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Development of soybean yield and seed productivity elements depending on the variety

Serhii Pylypenko*

Postgraduate Student

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<https://orcid.org/0009-0001-4455-545X>**Hanna Kovalyshyna**

Doctor of Agricultural Sciences, Professor

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<https://orcid.org/0000-0002-2715-7679>

Abstract. In the context of global climate change and the food crisis, soybeans (*Glycine max*) requires optimisation of the genetic potential to ensure stable and high productivity through the identification of genotypes with high adaptability in specific soil and climatic conditions, in particular the forest-steppe of Ukraine. The purpose of the study was to investigate the influence of varietal characteristics on the development of key morphological and productive features of soybeans and assess its compensatory ability during two years of research. The study was conducted during 2024-2025 using field, biometric, and correlation analyses to estimate plant height, the number of pods per plant, the number of branches, and the weight of 1,000 seeds. A high varietal dependence of all studied traits has been established, which emphasises the decisive importance of the genotype. A strong negative correlation was found between plant height and the number of pods per plant ($r = -0.897$), which indicates a negative effect of excessive vegetative growth on generative productivity due to a violation of the balance of sources and drains. It was confirmed that the intensity of branching had only a weak effect on crop development. The mechanism of compensatory ability during the years of research (phenotypic plasticity) was revealed: a decrease in the number of pods under unfavourable conditions led to a compensatory increase in the weight of 1,000 seeds. Among the samples studied, the varieties 'ES Mentor', 'Antracit' and 'Muza' had the most balanced combination of high seed productivity, seed quality, and satisfactory attachment height

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*Corresponding author



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of the lower pods. The results of the study provide important information for optimising the varietal composition in the region, and also serve as a basis for breeding work aimed at adapting soybeans and improving the efficiency of fruit setting in the forest-steppe zone

Keywords: genotype; morphological features; compensatory ability; vegetative growth; correlation analysis

Introduction

Global demand for soybeans as one of the leading oilseed and protein crops necessitates not only an increase in yield, but also greater stability in the face of climate change and growing anthropogenic pressure on agroecosystems. The development of the soybean crop is a complex biological process determined by the interaction of the genetic characteristics of the variety with the growing conditions and is implemented through a system of morphological and productive characteristics of the plant. It is the structure of the crop, which reflects the relationship between the elements of vegetative and generative development that plays a key role in realising the potential of the crop and ensuring its adaptability in specific soil and climatic conditions.

R. Rani *et al.* (2023a) analysed genotype-environment interactions for soybean agronomic traits, specifically seed number and yield. Using associative mapping, the researchers found out how different environmental conditions affect the genetic characteristics and productivity of soybeans, which is important for breeding programmes and optimising the cultivation of this crop in changing climatic conditions. R. Rani *et al.* (2023b) focused on the study of genetic variations in soybeans through genome-wide association analysis (GWAS), aimed at identifying candidate genes that are responsible for crop yield characteristics. The results showed the importance of certain genetic markers that can be used to improve soybean varieties, in particular, to increase yield and stress resistance. The need to create stable and highly productive varieties emphasises the critical importance of detailed analysis of varietal characteristics. Although the use of biostimulants, as shown by B. Mazurenko *et al.* (2025),

can significantly increase key yield components (number and weight of seeds), the authors themselves emphasise that these techniques only help to realise the genetic potential inherent in the variety, and their effectiveness largely depends on the biological characteristics of the crop, the initial level of genotype productivity, and the specific soil and climatic conditions of cultivation.

The key varietal trait is the plant architecture, which determines the efficiency of light use and resistance to lodging. N. Li *et al.* (2025) confirmed that varietal characteristics such as plant height, degree of branching, and height of attachment of lower pods are critical determinants, since their targeted genetic modification allows optimising the spatial organisation of shoots and increasing the outflow of assimilants to generative organs. The height of plants with high heritability serves as the basis for the development of nodes – potential places for the development of pods, which was analysed in detail by Q. Yang *et al.* (2021), who showed that this indicator is controlled by both stable genetic mechanisms and the response of plants to environmental conditions, in particular, temperature and water regime. Contemporary soybean breeding, according to research by S. Srivastava *et al.* (2025), is aimed at optimising the architecture (internode length, branching) to increase photosynthetic efficiency, since multivariate analysis of traits proved their direct and indirect effect on yield development through improved light interception and balance between vegetative and generative growth. Current research shows that soybean plant architecture is the result of the interaction of regulatory genes, hormonal signals, and environmental factors that control plant height, internode length,

and branching (Li *et al.*, 2024). J. Chandler (2025) found a paradox: although more nodes correlate with potentially more branches and pods, the total number of nodes can have a significant negative association with final yield. This is conditioned by the fact that varieties that over-invest resources in vegetative growth show a decrease in the efficiency of assimilation transfer to seeds.

A.T. Assfaw *et al.* (2025) found that the attachment height of lower pods is a highly inherited trait, giving breeders the opportunity to purposefully increase it. However, breeders' efforts to maximise the attachment height of the top pods face some challenges. The researchers have established a negative correlation between this indicator and the overall yield. This means that the energy resources spent on excessive elongation of the lower internodes (to increase the height of the pod attachment) can be diverted from the development of the crop. Thus, according to A.T. Assfaw *et al.*, indeterminate varieties that continue vegetative growth after the beginning of flowering usually form a higher attachment height of the lower pods, compared to determinant varieties.

Agricultural techniques (for example, narrow row spacing) can also be used to indirectly control this indicator, especially for early sowing. A.S. Karyawati *et al.* (2025), using path analysis, determined that the key traits with the highest direct positive impact on yield are the number of seeds in pods and the number of lower internodes.

The purpose of the study was to investigate the influence of varietal characteristics on the development of key morphological and productive features of soybeans and assess its compensatory ability during two years of research.

Materials and Methods

The objects of the study were 8 soybean varieties: 'Siverka', 'Arnika', 'Muza', 'Adamos', 'Aleksandrit', 'Antracit', 'ES Mentor', 'ES Vizitor' (Table 1). The study was carried out in accordance with the ethical standards provided for by the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973). The provisions of these documents aimed at protecting biological diversity and preventing threats to the species under study were observed.

Table 1. List of soybean varieties

No.	Variety	Type of development	Growing season, days	Originator
1	'Siverka'	semi-determinate	83-85	National Research Centre "Institute of Agriculture of the Ukrainian Academy of Agrarian Sciences of Ukraine"
2	'Arnika'	semi-determinate	83-85	National Research Centre "Institute of Agriculture of the Ukrainian Academy of Agrarian Sciences of Ukraine"
3	'Muza'	determinate	100-102	National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine"
4	'Adamos'	indeterminate	95-100	Liudmyla Biliavska
5	'Aleksandrit'	semi-determinate	95-100	Liudmyla Biliavska
6	'Antracit'	determinate	100-105	Poltava State Agrarian Academy, Liudmyla Biliavska
7	'ES Mentor'	semi-determinate	105-115	Euralis Semences LLC
8	'ES Vizitor'	indeterminate	105-110	Euralis Semences LLC

Source: compiled by the authors

The research was conducted during 2024-2025 in the fields of the "Agronomic Research Station", a separate division of the National University of Life and Environmental Sciences of Ukraine,

located in the forest-steppe soil and climate zone of Ukraine. To ensure the reliability and complexity of the assessment of economically valuable characteristics of soybean varieties, the study was

carried out using field and statistical and analytical methods that provide relevant results in real agroecological conditions.

The field method was the main method for obtaining primary empirical data, including direct field observations and biometric measurements. It was used to evaluate the main indicators of soybean productivity elements, namely: plant height, number of branches on the plant, number of pods on the plant, number of seeds in the pod, number of seeds from the plant, height of attachment of the lower pod, weight of 1,000 seeds, duration of the growing season, and type of growth. Field observations were used to determine the phenophases and duration of vegetation, and to determine the type of growth. Biometric measurements allowed quantifying the structural elements of the crop. The assessment was carried out in accordance with generally accepted methods, which allowed comparing varieties by the main indicators of productivity elements. The weight of 1,000 seeds was determined by laboratory field analysis at a base humidity of 12%. The experimental plots had an area of 5.6 m² for each variety, where the predecessor in all years of research was corn. Pre-sowing tillage included the introduction of a compensatory rate of fertilisers at the rate of N₉₀P₆₀K₉₀. A single treatment with the fungicide Amistar Gold (Syngenta) was carried out during the growing season at a rate of 0.8 l/ha.

The obtained data was processed using the statistical and analytical method, using Microsoft Excel software and the ANOVA online calculator.

Basic statistical calculations were performed using Excel, in particular, sums, averages, standard deviations, variation coefficients, and the least significant difference (LSD) between the studied indicators were determined. To perform dispersion analysis (ANOVA) for the purpose of comparing group averages and establishing the statistical significance of differences between varieties, ANOVA Calculator was used, namely, comparisons were made using the Tukey criterion (HSD). The use of statistical methods, in particular ANOVA, was justified because it allowed testing the influence of the “variety” factor on performance indicators and ensures the reliability of conclusions by separating random fluctuations from actual varietal differences. The difference between the indicators was considered statistically significant at a significance level of $p < 0.05$.

Results and Discussion

As a result of the conducted studies, a significant variability in the main morphological characteristics of soybean plants was established depending on the variety and year of cultivation. In 2024, the average plant height was 90.0 cm, ranging from 73.3 cm (‘Antracit’) to 104.7 cm (‘ES Vizitor’) (Table 2). The highest number of branches per plant was observed in varieties ‘Adamos’ (3.1 units) and ‘ES Vizitor’ (2.6 units). The number of pods on the plant varied from 27.3 units (‘Siverka’) up to 52.3 units (‘Adamos’), and the number of seeds per plant – from 51.8 to 127.3 units, which indicates a significant productivity of the varieties ‘ES Mentor’ and ‘Adamos’.

Table 2. Parameters of valuable economic characteristics of soybean varieties in 2024

Variety	Plant height, cm	Number of branches per plant, units	Number of pods per plant, units	Number of seeds per plant, units	Number of seeds per pod, unit	Height of lower pod attachment, cm	Weight of 1,000 seeds, g
‘Siverka’	103.0	1.4	27.3	51.8	1.8	21.1	161.0
‘Arnika’	78.8	2.5	44.7	115.9	2.6	15.6	122.0
‘Muza’	100.2	1.6	29.8	74.4	2.8	13.8	193.0
‘Adamos’	87.6	3.1	52.3	104.6	2.0	17.1	167.5
‘Aleksandrit’	97.2	1.9	28.6	67.1	2.4	17.8	157.5
‘Antracit’	73.3	2.2	48.4	114.8	2.4	13.2	185.5
‘ES Mentor’	74.8	1.5	43.3	127.3	2.9	13.6	175.0

Table 2. Continued

Variety	Plant height, cm	Number of branches per plant, units	Number of pods per plant, units	Number of seeds per plant, units	Number of seeds per pod, unit	Height of lower pod attachment, cm	Weight of 1,000 seeds, g
'ES Vizitor'	104.7	2.6	38.7	116.1	3.0	13.7	132.5
Average	90.0	2.1	39.1	96.5	2.5	15.7	161.8

Note: values in columns that are significantly higher than the average at a 5% significance level are highlighted in bold

Source: developed by the authors based on own research

The number of seeds per pod averaged 2.5 units, the highest statistically significant values were observed in the varieties 'ES Vizitor' (3.0 units), 'ES Mentor' (2.9 units) and 'Muza' (2.8 units). The height of attachment of the lower pods ranged from 13.2-21.1 cm, which indicates different suitability of varieties for mechanised harvesting. The highest attachment height was observed in the variety 'Siverka', which is a positive sign for reducing losses during harvesting.

The weight of 1,000 seeds varied from 122.0 g ('Arnika') to 193.0 g ('Muza'), averaging 161.8 g. This indicates the development of full-fledged, well-filled seeds under favourable growing conditions in 2024. In 2025, the average values of most attributes were lower compared to the previous year (Table 3). The average plant height was 75.3 cm, which is 14.7 cm less than in 2024. The highest were plants of the varieties 'Siverka' and 'Aleksandrit' (87.2 cm).

Table 3. Parameters of valuable economic characteristics of soybean varieties in 2025

Variety	Plant height, cm	Number of branches per plant, units	Number of pods per plant, units	Number of seeds per plant, units	Number of seeds per pod, unit	Height of lower pod attachment, cm	Weight of 1,000 seeds, g
'Siverka'	87.2	1.3	32.4	65.7	2.0	9.6	187.9
'Arnika'	65.4	2.3	38.0	73.9	1.9	7.3	186.4
'Muza'	80.0	1.7	35.5	86.8	2.4	8.1	110.1
'Adamos'	64.4	2.0	37.3	72.1	1.9	10.4	192.6
'Aleksandrit'	87.2	1.6	28.6	54.1	1.9	14.0	184.3
'Antracit'	79.5	1.5	30.4	63.2	2.1	7.4	194.0
'ES Mentor'	58.2	1.4	52.6	126.2	2.4	8.6	149.2
'ES Vizitor'	80.8	2.5	36.3	96.9	2.7	12.8	151.1
Average	75.3	1.8	36.4	79.9	2.2	9.8	169.5

Note: values in columns that are significantly higher than the average at a 5% significance level are highlighted in bold

Source: developed by the authors based on own research

The number of branches on average decreased to 1.8 units, and the maximum values were typical for varieties 'Arnika' (2.3 units) and 'EU Vizitor' (2.5 units). The number of pods on the plant was 36.4 units, the highest value was noted for the 'ES Mentor' variety (52.6 units). The average number of seeds per plant was 79.9 units, with a range from 54.1 ('Aleksandrit') to 126.2 units ('ES Mentor'). The number of seeds per pod

was stable – 2.2 units on average, with the highest indicators in the varieties 'Muza', 'ES Mentor' (2.4 units) and 'EU Vizitor' (2.7 units). The attachment height of the lower pods ranged from 7.3 cm ('Arnika') to 14.0 cm ('Aleksandrit'), which also indicates a varietal feature. The weight of 1,000 seeds in 2025 ranged from 110.1 g ('Muza') to 194.0 g ('Antracit'), the average value was 169.5 g, which was higher than in the previous year.

According to N. Li *et al.* (2025), the number of seeds per pod is usually in the range of 2.5 units, which coincides with the results of current studies, considering the natural error and varietal differences. In 2024, the development of generative organs and overall plant productivity were higher due to optimal year conditions. The availability of resources at critical stages of growth contributed to the development of the maximum number of nodes and pods. This observation is consistent with the findings of H. Berhanu *et al.* (2021), who established a positive and significant correlation between plant height and the number of commercial pods per plant ($r=0.821$), and between the number of commercial pods per plant and commercial pod yield ($r=0.822$). Thus, the high growth rates that were observed in 2024 (in particular, higher plant heights) could directly contribute to the development of more pods, which became a key factor in overall productivity. H. Berhanu *et al.* also noted that the number of commercial pods per plant, the weight of green beans, and the height of plants are important selection criteria for increasing yield, which confirms the significance of the indicators evaluated in the current study. In 2025, despite a decrease in the height of plants and the number of pods, which, according to the correlations described by H. Berhanu *et al.*, led to a general decrease in yield), an increase in the weight of 1,000 seeds was observed. This result indicates a redistribution of assimilants by the plant. A limited number of developed pods received more nutrients, which improved the quality of individual seeds. The observation of the current study that high overall productivity in 2024 was accompanied by favourable generative organ development and high growth rates is consistent with results by other researchers, including H. Berhanu *et al.*, that the height of plants indirectly affects the yield due to the number of pods. This highlights that in both years of research – both under favourable and less favourable conditions – the number of pods per plant remains the dominant element of productivity. According to J. Chinnarat *et al.* (2025), it

is not optimal to maximise the attachment height of the lower pods, but to reach the minimum allowable threshold (more than 10 cm), which ensures mechanised harvesting while maintaining the maximum yield potential. Three varieties corresponded to this parameter: 'Adamos' (10.4 cm), 'Aleksandrit' (14.0 cm), 'ES Vizitor' (12.8 cm).

The results of the study confirmed the high phenotypic plasticity of soybeans, which is a key adaptive feature of the crop. In particular, the data for 2025 clearly illustrate the mechanism of compensatory response: a decrease in the number of pods on the plant led to a statistically significant increase in the weight of 1,000 seeds. This fact confirms the existence of a classical negative correlation between quantitative and qualitative indicators of the crop structure. In conditions of limiting the number of nodes (for example, under the influence of stress), the plant redistributes assimilants, directing them to the remaining seed rudiments. This ensures better seed production and increases its seed value, serving as a mechanism for partially compensating for potential crop losses. The revealed compensatory ability of soybeans is consistent with the conclusions of a number of researchers who also studied the crop plasticity. X. Ran *et al.* (2023), examining the effect of density and seeding patterns, found that as row spacing increased, the yield and number of pods per plant decreased, but the weight of 1,000 seeds gradually increased. This confirms that in conditions of reduced competition (or a decrease in the number of elements), soybeans effectively move to an increase in individual seed weight as a compensatory element. A.A.B. Junior *et al.* (2018) emphasised that the most defining change associated with yield plasticity per plant is the number of pods on the side shoots, not the weight of 1,000 seeds. This suggests that compensatory mechanisms may be different: either due to morphogenesis (increased branching, as in A.A.B. Junior *et al.*), or due to physiological processes (an increase in the weight of 1,000 seeds, as in the current study and by X. Ran *et al.*). These differences are conditioned by varietal characteristics,

the phase in which stress occurred, and the type of agrotechnical factors. The ability of varieties to adapt effectively, as shown by O. Mazur *et al.* (2024) (classification of varieties 'Artemida', 'Hoverla', and 'Ametist' as highly plastic), emphasises that the compensatory potential is a variety-specific feature. The weight of 1,000 seeds is the most sensitive element of the crop structure to adverse conditions that occur in the late stages of development, especially during the grain filling phase. D.A. Kiriziy & O.O. Stasik, (2022) claimed that off-season stress (drought, high temperatures) can dramatically reduce seed size, which requires the development of more seeds to achieve the same weight per unit area.

According to the results of two years of research, the varieties 'ES Mentor', 'Antracit', and 'Muza' demonstrated the most balanced complex of morphological and productive characteristics. They combine satisfactory plant height, high seed productivity and the weight of 1,000 seeds, which indicates their high efficiency in regulating assimilates, ensuring reliable realisation of

yield potential in an unstable environment. Evaluating seed productivity, it should be noted that the varieties 'ES Mentor', 'Antracit', and 'Muza' were characterised by the highest indicators of the total weight of seeds per plant and the weight of 1,000 seeds, which indicates the effective use of photosynthetic products for grain filling. The high weight of 1,000 seeds, with a relatively moderate number of pods, is evidence of stable reproductive capacity, that is, high seed productivity. This combination of characteristics is desirable for varieties intended for seed production, since it ensures the development of homogeneous, aligned seeds with high germination.

To establish a significant difference between the average values of morphological features of soybean plants, multiple comparisons were performed using the Tukey criterion (HSD) (Table 4). The larger the numerical value of the difference, the more significantly the corresponding features differ from each other. Close relationships between individual traits and significant discrepancies between others were found.

Table 4. Results of multiple comparison of soybean morphological traits (average for 2024-2025) according to the Tukey criterion (HSD)

Pairs of indicators	Average difference between the compared groups	Standard error, SE	Tukey criterion, Q	Confidence interval limits		Critical average	p-value
x1-x2	80.66	4.10	19.66	62.83	98.50	17.84	1.327e-11
x1-x3	44.86	4.10	10.93	27.03	62.70	17.84	1.018e-8
x1-x4	5.55	4.10	1.35	-12.29	23.39	17.84	0.96
x1-x5	80.33	4.10	19.58	62.49	98.16	17.84	1.327e-11
x1-x6	69.90	4.10	17.04	52.06	87.74	17.84	1.329e-11
x1-x7	82.98	4.10	20.22	65.14	100.81	17.84	1.327e-11
x2-x3	35.80	4.10	8.73	17.96	53.64	17.84	0.00
x2-x4	86.21	4.10	21.01	68.38	104.05	17.84	1.327e-11
x2-x5	0.34	4.10	0.08	-17.50	18.17	17.84	1.00
x2-x6	10.76	4.10	2.62	-7.07	28.60	17.84	0.52
x2-x7	163.64	4.10	39.88	145.80	181.47	17.84	1.327e-11
x3-x4	50.41	4.10	12.29	32.58	68.25	17.84	3.719e-10
x3-x5	35.46	4.10	8.64	17.63	53.30	17.84	0.00
x3-x6	25.04	4.10	6.10	7.20	42.87	17.84	0.00
x3-x7	127.84	4.10	31.16	110.00	145.67	17.84	1.327e-11
x4-x5	85.88	4.10	20.93	68.04	103.71	17.84	1.327e-11
x4-x6	75.45	4.10	18.39	57.61	93.29	17.84	1.328e-11
x4-x7	77.43	4.10	18.87	59.59	95.26	17.84	1.328e-11
x5-x6	10.43	4.10	2.54	-7.41	28.26	17.84	0.56

Table 4. Continued

Pairs of indicators	Average difference between the compared groups	Standard error, SE	Tukey criterion, Q	Confidence interval limits		Critical average	p-value
x5-x7	163.30	4.10	39.80	145.46	181.14	17.84	1.327e-11
x6-x7	152.88	4.10	37.26	135.04	170.71	17.84	1.327e-11

Note: x1 – plant height; x2 – number of branches on the plant; x3 – number of pods on the plant; x4 – number of seeds per plant; x5 – number of seeds in the pod; x6 – height of attachment of the lower pods; x7 – weight of 1,000 seeds

Source: developed by the authors based on own research

According to the results of multiple comparison of soybean morphological features, most of the pairs compared had statistically significant differences ($p < 0.001$), which indicates significant variability of morphological features among the study groups. The largest differences were observed between the number of branches (x2) and the weight of 1,000 seeds (x7) (difference 163.64; $p < 0.001$), and between the number of seeds in a pod (x5) and the weight of 1,000 seeds (x7) (difference 163.30; $p < 0.001$). High values of differences were also found between the attachment height of the lower pods (x6) and the weight of 1,000 seeds (x7) (152.88; $p < 0.001$). That is, over the years of research, the weight of seeds changed regardless of the number of seeds per pod or the number of branches. Significant differences were also found between the number of seeds per plant (x4) and the number of pods (x3) (difference 50.41; $p < 0.001$), which

logically reflects the structural relationship between these elements of productivity. The smallest differences, which have no statistical significance ($p > 0.05$), were observed between pairs x2-x5 (difference 0.34) and x5-x6 (difference 10.43), which indicates a close relationship between the number of branches, the number of seeds in the pod and the height of attachment of the lower pods – these traits are relatively stable within the variety.

Based on the analysis of the Tukey test, the most variable indicators in the soybean plants under study were the weight of 1,000 seeds and the height of attachment of the lower pods, while the number of branches and the number of seeds per pod were relatively constant. During the analysis of the correlation matrix data, both direct and inverse relationships between the main morphological and productive characteristics of soybean plants were identified (Table 5).

Table 5. Nature of the relationship between the main biometric indicators and structural elements of the soybean crop

	Plant height, cm	Number of branches per plant, units	Number of pods per plant, units	Number of seeds per plant, units	Number of seeds per pod, unit	Height of lower pod attachment, cm	Weight of 1,000 seeds, g
Plant height, cm	1						
Number of branches per plant, units	-0.148	1					
Number of pods per plant, units	-0.897	0.357	1				
Number of seeds per plant, units	-0.688	0.262	0.852	1			

Table 5. *Continued*

	Plant height, cm	Number of branches per plant, units	Number of pods per plant, units	Number of seeds per plant, units	Number of seeds per pod, unit	Height of lower pod attachment, cm	Weight of 1,000 seeds, g
Number of seeds per pod, unit	-0.054	0.090	0.230	0.688	1		
Height of lower pod attachment, cm	0.625	-0.037	-0.566	-0.642	-0.513	1	
Weight of 1,000 seeds, g	-0.204	-0.247	0.031	-0.366	-0.735	0.124	1

Source: compiled by the authors

Plant height had a high negative correlation with the number of pods per plant ($r = -0.897$) and an average negative correlation with the number of seeds per plant ($r = -0.688$). This indicates a clear tendency to reduce the level of productivity with excessive vegetative growth. The relationship between plant height and the number of branches ($r = -0.148$) and the weight of 1,000 seeds ($r = -0.204$) was very weak and negative. Moreover, an average positive dependence ($r = 0.625$) was noted with the attachment height of the lower pods, which indicates the tendency of higher plants to form lower fruits at a higher height from the soil.

The results obtained contradict the data by J. Chandler (2025), who pointed out a significant positive correlation between plant height, number of nodes, and number of branches with the potential number of pods per plant. In particular, J. Chandler obtained a correlation coefficient of $r = 0.697$ between plant height and the number of pods per plant, which shows a direct relationship, while in the current study there is a strong inverse relationship ($r = -0.897$). The number of branches on the plant was weakly positively correlated with the number of pods ($r = 0.357$) and the number of seeds from the plant ($r = 0.262$), which indicates a weak direct relationship between the intensity of branching and overall productivity. The relationships with the weight of 1,000 seeds ($r = -0.247$) and the attachment height of the lower pods ($r = -0.037$) were weakly negative, which indicates that there was no significant influence of these

indicators in the sample of the current study. Genetic research by J. Chandler revealed an important paradox: despite the fact that a larger number of nodes is positively correlated with a larger number of branches ($r = 0.923$) and pods ($r = 0.899$), the total number of nodes in a plant can have a significant negative association with the final yield ($r = -0.611$). This conclusion confirms the importance of a balance between the growth of vegetative mass (number of nodes) and the efficiency of its use for generative production, which partly explains the negative relationship in the current study between the height and number of pods.

A high positive correlation was found between the number of pods per plant and the number of seeds per plant ($r = 0.852$), which confirms their close interdependence as the main structural elements of yield. The correlation with the number of seeds per pod ($r = 0.230$) was weakly positive, and with the attachment height of the lower pods – an average negative ($r = -0.566$), which indicates a tendency to decrease the number of pods as the node point increases. The number of seeds from the plant had an average positive association with the number of seeds in the pod ($r = 0.688$). A weak negative correlation was found between the number of seeds and the weight of 1,000 seeds ($r = -0.366$), reflecting a typical feedback loop between the number and size of seeds (compensatory mechanism). The number of seeds per pod had a high negative correlation with the weight of 1,000 seeds ($r = -0.735$). This pattern is explained by the fact that when more

seeds compete for assimilants within a single pod, their individual weight inevitably decreases.

The results obtained are consistent with modern ideas about soybean seed productivity as an integral indicator of the realisation of varietal potential. By definition of J.S.P.C. Evangelista *et al.* (2021), seed productivity, which combines quantitative and qualitative parameters of seeds, is a more stable feature compared to overall yield, since it is less susceptible to short-term fluctuations in environmental conditions. A similar opinion was expressed by Y. Gai *et al.* (2025), who in their review study emphasised that the ability to form full, well-filled seeds reflects the genetically determined effectiveness of the crop's reproductive system and can serve as a reliable criterion for variety adaptability. In conditions of high variability of agroecological factors, the stability of key elements of the crop structure in different years of cultivation becomes particularly important. This opinion is confirmed by the results of three-year studies by I. Havryliuk & H. Kovalyshyna (2024), who, using variance and correlation analysis, established significant genotypic differences in the weight of 1,000 seeds, the number of grains from the main reproductive unit, and their weight. The researchers concluded that it is the stability of these indicators that determines the adaptability of the variety, which is fully consistent with the differences between varieties in seed productivity parameters identified in the current study. According to A.M. Rybalchenko & Ye.V. Chub (2021), the assessment of soybean varieties cannot be limited to the analysis of individual elements of the crop structure, since such an assessment does not reflect the effectiveness of reproductive processes in general. The researchers emphasise the feasibility of an integrated approach, which includes the number of seeds per plant, the weight of seeds per plant, and the weight of 1,000 seeds as interrelated indicators of the realisation of varietal potential. Thus, the results of the current study, based on the simultaneous analysis of structural and seed indicators, confirm the feasibility of using seed productivity

as a key criterion for comparative evaluation of soybean varieties. Therefore, the generalisation of the results of the observations in combination with the literature data shows that seed productivity is not only an indicator of the level of yield, but also an indicator of genetic stability and adaptive potential of the variety, which is of fundamental importance for the selection of promising genotypes in an unstable environment.

As a result of the study of varietal characteristics of soybeans in the conditions of the forest-steppe of Ukraine, it was found that the genotype has a significant impact on the development of elements of the crop structure and seed productivity. Studies have shown that the number of pods per plant is the main factor determining productivity, and the height of the plant has a negative impact on this indicator due to excessive vegetative growth. In addition, it was found that soybeans can adapt to unfavourable conditions through compensatory ability, redistributing assimilates to ensure greater seed weight.

Conclusions

During a two-year analysis of varietal characteristics of soybean yield structure development in the forest-steppe soil and climate zone of Ukraine, it was established that the development of yield structure elements and seed productivity is a highly varietal-dependent process. This is confirmed by the significant variability of the morphological and productive traits under study, which is statistically significant for most of the compared pairs of varieties, which emphasises the critical role of the genotype in the realisation of yield potential. A number of key internal relationships that regulate performance were identified. It was found that the number of pods per plant is the dominant element of the crop structure, showing a high positive correlation with the number of seeds per plant ($r = 0.852$). Simultaneously, a strong negative correlation was found between plant height and the number of pods per plant ($r = -0.897$), which indicates a negative effect of excessive vegetative growth on generative

productivity. It should be noted that higher plants form lower pods at a higher altitude ($r = 0.625$), which is favourable for minimising losses during mechanised harvesting.

It was proved that soybean productivity is regulated by the mechanism of compensatory ability (phenotypic plasticity). In particular, in 2025, the activation of this mechanism was recorded, when a decrease in the number of pods led to a significant increase in the weight of 1,000 seeds. This reflects a fundamental negative correlation between quantitative and qualitative indicators, where limiting the number of nodes ensures better seed filling by redistributing assimilates. A similar high negative correlation was found between the number of seeds per pod and the weight of 1,000 seeds ($r = -0.735$), which confirms competition for resources between seeds in a pod. It was noted that the number of branches on the plant had only a weak positive correlation with the number of pods ($r = 0.357$) and the number of seeds from the plant ($r = 0.262$). This indicates that in the studied varieties under these conditions, the intensity of branching was not a determining factor in the development of seed productivity. The leading role in ensuring the final yield remains

with the productivity of the main stem and the efficiency of fruit setting on it. According to the results of research, the varieties 'ES Mentor', 'Antracit', and 'Muza' demonstrated the most balanced development of elements of the crop structure and high seed productivity. They combine high seed productivity with a weight of 1,000 seeds, which indicates their effective regulation of the distribution of assimilates, high adaptive potential, and makes them promising for introduction into production in the forest-steppe of Ukraine.

Prospects for further research consist in an in-depth study of the interaction between genotype and environmental conditions using long-term observations and an expanded set of soybean varieties to clarify the mechanisms of seed productivity and adaptive stability of the crop.

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Conflict of Interest

None.

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Формування елементів структури врожаю та насінневої продуктивності сої залежно від сорту

Сергій Пилипенко

Аспірант

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0009-0001-4455-545X>

Ганна Ковалишина

Доктор сільськогосподарських наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оброни, 15, м. Київ, Україна
<https://orcid.org/0000-0002-2715-7679>

Анотація. У контексті глобальних кліматичних змін та продовольчої кризи, соя (*Glycine max*) потребує оптимізації генетичного потенціалу для забезпечення стабільної та високої продуктивності через ідентифікацію генотипів з високою адаптивністю в конкретних ґрунтово-кліматичних умовах, зокрема Лісостепу України. Мета дослідження полягала у вивченні впливу сортових особливостей на формування ключових морфологічних і продуктивних ознак сої та оцінці її компенсаційної здатності протягом двох років досліджень. Дослідження проводили протягом 2024-2025 років із застосуванням польового, біометричного та кореляційного аналізів для оцінки висоти рослин, кількості бобів на рослині, кількості гілок та маси 1000 насінин. Встановлено високу сортову залежність усіх досліджуваних ознак, що підкреслює визначальне значення генотипу. Виявлено сильну від'ємну кореляцію між висотою рослини та кількістю бобів на рослину ($r = -0,897$), що свідчить про негативний вплив надмірного вегетативного росту на генеративну продуктивність через порушення балансу джерел і стоків. Підтверджено, що інтенсивність гілкування мала лише слабкий вплив на формування врожаю. Виявлено механізм компенсаційної здатності в роки досліджень (фенотипової пластичності): зниження кількості бобів у несприятливих умовах призводило до компенсаторного збільшення маси 1000 насінин. Серед досліджених зразків сорти 'ЕС Ментор', 'Антрацит' і 'Муза' мали найбільш збалансоване поєднання високої насінневої продуктивності, якості насіння та задовільної висоти прикріплення нижніх бобів. Результати дослідження надають важливу інформацію для оптимізації сортового складу в регіоні, а також слугують основою для селекційної роботи, спрямованої на адаптацію сої та підвищення ефективності зав'язування плодів у зоні Лісостепу

Ключові слова: генотип; морфологічні ознаки; компенсаційна здатність; вегетативний ріст; кореляційний аналіз