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Assessment of vegetable soybean (*Glycine max* L.) cultivars according to genotype-environment indicators: Ecological plasticity, stability, and adaptive response

Abstract. This study aimed to determine the quantitative and qualitative relationships between the effects of abiotic environmental factors, typical of the Right-Bank Forest-Steppe of Ukraine, and the productivity of soybean cultivars. The main methodological approaches included field experiments, which enabled the analysis of cultivation technology elements, and statistical analysis

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was used to verify the data obtained. It was established that the dry seed yield per plant among the soybean cultivars intended for sprout production ranged from 14.3 to 30.4 g. The highest yield was recorded in the cultivar Kytajska tsukrova No. 1 (Chinese Sugar No. 1), followed by Staroukrainska mistseva (Old Ukrainian Local) (the control variant), and Soybean for Sprouts No. 3 in third place. The coefficient of variation in plant productivity over the years of study ranged from 7.54% to 2.42%. The cultivars Soybean for Sprouts No. 3, Soybean for Sprouts No. 4, and IDO-21142 exhibited high regression coefficient values ($b_1 = 1.03-1.16$), indicating their increased sensitivity to changes in agroecological conditions. In contrast, the cultivar Kytajska tsukrova No. 1 was characterised by the lowest regression coefficient ($b_1 = 0.73$), indicating a reduced response to changes in growing conditions. According to the selection value index, the most promising cultivars were Kytajska tsukrova No. 1 ($BVG_1 = 26.56$) and Staroukrainska mistseva (control) ($BVG_1 = 19.64$). The studied soybean cultivars for green pea use demonstrated a wide range of dry seed productivity – ranging from 29.8 to 52.4 g per plant – with a coefficient of variation between 7.74% and 9.13%. Among the cultivars intended for green pea production, IDO-200905 ($b_1 = 0.78$) and IR-398 ($b_1 = 0.93$) were the least sensitive to improved growing conditions, whereas IR-1030 ($b_1 = 1.02$) and Smolianka (control) ($b_1 = 1.27$) exhibited the highest sensitivity. At the same time, IDO-200905 and IR-398 showed high homeostasis ($Hom = 3.48$ and 5.07 , respectively) and significant breeding value ($BVG_1 = 20.15$ and 23.59 , respectively), indicating an effective combination of high productivity and stability

Keywords: effective temperatures; precipitation; genotype; stress resistance; leguminous crops

INTRODUCTION

Climate change is accelerating the phenological development of agricultural crops, leading to a shortened growing season and potentially reduced yields. In addition, climatic uncertainty is increasing, manifested in uneven rainfall distribution, rising temperatures, and a higher frequency of extreme weather events, all of which pose a threat to food security. Population growth is another critical factor affecting the sustainability of global food systems. According to F. Rastegaripour *et al.* (2024), the global population is projected to reach 8.6 billion by 2050 and 11.2 billion by 2100. In connection with this demographic expansion, P. Khatri *et al.* (2024) note that the challenge of ensuring adequate food supply is intensifying, as arable land and water resources cannot expand indefinitely. As pointed out by N. Nirmal *et al.* (2024), the global distribution of food is highly unequal, resulting in over 800 million people living in a state of chronic hunger, while one-third of all food produced is lost or wasted. According to the findings of K. Agyenim-Boateng *et al.* (2022), leguminous crops – particularly soybeans – play a significant role in human nutrition worldwide. They provide essential nutrients such as protein, iron and calcium while requiring relatively

low inputs for cultivation. Vegetable soybeans are distinguished from grain soybeans by several key traits: larger seed size, a sweeter flavour, and the absence of the characteristic legume astringency. They can be consumed fresh, frozen or canned, and may be used as a substitute for peas or beans in a variety of dishes (Nair *et al.*, 2023a).

The current state of legume cultivation, as highlighted by A. Aboltins *et al.* (2024), reveals several challenges. One of the key issues is the need to adapt cultivars to changing environmental conditions, as noted in the research of S. Kumar *et al.* (2023). W. Abobatta *et al.* (2021) emphasise that successful crop cultivation requires careful consideration of potential yield, technological characteristics, maturity periods, and cultivar responses to climatic and soil conditions. According to J. Rane *et al.* (2021) and I. Fedosiy *et al.* (2022), grain legumes are sensitive to both biotic and abiotic factors that constrain yield potential. Climatic conditions – particularly drought and heat – negatively affect legume yields worldwide and pose a significant risk of water scarcity. Water shortages and recurring heat waves considerably reduce grain yield and the productivity of other plant components. The combined effect of heat and drought

is multiplicative, resulting in greater yield losses that are strongly influenced by the duration of stress exposure. K. Dave *et al.* (2024) stress the importance of identifying and introducing drought-tolerant cultivars to mitigate the adverse effects of drought conditions.

Moreover, the study by V. Mazur *et al.* (2021) indicates that current grain legume cultivars realise only about 50% of their yield potential. This highlights the need to optimise cultivation conditions and to develop technologies tailored to the specific requirements of individual cultivars. The main reason for this underperformance is the mismatch between cultivar characteristics and the environmental conditions in which they are grown, which requires urgent attention. In Ukraine, vegetable soybean is a relatively new and underutilised crop. Its cultivation could contribute to the food supply by providing products rich in essential amino acids and balanced in nutritional content. Soybeans are grown for a range of purposes, which has created the need to study different cultivar types: those for sprouting; for consumption of immature boiled seeds in pods (Edamame type); for consumption in the form of canned green peas (hulled and boiled seeds, Mikimame type); and for the production of dry seed (seed production type).

This study aimed to identify patterns of ecological plasticity and adaptability among various soybean cultivars under the conditions of the Right-Bank Forest-Steppe of Ukraine, as well as to assess their yield potential based on varietal characteristics, with a view to supporting the future development of vegetable soybean cultivars.

MATERIALS AND METHODS

Over a three-year period, from 2008 to 2010, an experimental study was conducted at the Fruit and Vegetable Garden educational laboratory of the National University of Life and Environmental Sciences of Ukraine. The field experiment took place on research plots located in the Right-Bank Forest-Steppe region of Ukraine, at approximately 50°22'42.10"N latitude and 30°30'4.59"E longitude, at an elevation of 158 metres above sea level. The soil cover was classified as dark grey, medium podzolic, light loamy soil, with a pH level of 6.1. The humus layer

ranged in depth from 24 to 28 centimetres. Soil analysis of the experimental site revealed a low humus content (1.5%-2.2%), moderate nitrogen levels (26-38 mg/kg), phosphorus (43-61 mg/kg), and potassium (28-34 mg/kg).

In January, there was an initial warming trend, with the average ten-day air temperature rising from -7.5°C in the first ten-day period to -3.7°C in the second – a difference of +3.8°C (Fig. 1). However, during the third ten-day period, the temperature dropped again to -3.9°C. The total monthly precipitation amounted to 21.2 mm. February was marked by a gradual increase in air temperature from -2.5°C in the first ten-day period to 0.6°C in the third, representing a rise of +3.1°C. Monthly precipitation totalled 20.4 mm, slightly lower than in the previous month. In March, the temperature continued to rise steadily, increasing from 0.8°C (first ten-day period) to 5.1°C (third ten-day period), a difference of +4.3°C. Total precipitation for the month was 20.8 mm. April saw a moderate rise in air temperature, from 10.3°C in the first ten-day period to 11.3°C in the third (+1.0°C), accompanied by an increase in precipitation to 31.9 mm. In May, the temperature rose from 14.7°C in the first ten-day period to 16.6°C in the third ten-day period (+1.9°C), while monthly rainfall amounted to 31.0 mm. June was notable for a more substantial increase in temperature – from 19.3°C in the first ten-day period to 22.1°C in the third ten-day period (+2.8°C) – and the highest monthly precipitation recorded during the year, at 48.8 mm. The peak rainfall occurred in the second ten-day period, reaching 26.2 mm. In July, the second ten-day period was the hottest, with an average temperature of 23.7°C. The monthly total precipitation was nearly identical to that of June, amounting to 48.6 mm. August (first and second ten-day periods) was marked by stable temperatures ranging from 23.1°C to 23.3°C; however, a notable drop to 19.3°C (-4.0°C) was recorded in the third ten-day period. The total monthly precipitation was the lowest of the year, amounting to just 18.1 mm. In September, air temperatures gradually declined from 17.4°C (first ten-day period) to 13.4°C (third ten-day period), a decrease of 4.0°C. Monthly precipitation amounted to 36.0 mm. October was characterised by a further decrease in average ten-day temperatures,

from 10.4°C to 7.1°C (-3.3°C). The total monthly rainfall was 15.1 mm, the second lowest after August. In November, temperatures continued to drop from 6.3°C (first ten-day period) to 3.4°C (third ten-day period), a fall of 2.9°C. The total monthly precipitation was 26.7 mm. December

experienced sharp temperature fluctuations, beginning at 1.6°C (first ten-day period), falling to -7.2°C in the second (-8.8°C), and then rising to -2.5°C in the third (+4.7°C). Despite these variations, December recorded a considerable amount of precipitation, totalling 41.2 mm.

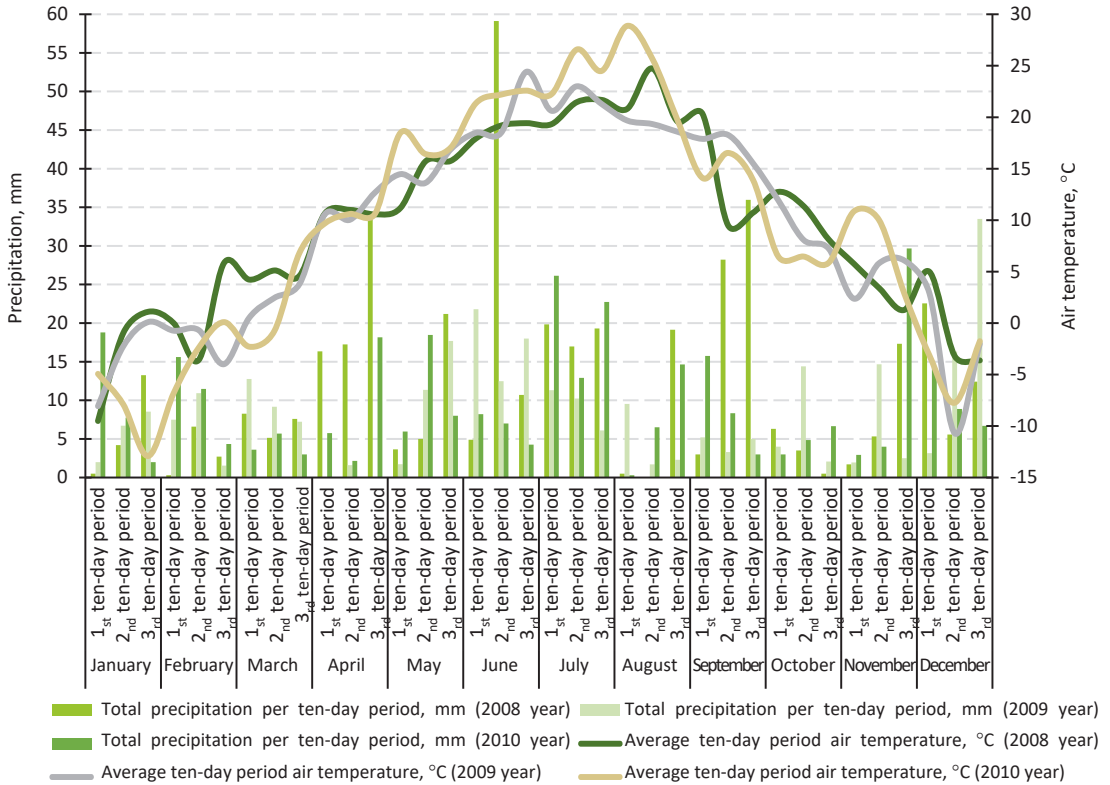


Figure 1. Dynamics of air temperature and precipitation, 2008-2010

Source: compiled by the authors based on the conducted study

Between 2008 and 2010, nine vegetable soybean accessions were studied – five intended for sprout production (Staroukrainska mistseva variety (control), Soybean for Sprouts No. 3, Soybean for Sprouts No. 4, IDO-21142, and Kytajska tsukrova No. 1), and four for green pea-type use (IDO-200905, IR-398, IR-1030, and Smolianka (control)). The experiment was arranged in three replicates using randomisation. The recorded plot area was 5 m². Seeds of all tested accessions were sown simultaneously on 12 May, using a planting scheme of 70 × 15 cm. Sowing was carried out at a high density, and final plant density

(95,000 plants per hectare) was established at the third true leaf stage. Seed depth ranged from 2 to 3 cm. The cultivation techniques for vegetable soybeans followed standard practices used in grain soybean production. Assessment of general adaptive capacity and specific adaptive capacity was based on the evaluation of genotypes (n) under environmental conditions (m), with the number of replications (c) following the methodology of I. Bobos *et al.* (2024). The formula used was:

$$x_{ikr} = U + V_i + d_k + (Vd)_{ik} + e_{ikr}, \quad (1)$$

where x_{ikr} is the phenotypic value of trait (i) of the genotype when grown in environment (k) and replication (r); U is the overall mean of the entire set of phenotypes; V_i is the effect of genotype (i); d_k is the effect of environment (k); $(Vd)_{ik}$ is the interaction effect of genotype (i) with environment (k); e_{ikr} is the effect caused by random factors and associated with phenotype (ekr).

The following constraints were applied to the model components:

$$\sum_i V_i = \sum_k d_k = \sum_k (vd)_{ik} = \sum_k (vd)_{ik} = \sum e_{ik} = 0. \quad (2)$$

The general adaptive capacity (GAC) effects were calculated as:

$$GAC_i = V_i = X_i - u. \quad (3)$$

The parameters of the species' specific adaptive capacity (SAC) were estimated using:

$$\sigma^2 SAC_i = \frac{1}{m-1} * \sum_R (d_R + Vd_{iR})^2 - \frac{m-1}{m} * \sigma^2. \quad (4)$$

$$\sigma SAC_i = \sqrt{\sigma^2 SAC_i}. \quad (5)$$

To compare the variability of different soybean traits across environments, the relative stability index (S_{gi}) was used:

$$S_{gi} = \frac{\sigma_{SAC_i}}{U+GAC} * 100 \%. \quad (6)$$

The soybean response to improved environmental conditions was determined using the regression coefficient b_i :

$$b_i = \frac{\sum X_{iR} * d_R}{\sum_R d_R^2}. \quad (7)$$

To identify soybean accessions combining both productivity and stability, the breeding value of the genotype (BVG) was calculated:

$$BVG_i = U + GAC_i - p \sigma_{SAC_i} \quad (8)$$

The Growing Degree Days method was applied to calculate the sum of effective air temperatures for each interphase period of soybean development based on actual temperature data:

$$\sum t_{eff} = (t_{avg} - B) * n, \quad (9)$$

where $\sum t_{eff}$ is the sum of effective air temperatures over the period, °C; t_{avg} is the average

air temperature for the period, °C; B is the value of the biological minimum, which in this analysis is taken to be 10°C; n is the number of days in this period.

The research results were processed using Statistica 13.1 software (StatSoft, Inc., Tulsa, OK, USA). Differences between varieties were evaluated using Tukey's test, with significance determined at $p < 0.05$ (with Bonferroni correction applied). To identify the direction and strength of associations between the studied variables, correlation coefficients were calculated. The study adhered to the principles of the Convention on Biological Diversity (1992)

RESULTS AND DISCUSSION

Figure 2 presents a box plot illustrating the distribution of dry seed yield for soybean varieties intended for sprouting. The dataset contains no significant outliers. For the varieties IDO-21142 and Kytayska tsukrova No. 1, the mean, median, and mode are located almost at the same point, closely resembling a normal distribution. In contrast, for Soybean for Sprouts No. 3, Soybean for Sprouts No. 4, and Staroukrainska mistseva (control), the measures of central tendency differ in location, indicating a non-normal distribution.

Between 2008 and 2010, during the growing season of soybean varieties intended for sprouting, the sum of effective air temperatures ($>10^\circ\text{C}$) ranged from 1,171°C to 1,459°C, while total precipitation varied from 129 to 180 mm. A strong positive correlation was identified between dry seed yield and the sum of effective temperatures ($r=0.73-0.99$) (Fig. 3). In contrast, an inverse correlation was observed between seed yield and total precipitation, with the strength of the correlation varying by variety: strong for Soybean for Sprouts No. 4, IDO-21142, and Kytayska tsukrova No. 1 ($r=-0.72$ to -0.76), moderate for Staroukrainska mistseva (control) ($r=-0.36$), and weak for Soybean for Sprouts No. 3 ($r=-0.29$) (Fig. 4). An increase of 10°C in the average sum of effective temperatures during the growing season resulted in a rise in dry seed yield per plant of 0.05-0.78 g in sprouting varieties. Conversely, every additional 10 mm of precipitation led to a reduction in yield of 0.36-1.45 g.

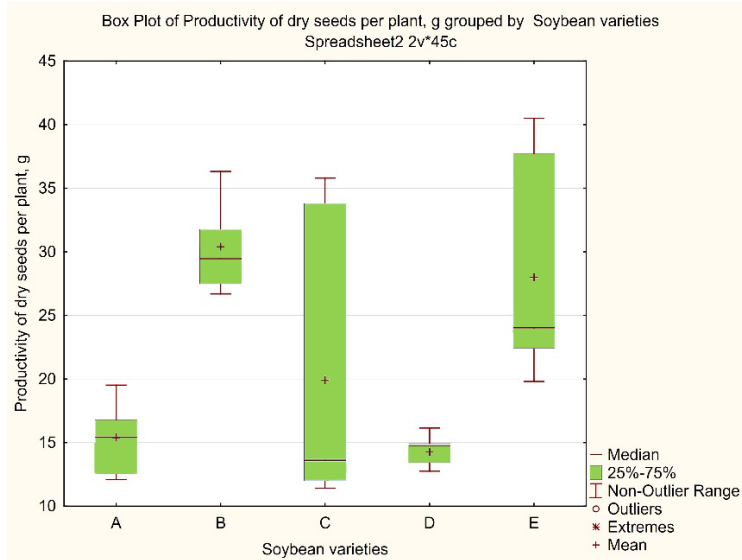


Figure 2. Box plot illustrating the yield performance of soybean varieties for sprouting

Note: A) Staroukrainska mistseva (control); B) Soybean for Sprouts No. 3; C) Soybean for Sprouts No. 4; D) IDO-21142; E) Kytaiska tsukrova No. 1 (2008-2010)

Source: compiled by the authors based on the conducted study

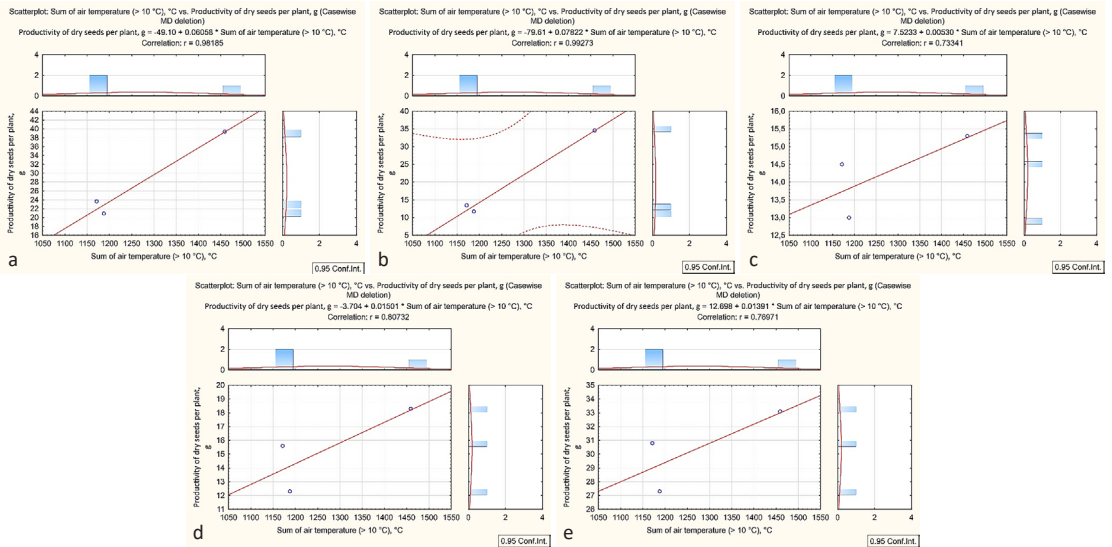


Figure 3. Analysis of the relationship between the yield of soybean varieties for sprouting and the sum of effective temperatures above 10°C during the sowing-to-harvest period

Note: a) Staroukrainska mistseva (control); b) Soybean for Sprouts No. 3; c) Soybean for Sprouts No. 4; d) IDO-21142; e) Kytaiska tsukrova No. 1 (2008-2010)

Source: compiled by the authors based on the conducted study

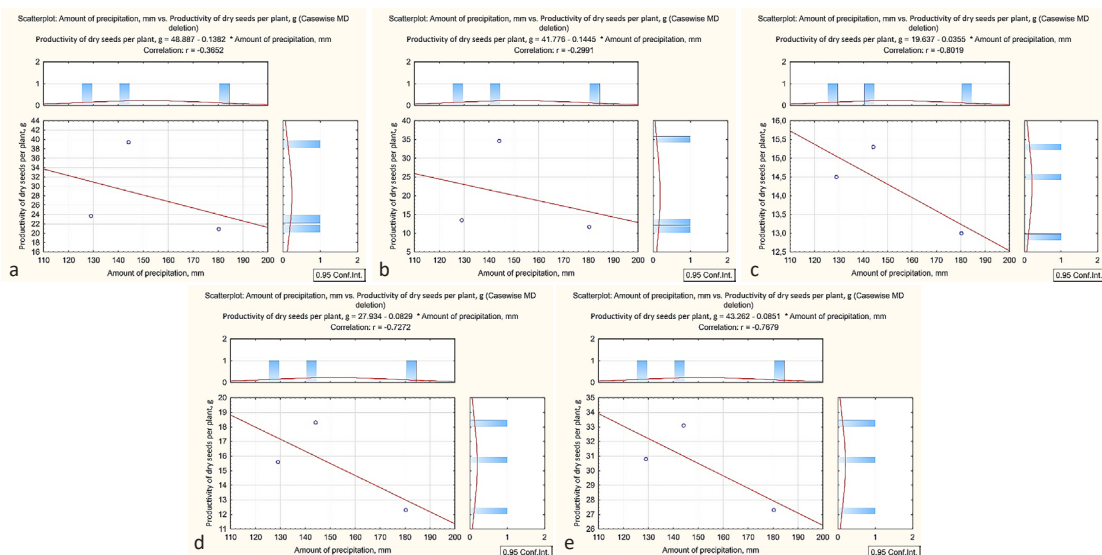


Figure 4. Analysis of the relationship between the yield of soybean varieties for sprouting and total precipitation during the sowing-to-harvest period

Note: a) Staroukrainska mistseva (control); b) Soybean for Sprouts No. 3; c) Soybean for Sprouts No. 4; d) IDO-21142; e) Kytaiska tsukrova No. 1 (2008-2010)

Source: compiled by the authors based on the conducted study

The variability in seed yield for the soybean variety for seedlings of Kytaiska tsukrova No. 1 variety was low, as indicated by a low coefficient of variation (7.54%) (Table 1). The Staroukrainska mistseva (control) and

Soybean for Sprouts No. 3 demonstrated moderate variability (10.36%-15.08%), while Soybean for Sprouts No. 4 and IDO-21142 showed high variability, with coefficients of variation ranging from 22.11% to 22.42%.

Table 1. Parameters of adaptive capacity and stability of soybean varieties for sprouting (2008-2010)

Indicator	Variety				
	Staroukrainska mistseva (control)	Soybean for Sprouts No. 3	Soybean for Sprouts No. 4	IDO-21142	Kytaiska tsukrova No. 1
Dry seed yield per plant, g (Mean)	28.0 ± 2.9 ^{bc}	19.9 ± 3.68 ^{ab}	14.3 ± 0.39 ^a	15.4 ± 0.9 ^a	30.4 ± 1.21 ^c
Coefficient of variation (V), %	10.36	15.08	22.42	22.11	7.54
General adaptive capacity (GAC)	6.39	-1.71	-7.28	-6.21	8.82
Specific adaptive capacity (SAC)	5.86	6.45	7.77	9.04	2.71
Relative stability (S_{gt}), %	20.92	32.39	54.21	58.68	8.90
Plasticity (b_j)	0.99	1.03	1.09	1.16	0.73
Homeostasis (Hom)	2.70	1.32	0.64	0.70	4.04
Breeding value of the genotype (BVG _j)	19.64	10.70	3.24	2.50	26.56

Note: different letters (a, b, c) denote values that differ significantly within a row, based on Tukey's test with Bonferroni correction

Source: compiled by the authors based on the conducted study

In examining the adaptive capacity of genotypes – that is, their ability to maintain phenotypic traits under varying conditions – it was found that the Staroukrainska mistseva (control) (6.39) and Kytajska tsukrova No.1 (8.82) varieties exhibited the highest levels of general adaptive capacity. In contrast, Soybean for Sprouts No. 4 (7.77) and IDO-21142 (9.04) showed the highest values of specific adaptive capacity, which reflects deviations in performance under particular environmental conditions. Notably, the Kytajska tsukrova No.1 and Staroukrainska mistseva (control) varieties demonstrated high relative stability (S_{gi} = 8.9% and 20.92%, respectively), indicating a strong capacity to maintain consistent phenotypic expression across different growing environments. Soybean for Sprouts No. 3 was also classified as stable (S_{gi} = 32.39%). Meanwhile, Soybean for Sprouts No. 4 and IDO-21142 were considered to exhibit moderate stability (S_{gi} = 54.21% and 68.68%, respectively).

Among the soybean varieties for sprouting, Kytajska tsukrova No.1 and Staroukrainska mistseva (control) were found to be the least responsive to improvements in growing

conditions. With each 1 g increase in the average dry seed yield per plant, their own yield increased by only 0.73 g and 0.99 g, respectively. Among the set of varieties studied, the most responsive to changes in yield levels at the trial sites were Soybean for Sprouts No. 3, Soybean for Sprouts No. 4, and IDO-21142. With each 1 g increase in the average productivity, these varieties increased their own yield by 1.03-1.16 g. High homeostasis was observed in the Staroukrainska mistseva (control) and Kytajska tsukrova No. 1 (Hom = 2.7 and 4.04, respectively), whereas the lowest value was recorded for IDO-21142 (Hom = 0.70). An analysis of the breeding value of the genotypes, based on a combination of yield and yield stability, revealed that the Kytajska tsukrova No. 1 variety (BVG_i = 26.56) had the highest selection value, followed by Staroukrainska mistseva (control) (BVG_i = 19.64) and Soybean for Sprouts No. 3 (BVG_i = 10.70). The dry seed productivity data for soybean varieties grown for green peas showed no outliers (Fig. 5). However, the distribution did not meet the criteria for normality, as the mean and median were not aligned.

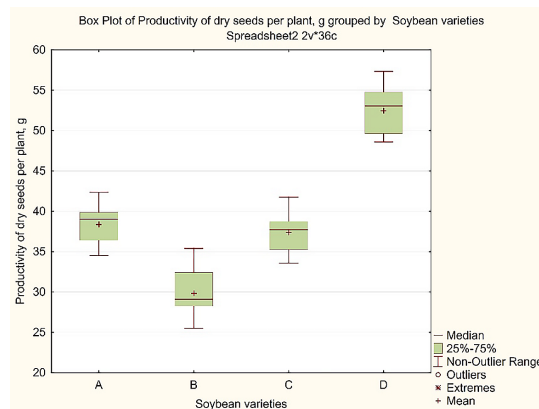


Figure 5. Box plot illustrating the productivity of soybean varieties grown for green peas
Note: A) IDO-200905; B) IR-398; C) IR-1030; D) Smolianka (control) (2008-2010)

Source: compiled by the authors based on the conducted study

A strong positive correlation was identified between the dry seed yield of soybean varieties for green peas and the sum of effective temperatures (r = 0.78-0.94) (Fig. 6). At the same time, a negative correlation was observed between dry seed yield and total precipitation, with the

strength of this relationship varying by variety. For example, a strong inverse correlation was recorded for the IR-1030 variety (r = -0.75), while a moderate inverse correlation was observed for IDO-200905, IR-398, and Smolianka (control) (r = -0.49 to -0.65) (Fig. 7). In

addition it was found that each 10°C increase in the average sum of effective air temperatures during the growing season contributed to a rise in dry seed yield per plant of 0.146-0.204 g

in soybean varieties for green pea production. Conversely, each additional 10 mm of precipitation led to a reduction in productivity of 0.66-12.22 g per plant.

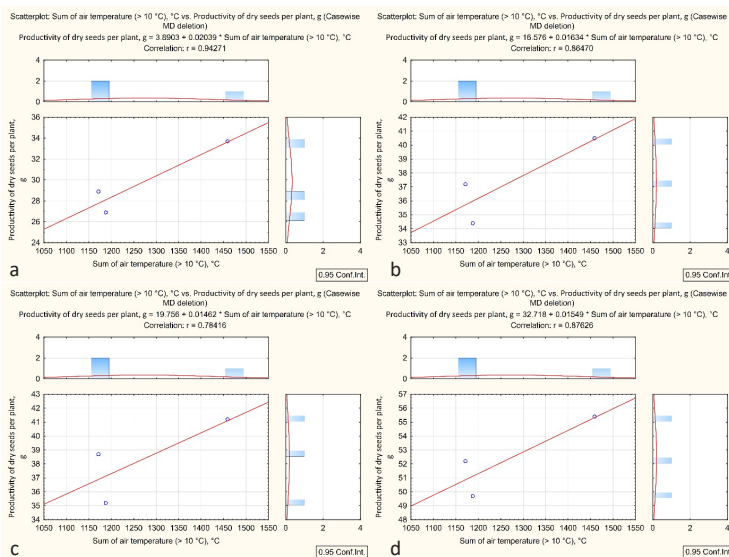


Figure 6. Analysis of the relationship between the productivity of soybean varieties for green peas and the sum of air temperatures above 10°C during the sowing-to-harvest period

Note: A) IDO-200905; B) IR-398; C) IR-1030; D) Smolianka (control) (2008-2010)

Source: compiled by the authors based on the conducted study

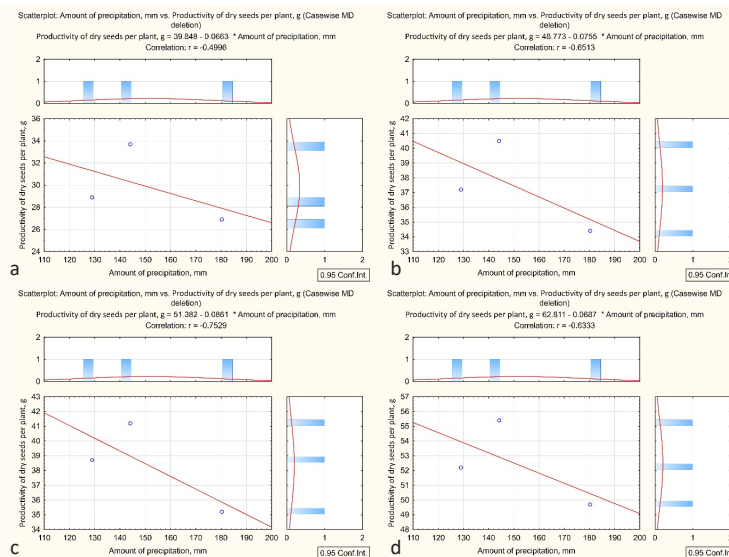


Figure 7. Analysis of the relationship between the productivity of soybean varieties for green peas and total precipitation during the sowing-to-harvest period

Note: A) IDO-200905; B) IR-398; C) IR-1030; D) Smolianka (control) (2008-2010)

Source: compiled by the authors based on the conducted study

According to the coefficient of variation, the dry seed yield of the examined soybean varieties for green pea production exhibited low variability ($V=7.74\%-9.13\%$) (Table 2). The analysis indicates that the variety Smolianka (control) showed the highest value for general adaptive capacity (12.33). Two varieties stood out in terms of specific adaptive capacity: Smolianka

(control) with a value of 16.34 and IR-1030 with 10.13. The dry seed yield of IDO-200905 and IR-398 was characterised by high stability ($S_{gi}=14.64\%$ and 17.99% , respectively) based on the relative stability index. In contrast, IR-1030 and Smolianka (control) were identified as demonstrating moderate relative stability ($S_{gi}=26.37\%$ and 31.27% , respectively).

Table 2. Parameters of adaptive capacity and stability of soybean varieties for green pea production (2008-2010)

Indicator	Variety			
	IDO-200905	IR-398	IR-1030	Smolianka (control)
Dry seed yield per plant, g (Mean)	29.8 ± 1.08 ^b	37.4 ± 0.96 ^a	38.4 ± 0.95 ^a	52.4 ± 1.03 ^c
Coefficient of variation (V), %	8.56	7.74	9.13	8.23
General adaptive capacity (GAC)	-10.10	-0.70	-1.54	12.33
Specific adaptive capacity (SAC)	4.37	7.06	10.13	16.34
Relative stability (S_{gi}), %	14.64	17.99	26.37	31.27
Plasticity (b_i)	0.78	0.93	1.02	1.27
Homeostasis (Hom)	3.48	5.07	4.21	6.35
Breeding value of the genotype (BVG _i)	20.15	23.59	15.96	16.06

Note: different letters (a, b, c) denote values that differ significantly within a row, based on Tukey's test with Bonferroni correction

Source: compiled by the authors based on the conducted study

An analysis of the linear regression coefficients revealed that the varieties IR-398 and IDO-200905 exhibited low sensitivity to changes in growing conditions. With an increase of 1 g in the average dry seed yield per plant, their productivity rose by only 0.78 g and 0.93 g, respectively. In contrast, the varieties IR-1030 and Smolianka (control) showed high sensitivity, increasing yield by 1.02 g and 1.27 g, respectively, under the same conditions. High homeostasis was recorded in IR-398 and Smolianka (control) (Hom = 5.07 and 6.35, respectively), while the lowest value was noted in IDO-200905 (Hom = 3.48). The highest values for genotype breeding value were observed in IDO-200905 and IR-398 (BVG_i = 20.15 and 23.59, respectively), whereas the variety IR-1030 recorded the lowest value (BVG_i = 15.96). The study found that the sprouting soybean varieties Staroukrainska mistseva (control) and Kytajska tsukrova No.1 showed the highest breeding value for dry seed yield per plant (BVG_i = 19.64 and 26.56, respectively), along with high relative stability (S_{gi} = 20.92% and 8.90%, respectively) and favourable plasticity coefficients (b_i = 0.99 and 0.73, respectively).

Among the varieties intended for green pea production, the best results were demonstrated by IDO-200905 and IR-398, which showed BVG_i values of 20.15 and 23.59, S_{gi} = 14.64% and 17.99%, and b_i of 0.78 and 0.93, respectively.

Improved crop varieties are essential technological tools for optimising agricultural production by increasing both potential yield and resilience to environmental and biological stresses. The study by R. Yofa *et al.* (2021) highlights that the adoption of improved soybean varieties is driven by a complex interplay of interrelated factors. Key among these are: the availability of qualified personnel for breeding programmes; the level of interest among agricultural producers in adopting high-yielding varieties; farmers' trust in the effectiveness of quality seed material; the physical and economic accessibility of innovative seed; and the presence of institutional support from local authorities aimed at facilitating access to high-quality varieties. When it comes to variety selection in soybean cultivation, early-stage growth vigour is an important trait that should be taken into account. The performance results of soybean

varieties are consistent with the correlations identified by J. Monzon *et al.* (2021) and L. Roth *et al.* (2022), which provide further evidence that yield is significantly and positively correlated with early growth vigour. The findings indicate that the influence of initial growth vigour on yield is linked to its role in the development of the assimilative surface area, the initiation of flowering, and pod-setting processes. L. Abdala *et al.* (2025) emphasise that selecting an appropriate maturity group enables agricultural producers to align the crop's critical growth stages with optimal agroclimatic conditions, make the most of the growing season, and mitigate climate-related risks.

One of the key indicators of soybean seed yield is seed size (Duan *et al.*, 2022). A global soybean collection, comprising samples from all continents except Antarctica, was divided by R. Nair *et al.* (2023b) into two distinct groups: the first included 456 large-seeded accessions (over 25 g per 100 seeds), while the second comprised 7,397 small-seeded accessions (less than 25 g per 100 seeds). Based on this classification, soybean varieties intended for sprouting were identified as small-seeded. Among the varieties used for vegetable soybean production, the Smolianka variety (control) was also small-seeded, whereas IDO-200905, IR-1030, and IR-398 were classified as largeseeded. This distinction makes it possible to differentiate vegetable soybeans, which are typically characterised by larger seed size, from grain soybeans, which tend to have smaller seeds. As highlighted by X. Li *et al.* (2024), seed size can influence germination speed and vigour, both of which are important for adaptation to varying sowing times and climatic conditions. Furthermore, a study by C. Xu *et al.* (2022) identified a negative correlation between yield stability index and 100-seed weight, suggesting that soybean varieties with larger seeds may not provide consistently high and stable yields.

Elevated air temperatures during the summer months are often accompanied by drought, which, according to M. Staniak *et al.* (2023), intensifies water stress. Such conditions typically result in accelerated soybean maturation and a shortened flowering and grain-filling phase, which may reduce seed yield by 24%-54%. Furthermore, as shown by the findings of

O. Tkachuk *et al.* (2022), varieties with greater drought adaptability exhibit not only stable yields but also reduced susceptibility to lodging. According to a study by M. Staniak *et al.* (2021), a seven-day cold stress event during the flowering stage negatively affected plant structure and yield traits, leading to a 19.1% reduction. Experimental research has also confirmed the sensitivity of yield performance in both sprouting and vegetable soybean varieties to temperature fluctuations during critical growth periods. O. Mazur *et al.* (2023) emphasise that breeders should aim to develop varieties with a short overall growing season but an extended flowering-to-maturity phase (BBCH 60-99). Such a growth pattern provides optimal conditions for pod formation and seed development, while a prolonged reproductive period allows plants to better compensate for potential yield losses caused by adverse conditions during this stage.

Studies on soybean varieties intended for sprouting and vegetable use have shown that an increase of 10°C in the average sum of effective air temperatures during the growing season contributes to a rise in dry seed yield per plant by 0.05-0.204 g. In contrast, an additional 10 mm of precipitation had the opposite effect, reducing yield by 0.36-12.22 g. According to A. Melnyk *et al.* (2022), an analysis of relative elasticity coefficients revealed that a 1% rise in temperature led to a yield increase of 10.7%-738.5% in early-maturing varieties, 17.6%-29.6% in mid-early varieties, and 2.7%-7.6% in mid-maturing varieties. It was also established that a reduction in precipitation by 1 mm could increase yields by 1.4-2.2 t/ha in early-maturing varieties, 4.9-6.5 t/ha in mid-early varieties, and 0.6-1.4 t/ha in mid-maturing varieties. Additionally, for fast-growing soybean varieties, a 1% increase in precipitation may result in a yield gain of 1.4%-4.2%. The study by M. Corbellini *et al.* (2024) explored the impact of environmental factors on the adaptability of soybean varieties. Using yield data from multiple locations and geostatistical methods, it was shown that the environment accounts for approximately 32.54% of genotype-environment interactions. The most influential factor was soil moisture availability, contributing 7.80%. Based on the experimental findings, genotypes of high breeding

value were identified: for sprouting purposes – Staroukrainska mistseva (control) and Kytayska tsukrova No. 1; for green peas – IDO-200905 and IR-398. The study by L. Biliavska *et al.* (2021) demonstrated that the soybean varieties Alexandrite and Aquamarine, developed through Poltava breeding programmes, possessed the highest breeding value due to their strong plasticity under varying soil and climatic conditions in Ukraine. These varieties were characterised by a plasticity coefficient greater than 1 and a variance close to zero.

In the context of a changing climate marked by temperature anomalies and precipitation deficits, agriculture increasingly requires progressive approaches. The findings from soybean research revealed significant differences among varieties in terms of yield performance and plant adaptability, which are essential for developing cultivation recommendations tailored to varietal characteristics and the climatic conditions of specific regions.

CONCLUSIONS

The productivity of soybean varieties was strongly influenced by climatic conditions (r =from 0.73 to 0.99 with the sum of effective temperatures; r =from -0.49 to -0.76 with total precipitation). Relative stability (S_{gr}) varied from 8.90% to 58.68%. The coefficient of variation for yield ranged from 7.54% to 22.42%, depending on the variety. Regression coefficient analysis (b_i) revealed differing sensitivities of soybean varieties to agroecological conditions. The varieties Soybean for Sprouts No. 3, No. 4, and

IDO-21142 exhibited high b_i values (1.03-1.16), indicating a strong response to improved growing conditions. In contrast, the Kytayska tsukrova No. 1 variety had a lower b_i value (0.73), demonstrating greater environmental stability. Among soybean varieties for green peas, the least sensitive to improved conditions were IDO-200905 (b_i =0.78) and IR-398 (b_i =0.93), while the most responsive were IR-1030 (b_i =1.02) and Smolianka (b_i =1.27). Cultivation of sprouting soybean varieties Kytayska tsukrova No. 1 and Staroukrainska mistseva (control) provided an optimal combination of high homeostasis (Hom =2.70-4.04), breeding value of the genotype (BVG_i =19.64-26.56), and dry seed yield (28.0-30.4 g per plant). Among soybean varieties for green peas, IDO-200905 and IR-398 demonstrated the highest breeding value (BVG_i =20.15-23.56), high homeostasis (Hom =3.48-5.07), and dry seed yield (29.8-37.4 g per plant).

Future research will focus on identifying optimal agronomic practices – such as sowing dates, plant density, fertilisation, and soil management – to maximise the environmental stability and adaptability of different vegetable soybean varieties under specific regional conditions.

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CONFLICT OF INTEREST

None.

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Оцінка сортів сої овочевої (*Glycine max* L.) за показниками генотип-середовище: екологічна пластичність, стабільність і адаптивна реакція

Анотація. Метою роботи було встановлення кількісних та якісних залежностей між дією абіотичних факторів середовища, типових для Правобережного Лісостепу України, та продуктивністю сортів сої. Основними методологічними підходами до вивчення даної проблеми були польові дослідження, що дозволили проаналізувати елементи технології вирощування, та статистичний аналіз, використаний для верифікації отриманих даних. Установлено, що продуктивність сухого насіння з однієї рослини у сортів сої, призначених для проростків, варіювала в межах від 14,3 до 30,4 г. Максимальні значення цього показника відзначено у сорту Китайська цукрова №1, другим за продуктивністю був сорт Староукраїнська місцева (контрольний варіант), третю позицію посів сорт Соя для проростків №3. Коефіцієнт варіації продуктивності рослин упродовж років досліджень становив від 7,54 до 22,42 %. Сорти Соя для проростків №3, Соя для проростків №4 та ІДО-21142 відзначалися високими значеннями коефіцієнта регресії ($b_1=1,03-1,16$), що вказує на їхню підвищену чутливість до змін агроекологічних умов. Натомість сорт Китайська цукрова №1 характеризувався найнижчим значенням коефіцієнта регресії ($b_1=0,73$), що свідчить про його нижчу реакцію на зміну умов вирощування. За показником селекційної

цінності найбільш перспективними виявилися сорти Китайська цукрова №1 ($GBV_i = 26,56$) та Староукраїнська місцева (контроль) ($GBV_i = 19,64$). Вивчені сорти сої для зеленого горошку характеризувалися широким діапазоном продуктивності сухого насіння – від 29,8 до 52,4 г/рослину, при коефіцієнті варіації в межах від 7,74 до 9,13 %. Серед сортів сої для використання у вигляді зеленого горошку найменш чутливими до покращення умов вирощування виявилися сорти ІДО-200905 ($b_i = 0,78$) та IR-398 ($b_i = 0,93$), тоді як найбільшу чутливість виявили сорти IR-1030 ($b_i = 1,02$) та Смолянка (контроль) ($b_i = 1,27$). Водночас сорти ІДО-200905 та IR-398 демонстрували високу гомеостатичність ($Hom = 3,48$ та $5,07$ відповідно) і значну селекційну цінність ($GBV_i = 20,15$ та $23,59$ відповідно), що свідчить про ефективне поєднання високої продуктивності та стабільності

Ключові слова: ефективні температури; опади; генотип; стресостійкість; бобові культури

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Models of sunflower hybrid productivity in the Right-Bank Forest-Steppe of Ukraine

Abstract. The relevance of this research lies in the need to identify the specific features of productivity formation in sunflower hybrids and to establish the relationship between dry matter accumulation at different growth stages and crop yield under varying nutritional conditions. This study aimed to examine the impact of nutritional regimes on the growth, development, and productivity formation of sunflower hybrid agrocenoses, with the application of mineral fertilisers and the growth regulator Kvadrostym, under specific soil and climatic conditions. The research employed both theoretical (statistical analysis) and practical (descriptive and comparative) methods. The following indicators were assessed: dry matter content in plant samples at defined stages of sunflower hybrid development, yield levels, and the interrelationship between these parameters. It was found that as sunflower plants progressed through their growth stages, dry matter accumulation increased accordingly. The values differed depending on the developmental

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characteristics of the hybrids under study. The highest values were recorded at the BBCH 74-77 growth stage. The indicators varied according to the hybrid and nutritional conditions, ranging from 6.12 to 8.62 t/ha. The highest dry matter accumulation was observed in crops of the hybrid ES Monalisa. The application of the growth regulator Kvadrostym contributed to increased dry matter accumulation and, consequently, to higher yields across all sunflower hybrids. The research results demonstrated a consistent relationship between dry matter accumulation in sunflower plants and crop yield at all stages of development. Analysis of linear regression models indicated a strong correlation between these parameters. At the BBCH 74-77 stage, the coefficient of determination varied by sunflower hybrid from 0.9829 to 0.9934. The findings support conclusions regarding the rational use of mineral fertilisers and growth-regulating products to create optimal nutritional conditions for sunflower hybrids

Keywords: *Helianthus annuus*; weather conditions; regression model; dry matter; fertilisers; yield

INTRODUCTION

The food security challenge and its resolution represent a global priority requiring immediate action. One effective approach involves increasing the productivity of agricultural crops through the intensification of agricultural production processes and the development and introduction of new crop varieties and hybrids adapted to specific soil and climatic conditions. Alongside higher yield indicators, the quality and safety of the resulting produce are gaining increasing importance. Sunflower remains the leading oilseed crop cultivated in Ukraine. The area under sunflower cultivation meets both domestic demand – from the population and industry – and supplies significant export volumes. However, the rapid expansion of sunflower cultivation areas has led to oversaturation in crop rotations, which in turn causes several issues, including soil depletion and desiccation. These challenges negatively affect the physical, chemical, and biological properties of soils. This situation highlights the need to optimise cultivation technologies and assess the adaptability of new varieties and hybrids now entering the market. Such measures would support the more complete realisation of their genetic potential under specific climatic conditions (Drobotko *et al.*, 2024; Zhao *et al.*, 2024).

A review of the literature indicates that there is considerable experience in studying the effects of environmental factors and cultivation technologies on dry matter accumulation in sunflower plants. However, ongoing climate change presents new challenges for

producers (Kalenska *et al.*, 2021; Hussain *et al.*, 2025). Identifying relationships between production processes – particularly dry matter accumulation and crop yield – requires further attention. According to K. Narayana Rao *et al.* (2020), the majority of essential nutrients (nitrogen, phosphorus, potassium), meso-elements (magnesium, calcium, sulphur), and micronutrients (zinc, molybdenum, copper, cobalt, manganese, etc.) are absorbed by the plant before the flowering stage. This period is marked by a rapid increase in vegetative biomass. Research by S. Li & Z. Liu (2025) shows that the separate application of nitrogen, phosphorus, and potassium can increase yield by 23%, 21%, and 12%, respectively. In contrast, the application of compound fertilisers (NP, NK, PK, NPK) results in even greater yield increases – 30%, 28%, 17%, and 42%, respectively. Sunflower plants have the highest nitrogen demand during the head formation and flowering stages.

According to the findings of T. Wang *et al.* (2021), adequate water availability facilitates the efficient transport of nitrogen compounds to the vegetative and generative organs of sunflower plants. Phosphorus uptake is at its highest during the emergence-to-flowering period, after which its absorption by the plant declines sharply. Potassium is the only element consistently absorbed by sunflower plants throughout the entire growing season. However, a critical period for potassium uptake has been identified – coinciding with the stages from head

formation to ripening – during which the plants consume the largest amount of this nutrient. To produce 1 tonne of seed along with the associated vegetative mass, sunflower plants require approximately 60 kg of nitrogen, 26 kg of phosphorus, and 170 kg of potassium. It is worth noting that sunflowers are capable of absorbing forms of potassium unavailable to other crops. Literature sources indicate that even when grown on chernozem soils, sunflower plants have a higher demand for nitrogen and phosphorus than for potassium. In addition, sunflower varieties tend to be less responsive to fertiliser application compared to hybrids.

An analysis of the literature also highlights the issue of soil depletion caused by continuous sunflower cultivation. At the same time, several studies indicate relatively high nutrient return rates via plant residues, which, depending on the level of nutrient removal by the crop, amount to: N – 74%, P_2O_5 – 54%, and K_2O – 94%. For comparison, maize returns are: N – 51%, P_2O_5 – 34%, K_2O – 98%; and for soybean: N – 27%, P_2O_5 – 28%, K_2O – 28%. Research by A. Alves *et al.* (2018), conducted under controlled soil conditions and focused on the impact of macronutrients on dry matter synthesis, demonstrated a significant reduction in the amount of organic matter synthesised by plants in the absence of nutrients. The results showed that in the absence of N, P, K, Ca, and S, dry matter synthesis and accumulation were considerably lower compared with variants treated with a complete nutrient solution. In the absence of K, Ca, and Mg, a nutrient imbalance was observed in the plants, characterised by elevated nitrogen levels compared to plants grown with complete fertilisation.

The study of supplementary elements in crop cultivation technologies has become increasingly relevant, particularly regarding seed treatment, foliar application of micronutrients, growth regulators, biopreparations, and anti-stress agents. These practices contribute to crop productivity by creating favourable conditions at specific stages of plant growth and development, as discussed in the studies of M. Carvalho *et al.* (2016), O. Laslo (2022), R. Mialkovskiy & D. Liubytka (2025). Establishing near-optimal conditions during critical growth

periods concerning specific limiting factors can enable crops to realise their full genetic potential. In turn, providing optimal nutritional conditions supports the development of sufficient assimilating surface area, promotes dry matter accumulation, and increases sunflower yield. This study aimed to examine the dynamics of dry matter accumulation in crops of sunflower hybrids Alzan, ES Monalisa, RGT Marllen, and RGT Wolf at specific growth stages under varying nutritional conditions established through different fertiliser treatments.

MATERIALS AND METHODS

The study was conducted during 2020–2022 at the Agronomic Research Station, a separate division of the National University of Life and Environmental Sciences of Ukraine, located in Kyiv Region. The trial was established within the department's long-term field crop rotation system. The soil of the experimental field was typical low-humus chernozem, with a humus content of 4.30%. Nitrogen availability was low (50 mg/kg), while phosphorus (54.3 mg/kg) and potassium (142 mg/kg) levels were moderate.

The field trial was arranged as a three-factor experiment. Factor A included sunflower hybrids – RGT Marllen, RGT Wolf, Alzan, and ES Monalisa. Factor B: application rates of mineral fertilisers, calculated using a balance method based on target yield – $N_{40}P_{20}K_{50}$; $N_{55}P_{50}K_{70}$; $N_{70}P_{80}K_{90}$; $N_{85}P_{110}K_{110}$. Factor C: foliar application of Kvadrostym against the background of basic fertilisation at BBCH stages 14–15 and 50–52, applied at a rate of 500 mg/ha. Each treatment was replicated four times. The preceding crop was winter wheat. The plant density at harvest was 55,000 plants/ha. Phosphorus and potassium fertilisers were applied in the autumn during primary tillage, while nitrogen fertilisers were incorporated during pre-sowing cultivation. The fertilisers used in the experiment included ammonium nitrate (34.4% N), single superphosphate (19% P), and potassium chloride (60% K). The composition of Kvadrostym was as follows: polyethylene glycol – 400 at 260 g/L, polyethylene glycol – 1,500 at 510 g/L, succinic acid – 0.5 g/L, arachidonic acid – 1.44 mg/L, and potassium (sodium) lignohumate – 3.3 g/L (Kvadrostym, n.d.).

The coefficients of the significance of agrometeorological elements deviations of the current year's from long-term average values were calculated using the following formula:

$$Cs = \frac{(Xi - \bar{X})}{\sigma}, \quad (1)$$

where Cs is the coefficients of the significance of deviation; X_i is the current year weather elements (mean monthly or ten-day period average values of temperature and precipitation); \bar{X} – long-term average value; σ – standard deviation.

The interpretation of these coefficients is as follows:

- $Cs = 0 \div 1$ – conditions close to normal;
- $Cs = 1 \div 2$ – conditions significantly differ from long-term averages;
- $Cs > 2$ – conditions approaching rare/extreme levels.

The dry matter content in plant samples was determined at specific stages of sunflower hybrid development using a thermostat-weight method. Plant samples were oven-dried to constant weight at 105°C. Yield data were obtained via combined harvesting from designated plot areas. The actual yield was adjusted to a standard moisture content (8%) and corrected for the presence of impurities, in line with the method described by A. Rozhkov *et*

al. (2016). The values for dry matter content and yield are presented as three-year averages, accounting for the mean values across treatments and replications.

Agro-climatic conditions and parameters considered (mean monthly air temperature and precipitation during the growing season) were calculated using average daily values recorded by the Fastiv meteorological station. Based on these data, coefficients of the significance of agrometeorological elements deviations during the sunflower growing season over the study period were calculated. Regression models were developed using correlation-regression analysis, and regression equations were provided. The research was conducted following the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The parameters of key agrometeorological indicators over the research period (2020-2022) demonstrate that the growing seasons differed in both temperature regimes and precipitation levels. An analysis of the temperature data revealed that, across all study years, values exceeded the longterm average (Fig. 1).

Precipitation during the growing seasons of the study years was insufficient and unevenly distributed (Fig. 2).

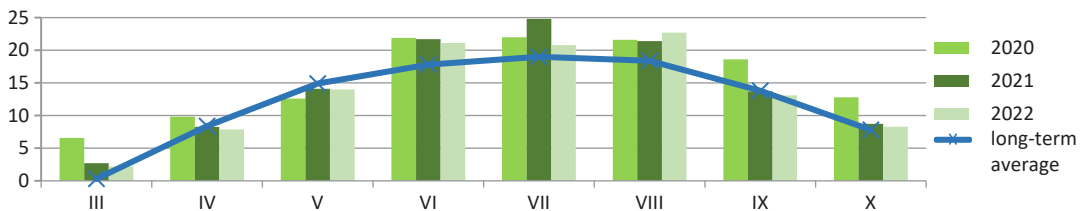


Figure 1. Mean air temperature values, 2020-2022, °C

Source: developed by the authors

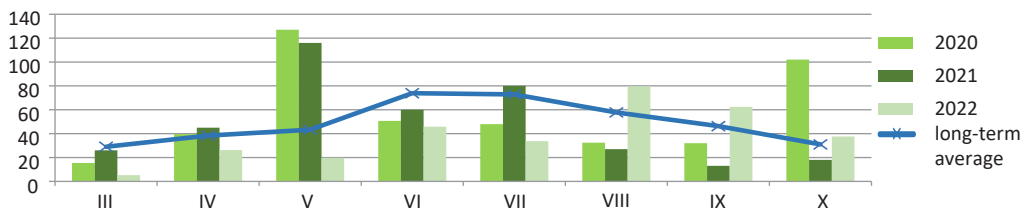


Figure 2. Precipitation levels, 2020-2022, mm

Source: developed by the authors

Calculations and analysis of the coefficients of the significance of average daily temperatures deviation from long-term data indicate that only 58% of the sunflower growing season months fell within the “conditions close

to normal” category. In contrast, 25% were categorised as “conditions significantly differ from long-term averages”, and 17% were considered “conditions approaching rare/extreme levels” (Fig. 3).

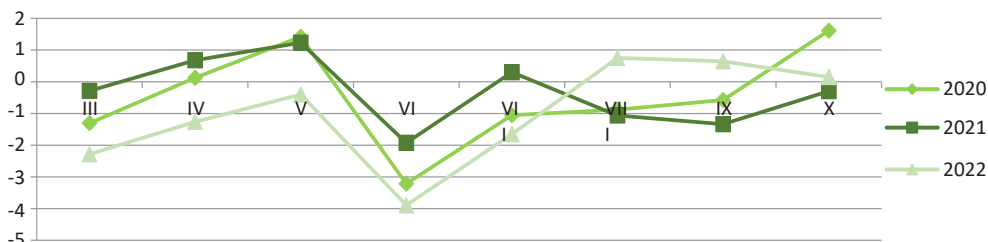


Figure 3. Coefficients of the significance of precipitation deviation from long-term averages, 2020-2022, mm

Source: developed by the authors

Calculations of the coefficients of the significance of average daily temperatures deviation from long-term data (Fig. 4) show that only 46% of the growing season months during 2020-2022 fell within the “conditions

close to normal” category. Meanwhile, 42% of the months were classified as “conditions significantly differ from long-term averages”, and 13% as “conditions approaching rare/extreme levels”.

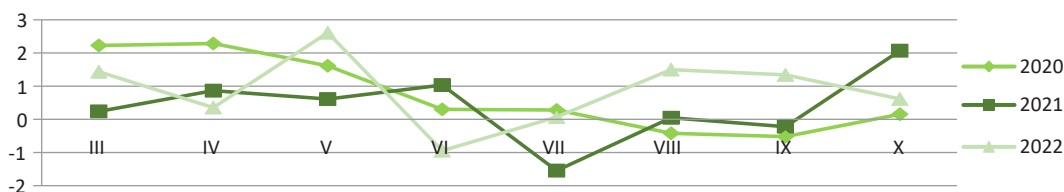


Figure 4. Coefficients of the significance of average daily temperatures deviation from long-term data

Source: developed by the authors

The weather conditions during the years of the study were not favourable for sunflower cultivation, as they did not meet the crop’s biological requirements. This adversely affected crop productivity. The synthesis and transformation of organic matter rely on the absorption of solar energy by the assimilating surface of the plant through the process of photosynthesis, which accounts for up to 90% of the dry matter produced. The remaining dry matter is formed through the uptake of mineral nutrients by the plant organism (Hamaiunova & Kudrina, 2020).

The productivity of crops is regulated by two key physiological processes in plants: the development of the assimilating surface and the

process of photosynthesis. The photosynthetic activity of crops is influenced by several exogenous factors, including light intensity, temperature regime, atmospheric carbon dioxide concentration, and regional weather conditions. Equally important is the availability of nutrients, which is a controllable factor. These elements, along with the specific characteristics of the variety or hybrid, play a crucial role in the formation and accumulation of dry matter in sunflower plants (Domaratskiy et al., 2018).

According to the research findings, the accumulation of dry matter in sunflower plants occurred gradually as the plants grew and developed. The highest values were observed at the BBCH 74-77 stage (Table 1). At this stage,

greater variation in dry matter accumulation was recorded across fertiliser treatments than at earlier stages of development. For instance, the RGT Marllen hybrid accumulated dry matter ranging

from 6.21 to 7.31 t/ha, depending on the fertilisation treatment, RGT Wolf from 6.63 to 7.82 t/ha, Alzan from 6.12 to 7.04 t/ha, and ES Monalisa from 6.92 to 8.31 t/ha.

Table 1. Dynamics of dry matter accumulation in sunflower crops, average for 2020-2022, t/ha

Fertiliser treatments	Microstage (BBCH scale)	ES Monalisa		RGT Wolf		RGT Marllen		Alzan	
		1	2	1	2	1	2	1	2
N ₄₀ P ₂₀ K ₅₀ N ₅₅ P ₅₀ K ₇₀ N ₇₀ P ₈₀ K ₉₀ N ₈₅ P ₁₁₀ K ₁₁₀ V, %	16-20	0.43	0.45	0.41	0.44	0.37	0.41	0.36	0.39
		0.59	0.65	0.55	0.51	0.46	0.52	0.42	0.51
		0.71	0.78	0.64	0.71	0.59	0.66	0.49	0.56
		0.83	0.93	0.77	0.87	0.75	0.83	0.61	0.74
		26.70	28.97	25.57	30.88	30.45	30.01	22.85	26.43
N ₄₀ P ₂₀ K ₅₀ N ₅₅ P ₅₀ K ₇₀ N ₇₀ P ₈₀ K ₉₀ N ₈₅ P ₁₁₀ K ₁₁₀ V, %	54-58	3.19	3.33	3.09	3.18	2.87	2.98	2.81	3.01
		3.41	3.64	3.27	3.41	3.03	3.22	3.01	3.19
		3.72	4.07	3.45	3.60	3.28	3.54	3.26	3.48
		3.97	4.29	3.81	4.02	3.61	3.79	3.54	3.68
		9.59	11.23	9.03	10.02	10.09	10.51	10.01	8.93
N ₄₀ P ₂₀ K ₅₀ N ₅₅ P ₅₀ K ₇₀ N ₇₀ P ₈₀ K ₉₀ N ₈₅ P ₁₁₀ K ₁₁₀ V, %	64-68	4.15	4.28	4.01	4.15	3.86	3.99	3.81	3.94
		4.39	4.67	4.12	4.39	4.10	4.27	3.96	4.17
		4.89	5.05	4.65	4.88	4.52	4.79	4.25	4.59
		5.27	5.61	4.94	5.28	4.81	5.01	4.51	4.71
		10.75	11.56	9.93	10.80	9.82	10.36	7.52	8.26
N ₄₀ P ₂₀ K ₅₀ N ₅₅ P ₅₀ K ₇₀ N ₇₀ P ₈₀ K ₉₀ N ₈₅ P ₁₁₀ K ₁₁₀ V, %	74-77	6.92	7.21	6.63	6.89	6.21	6.42	6.12	6.39
		7.39	7.59	6.97	7.21	6.43	6.71	6.29	6.56
		7.85	7.98	7.43	7.69	6.74	6.97	6.62	6.82
		8.31	8.62	7.82	8.02	7.31	7.49	7.04	7.17
		7.85	7.67	7.22	6.73	7.15	6.59	6.22	5.04

Note: 1 – without treatment control; 2 – foliar application of Kvadrostym alongside base fertilisation at BBCH stages 14-15 and 50-52 at a rate of 500 mg/ha

Source: developed by the authors

The application of Kvadrostym increased dry matter accumulation in the RGT Marllen hybrid to 6.42-7.49 t/ha, in RGT Wolf to 6.89-8.02 t/ha, in Alzan to 6.39-7.17 t/ha, and in ES Monalisa to 7.21-8.62 t/ha. Fertiliser application created favourable conditions for the formation and accumulation of dry matter in sunflower plants. A direct correlation was observed between the amount of fertiliser applied and the resulting crop productivity. The relationships between dry matter accumulation at specific growth stages and the yield of

sunflower hybrids, under different nutrient supply conditions, are presented in Table 2 in the form of linear regression models. The coefficients of determination obtained from these models indicate a strong association between accumulated dry matter and the yield of sunflower hybrids. At early growth stages, the coefficients of determination were slightly lower compared to those observed at BBCH stage 74-77. Similar patterns were observed in treatments where foliar applications of Kvadrostym were conducted twice during the growing season.

Table 2. Regression models of sunflower hybrid yield depending on dry matter accumulation, average for 2020-2022

Hybrid	Sunflower growth stage	Foliar application of PGR Kvadrostym	Regression model (linear)	Coefficient of determination, R ²
ES Monalisa	BBCH 16-20	-	$y = 0.3917x - 0.5301$	0.9069
		+	$y = 0.4131x - 0.6277$	0.9086
	BBCH 54-58	-	$y = 0.7936x + 1.2016$	0.9568
		+	$y = 0.883x + 0.9891$	0.9606
	BBCH 64-68	-	$y = 1.162x + 1.2035$	0.9749
		+	$y = 1.1578x + 1.1744$	0.9817
BBCH 74-77	-	$y = 1.3813x + 3.491$	0.9931	
	+	$y = 1.2248x + 3.906$	0.9936	
RGT Wollf	BBCH 16-20	-	$y = 0.4764x - 0.739$	0.9141
		+	$y = 0.5415x - 1.011$	0.9224
	BBCH 54-58	-	$y = 0.9661x + 0.7047$	0.9706
		+	$y = 0.9911x + 0.5446$	0.9715
	BBCH 64-68	-	$y = 1.3383x + 0.6894$	0.9776
		+	$y = 1.4112x + 0.3919$	0.9782
BBCH 74-77	-	$y = 1.6316x + 2.6522$	0.9835	
	+	$y = 1.4079x + 3.1795$	0.9906	
RGT Marllen	BBCH 16-20	-	$y = 0.4505x - 0.6637$	0.9323
		+	$y = 0.451x - 0.7064$	0.9371
	BBCH 54-58	-	$y = 0.8766x + 0.8504$	0.9701
		+	$y = 0.8929x + 0.7865$	0.9752
	BBCH 64-68	-	$y = 1.1531x + 1.2352$	0.9785
		+	$y = 1.1642x + 1.1302$	0.9608
BBCH 74-77	-	$y = 1.1148x + 3.6563$	0.9834	
	+	$y = 1.2858x + 3.2298$	0.9883	
Alzan	BBCH 16-20	-	$y = 0.3394x - 0.4066$	0.9472
		+	$y = 0.3814x - 0.5151$	0.9487
	BBCH 54-58	-	$y = 1.0013x + 0.5692$	0.9651
		+	$y = 0.7952x + 1.119$	0.9707
	BBCH 64-68	-	$y = 0.9725x + 1.621$	0.9790
		+	$y = 0.9468x + 1.7086$	0.9761
BBCH 74-77	-	$y = 1.2668x + 3.2461$	0.9829	
	+	$y = 0.8947x + 4.2365$	0.9864	

Source: developed by the authors

The results of the study demonstrated that fertiliser application had a positive effect on the productivity of sunflower hybrids. Yields varied depending on nutrient supply and, on average

across the study years, ranged from 2.08 to 2.86 t/ha for RGT Marllen, 2.29-3.19 t/ha for RGT Wollf, 2.09-2.87 t/ha for Alzan, and 2.35-3.42 t/ha for ES Monalisa (Fig. 5).

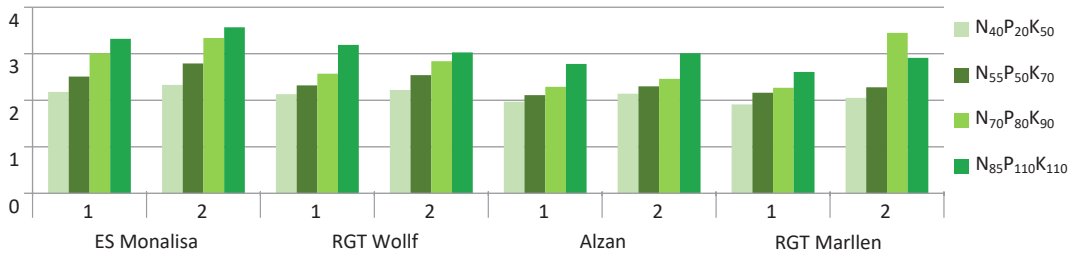


Figure 5. Yield of sunflower hybrids, t/ha, average for 2020-2022

Note: 1 – water treatment; 2 – Kvadrostym treatment at BBCH stages 14-15 and 50-52 at a rate of 500 mg/ha

Source: developed by the authors

In the treatments where foliar application of Kvadrostym was performed at BBCH micro-stages 14-15 and 50-51, yields were higher and reached 2.23-3.12 t/ha for RGT Marllen, 2.42-3.24 t/ha for RGT Wollf, 2.24-3.11 t/ha for Alzan, and 2.51-3.68 t/ha for ES Monalisa. A direct correlation between fertiliser rates and hybrid yield was identified, with a strong positive correlation observed. Correlation coefficients varied depending on hybrid characteristics and ranged from 0.975 to 0.986. The results of the study showed that, as the plants grew and developed, the biomass of sunflower plants increased. An intensive accumulation of dry matter was observed up to the end of the flowering stage. During this period, plants accumulated the highest amounts of both fresh biomass and dry matter. Further plant development was characterised by a decline in above-ground biomass. Similar findings were reported in studies by V. Hamaiunova & V. Kudrina (2020), which investigated the effects of foliar feeding with modern plant growth regulators (Fresh Energy, Fresh Florid, Retardyn) on sunflowers. The application of these products led to an increased rate of dry matter accumulation, with the amount depending on the type of biopreparation, its dosage, and the growth stage at which it was applied.

The application of fertilisers created conditions that promoted the formation and accumulation of dry matter in sunflower plants. Studies conducted by A. Mahapatra *et al.* (2020; 2021) indicate a gradual accumulation of dry matter in sunflowers, reaching a peak during the ripening stage, which supports the findings of the present research. According to F. Villalobos *et*

al. (1994), the distribution of dry matter and yield formation are critical factors for the successful modelling of crop productivity. The genetic characteristics of sunflower hybrids influenced the synthesis, accumulation, and distribution of dry matter within the plants, as evidenced by the results obtained. Field studies by O. Polyakov & S. Litoshko (2022) demonstrated that the highest dry matter accumulation in sunflowers was achieved with the application of a complete mineral fertiliser at a rate of N₆₀P₆₀K₆₀. The use of plant growth regulators promoted increased dry matter accumulation at all stages of plant growth and development, regardless of the mineral fertiliser background.

According to the findings of H. Pinkovskiy (2019) and H. Pinkovskiy & Yu. Mashchenka (2019), the development of high sunflower productivity depends on the genetic characteristics of the hybrid, weather conditions during the growing season and the availability of essential nutrients. The most favourable conditions for sunflower growth and development were observed with the application of a complete mineral fertiliser at a rate of N₄₀P₄₀K₄₀, combined with fertilisation using the by-products of the preceding crop. Three-year research conducted by O. Polyakov & A. Shcherbak (2022) under the conditions of the Southern Steppe of Ukraine confirmed the positive impact of mineral fertilisers and growth regulators on the dynamics of dry matter accumulation in sunflower plants. The highest increase in dry matter was recorded during the grain-filling to maturity stages with the application of a complete mineral fertiliser at a rate of N₆₀P₆₀K₆₀. The use of growth regulators enhanced the accumulation

of dry matter at all stages of plant growth and development, regardless of the mineral nutrition background under investigation.

According to the findings of V. Hanhur *et al.* (2020; 2022), which focused on the effects of fertilisation and the application of biopreparations under the conditions of the Poltava Region, the highest yield was achieved when the Kame-niar hybrid was cultivated with the application of $N_{32}P_{32}K_{32}$ and foliar treatments using the biopreparations Organic-Balance (0.5 L/ha) and Liposam (0.5 L/ha), resulting in a yield of 3.02 t/ha. A direct relationship was identified between the amount of fertiliser applied and the resulting crop productivity. In field experiments conducted by V. Sendetskyi *et al.* (2022), it was established that the use of the growth regulators Vermymah and Vermiyodis influenced the intensity of sunflower plant growth processes, contributing to an increase in leaf surface area, the accumulation of dry matter, and improvements in yield structure elements. Based on a mathematical and statistical analysis, structural indicator models were proposed, revealing a direct correlation between the experimental factors and yield outcomes.

The study by O. Sakharchuk & L. Harbar (2018) demonstrated an increase in dry matter accumulation and yield of sunflower hybrids as a result of applying fertilisers and micronutrients. However, findings from research conducted by E. Domaratskiy *et al.* (2018) under Steppe conditions indicate that optimising the nutritional regime for sunflower plants depends not solely on fertiliser application. During the early stages of development, sunflower plants are exposed to stress due to herbicide application or lack of moisture. The adverse effects of such stress conditions can be mitigated, and nutrient uptake can be enhanced, through the use of growth regulators in combination with mineral fertilisation. The application of growth regulators was found to increase yield by 11.0-13.6%. Research by W. Nasim *et al.* (2016), which investigated the effects of different nitrogen fertiliser rates on the growth, development, and productivity of sunflower hybrids under varying climatic conditions, yielded somewhat different results. Their findings indicated that nitrogen fertilisers directly affect the synthesis and accumulation of dry matter in sunflower plants, and consequently, their yield. The highest dry

matter accumulation and yield were recorded under the treatment with the highest nitrogen dose (N_{180}). Thus, both the research findings and the literature evidence strongly suggest that optimising mineral nutrition in combination with the use of biopreparations and growth regulators is a key factor in enhancing biomass accumulation and achieving high productivity in sunflower crops, which is reflected in increased yield.

CONCLUSIONS

An analysis of the key agrometeorological indicators during the growing seasons of the study years (2020-2022) revealed significant variation in both temperature patterns and precipitation levels. Temperature readings were consistently higher during the study period compared with long-term averages. Precipitation was insufficient and unevenly distributed throughout the growing seasons. Overall, the weather conditions were not favourable for sunflower cultivation, as they did not meet the biological requirements of the crop. The findings indicated that the highest accumulation of dry matter occurred at the BBCH growth stage 74-77. During this stage, the following levels were recorded: for the RGT Marllen hybrid, 6.21-7.31 t/ha; RGT Wolf, 6.63-7.82 t/ha; Alzan, 6.12-7.04 t/ha; and ES Monalisa, 6.92-8.31 t/ha. The application of Kvadrostym contributed to further increases in dry matter accumulation, raising values to 6.42-7.49 t/ha for RGT Marllen, 6.89-8.02 t/ha for RGT Wolf, 6.39-7.17 t/ha for Alzan, and 7.21-8.62 t/ha for ES Monalisa. The highest dry matter accumulation across all sunflower plots was observed under the treatment with $N_{85}P_{110}K_{110}$ fertiliser during the cultivation of the ES Monalisa hybrid, reaching 8.31 t/ha. Foliar application of Kvadrostym further increased this value to 8.62 t/ha. The maximum seed yield was also recorded for the ES Monalisa hybrid under the $N_{85}P_{110}K_{110}$ fertiliser regime, at 3.42 t/ha, with Kvadrostym treatment contributing to an increase in yield to 3.68 t/ha.

The research findings demonstrated a clear relationship between dry matter accumulation in sunflower plants and crop yield at all stages of development. Analysis of linear regression models indicated a strong association between these parameters. At the BBCH 74-77 growth stage, the coefficient of determination varied by hybrid,

ranging from 0.9829 to 0.9934. Regression models describing yield as a function of dry matter accumulation at different developmental stages confirmed the strength of this relationship. A direct correlation was also established between fertilisation treatments and yield indicators, with correlation coefficients ranging from 0.975 to 0.986. These results highlight the potential for further comprehensive investigation into the influence of nutrient elements, novel bioproducts, growth regulators, and cultivation technologies

on the growth, development, and productivity of sunflowers under conditions of climate change.

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CONFLICT OF INTEREST

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Моделі продуктивності гібридів соняшнику в умовах Правобережного Лісостепу України

Анотація. Актуальність досліджень полягає у необхідності виявлення особливостей формування продуктивності гібридів соняшнику та встановлення взаємозв'язку між накопиченням сухої речовини на окремих стадіях росту та розвитку культури і її урожайністю за впливу різних умов живлення. Мета досліджень полягала у вивченні впливу умов живлення на ріст, розвиток, формування продуктивності агроценозів гібридів соняшнику за внесення мінеральних добрив і ріст регулюючого препарату «Квадростим» за впливу конкретних ґрунтово-кліматичних умов. У процесі проведення досліджень використовували такі методи: теоретичні (статистична обробка) та практичні (описові, порівняльні). Проводили оцінку наступних показників: вмісту сухої речовини у рослинних зразках у певні періоди розвитку гібридів соняшнику, урожайності та взаємозв'язку між ними. Встановлено, що по мірі росту та розвитку рослин соняшнику спостерігалось збільшення показників накопичення сухої речовини. Значення різнилися залежно від особливостей розвитку гібридів, які вивчали. Максимального значення показники сягали на стадії ВВСН 74-77. Показники варіювали залежно від гібриду та умов живлення від 6,12 до 8,62 т/га. Максимальне значення сухої речовини накопичували посіви гібриду ЕС Моналіза. Застосування препарату «Квадростим» сприяло накопиченню сухої речовини посівами та, відповідно, зростанню урожайності всіх гібридів культури. Результати досліджень засвідчили залежність між накопиченням сухої речовини рослинами соняшнику та урожайністю культури на всіх етапах їх розвитку. Аналіз регресійних моделей лінійного типу вказував на сильний зв'язок між зазначеними показниками. На стадії ВВСН 74-77 коефіцієнт детермінації змінювався залежно від гібриду соняшника від 0,9829 до 0,9934. Результати досліджень дозволяють зробити висновки щодо раціонального використання мінеральних добрив та ріст регулюючих препаратів для створення оптимальних умов живлення гібридів соняшнику

Ключові слова: *Helianthus annuus*; погодні умови; регресійна модель; суха речовина; добрива; урожайність

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The influence of genetic traits of the variety on the preservation of bioactive compounds in blue honeysuckle (*Lonicera caerulea* L.) fruits during sublimation and drying

Abstract. The value of blue honeysuckle fruits lies in their significant content of biologically active substances that perform antioxidant functions in the human body. Since fresh honeysuckle has a short shelf life, the goal of this research was to find processing methods that would ensure maximum preservation of both sensory and phytochemical properties. Fresh, dried, and freeze-dried fruits were tested in the laboratory to determine the content of vitamin C, polyphenols, flavonoids, and anthocyanins, and to conduct a sensory assessment of the quality of the samples under study. Statistical analysis of the research data was performed using STATISTICA software suite and ANOVA variance analysis. As a result of the research, it was found that the sensory quality indicators, namely, appearance and colour, were best preserved in the freeze-dried fruits of the Duet variety, while the Spokusa berries had an excellent taste rating of 4.8 points. It was determined that freeze-dried blue honeysuckle fruits retained 27.5% more ascorbic acid than dried ones, which accounts for 89.5% of the content found in fresh fruit. The least vitamin C was lost in the fruits of the Alicia variety. The loss of total phenols during drying ranged from 19.0% to 46.2%, which is 10.0% to 23.1% more than during freeze-drying. The most significant losses of total phenols occurred in the Duet variety for both drying and freeze-drying, while the least occurred in the Aurora variety. During drying and freeze-drying, blue honeysuckle fruits lost the most flavonoids and anthocyanins – 76.8% and 43.8%, respectively. The amount of anthocyanins decreased by 137 mg during freeze-drying and by 239 mg during drying. The results of this research can be used by producers to select blue honeysuckle varieties for the establishment of industrial plantations for drying and freeze-drying

Keywords: freeze-drying; vitamin C; polyphenols; flavonoids; anthocyanins

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INTRODUCTION

The food market is evolving rapidly, with healthy eating as a major trend. At the centre of this evolution are natural bio-organic extracts rich in antioxidants, polyphenols, flavonoids, carotenoids, and vitamins, which can enrich traditional food products, including fruit juices, increasing their value for human health (Sorrenti *et al.*, 2023; Krakowska-Sieprawska *et al.*, 2024). One of these valuable foods is the fruit of berry crops. As noted by O. Golovinskaia & C. Wang (2021), whether consumed fresh, frozen, freeze-dried, or dried, they offer significant health benefits. Blue honeysuckle is a valuable crop because its fruits ripen the earliest and have significant biochemical value. Due to the presence of biologically active substances with health benefits, including antioxidant and anti-inflammatory functions, blue honeysuckle fruits have gained attention from health-conscious consumers (Rupasinghe *et al.*, 2018).

In recent years, a new berry crop, blue honeysuckle, has been introduced to Ukraine's plantations that has not been grown before. Its value lies in its high winter hardiness and significant resistance to disease and pests. In addition, the fruits of blue honeysuckle open the season of fresh berries. With good agricultural practices, it is possible to get up to 4-5 kg of fruit from a bush. Other valuable compounds in blue honeysuckle include polyphenolic substances. However, according to E. Bassey *et al.* (2021), due to their high water content, these berries spoil quickly. To minimise qualitative and quantitative losses after harvesting, advanced processing technologies are required to prevent undesirable changes in weight, colour, texture, and flavour (Mencarelli & Bellincontro, 2020).

Drying is one of the simplest and most energy-efficient methods of processing fruit products. Hot air drying involves heating the air using thermal energy to evaporate moisture from the fruit. However, according to X. Zhang *et al.* (2023), traditional drying methods are inefficient and result in poor quality, although this statement does not apply to all fruit crops. Currently, vacuum freeze-drying, a more advanced technology, is gaining popularity (Liu *et al.*, 2022). Freeze-drying is a process in which water in the form of ice is removed from a material under low pressure

by sublimation (Stevanović *et al.*, 2021). As noted by Y. Qi *et al.* (2021), this dehydration technique preserves fruit and its juices, extending shelf life while reducing volume and weight, which lowers packaging, storage, and transportation costs. Freeze-drying is the preferred method for drying foods containing temperature-sensitive and oxidation-prone compounds, as it operates at low temperatures and under high vacuum conditions. Lyophilised berries, due to their biologically active compounds and extended shelf life without compromising nutritional value, can be used as ready-made functional foods (Silicka *et al.*, 2020). Freeze-drying is one of the most expensive methods of fruit processing, as it requires expensive equipment that first freezes the produce and then extracts moisture from it. For this reason, this processing method is not always affordable for producers. The preservation of product quality indicators depends heavily on the biological characteristics of the variety.

Blue honeysuckle is a new crop for the Ukrainian market that requires a comprehensive study. Particular attention should be focused on establishing the areas of product use, as honeysuckle is a new product on the Ukrainian market. In addition, the presence of a large amount of water in the berries makes it a product of short consumption period. In view of this, the research was aimed at establishing the suitability of blue honeysuckle fruits for processing by methods that would maximise the preservation of the product's sensory and consumer quality indicators. The purpose of the study was to determine the suitability of different varieties of honeysuckle for processing by hot air drying and freeze-drying according to a set of quality indicators, including sensory factors (appearance, colour, taste) and the content of biologically active substances (vitamin C, total phenols, flavonoids, anthocyanins). This is important for further recommendations on the use of the fruits of the blue honeysuckle varieties Spokusa, Alicia, Aurora, Karina, and Duet.

MATERIALS AND METHODS

The research was carried out in the analytical laboratory of the Department of Storage, Processing, and Analytical Research of the Institute

of Horticulture of the National Academy of Agrarian Sciences of Ukraine (IS NAAS). The fruits of blue honeysuckle varieties Spokusa, Alicia, Aurora, Karina, and Duet were collected for analytical studies, drying, and freeze-drying in the experimental plantations of the IS NAAS, 2023 harvest. On the day of harvest, fresh fruits were analysed, dried, and freeze-dried. Blue honeysuckle fruits were dried for 14 hours at 65°C in a drying oven “Sadochok 2M” (Ukraine). Freeze-drying of blue honeysuckle berries was carried out in a Ukrainian-made freeze-dryer S.S.02 in two stages. The berries were frozen for 12 hours at -10°C and dried for 15 hours at +55°C. For drying and freeze-drying, the fruits were cut in half and then placed in a single layer on trays for feeding into the drying oven and freeze-dryer. Immediately after drying and freeze-drying, the samples were packed in 85 µm thick plastic bags and stored in a dark place. Analytical studies of dried and freeze-dried fruits were performed on the second day after the completion of the drying and freezing process.

The sensory evaluation of dried and freeze-dried blue honeysuckle fruits was carried out by tasting and expressed in points. The samples were evaluated by experienced experts on the following sensory parameters: appearance, colour, taste, and aroma. The tasting group consisted of 9 scientists from the Institute of Horticulture of the National Academy of Sciences of Ukraine. The sensory analysis of dried and freeze-dried samples was performed on a 5-point hedonic scale with the following levels of preference: from 5 to 4 points – optimal quality, from 4 to 3 points – good quality, from 3 to 2 points – acceptable quality, from 2 to 1 point – poor quality, 1 point – very poor quality (Kondratenko *et al.*, 2008). To evaluate the sensory quality of dried and freeze-dried fruits, each taster was given 40 g samples on a separate plate. Each sample had an individual number. The results of the evaluation of sensory quality indicators, namely: appearance, colour, and taste, were reflected in points, mathematically processed, and presented as the mean value \pm standard error (mean \pm SE).

The content of vitamin C, total phenols, flavonoids, and anthocyanins was determined in fresh, dried, and freeze-dried fruits according

to the Methodology for Assessing the Quality of Fruit and Berry Products (Kondratenko *et al.*, 2008). Fresh, dried, and freeze-dried fruit samples were prepared to determine the content of polyphenols, vitamin C, flavonoids, and anthocyanins using a Waring 800S blender (USA). The dry matter content of blue honeysuckle fruits was determined by drying at 105°C to constant weight. The difference in weight between the fresh and dried samples was used to calculate the dry matter content (%).

To determine the content of vitamin C in fresh, dried, and freeze-dried fruits, a method was used that involves the extraction of crushed samples for 10 minutes with aqueous solutions of oxalic and hydrochloric acid (80+20, v/v). After settling, the working solution was filtered. Subsequently, 10 ml of the solution was taken from the filtrate, which was titrated with a solution of the sodium salt of 2,6-dichlorophenol-indophenol. The content of vitamin C was determined by the amount of sodium salt solution used to filter the working solution until it changed colour to yellow. The control was a mixture of acetic and oxalic acids (Kondratenko *et al.*, 2008).

The content of total phenolics in the fruits of blue honeysuckle was determined by the method of extraction of samples with ethyl alcohol. Filtering of the crushed fruit sample, which was washed until the colour disappeared with ethyl alcohol, was carried out through a blue paper filter into a Bunsen flask. Filtering of blue honeysuckle samples of fresh and dried fruits was carried out 3 times, and freeze-dried fruits – 5 times. The volume of alcohol used for filtration was recorded. The subsequent process of determining total phenols involved mixing for 3 minutes a mixture of 0.1 ml of alcoholic fruit extract, 1 ml of Folin-Dennis reagent and 7.9 ml of distilled water, followed by the addition of 1 ml of saturated sodium carbonate solution. After an hour of settling the working solution, the content of total phenols in fresh, dried, and freeze-dried samples was determined. A ULAB 102UV spectrophotometer (China) with a wavelength of 640 nm was used for the determination. A mixture of distilled water with 1 ml of Folin-Dennis reagent and 1 ml of saturated sodium carbonate solution was used as a control for the experimental samples (Kondratenko *et al.*, 2008).

The amount of phenols in fresh, dried, and freeze-dried fruits of blue honeysuckle was determined by the equation (1):

$$X = (A \times V \times 100) \div (V_1 \times M), \quad (1)$$

where X – content of total polyphenols in the sample, mg/100 g; A – amount of chlorogenic acid in the volume taken for spectrophotometric determination, found by the calibration chart, μg ; V – total volume of the final sample extract, ml; V_1 – volume of the aliquot of the final sample extract taken for analysis, ml; M – mass of the sample, g (Kondratenko *et al.*, 2008).

The amount of flavonoids in the samples of blue honeysuckle under study was determined using a ULAB 102UV spectrophotometer (China) at a wavelength of 410 nm. The method of absorption spectrophotometry for the determination of flavonoids is based on the measurement of the absorption of the flavonoid complex by a 3% aluminium chloride solution (Vronska, 2018). For the determination of anthocyanins from fresh, dried, and freeze-dried blue honeysuckle fruits, an alcohol extract was prepared and acidified with 3.5% hydrochloric acid. Subsequently, anthocyanins were determined at a wavelength of 530 nm using a ULAB 102UV spectrophotometer (China) (Kryventsov, 1982).

The data obtained as a result of statistical processing were presented as mean \pm standard error ($\bar{x} \pm \text{SE}$), for this purpose, the STATISTICA 13/1 software suite (StatSoft, Inc., USA) was used. The ANOVA statistical analysis was used to determine the correspondence between replicates and the mean value between varieties. The data obtained were presented at the level of

significance $P < 0.05$. The analysis of the reliability of the influence of biological characteristics of the variety and drying methods on the content of vitamin C, total phenols, flavonoids, and anthocyanins was performed using one-factor analysis of variance in Excel, 'Data analysis' tab. The research was carried out as part of scientific work, the results presented in the paper comply with the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

According to Ya. Yevchuk *et al.* (2019), drying is the easiest way to extend the shelf life of fruits, especially berries. Every year, the technology of vacuum freeze drying is becoming more and more widely used (Gronbach *et al.*, 2021). The sensory quality of dried and freeze-dried products largely determines their price on the market, which significantly affects the economic efficiency of freeze-dried and dried fruit production. Preserving the natural colour of dried food products is very important, as visual appearance is one of the first judgments consumers make. During the drying and freeze-drying process, physical characteristics such as colour, taste, and aroma change (Hamad *et al.*, 2023), and not always for the better, and these changes are highly dependent on the type of fruit and genetic characteristics of the variety. Of the blue honeysuckle varieties under study, the freeze-dried fruits of the Duet variety had the highest tasting score of 4.8 points for appearance and 4.9 points for colour (Fig. 1).

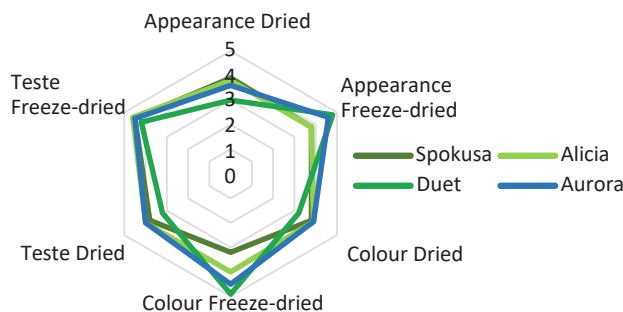


Figure 1. Sensory evaluation of dried and freeze-dried blue honeysuckle fruits

Source: photographed by the authors

The berries of this variety had no signs of cracking and wrinkling and also had the colour typical of fresh berries with a blue waxy bloom characteristic of honeysuckle. The freeze-dried berries of the Alicia and Spokusa varieties were rated 3.8 points for their appearance, as some of them had minor cracks in the samples submitted for tasting. The dried honeysuckle fruits were much worse in appearance. The fruits of all varieties, without exception, were wrinkled, dull black in colour without the blue waxy coating typical of honeysuckle fruits. The taste of freeze-dried fruits was rated at 4.2 (Duet) and 4.6 points (Temptation). This trend of priorities was maintained when evaluating the taste of dried fruits, the highest score was given to

Spokusa, and the lowest to Duet, with 3.8 and 3.2 points, respectively (Fig. 1).

The content of vitamin C in dried fruits of blue honeysuckle varied from 103 to 138 mg/100, which is 32.9-43.7% less than in fresh berries. In all the studied varieties, the loss of ascorbic acid during the drying process was significant in relation to the content in both fresh and freeze-dried fruits. The amount of ascorbic acid in freeze-dried honeysuckle was the lowest in the Spokusa variety (123 mg/100 g), and the highest in the Alicia variety (185 mg/100 g), which was 20.5% and 4.8% of the loss, respectively, compared to the content in fresh fruits. Insignificant losses of this vitamin were also observed in fruits of the Aurora variety (9.0%) (Table 1).

Table 1. Ascorbic acid content in fresh, dried and freeze-dried fruits of blue honeysuckle mg/100 g dry weight

Varieties	Fresh	Dried	Freeze-dried	Losses, %	
				In dried	In freeze-dried
Spokusa	155 ± 9.9 ^b	104 ± 6.7 ^c	123 ± 5.7 ^{bc}	32.9	20.5
Alicia	194 ± 12.3	117 ± 6.4 ^{cd}	185 ± 8.7	39.7	4.8
Duet	214 ± 12.3 ^a	138 ± 9.0 ^{cd}	194 ± 8.7 ^a	35.5	9.6
Aurora	182 ± 11.3	103 ± 8.1 ^{cd}	166 ± 11.0	43.7	9.0
Mean ± SE	186 ± 11.5	116 ± 7.5 ^{cd}	167 ± 8.5	38.0	10.5
Coefficient of variation, %	13.3	14.3	18.7		
min	155 ± 9.9	103 ± 8.1 ^{cd}	123 ± 5.7	32.9	4.8
max	214 ± 12.3	138 ± 9.0 ^{cd}	194 ± 8.7	39.7	20.5

Note: the upper indices (a and b) in the rows next to the indicators indicate significantly different values of ascorbic acid relative to the average content (x), index (c) – relative to the content in fresh fruits for each variety, index (d) – relative to the content in freeze-dried fruits for the study group at P < 0.05

Source: developed by the authors

S. Bhatta *et al.* (2020) found that freeze-drying retains 34% more vitamin C than conventional drying. Therefore, freeze-dried fruits are beneficial for the human body (Vahapoglu *et al.*, 2021). Recent studies have also revealed anti-diabetic properties in blue honeysuckle (De Silva & Rupasinghe, 2020). These data are comparable to those obtained in studies of individual varieties, namely: Alicia, Duet, and Aurora, where the loss of vitamin C during freeze-drying was 34.9, 25.9, and 34.7% less than during drying, respectively. According to the average inter-varietal index, the loss of ascorbic acid during drying was 38.5%, and during freeze-drying – 10.0% compared to the

content in fresh fruits (Table 1). Lower losses of ascorbic acid during freeze-drying compared to freeze-drying, but in sea buckthorn fruit, were reported by Z. Geng *et al.* (2023), they noted that the decrease in the content of this vitamin during freeze-drying was 45.39%, and after hot air drying 79.93% compared to fresh samples. M. Hawlader *et al.* (2006) proved that the preservation of vitamin C in papaya and guava after freeze-drying was 88 and 63%, respectively, which is also consistent with the data obtained in the present study. A. Krzykowski *et al.* (2023) noted that the loss of ascorbic acid during freeze-drying also significantly depends on the temperature of the heating plates, in particular,

at a temperature of 30°C, the loss compared to fresh samples was approximately 15%, and at a temperature of 70°C – approximately 38%.

Of the studied varieties of blue honeysuckle, the highest content of total phenolics was found in the fruits of the Spokusa variety, 6,442 mg/100 g, which is significantly higher than the average value established for this group of varieties. In the dried fruits

of blue honeysuckle, the content of total phenolics varied from 4,556 mg/100 g in Aurora to 2,801 mg/100 g in Duet, which is 53 mg and 1,163 mg less than in fresh fruits, or 19.0 and 46.2% less. The decrease in total phenols in dried fruits compared to fresh fruits was 18.2% higher than in freeze-dried fruits. In particular, Spokusa by 10.0%, Alicia by 23.0%, Duet by 23.9%, and Aurora by 18.1% (Table 2).

Table 2. Polyphenol content in fresh, dried and freeze-dried fruits of blue honeysuckle mg/100 g dry weight

Varieties	Fresh	Dried	Freeze-dried	Losses, %	
				in dried	in freeze-dried
Spokusa	6,442 ± 435 ^a	4,312 ± 170 ^{acd}	4,946 ± 46 ^{ac}	33.1	23.1
Alicia	5,107 ± 286	3,331 ± 163 ^{bcd}	4,506 ± 108 ^{ac}	34.8	11.8
Duet	5,209 ± 279 ^b	2,801 ± 119 ^{bcd}	4,047 ± 101 ^{bc}	46.2	22.3
Aurora	5,622 ± 300	4,556 ± 61 ^{acd}	5,569 ± 134 ^a	19.0	0.9
Mean ± SE	5,595 ± 188	3,750 ± 111 ^{cd}	4,767 ± 97 ^c	33.0	14.8
Coefficient of variation, %	11.2	22.0	13.6		
min	5,107 ± 286	2,801 ± 119 ^{bcd}	4,047 ± 101 ^{bc}	19.0	0.9
max	6,442 ± 435 ^a	4,556 ± 61 ^{acd}	5,569 ± 134 ^a	46.2	23.1

Note: the upper indices (a and b) in the rows next to the indicators indicate significantly different values of total phenols relative to the average content (x), index (c) – relative to the content in fresh fruits for each variety, index (d) – relative to the content in freeze-dried fruits for the study group at P < 0.05

Source: developed by the authors

The highest losses of total phenols in freeze-dried honeysuckle fruits compared to fresh ones were observed in the varieties Spokusa (23.1%) and Duet (22.3%), while the content of these substances was almost unchanged in the Aurora variety (0.9%). The freeze-dried fruits of this variety contained the highest amount of total phenols – 5,569 mg/100 g, which is 802 mg more than the average content for this group of varieties (Table 2). The high level of retention of biologically active compounds by lyophilised fruit powders, in particular, polyphenols and anthocyanins from 68.2 to 99.6%, depending on the fruit, was reported by C. Casati *et al.* (2019). J. Samoticha *et al.* (2016) also noted that the highest content of biologically active substances was in freeze-dried samples compared to fresh ones. Other researchers have shown that freeze-drying retains 11% more total phenolics than conventional drying (Bhatta *et al.*, 2020). Studies with blue honeysuckle have shown that the

retention of total phenolics in freeze-dried fruits was 10.0-23.9% higher than in dried fruits. There is an opposite opinion, which is not supported by the findings, in particular, that the freeze-drying process reduces the total polyphenol content by up to 63%, studies were carried out with blueberries (Muñoz-Fariña *et al.*, 2023).

The number of flavonoids in fresh fruits of blue honeysuckle varied from 1,150 (Spokusa) to 1,995 mg/100g (Duet). The highest losses of flavonoids during drying were observed in the fruits of the Duet variety (82.3%), while in the other studied varieties, they were above 70.0%, namely in the Spokusa variety – 74.6%, Alicia – 78.2%, and Aurora – 70.3%. The loss of flavonoids was also significant during freeze-drying, ranging from 43.8% (Spokusa) to 71.0% (Duet). However, the dried fruits of the studied varieties of blue honeysuckle contained 20.4% fewer flavonoids than the freeze-dried ones (Table 3). A. Synowiec-Wojtarowicz *et al.* (2014),

N. Osokina *et al.* (2022) showed that heat treatment has a positive effect on the flavonoid content of fruit juices. In the case of orange juice, they recorded a 31% increase. Other researchers have also reported a significantly higher

flavonoid content in freeze-dried fruit compared to dried fruit. They noted that fruit samples obtained by freeze-drying contained 1.1-2.4 times more flavonoids than those obtained by hot air drying (Krzykowski *et al.*, 2023).

Table 3. Flavonoid content in fresh, dried and freeze-dried fruits of blue honeysuckle mg/100 g dry weight

Varieties	Fresh	Dried	Freeze-dried	Losses, %	
				in dried	in freeze-dried
Spokusa	1,150 ± 63 ^b	292 ± 20.0 ^{bcd}	646 ± 28.8 ^c	74.6	43.8
Alicia	1,182 ± 83 ^b	257 ± 9.5 ^{bcd}	583 ± 24.0 ^{bc}	78.2	50.7
Duet	1,995 ± 74 ^a	352 ± 9.8 ^{cd}	578 ± 10.7 ^{bc}	82.3	71.0
Aurora	1,573 ± 64	467 ± 11.8 ^{acd}	766 ± 24.8 ^{ac}	70.3	51.3
Mean ± SE	1,475 ± 71	342 ± 13.0 ^{cd}	643 ± 24.8 ^c	76.8	56.4
Coefficient of variation, %	26.8	26.8	13.6		
min	1,150 ± 63 ^b	257 ± 9.5 ^c	578 ± 10.7 ^c	70.3	43.8
max	1,995 ± 74 ^a	467 ± 11.8 ^c	766 ± 24.8 ^c	82.3	71.0

Note: the upper indices (a and b) in the rows next to the indicators indicate significantly different values of flavonoids relative to the average content (x), index (c) – relative to the content in fresh fruits for each variety, index (d) – relative to the content in freeze-dried fruits for the study group at P < 0.05

Source: developed by the authors

The anthocyanin component of fresh fruits of blue honeysuckle was 875 mg/100 g with a maximum of 996 (Aurora) and a minimum of

784 mg/100 g (Alicia). During the drying process, the loss of anthocyanins was 27%, which is 11% more than during freeze-drying (Table 4).

Table 4. Anthocyanin content in fresh, dried and freeze-dried fruits of blue honeysuckle mg/100 g dry weight

Varieties	Fresh	Dried	Freeze-dried	Losses, %	
				in dried	in freeze-dried
Spokusa	800 ± 43	640 ± 26 ^{cd}	744 ± 18 ^c	20	11
Alicia	784 ± 41 ^b	643 ± 26 ^{cd}	730 ± 19 ^c	18	7
Duet	916 ± 41	539 ± 23 ^{bcd}	706 ± 14 ^{bc}	41	23
Aurora	996 ± 56 ^a	716 ± 30 ^{acd}	767 ± 11 ^{ac}	28	23
Mean ± SE	874 ± 45	635 ± 26 ^{cd}	737 ± 16 ^c	27	16
Coefficient of variation, %	15.5	15.5	3.5		
min	784 ± 41 ^b	539 ± 23 ^{bc}	706 ± 14 ^{bc}	18	7
max	996 ± 56 ^a	716 ± 30 ^{ac}	767 ± 11 ^{ac}	41	23

Note: the upper indices (a and b) in the rows next to the indicators indicate significantly different values of anthocyanins relative to the average content (x), index (c) – relative to the content in fresh fruits for each variety, index (d) – relative to the content in freeze-dried fruits for the study group at P < 0.05

Source: developed by the authors

Duet fruits lost most of this pigment during drying (41%), which is 18% or 167 mg more than during freeze-drying. Compared to fresh fruits, the anthocyanin content in the fruits of this

variety decreased by 377 mg during drying. The loss of anthocyanins during drying was 20% and 28% in Spokusa and Aurora, respectively, which is significantly less than in dried chokeberry,

where the loss was 43% to 80% (Samoticha *et al.*, 2016). In freeze-dried fruits, the highest losses of anthocyanins compared to fresh fruits were in Duet and Aurora varieties 210 mg and 229 mg, respectively, which amounted to 23% in both varieties. The lowest losses of anthocyanins, both during drying and freeze-drying, were in the variety Alicia 18% and 7%, respectively.

A 99.4% reduction in anthocyanins in extracts from jostaberry compared to freeze-drying was previously reported by V. Bulgaru *et al.* (2024). In turn, A. Wilkowska *et al.* (2016) observed that lyophilised powders had 1.5 times more anthocyanin retention than dried ones. In studies with blue honeysuckle, no significant difference was found; depending on the variety, the difference in anthocyanin content in freeze-dried and dried fruits was 1.1 (Alicia, Aurora), 1.2 (Spokusa), and 1.3 times (Duet).

CONCLUSIONS

As a result of the research, it was found that freeze-drying contributes to better preservation of sensory quality indicators and antioxidant properties of blue honeysuckle fruits of Alicia, Spokusa, Duet, and Aurora varieties than conventional hot air drying. According to the sensory quality indicators of appearance, colour, and taste, freeze-dried fruits of the Duet variety were rated the highest. After drying, blue honeysuckle berries contained 116.0 mg and 167 mg less ascorbic acid, respectively, which is 62.0% and 89.5% of the content they had in fresh form. The lowest losses of vitamin C during freeze-drying were in the Duet variety – 25.9%. The decrease in total phenols in dried fruits was 1,845 mg and in freeze-dried fruits 828 mg. The fruits of all studied varieties lost more than 32% of total phenols during freeze-drying. The loss of these substances during freeze-drying in three of the four studied varieties was less than 10.0%, namely: Alicia (4.8), Aurora (9.0), and Duet (9.6%). Heat treatment of blue honeysuckle fruits, both drying, and freeze-drying,

had the most negative effect on the flavonoid content of the finished product, in particular, during drying, the loss of flavonoids was 76.8%, and during freeze-drying was 56.4%, the highest in the Duet variety. Conversely, the decrease in the amount of anthocyanins in both heat treatment methods was insignificant in relation to the content in fresh fruit. During freeze-drying, the loss of anthocyanins was 16% and during drying – 27%, in physical terms, it was 137 mg and 239 mg, respectively, while the content in fresh fruit was 874 mg/100g. The data obtained as a result of the research will be useful for scientists in the development of functional foods with increased biological value, and for producers in the creation of raw material plantations of blue honeysuckle and farms producing freeze-dried products. It is recommended to use the Duet variety for the production of whole freeze-dried berries. For the production of fruit powders with increased biological value in terms of total phenols, flavonoids, and anthocyanins, freeze-dried fruits of the Spokusa and Aurora varieties are the most suitable. The dried fruits of the latter variety can also be used to create functional foods, as they retain phytochemicals better than fresh ones. Given the prospect of widespread use of freeze-dried blue honeysuckle berries in the food industry, further research is required, the purpose of which will be to establish the duration of preservation of sensory and consumer qualities of freeze-dried berries, and the preservation of the content of bioactive substances in them in the manufacture of fruit powders.

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Вплив генетичних особливостей сорту на збереження біологічно активних речовин у плодах жимолості голубої (*Lonicera caerulea* L.) при сублімуванні та сушінні

Анотація. Цінність плодів жимолості голубої полягає у значному вмісті біологічно активних речовин, які виконують антиоксидантну функцію в організмі людини. Оскільки свіжими вони мають нетривалий строк придатності, метою праведних досліджень був пошук способів перероблення, які б забезпечили максимальне збереження як сенсорних, так і фітоцінних речовин. Дослідження свіжих, сушених та сублімованих плодів проводилися в лабораторних умовах, визначали вміст вітаміну С, поліфенолів, флавоноїдів та антоціанів, а також робили сенсорну оцінку якості зразків, що досліджували. З допомогою програми STATISTICA та дисперсійного аналізу ANOVA виконували статистичний аналіз отриманих даних досліджень. В результаті досліджень було встановлено, що сенсорні показники якості, а саме зовнішній вигляд та забарвлення найкраще зберегли сублімовані плоди сорту Дует, відмінний смак на рівні 4,8 бала мали ягоди Спокуси. Було встановлено, що сублімовані плоди жимолості голубої зберігають на 27,5 % більше аскорбінової кислоти, ніж сушені, що становить 89,5 % від вмісту, який вони мали у свіжому вигляді. Найменше втрачали вітаміну С плоди сорту Алісія. Втрати загальних фенолів при сушінні становили 19,0-46,2 %, що більше, ніж при сублімуванні, на 10,0-23,1 %. Найбільш значними втрати загальних фенолів були у сорту Дует як при сушінні, так і при сублімуванні, а найменшими – у сорту Аврора. З біологічно активних речовин у процесі сушіння та сублімування плоди жимолості голубої найбільше втрачали флавоноїдів та антоціанів – 76,8, та 43,8 % відповідно. Кількість антоціанів у процесі сублімування знизилася на 137, а в процесі сушіння – на 239 мг. Результати досліджень можуть бути використані виробниками при підборі сортів жимолості голубої для створення промислових насаджень, цільове використання яких – сушіння та сублімування

Ключові слова: сублімування; вітамін С; поліфеноли; флавоноїди; антоціани

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Analysis of the productivity of sown legume-grass stands depending on alfalfa content, biostimulant application and weather conditions

Abstract. Intensive arable farming based on monoculture cropping leads to soil erosion, loss of biodiversity, and chemical contamination. One approach to mitigating these negative effects involves diversifying agroecosystems through the use of mixed cropping, particularly legume-grass mixtures. Such systems contribute to improved soil fertility, increased yields, and enhanced crop resilience to biotic and abiotic stresses. However, limited awareness of the composition and effectiveness of these mixtures hinders their widespread adoption in agricultural practice. This study aimed to investigate the development of alfalfa-grass mixtures depending on alfalfa content and to identify the most productive variants suitable for the Right-Bank Forest-Steppe zone of Ukraine, capable of delivering high and stable yields over extended periods. The research was conducted in the Forest-Steppe of Ukraine during 2021-2023 within permanent crop rotations at the experimental field of the Agronomic Research Station of the National University of Life and Environmental Sciences of Ukraine, located in Pshenychne Village, Bila Tserkva District, Kyiv Region. Several variants of alfalfa-grass mixtures were tested, with alfalfa content ranging from 35% to 75% and with the application of biostimulants (biochar, humic extract). The experiment was conducted according to a multifactorial field trial design with four replications. The primary indicator for evaluation was the yield of the grass mixtures over a three-year period. The findings revealed that the most productive mixtures were those containing 65-75% alfalfa, achieving the highest yields in the range of 35-37.6%. The use of biostimulants contributed to increased productivity; however, excessive application of these substances could reduce yields. The highest yield was recorded in the second year of the experiment, which was attributed to increased plant viability and favourable weather conditions. The results confirmed that an optimal alfalfa-to-

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grass ratio within the mixture is a critical factor in achieving stable yields. The effectiveness of biostimulants was influenced by the composition of the mixture and the growing conditions. Cultivating alfalfa-grass mixtures with 65-75% alfalfa proved to be an effective strategy for enhancing forage yield and production stability. The application of biostimulants can further improve productivity, although their efficiency depends on specific environmental conditions. The findings can be used to optimise crop area structure and support the adoption of environmentally sustainable agricultural practices

Keywords: biodiversity; grass mixtures; yield; crop resilience

INTRODUCTION

Cultivation of monocultures under intensive arable farming systems has a detrimental impact on the environment, leading to soil erosion and degradation, chemical contamination, and loss of biodiversity. In contrast, intercropping in agroecosystems helps restore ecological stability, promotes biodiversity, enhances plant interactions, and supports natural regulatory mechanisms. Long-term studies conducted by X. Li *et al.* (2021) demonstrated a significant (average 22%) increase in yield and greater yield stability of cereal crops under intercropping compared with monocultures, along with improved soil fertility over time. These findings highlight the potential of intercropping to enhance productivity and long-term sustainability in agriculture. J. Timaeus *et al.* (2022) showed that the use of wheat variety mixtures and heterogeneous populations in organic arable farming improves grain quality, suppresses weeds, makes more efficient use of resources, increases yields, and reduces lodging, particularly under drought conditions and on poor soils. Notably, heterogeneous populations exhibited greater yield stability than pure-line varieties. A study by Ya. Chabaniuk *et al.* (2024) on the relationship between soybean yield and meteorological conditions underscored the importance of climatic factors in crop productivity. Additional strategies include the application of organic fertilisers and the cultivation of forage legumes in combination with cereals (Danso-Abbeam *et al.*, 2021).

According to Y. Zhu *et al.* (2022), intercropping wheat with forage legumes, compared with wheat monoculture, led to increased yields of grain protein and amino acids, as well as higher gliadin content. These positive effects were further enhanced under moderate levels of nitrogen fertilisation, demonstrating the potential of intercropping to simultaneously improve both

the yield and quality of wheat grain. Similarly, A. Zymarioieva & O. Zhukov (2020) found that including legumes in mixtures with cereals resulted in higher grain protein concentration, improved grain yield, and greater yield stability. S. Li (2024) reported that this approach enhances drought resilience by altering the composition of soil microorganisms and improving resistance to both abiotic and biotic stress factors more effectively than sole cropping.

The productivity of intercrops depends on the species included in the mixture. H. Berghuijs *et al.* (2020) emphasised the importance of selecting compatible genotypes for intercropping. They developed a new model to simulate strip intercropping of cereals and legumes under conditions of limited nitrogen availability and sufficient moisture. This model enabled the identification of optimal combinations of agronomic practices and plant traits to achieve higher yields in intercropped systems compared with monocultures. Research by L. Burko *et al.* (2021) conducted in the Right-Bank Forest-Steppe of Ukraine demonstrated a significant increase in the productivity of sown meadow grasslands when alfalfa was included – both in pure stands and in legume-grass mixtures. This effect was particularly evident under conditions without mineral nitrogen application, where productivity increased by 1.8 to 3.0 times compared with grass-dominated stands.

The cultivation of low-protein forage is a major factor contributing to reduced feed production and protein imbalance. This applies particularly to pure stands of cereal forage grasses. Such monocultures are typically deficient in protein, macro- and micronutrients, and other essential nutrients, leading to overconsumption of feed and reduced livestock productivity (Xu *et al.*, 2020). Scientific

research and practical experience in forage production indicate that high-yielding legume-grass mixtures represent a reliable source of nutritionally balanced and consistently high-quality forage. As a result, modern forage production requires that perennial grasses occupy at least 50% of the total sown area. However, these mixtures currently cover only limited areas, and their yields remain relatively low. The slow adoption of grass mixtures in agricultural production is largely due to limited awareness of their nutritional value and significant advantages over pure stands. It should be noted that current literature provides limited guidance on the formulation of highly productive legume-grass mixtures, both in general and for specific zones and regions. As a result, many grass mixtures that are developed and sown often fail to meet expectations. The cultivation of legume-grass mixtures holds considerable agronomic value. After harvesting, a substantial amount of organic residue remains in the soil, which improves its structure and fertility. Numerous researchers have emphasised that the yield, quality, and nutritional balance of grass stands depend on the proportion of legumes within the mixture. Moreover, these mixtures contribute to carbon sequestration and reduce nitrous oxide emissions (Li *et al.*, 2020; Pulina *et al.*, 2023).

This study aimed to investigate the development of alfalfa-grass mixtures depending on the proportion of alfalfa in the composition and to identify the most productive combinations for the Right-Bank Forest-Steppe zone of Ukraine, capable of delivering high and stable yields over an extended period.

MATERIALS AND METHODS

The experiment was established in 2020, and research was conducted between 2021 and 2023 in the Forest-Steppe zone of Ukraine. The study took place at the research laboratory of the Department of Forage Production, using the stationary crop rotations of the experimental field within the educational and research farm of the National University of Life and Environmental Sciences of Ukraine (NULES of Ukraine) Agronomic Research Station (ARS) in Pshenychne Village, Bila Tserkva District, Kyiv Region. The

soil on the experimental site is a typical low-humus chernozem with coarse-silty, medium loam texture on carbonate loess. The experiment used four replications and a systematic arrangement of treatments. The total plot area was 100 m² with an accounting area of 50 m².

The climatic conditions during the study period were marked by unstable moisture regimes and fluctuating temperatures. In 2021, spring precipitation was within the normal range; however, June and July experienced a moisture deficit, which affected yield. The year 2022 proved to be the most extreme, as a significant lack of rainfall during May-July, combined with high temperatures, led to reduced crop productivity. In 2023, soil moisture at the beginning of the growing season was adequate, compensating for the rainfall shortage in May-June, while moderately warm summer conditions supported good plant development. An analysis of the significance coefficients for weather anomalies confirmed that 2023 was the most favourable year, whereas 2022 was the least favourable. Irregular precipitation patterns and temperature fluctuations influenced yield formation – typical for regions with variable moisture availability. Overall, weather conditions during the study period were generally favourable for the growth and development of perennial grasses. The preceding crop consisted of post-harvest catch crops, specifically a vetch-oat mixture sown after spring barley. The alfalfa-grass mixtures were sown under a cover crop of oats, with the seeding rate of the cover crop reduced by 30%. The cover crop was harvested for forage at the early heading stage. The alfalfa-grass mixtures were sown using a Klen-1.2 seed drill.

A range of research methods was employed: the calculated-weight method was used to assess crop density, weed infestation, crop productivity, and yield structure; the morphophysiological method was used to determine plant biometric parameters; and the mathematical-statistical method (analysis of variance) was applied to evaluate the reliability of the field trial results. Agronomic practices for cultivating alfalfa-grass mixtures followed standard recommendations for the Forest-Steppe zone, except for the experimental treatments under investigation. The stand was harvested at the heading stage of

cereals and the budding stage of legumes. The field experiment was designed as a multifactorial split-plot trial. Each plot measured 15 m², and the experiment was replicated three times.

The experimental treatments were as follows:

T.1 – Control; T.2 – Biochar (250 kg/ha applied during primary tillage); T.3 – Humus extract (50 L/ha at 30 days after emergence (DAE) + 50 L/ha at 60 DAE).

The control treatment involved standard soil cultivation and crop management without the use of any specialised technological inputs. This allowed for comparison with the other treatments and facilitated the evaluation of yield parameters and product quality under natural growing conditions.

Biochar is a form of charcoal produced through the thermal processing of biological materials. Its application to soil can improve structure, enhance water retention, increase organic carbon content, and contribute to mineral fertilisation. Biochar IDEALE (n.d.) is a highly active soil additive and an important component for improving soil fertility. Its main constituent is carbon (92-96%), accumulated in biomass processed through hydrothermal carbonisation. The product is manufactured by the Organic Farming Club.

Humus extract is an organic product derived from the processing of humified waste. This input can increase the soil's organic matter content and improve fertility.

Weather data were collected throughout the growing season based on meteorological reports (Meteopost, n.d.). The typicality of weather conditions was assessed using the method described by Yu. Manko, based on the coefficients

of the significance of deviation (C_s), calculated as $C_s = x - \bar{x}/s$, where x is the value for the research year, \bar{x} is the long-term average, and s is the standard deviation from the meteorological data variation series. The analysis of the productivity of sown legume-grass stands – depending on alfalfa content, the use of biostimulants, and weather conditions – was conducted following ethical standards for biological research, including those relating to plants, in line with the Ethical Code of the Scientist of Ukraine (National Academy of Sciences of Ukraine, 2009).

RESULTS AND DISCUSSION

The research findings indicated that the yield of the sown grass stands was significantly influenced not only by weather conditions but also by the proportion of alfalfa in the mixture. The highest yield was recorded in the second year of use when the plants exhibited the greatest vitality, the highest stand density, and substantial leaf area (Table 1). Four years of data revealed that the productivity of alfalfa-grass mixtures was largely determined by species composition, alfalfa proportion, application of biostimulants, and environmental conditions. The highest yields were recorded in mixtures containing 65-75% alfalfa, with an average yield of 33.0-33.4 t/ha. The maximum productivity (34.3 t/ha) was achieved in the variant with 75% alfalfa and without biostimulants, suggesting the effectiveness of this ratio for establishing highly productive forage stands. The high yield of the grass mixture at this level of legume content was largely due to alfalfa's strong nitrogen fixation capacity, which contributed positively to plant growth, development of the grass stands, and ultimately, to increased yield.

Table 1. Productivity of grass mixtures depending on their composition and the use of biostimulants, SD NULES of Ukraine Agronomic Research Station, 2021-2023, t/ha

Proportion of alfalfa in the grass mixture	Biostimulant	Yield by year			Average
		2021	2022	2023	
100%, Alfalfa (<i>Medicago sativa</i>)	No biostimulant (Control)	24.1	24.6	25.3	24.7
	Biochar	22.1	23.4	24.8	23.4
	Humus extract	27.4	28.1	26.3	27.3
100% grasses, Reed canary grass (<i>Phalaris arundinacea</i>) + Red fescue (<i>Festuca rubra</i> L.)	No biostimulant (Control)	25.1	23.7	23.2	24.0
	Biochar	26.3	25.1	24.7	25.4
	Humus extract	29.1	27.4	28.1	28.2

Table 1, Continued

Proportion of alfalfa in the grass mixture	Biostimulant	Yield by year			Average
		2021	2022	2023	
Alfalfa (<i>Medicago sativa</i>) (35%) + Reed canary grass (<i>Phalaris arundinacea</i>) + Red fescue (<i>Festuca rubra</i> L.) (65%)	No biostimulant (Control)	25.7	23.3	23	24.0
	Biochar	25.4	25.5	24	25.0
	Humus extract	27.3	25.8	25.5	26.2
Alfalfa (<i>Medicago sativa</i>) (45%) + Reed canary grass (<i>Phalaris arundinacea</i>) + Red fescue (<i>Festuca rubra</i> L.) (55%)	No biostimulant (Control)	27.3	26.5	25.1	26.3
	Biochar	27.7	27.2	26.5	27.1
	Humus extract	29.5	27.6	26.3	27.8
Alfalfa (<i>Medicago sativa</i>) (55%) + Reed canary grass (<i>Phalaris arundinacea</i>) + Red fescue (<i>Festuca rubra</i> L.) (45%)	No biostimulant (Control)	30.1	27.8	26.7	28.2
	Biochar	29.7	28.9	27.8	28.8
	Humus extract	28.8	28	27.7	28.2
Alfalfa (<i>Medicago sativa</i>) (65%) + Reed canary grass (<i>Phalaris arundinacea</i>) + Red fescue (<i>Festuca rubra</i> L.) (35%)	No biostimulant (Control)	33.8	33.3	32.1	33.1
	Biochar	32.8	32.4	31.5	32.2
	Humus extract	30.1	29.2	28.7	29.3
Alfalfa (<i>Medicago sativa</i>) (75%) + Reed canary grass (<i>Phalaris arundinacea</i>) + Red fescue (<i>Festuca rubra</i> L.) (55%)	No biostimulant (Control)	34.8	34.4	33.8	34.3
	Biochar	34.8	34.4	33.2	34.1
	Humus extract	31.7	29.5	28.6	29.9
LSD 0.95		1.52	1.47	1.43	

Note: LSD 0.95 – least significant difference at the 0.95 confidence level

Source: compiled by the authors

The use of biostimulants had a differentiated effect. The application of biochar resulted in a slight increase in yield, as indicated by the figure of 34.1 t/ha in the variant with 75% alfalfa. In contrast, humus extract led to a reduction in yield in some grass mixtures with a high proportion of alfalfa – 29.9 t/ha at 75% alfalfa – suggesting a potential disruption of the nutrient balance. Yield dynamics over the three years of the experiment showed that the highest yields were achieved in the second year of cultivation. Notably, in the variants with 65-75% alfalfa, yields in the second year reached 33.1-34.4 t/ha, exceeding those of the first and third years. Excessive use of biostimulants in some

cases led to reduced yields, highlighting the need to optimise dosage depending on the composition of the grass mixture and the growing conditions. At the same time, the findings indicated that pure stands of either alfalfa or grasses produced lower yields and are not considered promising in grass stand cultivation. An analysis of the typical deviations in average daily air temperature and precipitation from long-term averages is presented in Tables 2 and 3. According to the method of Yu. Manko, the typology of weather conditions is as follows: values from 0 to 1 are considered close to normal; from 1 to 2, moderately significant; and greater than 2, approaching extreme weather conditions.

Table 2. Average monthly air temperature and assessment of deviation typology, SD NULES of Ukraine Agronomic Research Station, 2021-2023

Year	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Average monthly air temperature, °C												
2021	-2.5	-4.5	2.7	8.0	14.3	21.3	24.6	21.1	13.5	8.4	4.8	-1.5
2022	-1.3	1.8	2.6	8.1	14.6	21.7	20.8	22.3	12.7	10.6	3.1	-0.7
2023	-0.3	-0.2	4.8	9.6	16.0	19.6	21.5	23.8	18.8	11.4	4.1	0.7
Long-term average	-3.2	-2.3	2.5	10	15.8	19.5	21.3	20.4	14.9	8.6	2.6	-1.8

Table 2, Continued

Year	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Typology of air temperature deviations, 2021-2023												
2021	-0.08	0.24	-0.02	0.22	0.16	-0.19	-0.35	-0.08	0.15	0.02	-0.24	-0.03
2022	-0.20	-0.54	-0.62	-1.22	-1.91	-2.68	-2.58	-2.74	-1.71	-1.46	-0.68	-0.27
2023	-0.31	-0.32	-0.86	-1.38	-2.06	-2.45	-2.67	-2.90	-2.37	-1.57	-0.78	-0.42

Source: compiled by the authors

A slight increase in average daily air temperatures was observed in June and July compared with long-term averages, which had an adverse effect on flowering, as well as pod formation and filling in alfalfa. In terms of precipitation distribution, 2021 was relatively dry,

with 454 mm of rainfall – 100 mm below the long-term average – representing a significant shortfall (-1.8) (Table 3). This moisture deficit negatively affected the subsequent growth and development of alfalfa plants and their ability to achieve optimal yield levels.

Table 3. Precipitation and typology of deviations, 2021-2023

Year	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021	40	48.5	21.5	23.7	95.3	34.9	45.6	56.1	16.8	0.6	20.2	50.8
2022	30.9	10.6	8.5	37.6	31.2	37	36.8	51.2	43.1	18	11.2	3.1
2023	18.3	21.6	33.4	82.5	5.2	79.6	116	18.4	6.6	64.2	89.1	61.4
Long-term average	28	30.7	34.2	39	83.5	95.4	81.9	28.2	26.6	33.9	26.2	46.3
Typology of precipitation deviations												
2021	-1.9	-3.3	1.0	0.7	-10.7	-1.1	-2.8	-4.5	1.8	4.4	1.24	-3.6
2022	-0.5	2.7	3.1	-1.5	-0.5	-1.4	-1.4	-3.7	-2.4	1.6	4.3	4.4
2023	1.5	1.0	-0.9	-8.7	3.6	-8.2	-14.0	1.5	3.4	-5.8	-9.7	-5.3

Source: compiled by the authors based on the data of Meteopost (n.d.)

As in the previous year of the study, the spring, autumn (in part), and winter periods of 2022 were characterised by a precipitation deficit. The annual reduction in rainfall was substantial, amounting to 235 mm, with a typology deviation of -3.1. The average monthly temperatures were also higher than the long-term averages. In 2023, a slight increase in precipitation was recorded, with a typology coefficient of 0.6. However, the distribution of rainfall was uneven, with minimal precipitation in May and September and the highest levels occurring in June and July.

Thus, in terms of moisture regime, the conditions in Kyiv Region correspond to an unstable level of water availability. At the same time, the initial availability of soil moisture is a crucial factor for alfalfa cultivation. If heavy rainfall occurs

between March and April, sufficient to replenish the reserves of productive soil moisture, a subsequent deficit in May and June is unlikely to have a significant negative effect on crop productivity. In 2021, March differed considerably from the average in terms of rainfall, while April, May, and July saw precipitation levels close to the long-term norms. In contrast, June experienced significant deviations from the average values. Overall, multiyear studies have demonstrated that irregular rainfall distribution and extended periods of heat during the alfalfa growing season adversely affect its growth and productivity.

The research findings confirm that the soil and climatic conditions of the Right-Bank Forest-Steppe are favourable for cultivating high-yielding alfalfa-grass stands. The present

study demonstrated that the proportion of alfalfa in the grass stand is a key factor influencing yield formation. The highest yields were obtained when alfalfa made up 65-75% of the grass mixture, without the use of fertilisers or with the application of phosphorus and potassium only. An important outcome of the study is that pure stands of either alfalfa or grasses produced lower yields compared with legume-grass mixtures. This aligns with findings indicating that mixed sowings of legumes and grasses provide higher productivity and improved forage composition compared with monocultures (Savchuk & Vyhovsky, 2019).

Moreover, the application of mineral fertilisers and biostimulants has a positive effect on both yield and the chemical composition of alfalfa-grass mixtures. Specifically, the study found that mineral fertilisers and stimulants enhance dry matter yield and improve the biochemical composition of the forage (Savchuk & Vyhovsky, 2019). These results support the conclusion that the use of biostimulants is effective in the cultivation of alfalfa-grass stands. It is also worth noting that liming the soil contributes to the improved productivity of legume-grass stands (Hetman & Danyliuk, 2024). Research by V. Kurhak *et al.* (2022) showed that lime application during pre-sowing cultivation or annual application of phosphorus and potassium fertilisers increased yield by 5-9%, while their combined use led to a 9-15% increase. This highlights the importance of an integrated fertilisation approach in the cultivation of alfalfa-grass mixtures.

Additional findings also confirm that an optimal ratio of alfalfa to grass components in forage grass mixtures contributes to increased yields and improved forage quality (Anil *et al.*, 1998). This is consistent with the conclusions of the present study, which found that alfalfa-grass mixtures with a balanced component ratio deliver high yields and enhanced nutritional value. Legume-grass mixtures significantly outperform pure grass stands in terms of protein content and amino acid composition. They produce more tender forage, in which carbohydrate and protein compounds, mineral salts, carotene, and other nutrients essential for animal health are well balanced. Such forage fully meets the physiological needs of livestock

(Demidas *et al.*, 2013). The conclusions of this study align with those of other researchers, including G. Demidas *et al.* (2019) and U. Karbivska *et al.* (2020), and underscore the importance of an integrated approach to cultivating legume-grass stands. In summary, the findings confirm the effectiveness of growing legume-grass stands in the Right-Bank ForestSteppe of Ukraine. Optimal alfalfa content in the grass mixtures, along with the application of appropriate agronomic practices, mineral fertilisers, and biostimulants, are key factors in achieving high yields and improving forage quality.

CONCLUSIONS

The conducted research confirmed that the productivity of cultivated alfalfa-grass stands largely depends on their species composition, the proportion of alfalfa, the application of biostimulants, and the environmental growing conditions. The highest yields were recorded in the second year of use when the plants exhibited peak vitality, the highest stand density, and a substantial leaf surface area. This highlights the importance of considering the age-related dynamics of grass mixtures in forage production. The optimal component ratio in the mixtures was found to be an alfalfa content of 65-75%. Such mixtures delivered average yields ranging from 33.0 to 33.4 t/ha, with maximum productivity (34.3 t/ha) achieved in the variant containing 75% alfalfa without the use of biostimulants. This indicates the effectiveness of this proportion for establishing high-yielding forage stands. The high level of nitrogen fixation by alfalfa supported improved growth and development of the grass stand and increased yield without the need for additional nitrogen fertilisers.

The use of biostimulants showed a varied effect on the yield of the grass mixtures. Biochar contributed to a slight increase in productivity, whereas humic extract, in some cases, reduced yield – particularly in mixtures with a high proportion of alfalfa. This may be attributed to a disruption in soil nutrient balance or species-specific differences in fertiliser uptake. Therefore, the application of biostimulants requires further research to determine optimal dosages and assess their suitability under varying agroclimatic conditions.

The distribution of precipitation and temperature conditions had a significant impact on the productivity of the grass mixtures. The year 2021 was marked by a moisture deficit, which adversely affected the growth and development of alfalfa. Analysis of the weather conditions confirmed that uneven rainfall distribution and increased average monthly temperatures can substantially influence yields, particularly during critical stages of plant development. Under such conditions, it is important to consider not only the species composition of the grass stand but also the potential for applying additional agronomic practices to enhance crop resilience during dry periods.

The analysis of the obtained results aligns with other studies, confirming that mixed sowings of legumes and grasses provide higher yields and improved nutritional value of forage compared to monocultures. It was also found that the effectiveness of fertiliser use depends greatly on the component ratio in the mixture, and excessive application may not only fail to

increase yield but may also reduce it. This highlights the need for further research into optimising fertilisation regimes and the use of biostimulants in alfalfa-grass mixtures. Future research in this area should involve a more detailed investigation of the long-term effects of weather conditions on the productivity of grass mixtures. It is also necessary to explore the potential for adjusting agronomic practices in response to changing climatic conditions. Further experiments should aim to determine the optimal types and dosages of biostimulants based on the composition of the grass mixtures.

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CONFLICT OF INTEREST

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<https://orcid.org/0000-0001-7158-825X>**Аналіз продуктивності сіяних бобово-злакових травостоїв залежно від насичення їх люцерною, застосування біостимуляторів і погодних умов**

Анотація. Інтенсивне землеробство, засноване на монокультурних посівах, призводить до ерозії ґрунту, втрати біорізноманіття та хімічного забруднення. Одним зі способів мінімізації таких негативних наслідків є диверсифікація агроєкосистем через використання змішаних культур, зокрема бобово-злакових травосумішок, які сприяють покращенню родючості ґрунту, підвищенню врожайності та стійкості посівів до біотичних й абіотичних стресів. Однак недостатня проінформованість про склад і ефективність таких травосумішок уповільнює їх широке впровадження в аграрне виробництво. Метою роботи було дослідження процесу формування люцерно-злакових травосумішок залежно від вмісту люцерни в їхньому складі та визначення найбільш продуктивних варіантів для зони Лісостепу Правобережної України, які здатні забезпечити високі й стабільні врожаї упродовж тривалого періоду. Дослідження проводилося в Лісостепу України впродовж 2021-2023 рр. на стаціонарних сівозмінах дослідного поля в навчально-дослідному господарстві Національного університету біоресурсів і природокористування України Агронічної дослідної станції (с. Пшеничне, Білоцерківський район, Київська область). Випробовано кілька варіантів люцерно-злакових травосумішок із різною часткою люцерни (35-75 %) та застосуванням біостимуляторів (біочар, гумус екстракт). Експеримент проводився за схемою багатофакторного польового дослідження з чотириразовою повторністю. Основним показником оцінки була врожайність травосумішок упродовж трьох років. Встановлено, що найбільш продуктивними були травосумішки з часткою люцерни в межах 65-75 %, що забезпечувало найвищу врожайність на рівні 35-37,6 %. Використання біостимуляторів сприяло підвищенню продуктивності, але надмірна кількість біологічних стимуляторів могла знижувати врожайність. Найвищу врожайність спостерігали на другий рік експерименту, що пов'язано зі збільшенням життєздатності рослин і сприятливими погодними умовами. Результати дослідження підтвердили, що оптимальне співвідношення люцерни і злаків у травосумішці є критичним чинником для досягнення стабільної врожайності. Ефективність біостимуляторів залежала від складу травосумішки та умов вирощування. Вирощування люцерно-злакових травосумішок із часткою люцерни 65-75 % є ефективним способом підвищення врожайності та стабільності кормовиробництва. Використання біостимуляторів може додатково покращити продуктивність, проте їх ефективність залежить від конкретних умов. Отримані результати можуть бути використані для оптимізації структури посівних площ та впровадження екологічно сталих методів ведення сільського господарства

Ключові слова: біорізноманіття; травосумішки; врожайність; стійкість посівів

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Effect of pre-sowing seed inoculation and foliar dressing on grain productivity and symbiotic activity of chickpea plants

Abstract. The relevance of the study lies in the fact that in the context of the rapid pace of global climate change and war in Ukraine, farmers are interested in finding modern and innovative approaches that would allow obtaining high yields and optimising acreage in the Right-Bank Forest-Steppe zone, considering their reduction in those areas where sustainable chickpea grain cultivation was ensured. The purpose of the study was to substantiate and show the importance and necessity of using trace elements for foliar dressing, both in variations with and without seed inoculation. It was found that pre-sowing inoculation of chickpea seeds and the use of the trace element boron in double foliar top dressing during intensive growth (budding) and in the flowering phase at its initial stage provides a specific effect on the symbiotic activity of bacteria of the genus *Rhizobium* and grain productivity of chickpea plants. During pre-sowing seed treatment with bioinoculant BTU®-p and carrying out two foliar dressings in two different phases with microfertiliser Help Rost®-Boron, there was a significant increase in the weight and number of nodule bacteria, the weight of 1,000 seeds, germination energy, green mass, and plant height, which ultimately had an excellent effect on the final yield indicators of various variants compared to the control. The maximum weight and number of nodules during the research period was formed in the flowering phase, namely, at the end of this phase. The largest number of nodule bacteria was 38.2 units/plant with a weight of 625.1 mg/plant on roots and root hairs was recorded in the variant with sowing of the Triumph variety, where two foliar dressings with microfertilisers and pre-sowing seed treatment with BTU®-p inoculant were used, which as a result exceeded the control by 11.2 units/plant and 24.9 mg/plant in the same growing season of the plant. It was found that the use of pre-sowing inoculation of chickpea seeds and foliar dressing during two different phases of vegetation allowed increasing the yield to 3.07-3.18 t/ha

Keywords: nitrogen-fixing nodules; pre-sowing seed treatment; trace elements; variety; *Rhizobium* bacteria; growing season phases; drought resistance

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INTRODUCTION

Chickpea *Cicer arietinum* L. is one of the oldest crops known to mankind, it was grown in Mesopotamia, Ancient Egypt, and Greece. Ukraine has all the prerequisites for expanding the acreage of chickpeas, especially in the southern and central regions, where climatic conditions favour its vegetation (Shcatula *et al.*, 2024). Chickpea is one of the most promising and valuable among leguminous crops in terms of various taste and nutritional properties. Chickpea seeds, depending on the variety, contain from 20.1 to 32.4% protein, which is easily digested unlike other legumes, and has a high index of essential amino acids (38.51%), methionine (3.11%), lysine (7.65%), isoleucine (6.81%), and tryptophan (1.10%). According to these indicators, chickpeas are superior to peas, beans, lentils by about 3-7%, and second only to soybeans. Chickpeas are a good source of B vitamin complex (B1, B2, B6, PP), micro- and macronutrients, and contain 50-60% easily digestible carbohydrates and up to 7% fat (Kalenska & Okhota, 2018).

The prospect of growing chickpeas is not only to solve and solve food security problems, but also that due to the fact that the root system contains nodule bacteria, this allows fixing nitrogen from the air and enriching the soil with it, and root secretions with high acidity allow quickly dissolving phosphates. Therefore, as noted by Y. Romanko *et al.* (2024), after harvesting, the plant leaves up to 80-120 kg/ha of nitrogen in the soil. This allows increasing the yield of crops that will be in the crop rotation in the future, reduce the application rates of synthetic nitrogen fertilisers, thereby reducing mechanical and chemical loads on the soil, save money, and protect the environment.

In addition to its agronomic advantages, the growing demand for chickpeas on the global market is also important. Interest in it is conditioned only by its high nutritional value, but also to healthy eating trends and the growing popularity of vegetarian and vegan diets. Countries such as India, Turkey, Pakistan, and Egypt remain the largest consumers and importers of chickpeas, which opens up export prospects for Ukrainian producers, according to S. Sots *et al.* (2023). However, despite the significant

potential of chickpea cultivation, producers face a number of challenges, including vulnerability to diseases, pests, adverse weather conditions, and restrictions related to the genetic diversity of the crop (Kryvenko *et al.*, 2023). That is why it is important to conduct scientific research aimed at investigating the agrobiological features of chickpeas, developing new varieties with improved characteristics, and improving technologies for growing, storing, and processing. One of the key factors for the growth and development of chickpeas is drought resistance, which is higher than that of soybeans and peas. By doing this, the plant has the ability to produce consistently high yields in the face of climate change, and due to the deep-penetrating tap root system, chickpea plants accumulate nutrients better and consume moisture more economically. According to A. Dobrovolsky *et al.* (2020), to increase the competitiveness of chickpeas, it is necessary to improve their cultivation technologies, including adaptation to climate change, selection of disease-resistant varieties, and the introduction of modern agricultural technologies. Investments in the development of the processing industry, in particular, the production of chickpea flour and protein concentrates, can contribute to creating added value and strengthening Ukraine's position in the international leguminous market (Rakhmentov *et al.*, 2023).

Thus, chickpeas are a promising crop for the development of the Ukrainian agricultural sector. Its cultivation not only increases soil fertility and reduces fertiliser costs, but also opens up new economic opportunities for farmers and exporters. Given the current trends in agriculture and the food industry, further research and popularisation of chickpeas can contribute to strengthening food security and sustainable development of agricultural production in Ukraine. Therefore, the purpose of this study was to consider relevant scientific approaches to the investigation of chickpeas, its food and agronomic value, the main problems facing the industry, and the prospects for the development of this crop in the context of global challenges related to ensuring food security and sustainable agricultural development.

LITERATURE REVIEW

Researchers from all over the country have devoted years of their research to the issues of global chickpea production, its importance for world food and the role of Ukraine in this. Thus, H. Pantsyreva (2024) revealed the features of the development of yield and quality of chickpea seeds depending on the varietal composition, pre-sowing treatment with a bacterial preparation, and the use of different concentrations of retardant. Based on the results of the study, it was determined that the best results were observed when treating seeds with Rizohumin-Plus and twice spraying crops with chlormequat-chloride retardant: the first time – in the phase of the third tripinnately compound leaf, the second – in the budding phase. The highest content of crude protein and fat in chickpea seeds was recorded in the Pegas variety (30.42% and 4.84%) and the Skarb variety (27.66% and 3.61%). Such indicators were obtained during pre-sowing treatment of seeds with the bacterial preparation Rizohumin-Plus and double spraying of plants with a 0.75% retardant solution during the growing season. It was proved that the use of chlormequat chloride (0.75%) in the phases of the third tripinnately compound leaf and budding creates optimal conditions for the growth and development of high yield of chickpeas of the Skarb and Pegas varieties, which is 2.53-3.02 t/ha.

The study by I. Didur & M. Temchenko (2017) explained the importance of regulating chickpea crop density for optimal plant development and yield. Since the density of sowing is an important factor, it affects the rate of plant development, morphological features, generative organs, and flowering time. Density control can regulate development: depending on the characteristics of the crop, increasing or decreasing density can accelerate or slow growth. Negative effects of excessive thickening: because chickpeas are prone to branching, in dense crops, plants compete for light, moisture, and nutrients, which reduces the productivity of each individual plant. According to the study, the highest chickpea plants in terms of the main phases of growth and development during seed inoculation and double fertilisation with microfertilisers were in the Pegas variety – branching – 33.7 cm, budding – 48.7 cm, flowering – 61.5 cm, physiological ripeness – 60.1 cm.

The highest density of plant standing was observed during pretreatment of seeds with Biomag Nut inoculant and double fertilisation with microfertilisers during the period of physiological ripeness – 529 thousand units/ha, survival rate – 88%. Therefore, density should be considered as one of the important factors that, in combination with others, can positively affect the yield. By changing the sowing density, it is possible to influence the pace of plant development, morphology, the time of laying generative organs and flowering, and thus, depending on the biological characteristics of the plants, accelerate or slow down their development.

The purpose of the study by V. Mazur *et al.* (2021) was to investigate the impact of aspects of chickpea cultivation technology, considering the economic efficiency of these methods. In the study, the highest rates of net profit and profitability were obtained by pre-treating seeds with Rizolin + Rizosave bioinoculant and two foliar fertilisations with Urozhai Bobovi microfertiliser and amounted to 17,815 UAH/ha and 155% in Pegas variety, which is 68% more than in the control, and 15,793 UAH/ha and 139% in Triumph variety, respectively, which is 62% more than in the control. The analysis of economic indicators in this paper showed that in the conditions of the Right-Bank Forest-Steppe on grey forest soils, the intensification of chickpea cultivation under the condition of seed treatment before sowing and double foliar dressing is a cost-effective method. From an economic standpoint of view, the most effective way is to grow chickpeas of the Pegas variety using bacterial preparations Rizoline + Rizosave during pre-sowing seed treatment and two foliar dressings with microfertiliser Urozhai Bobovi. Each of the researchers contributed to the solution of tasks of different types and nature and proved that these studies can be used to improve the technology of growing chickpeas.

With the growing popularity of healthy eating, Ukrainians are increasingly paying attention to the beneficial properties of chickpeas, a legume that is still a relatively new crop for Ukraine. Moreover, this plant ranks third in the world in terms of crop area, second only to soybeans and beans. Chickpeas are in high demand on the global market, especially in Central Asia,

East Africa, Europe, and the Mediterranean region (Koloianidi, 2021). Chickpea cultivation is economically profitable for farmers due to stable demand, high profitability, and the ability to export products to international markets. Its grains are widely used for making soups, side dishes, pastries, national dishes, and as a component of animal feed. Global chickpea crops cover up to 13 million hectares. The leader in cultivation is India, which provides up to 70% of the world's land area, followed by Australia with 5-10%, Pakistan – up to 5%, and Turkey – about 4% (Honchar, 2023). Ukrainian farmers are also increasingly choosing chickpeas for cultivation. Thus, according to the State Statistics Service of Ukraine (n.d.), in 2018, about 36 thousand hectares were sown, and in 2019 the area increased to 46.9 thousand hectares, with a yield of 1.0 to 4.0 t/ha. The main growing regions are Odesa, Zaporizhzhia, Mykolaiv, Chernivtsi, and Vinnytsia oblasts. For example, farms in the Odesa Oblast noted a significant increase in yield due to the introduction of modern agrotechnical technologies, which indicates the successful experience of growing this crop in Ukraine.

In addition, chickpeas, like other legumes, play an important role in animal husbandry, as they help to solve the problem of providing feed protein. It is used for the production of mixed feeds, in particular, as a source of protein for cattle, pigs, and poultry. The high protein content of chickpea seeds improves the growth and development of animals, increases their productivity and overall health. This crop also helps to improve soil fertility, reducing the environmental burden on the agrobiocenosis. Under favourable conditions such as moderate temperature, sufficient rainfall or efficient irrigation, providing fertile soil with a neutral pH level and balanced fertilisation, and proper care, including timely weed removal and pest protection, chickpea yields can exceed 3.0-3.5 t/ha (Kolesnikov & Kadyrov, 2022).

Chickpeas are also an effective precursor for cereals, as they help to increase their yield, often exceeding the indicators after black fallow. According to Y. Rakova (2021), chickpeas are unpretentious to the type of soil, but grow best on light chernozems, dark chestnut soils, because such soils provide optimal aeration of the root system, retain sufficient moisture, and have a

high content of nutrients, which contributes to healthy plant growth and the development of high yields, with a neutral or slightly alkaline reaction (pH 6.5-8.5). Heavy, acidic, or waterlogged soils negatively affect plant growth, increasing the risk of root rot. Chickpeas respond positively to a balanced diet and make good use of the remnants of organic and mineral fertilisers applied under the previous crop. The consumption of macro- and microelements depends on the planned yield and the results of agrochemical soil analysis. For example, for a yield of 2.0 t/ha, it is necessary to provide 106 kg of nitrogen, 36 kg of phosphorus, 150 kg of potassium, and 23 kg of magnesium.

The issues of stress tolerance were considered in the paper by A. Bahan (2023), considering weather conditions, varietal characteristics, seeding rates, and sowing methods. It was found that with the conventional row method, the optimal seeding rate is 1.0 million seeds/ha, while with a row spacing of 45 cm – 0.8 million/ha using $N_{30}P_{60}K_{60}$. The yield increases by 0.12 t/ha. According to V. Pushchak (2018), Privo 1 and Krasnokutskiy 36 varieties are recommended to be sown at a rate of 1.0 million/ha, and the Zoloty Yuvilei variety – 0.7 million/ha. With a wide-row seeding method, the optimal rate is 0.8 million/ha. According to N. Koloianidi (2019), the yield of the Pamyat variety without fertilisation was 2.42 t/ha, and with the addition of phosphorus and potassium it increased to 2.60 t/ha. A further increase in fertiliser doses contributed to an increase in yield to 2.74-2.82 t/ha, which is 13.2-16.5% more. Additional nitrogen application further improved the results.

When laying a grain crop, the quality and quantity of products directly depend on climatic conditions. Favourable weather conditions such as optimal temperatures, precipitation levels, and other factors can significantly increase yields, while adverse conditions such as droughts or excessive rains can significantly reduce this rate (Mazur & Pinchuk, 2022). In this regard, to ensure stable chickpea production in regions with unstable environmental conditions, it is important to use varieties that can adapt to variable factors and demonstrate the highest efficiency in such conditions. According to O. Tryhuba *et al.* (2024), the choice

of such varieties can reduce risks and ensure a high yield even in adverse weather conditions. Despite the presence of a large number of studies, every year there is a need to review and introduce new results and proposals, considering new global and national interests and trends.

MATERIALS AND METHODS

Field research to investigate and obtain the results of the impact of seed treatment with BTU®-p inoculant before sowing and two-time foliar application of Help Rost®-Boron (B) microfertiliser on the quantitative and qualitative indicators of chickpea yield and symbiotic productivity was conducted at the Agronomichne research site of Vinnytsia National University, located in the village of Agronomichne, Vinnytsia district (Ukraine) during 2023-2024. The soil cover consisted of grey forest soils, which are typical of temperate climates with moderate humidity. The depth of the humus-eluvial horizon reached 30 cm, its colour – grey, which indicates an average level of fertility. According to the results of the soil survey, the soils of the experimental site are characterised by a low humus content of up to 2%. This indicates the need to take additional measures to improve soil fertility. The content of

alkaline hydrolysed nitrogen (Kornfield method) was 70 mg/kg of soil, which indicates the average level of soil nitrogen supply. Mobile phosphorus (Chirikov method) was contained in the amount of 145 mg/kg of soil, and exchange potassium (Chirikov method) – 95 mg/kg of soil, which also meets the standards for agricultural land in this category. The content of absorbed bases was 1.30 mg-Eq. per 100 g of soil, which indicates a certain level of alkaline environment in the soil (Nastiuk, 2023). The hydrolytic acidity is 3.5 mg-Eq./100 g of soil, which indicates moderate acidity. The reaction of the soil solution varied from 5 to 5.5 pH, which means a slightly acidic reaction that is optimal for many crops. The main amount of water and the process of moistening the soil occurs due to precipitation, since the ground water level is at a depth of up to 15 m, which makes the soil more stable in conditions of variable humidity and the absence of precipitation for a long time. However, depending on weather conditions, the moisture content in the soil may vary. The agrochemical characteristics of grey forest soils are shown in Table 1, which allows assessing the condition of the soils and developing appropriate recommendations for their improvement for agricultural needs.

Table 1. Agrochemical indicators of soils of the research site Agronomichne (based on the materials of the soil survey 2020)

Soil profile depth, cm	Humus, %	pH	Hydrolytic acidity, mg/100 g of soil	Absorbed bases, mg/100 g of soil	Degree of saturation with the bases, %
0-20	2	5.5	3.65	14.8	85
30-40	1.58	5.3	3.6	14	96
65-75	0.84	5	3.47	13.8	83
95-105	Not defined	4.9	3.35	13.6	84
125-135	Not defined	4.7	3.1	13.3	88

Source: compiled by the author based on the research by A. Nastiuk (2023)

After analysing climate data for the period 2023-2024, it was found that hydrothermal

conditions in this region are very favourable for chickpea cultivation (Table 2).

Table 2. Precipitation and temperature (per first ten days of month) during the growing season of agricultural crops in the period 2023-2024

Month	Ten days	Temperature, °C			Amount of precipitation, mm		
		Average for the growing season	2023	2024	Average for the growing season	2023	2024
April	1	13.1	12.1	14.1	24.5	49	0
	2	11.1	10.9	11.4	39	25	53
	3	12.5	12.3	12.7	28	9	47
	per month	12.2	11.7	12.7	91.5	83	100

Table 2, Continued

Month	Ten days	Temperature, °C			Amount of precipitation, mm		
		Average for the growing season	2023	2024	Average for the growing season	2023	2024
May	1	15.4	15.1	15.7	3	1	5
	2	14.8	15.3	14.3	0	0	0
	3	18.5	16.4	20.6	21.5	1	42
	per month	16.2	15.6	16.8	24.5	2	47
June	1	20.95	21.3	20.6	51.5	23	80
	2	19.35	20.4	18.3	46.5	46	47
	3	22.5	22.6	22.4	10	14	6
	per month	20.9	21.4	20.4	108	83	133
July	1	26.2	25.6	26.9	22.5	27	18
	2	28.2	27.3	29.2	3.5	4	3
	3	26.1	28.1	24.2	43.5	23	64
	per month	26.8	27	26.7	69.5	54	85
August	1	22.6	23.1	22.1	16.5	19	24
	2	23.8	23.4	24.3	0	0	0
	3	25.2	24.8	25.6	6.5	13	0
	per month	23.8	23.8	24	28	32	24
April-August		19.9	19.9	20.1	64.3	254	389

Source: created by the author based on Meteoblue data (n.d.)

The study examined the influence and interaction of three factors, namely:

Research factors:

1. Plant varieties (A):

A. Triumph;

B. Pamyat.

2. Methods of pre-sowing seed treatment (B):

A. Without seed treatment before sowing;

B. Bioinoculant BTU®-p (3 l/t).

3. Foliar dressing (C):

A. Without dressing (control option);

B. One fertilisation with Help Rost®-Boron microfertiliser (3 l/ha) during intensive growth (budding phase);

C. One fertilisation with Help Rost®-Boron microfertiliser (3 l/ha) in the initial flowering phase.

The study met the requirements of Convention on Biological Diversity (1992) and Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

In the course of the study, it was found that there is a dependence on pre-sowing treatment for chickpea seeds with BTU®-p inoculant (3 l/t); and the use of Help Rost®-Boron microfertiliser (3 l/ha) for two foliar dressings. The legume harvest showed a positive trend in the growth of certain quantitative and qualitative indicators of the chickpea harvest, and especially an increase in the symbiotic activity of *Rhizobium* bacteria, in particular, their number and weight, as shown in Table 3.

Table 3. Dependence of the weight and number of nodule bacteria on seed inoculation and foliar dressing (2023-2024)

Variety	Inoculation	Fertilisation	Budding		Beginning of flowering		End of flowering		Full seed filling	
			Number of nodules, units/plant	Nodule weight, mg/plant	Number of nodules, units/plant	Nodule weight, mg/plant	Number of nodules, units/plant	Nodule weight, mg/plant	Number of nodules, units/plant	Nodule weight, mg/plant
Triumph	BTU®-p (3l/t)	Help Rost®-Boron 3 l/ha (2 dressings)	13.1	73.5	33.4	260.5	38.2	625.1	30.6	170.6
Triumph	BTU®-p (3l/t)	Help Rost®-Boron 3 l/ha (1 dressing)	12.5	72.1	31.5	256.4	36.7	621.3	28.7	162.9

Table 3, Continued

Variety	Inoculation	Fertilisation	Budding		Beginning of flowering		End of flowering		Full seed filling	
			Number of nodules, units/plant	Nodule weight, mg/plant	Number of nodules, units/plant	Nodule weight, mg/plant	Number of nodules, units/plant	Nodule weight, mg/plant	Number of nodules, units/plant	Nodule weight, mg/plant
Triumph	BTU ^{-p} (3l/t)	–	11.9	68.3	30.7	245.6	35.5	609.6	27.5	158.4
Triumph	–	Help Rost [®] -Boron 3 l/ha (2 dressings)	10.3	66.2	28.2	242.3	32.3	608.1	24.2	150.1
Triumph	–	Help Rost [®] -Boron 3 l/ha (1 dressing)	10.2	64.4	27.2	238.4	31	606.4	23.1	148.9
Triumph	Control	Control	9.3	61.1	24.1	221.5	27	600.2	21.4	135.8
Pamyat	BTU ^{-p} (3l/t)	Help Rost [®] -Boron 3 l/ha (2 dressings)	12.5	71.4	31.2	252.3	36.4	614.8	28.9	163.4
Pamyat	BTU ^{-p} (3l/t)	Help Rost ⁻ -Boron 3 l/ha (1 dressing)	12.1	70.2	30.4	251.4	35.2	610.8	27.6	162.1
Pamyat	BTU ^{-p} (3l/t)	–	11.7	65.4	29.5	248.6	33.1	605.4	26.4	158.6
Pamyat	–	Help Rost [®] -Boron 3 l/ha (2 dressings)	10.9	66.9	26.1	250.1	31.4	607.8	24.2	160.4
Pamyat	–	Help Rost [®] -Boron 3 l/ha (1 dressing)	10.8	66.1	25.9	249.4	31.1	606.1	23.5	158.7
Pamyat	Control	Control	9.1	60.4	23.8	216.5	26.1	601.4	21.3	132.7

Source: developed by the author

The first indicator of the amount and their weight on the roots of chickpea plants was carried out in the budding phase, where the best indicator was in the Triumph variety, where an inoculant and two dressings were used. The number of bacteria was 13.1 units/plant, and their weight was 73.5 mg/plant. The worst result was recorded in the control where the number of nodules numbered 9.3 units/plant and had a weight of 61.1 mg/plant. The indicators of the Pamyat variety had a slightly worse situation, but it was similar to the Triumph variety. The best results among the 6 variants were observed where pre-sowing treatment of seeds with inoculant and two dressings were applied. The number of bacteria was 12.5 units/plant, and their weight was 71.4 mg/plant. The worst result was the control, where the weight of nodules was 9.1 mg/plant, and their number was 60.4 units/plant.

The next accounting of the weight and number of nodules on the roots of plants was carried out at the stage of completion of flowering. In the control variant for the Triumph variety, 27 nodules were recorded per plant with a weight of 600.2 mg. The highest indicator of the number and weight of nodules was observed when using pre-sowing seed treatment and double dressing with microfertilisers. In this case, 38.2 nodules per plant weighing 625.1 mg were found on chickpea roots. This result was confirmed by observations during excavation and root washing, when a significant number of red nodules were visible, indicating active symbiosis and nitrogen accumulation.

Compared to the control, the increase was 11.2 nodules per plant and 24.9 mg of weight in the same growing season. The average growth of nodules compared to the control was from 3.8 to 9.2 nodules per plant. The analysis of variance

showed that all increments are reliable, since they exceed the least significant difference (LSD). As a result of the study, it was found that the most effective method for increasing the number and weight of nodules is pre-sowing seed treatment with BTU®-p inoculant (3 l/t) and double foliar dressing with Help Rost®-Boron

microfertiliser (3 l/ha). This ensured the development of the maximum indicator of nodules at all stages of plant growth. An important indicator in the study was the yield. Its development largely depended on the annual growing conditions, but the factors tested also had a significant impact on the crop growth trend, as shown in Table 4.

Table 4. Dependence of chickpea yield on inoculation and dressing t/ha (2023-2024)

Variety	Inoculation	Dressing	Yield, t/ha		Average yield, t/ha	increase in control, t/ha		increase in control, %	
			2023	2024		2023	2024	2023	2024
Triumph	BTU®-p	Help Rost®-Boron 3 l/ha (2 dressings)	3.16	3.20	3.18	0.76	0.90	31.67	39.13
Triumph	BTU®-p	Help Rost®-Boron 3 l/ha (1 dressing)	2.84	2.96	2.90	0.44	0.66	18.33	28.70
Triumph	BTU®-p	–	2.6	2.65	2.63	0.20	0.35	8.33	15.22
Triumph	–	Help Rost®-Boron 3 l/ha (2 dressings)	2.76	2.80	2.78	0.36	0.50	15.00	21.74
Triumph	–	Help Rost®-Boron 3 l/ha (1 dressing)	2.70	2.75	2.73	0.30	0.45	12.50	19.57
Triumph	Control	Control	2.4	2.3	2.35	–	–	–	–
Pamyat	BTU®-p	Help Rost®-Boron 3 l/ha (2 dressings)	3.03	3.11	3.07	0.68	0.86	28.94	38.22
Pamyat	BTU®-p	Help Rost®-Boron 3 l/ha (1 dressing)	2.8	2.91	2.86	0.45	0.66	19.15	29.33
Pamyat	BTU®-p	–	2.5	2.53	2.52	0.15	0.28	6.38	12.44
Pamyat	–	Help Rost®-Boron 3 l/ha (2 dressings)	2.54	2.62	2.58	0.19	0.37	8.09	16.44
Pamyat	–	Help Rost®-Boron 3 l/ha (1 dressing)	2.48	2.56	2.52	0.13	0.31	5.53	13.78
Pamyat	Control	Control	2.35	2.25	2.30	–	–	–	–

Source: developed by the author

When analysing the studied factors affecting the yield of chickpeas, a noticeable increase in yield was revealed in comparison with the results obtained at the control. Table 4 showed that the lowest yield was recorded in the control, where dressing and seed inoculation were not carried out and amounted to 2.35 t/ha for the Triumph variety and 2.3 t/ha for the Pamyat variety. In the variant where two dressings was carried out, the yield increased by 0.43 t/ha to 2.78 t/ha for the Triumph variety, and by 0.22 t/ha to 2.52 t/ha for the Pamyat variety. The best yield was demonstrated in the variant where pre-sowing seed inoculation and two foliar treatments were used. The yield of the Triumph variety increased by 0.83 t/ha to 3.18 t/ha, and by 0.77 t/ha to 3.07 t/ha

for the Pamyat variety. Therefore, these results indicate that when growing chickpeas, the best conditions for the growth and development, namely, the crop, were formed when using pre-sowing seed treatment with inoculant and two dressings was carried out in the budding phase and the beginning of flowering.

The study by M. Mordvaniuk (2019) found that the best results in the number and weight of nodule bacteria at the end of flowering and yield of chickpeas were observed with double foliar treatment with microfertiliser (Urozhai Bobovi) and pre-sowing seed inoculation (Biomag Nut) where the amount is 39.2 units/plant, weight – 611.4 mg, with an average yield of 2.92 t/ha for 3 years of research. L. Poberezhna (2023)

substantiated the importance of foliar top dressing with trace elements (boron) and (molybdenum). It was found that the best results were demonstrated at the site where the Pamyat variety was grown with pre-sowing application of mineral fertilisers at the rate $N_{30}P_{20}K_{20}$ and foliar top dressing with boron and molybdenum. The yield at this experimental site was 2.54 t/ha. The results of this study correspond to the findings of other researchers. Moreover, the results obtained are slightly better compared to M. Mordvaniuk (2019), and compared to L. Poberezhna (2023), the results of the current study are much better. Thus, the results of the study confirmed the effectiveness of using pre-sowing seed inoculation and foliar top dressing to increase the yield of chickpeas, which is consistent with the data of other researchers, demonstrating the potential for optimising agrotechnical techniques to increase the productivity of this crop.

CONCLUSIONS

In the course of the study, the significance and importance of pre-sowing seed treatment with BTU®-p inoculant and the use of two dressings with Help Rost®-Boron microfertiliser (3 l/ha) on chickpea yield and the activity of symbiotic bacteria of the genus *Rhizobium* were investigated and analysed. The results showed that the combination of these agrotechnical measures is most effective for ensuring high yield indicators, improving biological nitrogen fixation and increasing plant resistance to adverse conditions. The best indicators of average yield for two years of research were achieved on variants using an inoculant and two dressings: 3.18 t/ha for the Triumph variety and 3.07 t/ha for the Pamyat variety. This indicates the high efficiency of the technology. Control variants, without the use of inoculant and

fertilisation, showed the lowest yield: 2.35 t/ha for the Triumph variety and 2.30 t/ha for the Pamyat variety. The average yield increase in the treated variants ranged from 0.77 to 0.83 t/ha, which is a significant increase relative to the control.

Regarding the symbiotic activity of the *Rhizobium* bacteria, the highest number and weight of nodule bacteria was observed in the Triumph variety on variants with two dressings and inoculation: 38.2 nodules/plant with a weight of 625.1 mg. In the Pamyat variety, the highest indicators were also recorded on similar variants: 36.4 nodules/plant with a weight of 614.8 mg. Control variants showed the lowest rates: an average of 21.4 nodules/plant and a weight of 135.8 mg. This indicates the importance of inoculation and feeding to increase symbiotic activity, which is the basis of biological nitrogen nutrition in plants. Therefore, this study confirmed the high efficiency of agrotechnological measures that were implemented. The use of seed inoculation and microfertilisers significantly increased not only yield, but also symbiotic productivity. That is why it is planned to conduct a study of the third year in order to obtain the best results and confirm the feasibility of implementing these measures in chickpea cultivation to increase productivity, economic profitability, and environmental sustainability of agricultural production of this crop in Ukraine.

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None.

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Вплив передпосівної інокуляції насіння і позакореневих підживлень на зернову продуктивність та симбіотичну діяльність рослин нуту

Анотація. Актуальність дослідження полягає у тому, що в умовах швидкого темпу глобальної зміни клімату та війни в Україні аграрії зацікавлені у пошуку сучасних та інноваційних підходів, що даватимуть змогу отримати високі врожаї та оптимізувати посівні площі у зоні Лісостепу Правобережного з огляду на їх скорочення в тих зонах, де забезпечувалося стає вирощування зерна нуту. Метою статті було обґрунтувати та показати важливість та необхідність застосування мікроелементів для позакореневих підживлень як у варіації з інокуляцією насіння, так і без неї. Досліджено, що передпосівна інокуляція насіння нуту та застосування мікроелементів бор у дворазовому позакореневому підживленні під час інтенсивного росту (бутонізація) та у фазі цвітіння на її початковій стадії завбачає питомий вплив на симбіотичну діяльність бактерій роду *Rhizobium* та зернову продуктивність рослин нуту. Під час передпосівної обробки насіння біоінокулянтотом БТУ®-р та проведення двох позакореневих підживлень у двох різних фазах мікродобривом «Help Rost® – Бор» спостерігалось значне збільшення маси та кількості бульбочкових бактерій, маси 1000 насінин, енергії проростання, зеленої маси та висоти рослин, що у підсумку відмінно позначилося на кінцевих показниках врожайності різних варіантів у порівнянні з контролем. Досліджено, що максимальна маса та кількість бульбочок за період проведення досліджень була сформована у фазі цвітіння, а саме в кінці цієї фази. Найбільша кількість бульбочкових бактерій – 38,2 шт./рослину з масою 625,1 мг/рослину на коренях та кореневих волосках була зафіксована у варіанті з посівом сорту Тріумф, де застосовувалися два позакореневі підживлення мікродобривом та передпосівна обробка насіння інокулянтотом БТУ®-р, що в результаті перевищило контроль на 11,2 шт./рослину і 24,9 мг/рослину в один і той самий період вегетації рослини. Встановлено, що використання передпосівної інокуляції насіння нуту та проведення позакореневих підживлень під час двох різних фаз вегетації дало змогу підвищити врожайність до 3,07-3,18 т/га

Ключові слова: азотфіксуючі бульбочки; передпосівна обробка насіння; мікроелементи; сорт; бактерії *Rhizobium*; фази вегетації; посухостійкість

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