of implementation of information management processes of category management (*Siz*)	0.15	2	0.3	3	0.45	1	0.15	1	0.15
2	Status of completeness and quality of implementation of the processes of methodological support of category management (*Smz*)	0.2	2	0.4	2	0.4	1	0.2	1	0.2
3	Status of completeness and effectiveness of the implementation of the processes of resource provision of category management (*Srz*)	0.25	3	0.75	2	0.5	2	0.50	1	0.25
4	Status of completeness and quality of implementation of technical support processes of category management (*Stz*)	0.2	3	0.6	2	0.4	2	0.4	2	0.4
5	Status of completeness, quality, and effectiveness of the implementation of the processes of organizational support of category management (*Soz*)	0.2	3	0.6	3	0.6	1	0.2	2	0.4
	Provision of category management			Σ=2.65		Σ=2.35		Σ=1.45		Σ=1.40
	Monitoring of the evaluation of the organisational effect in the field of category management									
1	Status of assortment management (*Sko*)	0.15	3	0.45	2	0.3	2	0.3	3	0.45
2	Status of defining the roles of categories (*Skn*)	0.2	2	0.4	3	0.6	1	0.2	1	0.2
3	Status of inventory management (*Stb*)	0.25	2	0.5	2	0.5	2	0.5	2	0.5
4	Status of management of work with suppliers (*Std*)	0.2	3	0.6	2	0.4	2	0.4	2	0.4
5	Status of selection of categories and subcategories (*Svd*)	0.2	3	0.6	2	0.4	2	0.4	1	0.2
	Organisational effect in the field of category management			Σ=2.55		Σ=2.20		Σ=1.80		Σ=1.75

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

Next, the study considers in more detail the global macro-trends of the survey, which was attended by 163 respondents aged 20+, with different social statuses, professional skills, and positions from 64 enterprises in Ukraine, which have different sectoral groups, ownership, several employees, working conditions and technologies (Table 7).

The radical changes that are already taking place today in consumer markets have accelerated with the onset of the pandemic and the conditions of martial law in Ukraine. Thus, within the scope of this study, it is expedient to consider the global macro trends revealed as a result of the survey, which are transforming category management: the store of the future; relevance of the brand; digital supply system; future of the food market; rapid growth of the role of environmental, social and corporate responsibility (Fig. 2).

Thus, according to global trends that have changed the face of contemporary category management, there is an undeniable fact that the world of physical stores has gone into the past. It has been replaced by an integrated store model with powerful innovative technologies and the transition to omnichannel functioning, providing meaningful value propositions, perfect service for consumers, and strengthening the role of environmental, social, and corporate responsibility. The system of providing modern enterprises has also transformed the activation of the ECR (Efficient

Consumer Response), SCM (Supply Chain Management) and CRM (Customer Relationship Management) functions by establishing interactive interaction of enterprises with permanent partners via the Internet, building a system of forecasting expectations and behaviour models for consumers and rapid response to them, implementing digital supply technologies, using of smart contracts, etc.

***Table 7**. Analysis of the results of the questionnaire survey "The Future of Category Management"*

Question	Answer	Number of respondents	% of answers
Please indicate to what extent you agree or disagree with such statements about the importance of environmental friendliness in shopping.	I buy products from companies that are conscious of the environment and help protect it	62	38
	I choose products whose origin information is open and transparent	45	28
	I buy more biodegradable/environmentally friendly products	25	15
	I deliberately buy goods in ecological packaging or with minimal packaging	21	13
	I practically don't consider the environmental factor	10	6
Which features in these product categories are you willing to pay more for? (Consumer goods, including food and beverages)	Health benefits	43	26
	Made in your country/from local ingredients	38	23
	Eco-friendly/ecological packing of better quality	32	20
	Ethically produced trademarks are known for their ethical principles	30	18
	Luxury brands	12	7
	I'm not willing to pay more for any of the above	8	5
What will the development of category management at an industrial enterprise lead to?	Clearer selection of categories and subcategories	47	29
	Defining the roles of categories	39	24
	Category analysis and strategy definition	41	25
	Formation of tactics in work	36	22
What areas of a category manager's work do digital technologies have a greater impact on?	Logistics	19	12
	Merchandising	17	10
	Procurement system	38	23
	Keeping records of product categories	41	25
	Financial activity	12	7
	Project management	15	9
	Cross-categorical analysis	21	13
What will the development of category management lead to (in your opinion)?	Increasing the competitiveness of the enterprise	52	32
	Attracting new consumers	57	35
	The growing role of environmental, social, and corporate responsibility	31	19
	Improving reputation and image	14	9
	Brand development	9	6

***Source:** calculated based on the data of a questionnaire survey of 163 respondents from 64 enterprises in Ukraine in May 2022*

The digital supply system will continue to integrate all relevant internal functions, such as merchandising, category management, store operations, financial activities, and taxation, and integrate the activities of all supply system participants, including suppliers, logistics organisations, customers, and partners of innovative projects.

Many of the trends currently determining the future of consumer markets O. Penkova *et al*. (2022) will generally have a marked impact on the future of the food market. The future of the food market will also be characterised by increasing personalisation, even excessive, and ambiguous attitudes towards it by some consumers, as this degree of personalisation is achieved through data collection and tracking of consumer behaviour.

Sharing the opinion D. Honcharenko (2021) even before the pandemic, there was a trend among consumers to demand healthy and environmentally friendly health and food products, and to limit the consumption of certain food groups and the use of food additives. The authors' consumer survey showed that half of the respond-

ents include more plant-based foods in their diets. It was expected that this trend will intensify and gain momentum. Therefore, according to the popularisation of healthy food trends and a healthy lifestyle and considering the conditions of martial law in Ukraine, there is an increase in consumer demand for healthy, organic food products, pre-packaged products, and goods of local manufacturers, produced from local components and ingredients.

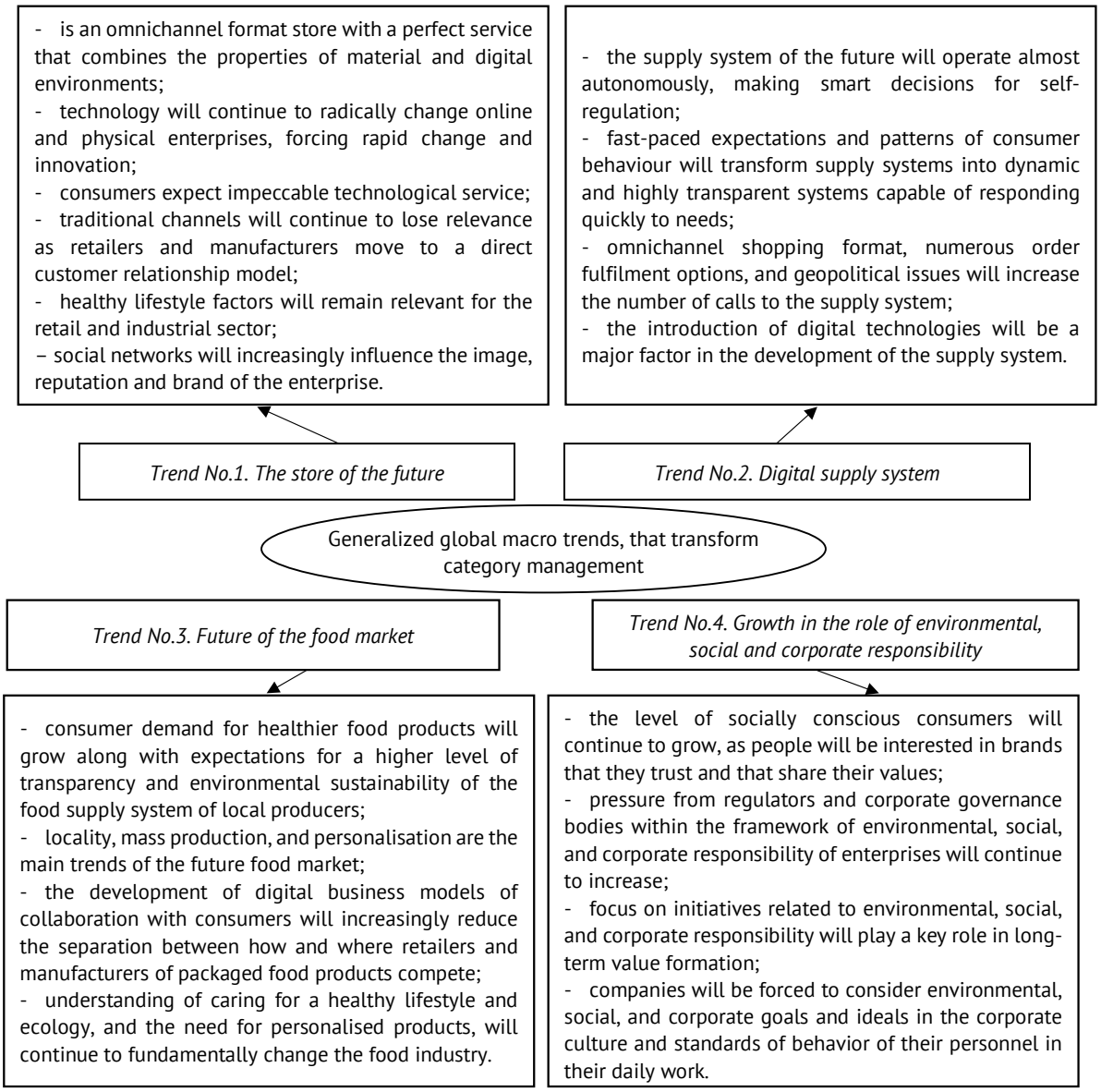

***Figure 2**. Generalised global macro trends, that transform category management*
***Source:** compiled by the authors based on the PwC database "The future of consumer markets" (2021); Vanharanta et al. (2022)*

Consumers demand accountability and transparency on a range of socio-environmental issues in category management, including the reduction of packaging waste, transparency of the supply chain, and fair employment practices. All participants in the production and distribution chains, including agribusiness, commodity producers, and trade enterprises, will have to meet these expectations if they want to stay in the market. Therefore, the practical aspects of category management are important for enterprises of both trade and industry.

CONCLUSIONS

Category management is one of the most effective management approaches to managing the range of goods in the trade sphere or the product range of goods and material values in the sphere of industry. Its application allows optimising business processes from the purchase to the sale of goods (or internal use of materials, depending on the field of activity). Despite several subtleties that distinguish category management in trade and industry, their common characteristic is the ability

to differentiate approaches to the purchase of different categories of goods or materials, to involve functional consultants in the development of a category strategy, and to increase the efficiency of the evaluation and selection processes of suppliers.

The presented methodology for monitoring the state of security and evaluating the organisational effect in the field of category management was tested at real trade and industrial enterprises in Ukraine and provided several important conclusions. The processes of identifying the roles of product categories and analysing the potential of categories based on information about consumers, suppliers, and competitors are the least developed in the category management of industrial enterprises. Therefore, the conducted research proved the existence of significant reserves for the development of category management at industrial enterprises. Prospects for further study are related to the development of methods for analysing the potential of industrial enterprise categories based on information about consumers, suppliers, and competitors.

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None.

CONFLICT OF INTEREST

None.

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Анотація. Ідентифікувати особливості категорійного менеджменту на підприємствах торгівлі і промисловості, розробити та апробувати методику оцінки категорійного менеджменту в світлі глобальних макротенденденцій, які трансформують категорійний менеджмент за нинішніх умов обумовили актуальність дослідження. Сьогодні категорійний менеджмент сприймається більшістю організацій як безперервний бізнес-процес, де діяльність з управління категоріями є невід'ємною частиною бізнесу. Саме тому метою дослідження було з'ясувати зміни макротенденцій та можливості застосування моделей категорійного менеджменту у різних галузях діяльності. В процесі їх опрацювання були використані такі науково-емпіричні методи, як причинно-наслідковий аналіз та синтез, дедукція та індукція, систематизація та узагальнення, а також системний та процесний підходи. Проведені дослідження дозволили виявити наявність значних резервів розвитку категорійного менеджменту на промислових підприємствах. За результатами проведення опитування «Майбутнє категорійного менеджменту» ідентифіковано такі глобальні макротенденденції трансформації категорійного менеджменту, як магазин майбутнього; цифрова система постачання; майбутнє продовольчого ринку; зростання ролі екологічної, соціальної та корпоративної відповідальності. Запропоновано підхід стосовно оцінки стану категорійного менеджменту на підприємстві торгівлі та промисловості, за допомогою контрольних листів моніторингу стану забезпечення категорійного менеджменту та моніторингу оцінки організаційного ефекту в сфері категорійного менеджменту підприємства. Запропонований підхід стосовно оцінки стану категорійного менеджменту буде сприяти вдосконаленню підходів щодо планування, інформаційно-аналітичного забезпечення та контролю за основними процесами управління на підприємстві

Ключові слова: товарна категорія; управління; стратегія; маркетинг; рітейл; бренд; технологія

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