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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 Kytaiska 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_i = 1.03-1.16), indicating their increased sensitivity to changes in agroecological conditions. In contrast, the cultivar Kytaiska tsukrova No. 1 was characterised by the lowest regression coefficient (b_i = 0.73), indicating a reduced response to changes in growing conditions. According to the selection value index, the most promising cultivars were Kytaiska tsukrova No. 1 (BVG_i = 26.56) and Staroukrainska mistseva (control) (BVG_i = 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_i = 0.78) and IR-398 (b_i = 0.93) were the least sensitive to improved growing conditions, whereas IR-1030 (b_i = 1.02) and Smolianka (control) (b_i = 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_i = 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 aftertaste. 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 tenday 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.

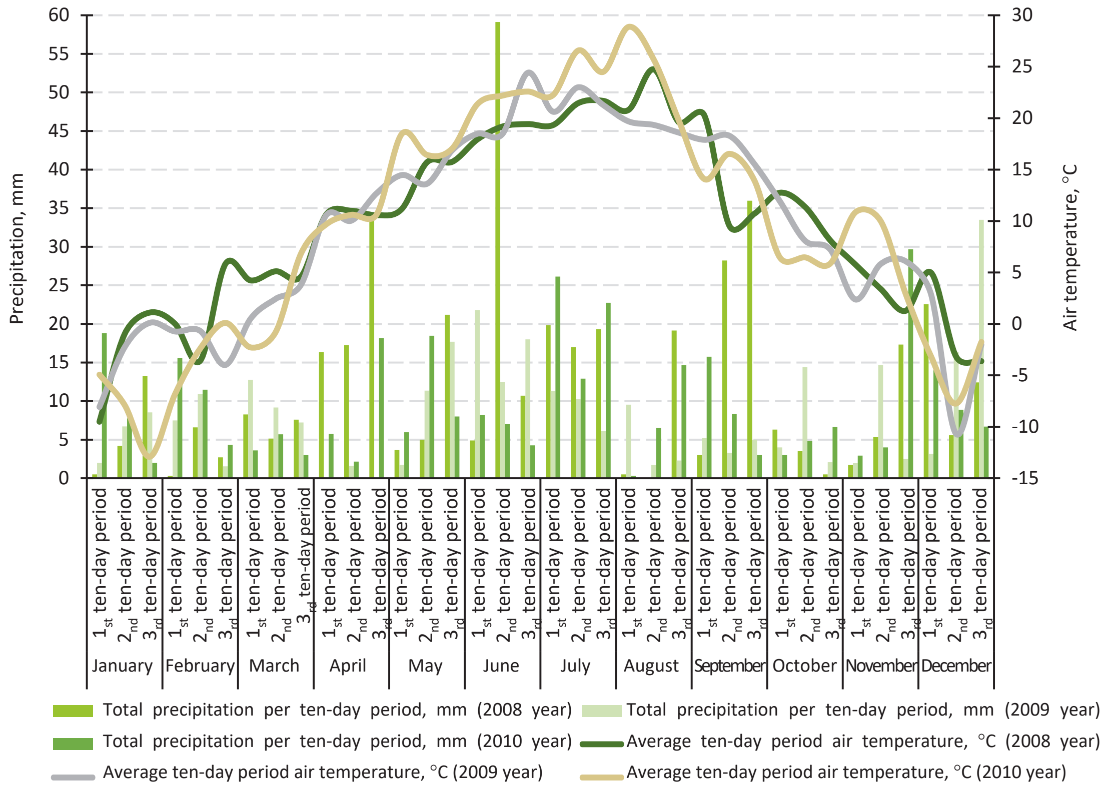

Figure 1. Dynamics of air temperature and precipitation, 2008-2010
Source: compiled by the authors based on the conducted study

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 Kytaiska 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 m^2. 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:

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

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 $\Sigma\ t_{eff}$ 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 Kytaiska 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°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 Kytaiska 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.

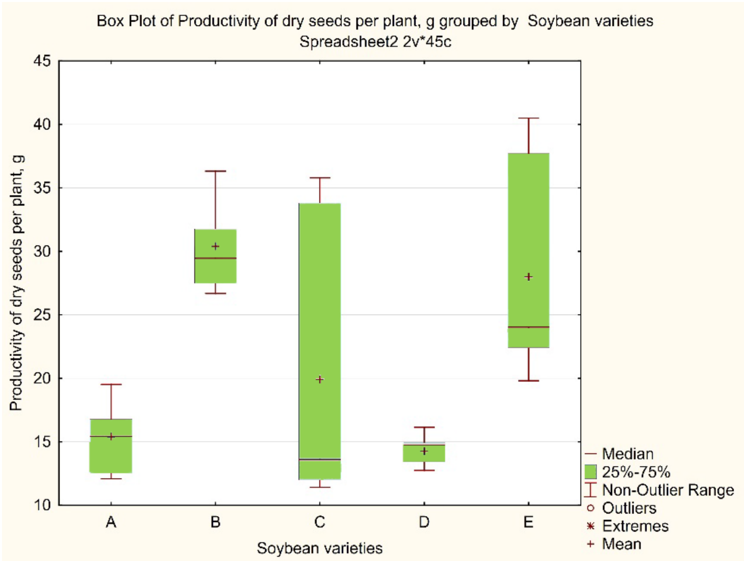

Figure 2. Box plot illustrating the yield performance of soybean varieties for sprouting

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

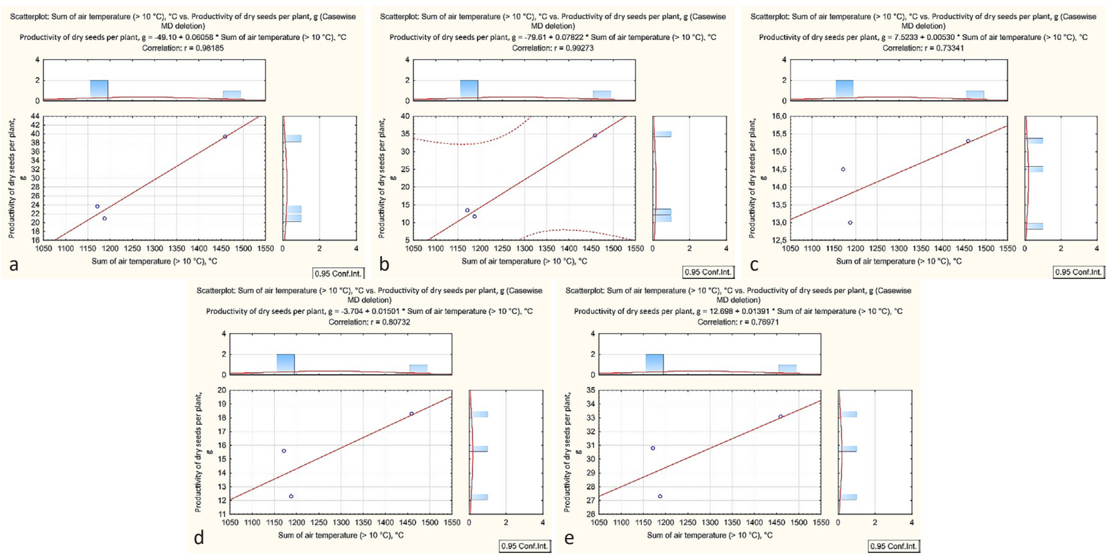

Figure 3. Analysis of the relationship between the yield of soybean varieties for sprouting and the sum of effective temperatures above 10°C during the sowing-to-harvest period

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

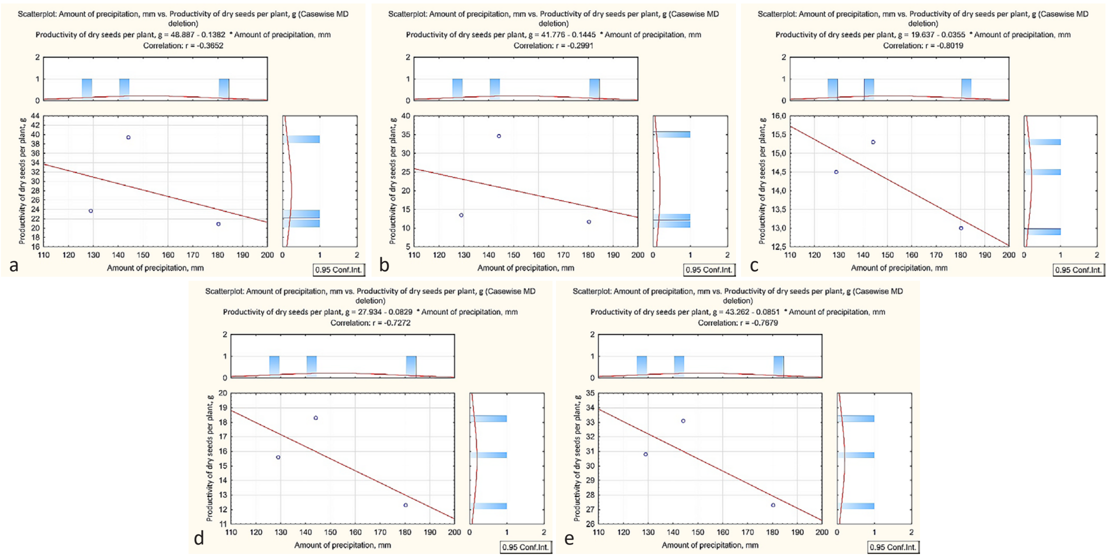

Figure 4. Analysis of the relationship between the yield of soybean varieties for sprouting and total precipitation during the sowing-to-harvest period

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_{gi}), %	20.92	32.39	54.21	58.68	8.90
Plasticity (b_i)	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_i)	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 Kytaiska 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 Kytaiska 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, Kytaiska 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 Kytaiska 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 Kytaiska 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.

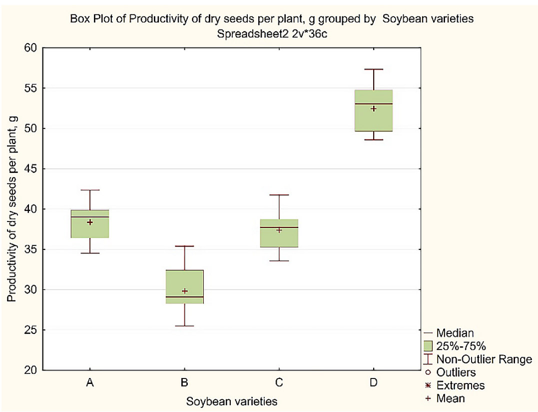

Figure 5. Box plot illustrating the productivity of soybean varieties grown for green peas
Note: A) IDO-200905; B) IR-398; C) IR-1030; D) Smolianka (control) (2008-2010)
Source: compiled by the authors based on the conducted study

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.

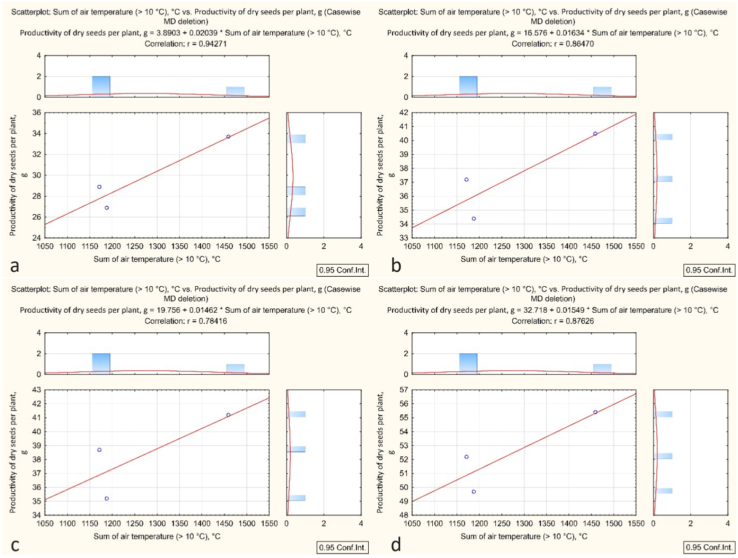

Figure 6. Analysis of the relationship between the productivity of soybean varieties for green peas and the sum of air temperatures above 10°C during the sowing-to-harvest period

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

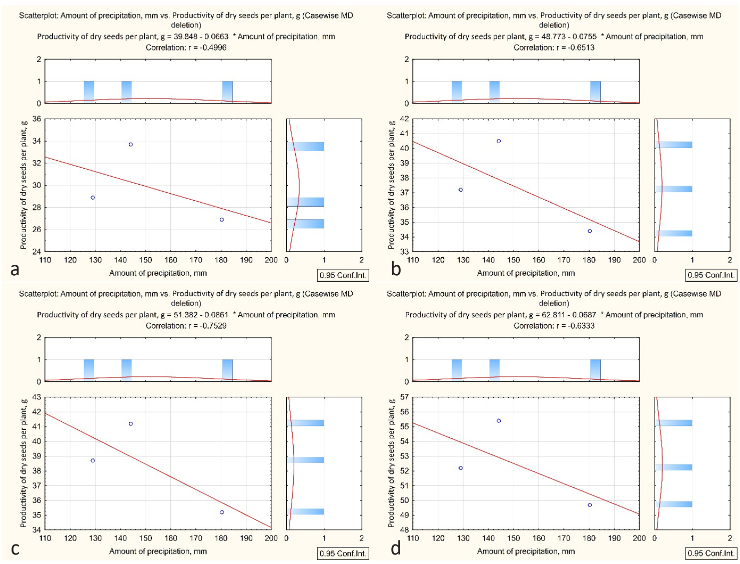

Figure 7. Analysis of the relationship between the productivity of soybean varieties for green peas and total precipitation during the sowing-to-harvest period

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 soyean varieties Staroukrainska mistseva (control) and Kytaiska 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 Kytaiska 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_{gi}) 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 Kytaiska 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 Kytaiska 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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REFERENCES

[1] Abdala, L.J., Tamagno, S., Ruiz, A., Schwalbert, R.A., Correndo, A.A., & Martin, N. (2025). Yield environment changes the ranking of soybean genotypes. *Field Crops Research*, 321, article number 109661. doi: 10.1016/j.fcr.2024.109661.

[2] Abobatta, W.F., ElHashash, E.F., & Hegab, R.H. (2021). Challenges and opportunities for the global cultivation and adaption of legumes. *Journal of Applied Biotechnology & Bioengineering*, 8(5), 160-172. doi: 10.15406/jabb.2021.08.00270.

[3] Aboltins, A., Rucins, A., Bobos, I., Fedosiy, I., Komar, O., Zavadska, O., Sych, Z., Havrys, I., Retman, M., & Zavgorodniy, V. (2024). Evaluation of productivity and morphological variability of asparagus cowpea (*Vigna unguiculata* (L.) Walp. subsp. *sesquipedalis* (L.) Verdc.) cultivars intended for vegetable production. *Agronomy*, 14(12), article number 2906. doi: 10.3390/agronomy14122906.

[4] Agyenim-Boateng, K.G., *et al.* (2022). The nutritional composition of the vegetable soybean (maodou) and its potential in combatting malnutrition. *Frontiers in Nutrition*, 9, article number 1034115. doi: 10.3389/fnut.2022.1034115.

[5] Biliavska, L., Biliavskiy, Y., Mazur, O., & Mazur, O. (2021). Adaptability and breeding value of soybean varieties of Poltava breeding. *Bulgarian Journal of Agricultural Science*, 27(2), 312-322.

[6] Bobos, I., Komar, O., Havrys, I., Shemetun, O., & Kokoiko, V. (2024). Ecological stability, plasticity, and adaptability of cowpea varieties (*Vigna unguiculata* (L.) Walp. subsp. sesquipedalis (L.) Verdc.). *Scientific Horizons*, 27(5), 68-78. doi: 10.48077/scihor5.2024.68.

[7] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[8] Convention on International Trade in Endangered Species of Wild Fauna and Flora. (1973, June). Retrieved from https://cites.org/eng.

[9] Corbellini, M., Bobek, D.V., de Toledo, J.F.F., Ferreira, L.U., Santana, D.C., Gilio, T.A.S., Teodoro, L.P.R., Teodoro, P.E., & Tardin, F.D. (2024). Geographical adaptability for optimizing the recommendation of soybean cultivars in the Brazilian Cerrado. *Scientific Reports*, 14, article number 13076. doi: 10.1038/s41598-024-63809-y.

[10] Dave, K., Kumar, A., Dave, N., Jain, M., Dhanda, P.S., Yadav, A., & Kaushik, P. (2024). Climate change impacts on legume physiology and ecosystem dynamics: A multifaceted perspective. *Sustainability*, 16(14), article number 6026. doi: 10.3390/su16146026.

[11] Duan, Z., *et al*. (2022). Natural allelic variation of *GmST05* controlling seed size and quality in soybean. *Plant Biotechnology Journal*, 20(9), 1807-1818. doi: 10.1111/pbi.13865.

[12] Fedosiy, I., Bobos, I., Zavadska, O., Komar, O., Tonkha, O., Furdyha, M., Polishchuk, S., Margus, A., & Olt, J. (2022). Research into properties of blue melilot and fenugreek cultivated using different sowing times. *Agronomy Research,* 20(1), 103-123. doi: 10.15159/AR.22.005.

[13] Khatri, P., Kumar, P., Shakya, K.S., Kirlas, M.C., & Tiwari, K.K. (2024). Understanding the intertwined nature of rising multiple risks in modern agriculture and food system. *Environment, Development and Sustainability*, 26, 24107-24150. doi: 10.1007/s10668-023-03638-7.

[14] Kumar, S., Gopinath, K.A., Sheoran, S., Meena, R.S., Srinivasarao, C., Bedwal, S., Jangir, C.K., Mrunalini, K., Jat, R., & Praharaj, C.S. (2023). Pulse-based cropping systems for soil health restoration, resources conservation, and nutritional and environmental security in rainfed agroecosystems. *Frontiers in Microbiology*, 13, article number 1041124. doi: 10.3389/fmicb.2022.1041124.

[15] Li, X., Liu, K., Rideout, S., Rosso, L., Zhang, B., & Welbaum, G.E. (2024). Seed physiological traits and environmental factors influence seedling establishment of vegetable soybean (*Glycine max* L.). *Frontiers in Plant Science*, 15, article number 1344895. doi: 10.3389/fpls.2024.1344895.

[16] Mazur, O., Kupchuk, I., Biliavska, L., Biliavskyi, Y., Voloshyna, O., Mazur, O., & Razanov, S. (2023). Ecological plasticity and stability of soybean varieties under climate change in Ukraine. *Acta Fytotechnica et Zootechnica*, 26(4), 398-411. doi: 10.15414/afz.2023.26.04.398-411.

[17] Mazur, V., Didur, I., Tkachuk, O., Pantsyreva, H., & Ovcharuk, V. (2021). Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. *Scientific Horizons*, 24(1), 54-60. doi: 10.48077/scihor.24(1).2021.54-60.

[18] Melnyk, A., Romanko, Y., Dudka, A., Chervona, V., Brunyov, M., & Sorokolit, E. (2022). Ecological elasticity of soybean varieties' performance according to climatic factors in Ukraine. *AgroLife Scientific Journal*, 11(2), 91-99. doi: 10.17930/AGL2022212.

[19] Monzon, J.P., La Menza, N.C., Cerrudo, A., Canepa, M., Edreira, J.I.R., Specht, J., Andrade, F.H., & Grassini, P. (2021). Critical period for seed number determination in soybean as determined by crop growth rate, duration, and dry matter accumulation. *Field Crops Research*, 261, article number 108016. doi: 10.1016/j.fcr.2020.108016.

[20] Nair, R.M., Boddepalli, V.N., Yan, M.R., Kumar, V., Gill, B., Pan, R.S., Wang, C., Hartman, G.L., e Souza R.S., & Somta, P. (2023a). Global status of vegetable soybean. *Plants*, 12(3), article number 609. doi: 10.3390/plants12030609.

[21] Nair, R.M., Yan, M.R., Vemula, A.K., Rathore, A., van Zonneveld, M., & Schafleitner, R. (2023b). Development of core collections in soybean on the basis of seed size. *Legume Science*, 5(1), article number e158. doi: 10.1002/leg3.158.

[22] Nirmal, N., Anyimadu, C.F., Khanashyam, A.C., Bekhit, A.E.D.A., & Dhar, B.K. (2024). Alternative protein sources: Addressing global food security and environmental sustainability. *Sustainable Development*, 33(3), 3958-3969.. doi: 10.1002/sd.3338.
[23] Rane, J., Singh, A.K., Kumar, M., Boraiah, K.M., Meena, K.K., Pradhan, A., & Prasad, P.V.V. (2021). The adaptation and tolerance of major cereals and legumes to important abiotic stresses. *International Journal of Molecular Sciences*, 22(23), article number 12970. doi: 10.3390/ijms222312970.
[24] Rastegaripour, F., Tavassoli, A., Babaeian, M., Fernández-Gálvez, J., & Caballero-Calvo, A. (2024). Assessing the impacts of climate change on water resource management and crop patterns in Eastern Iran. *Agricultural Water Management*, 295, article number 108774. doi: 10.1016/j.agwat.2024.108774.
[25] Roth, L., Barendregt, C., Bétrix, C.A., Hund, A., & Walter, A. (2022). High-throughput field phenotyping of soybean: Spotting an ideotype. *Remote Sensing of Environment*, 269, article number 112797. doi: 10.1016/j.rse.2021.112797.
[26] Staniak, M., Czopek, K., Stępień-Warda, A., Kocira, A., & Przybyś, M. (2021). Cold stress during flowering alters plant structure, yield and seed quality of different soybean genotypes. *Agronomy*, 11(10), article number 2059. doi: 10.3390/agronomy11102059.
[27] Staniak, M., Szpunar-Krok, E., & Kocira, A. (2023). Responses of soybean to selected abiotic stresses-photoperiod, temperature and water. *Agriculture*, 13(1), article number 146. doi: 10.3390/agriculture13010146.
[28] Tkachuk, O.P., Didur, I.M., & Mazur, O.V. (2022). Adaptability, sustainability and productivity of mid-early soybean varieties. *Agrarian Innovations*, 16, 70-79. doi: 10.32848/agrar.innov.2022.16.12.
[29] Xu, C., Wu, T., Yuan, S., Sun, S., Han, T., Song, W., & Wu, C. (2022). Can soybean cultivars with larger seed size produce more protein, lipids, and seed yield? A meta-analysis. *Foods*, 11(24), article number 4059. doi: 10.3390/foods11244059.
[30] Yofa, R.D., Perdana, R.P., Aldillah, R., Muslim, C., Sunarsih, & Agustian, A. (2021). Strategies to increase soybean production by increasing the distribution of new superior varieties. In *IOP conference series: Earth and environmental science* (Vol. 892, article number 012067). Bristol: IOP Publishing. doi: 10.1088/1755-1315/892/1/012067.

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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_i=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_i=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