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Original Paper

Adaptive Value of Soybean Varieties by the Seed Quality Parameters

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Production requires highly adaptive varieties that have a high level of genetic protection of the crop from biotic and abiotic factors of the environment and can maximally realize the potential of the crop in combination with high-quality seeds. The article presents the results of studies on the assessment of soybean varieties by the adaptability of qualitative characteristics in different soil and climatic conditions in terms of the years of research according to the content and output of oil and protein, as well as the intensity of oil and protein formation in soybean seeds. The adaptability of soybean seed quality of the studied varieties was determined by the Eberhard and Russell method. According to the research results, the highest oil content in the seed was observed in the following varieties: Hoverla (22.2%), Artemida (21.1%), and Zolotysta (20.7%), and the highest protein content was recorded in Artemida (39.2%) and Zolotysta (39.3%). It should be noted that the indicated varieties are conservative (bi <1) by the response to changes in the hydrothermal regime, except for Hoverla, which is highly plastic (bi >1) in terms of oil content in the seeds. These varieties have the highest indicators of agronomic stability (As) in terms of protein content in seeds: 99.2; 99.0%, as well as the sequence of distribution of varieties according to homeostaticity of the first (Nom1) and second (Nom2) types: Artemida – 131.4 and 109.5; Zolotysta – 99.2 and 62.0. The highest output of oil and protein from seeds was recorded in Hoverla – 0.48 and 0.805 t.ha^{-1}, Artemida – 0.43 and 0.803 t.ha^{-1}, which belong to highly plastic varieties by the response to the improvement of the agro-background of cultivation, the variance of stability (Si^2) in which is as close to zero as possible. The combination of high yield of oil and protein became possible due to the high productivity of Hoverla, as for Artemida, these traits are at the level of above mean values. The highest intensity of oil and protein formation in seeds was observed in Hoverla– 4.25 and 7.12, Artemida – 3.8 and 7.06, Amethyst – 3.43 and 6.72 kg.ha^{-1} per day, which belong to highly plastic varieties (bi >1), and the stability variance (Si^2) in which is as close to zero as possible.

Keywords: oil, protein, adaptability, variance, homeostaticity, plasticity, stability

1 Introduction

Ukraine is one of the leading exporters of soybean seeds in the world, however, the strengthening of its position in the world market is constrained by the significant fluctuation of soybean seed production in different years, which is primarily due to insufficient adaptability and significant sensitivity of modern varieties to weather fluctuations. Agricultural production requires highly adaptive soybean varieties with high yield and seed quality (Puyu et al., 2021; Mazur O. et al., 2023a).

Stabilization of crop production, along with rational placement of crops and the effect of other factors, is largely determined by the growing requirements for selecting varieties that are maximally adapted to growing in different soil and climatic zones, which are characterized by high ecological plasticity. The increased significance of this element of technology is caused, first of all, by the ability of varieties as active biological factors to effectively counteract the adverse effects of other factors, which can disrupt the balance of natural ecosystems and initiate processes of environmental pollution, in the process of self-regulation of ecological systems (Kaminskyi, 2006; Branitskyi et al., 2022).

Soybean productivity can be increased by 30–45% due to varietal replacement and varietal renewal, as well as the development of adaptive varietal technology of cultivation (Babych and Babych-Poberezhna, 2012;

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Myronova et al., 2023). The opinions of researchers about the role of variety in crop formation differ. It accounts for 20–60%, depending on the effect of a complex of environmental conditions (fertility level and hydrothermal regime) and crop cultivation technology (Bellaloui et al., 2015). That is why expanding the response rate of varieties to environmental conditions is the main task of crop breeding, especially for regions with stressful weather conditions (Prysiazhniuk et al., 2013; Mazur O. et al., 2023a).

Scientists from all over the world evaluate and characterize soybean varieties according to quantitative and qualitative characteristics. First of all, they should include yield characteristics, i.e. the number of beans and seeds per bean; the weight of 1,000 seeds, the ability to resist diseases, pests, and extreme environmental conditions, resistance to lodging and seeds fall, etc.; and qualitative characteristics, i.e. protein and oil content in seeds, the proportion of anti-nutritional substances in seeds, pubescence of fruits, etc. (Dydiv et al., 2023).

In this regard, most breeding programs targeted at creating soybean varieties are primarily focused on two characteristics, namely yield and chemical composition of seeds. This results from the negative correlation between protein and oil content. In the 1950s, in the USA, the efforts of breeders were aimed at increasing the oil content of seeds. The areas under soybean were expanding, and due to this there was experienced a reorientation towards protein content. However, in each breeding approach, attention was paid to the resistance of plants to lodging and shedding of seeds, these traits contribute to quality improvement (Yatsenko et al., 2023).

Along with the yield, the quality traits of the seed, i.e. protein and oil content, are important for soybeans. These traits of soybean seed quality are mostly genetic traits, but to some extent, they can change under the influence of weather conditions during the period of seed formation, filling, and ripening.

Breeding soybean for seed quality is no less difficult than for yield, taking into account the factor of environmental influence and the relationship with other features and properties of the genotype, resistance to pathogens, ability to fix nitrogen, etc. Taking into account the diversity of the chemical composition, it is necessary, first of all, to give priority to differentiated directions to the soybean breeding for quality and to create sources and donors according to various characteristics, using new principles and progressive methods of work (Yatsenko et al., 2023; Vdovenko et al., 2024).

Although the existence of a strong inverse relationship between the content of protein and oil in soybean seeds has been established (Kushnir, 2014), not all growing areas have a high negative correlation between protein and oil content, as these traits are strongly influenced by environmental factors (Kushnir, 2014). There were created genotypes in which the oil content varies within 20.4–24.3% under a protein content of 34.3–37.9%. It was established that the method of intravarietal selection enables to increase the content of one of the components without substantial reduction of the other (Mazur O. et al., 2023b; Mazur O. et al., 2024).

In order to optimally combine the content of protein and oil in the seed, it is advisable to select parental components in such a way that one of them has a high protein content with an average oil content, and the other – vice versa. At the same time, they should be productive and similar in the duration of the vegetation period, which makes it possible to combine high traits in hybrids of one of the components without reducing the other (Mazur V. et al., 2023).

For selection aimed to increase the oil content, genotypes are considered to be valuable if the oil content almost did not change in the years unfavorable for oil accumulation. Selection for potentially high oil content is better to be carried out in wet years, when its maximum value is most evident, as well as against the background of increased doses of phosphorus fertilizers.

The level of protein and oil content in the soybean seed is highly variable (Koruniak et al., 2006), which indicates the possibility of targeted selection of specialized high-protein and high-oil genotypes.

The content of protein and oil in the seed depends not only on the genotype, however, it is also modified by environmental factors (Piper and Boote, 1999).

The results of analysis of traits of the qualitative composition of grain in the varieties of domestic breeding indicate their dependence on the variety and climatic conditions (Biliavska, 2007).

The chemical composition of soybean significantly depends on varietal characteristics and growing conditions (geographical, soil, meteorological, and agrotechnical. The temperature regime, which is the limiting factor, has the main effect on the content of protein and oil in the soybean seed. At increased temperatures during the "blooming – ripening" period, the oil content increases, and the protein content decreases. Most scientists believe that an increase in precipitation and a decrease in air temperature during the formation and ripening of seeds affect the increase in oil content and decrease in protein. In the zone of insufficient and unstable moisture, a low oil content and an increased percentage of protein are formed (Korobko et al., 2024).

Research conducted in the North Caucasus during 1987–2015 found an increase in the sum of active temperatures by 218 °C and an unreliable decrease in precipitation by 20.9 mm over 10 years. In the dynamics of the protein content, a tendency towards 2.5% growth over 10 years was revealed, but there was no reliable tendency in the oil content. The highest average oil content and the lowest protein content were in mid-ripe samples (22.2% and 38.8%, respectively), while relatively high oil and protein content characterized early (21.6% and 40.0%) and late (20.2% and 39.9%) samples. The protein content increased with increasing duration of the period with temperatures above 22 °C and decreased with increasing precipitation during the period with temperatures above 18 °C. The accumulation of oil in seeds was facilitated by an increase in hydro-thermal coefficient (HTC) during the period with temperatures above 19 °C, in late varieties this was hindered by a long autumn period with temperatures below 15 °C. The long-term increase in protein content is caused by both climate change and genetic improvement of varieties (Mazur V. et al., 2021a; Mazur V. et al., 2021b).

The ability of varieties to synthesize the main components of the biochemical composition of seeds (protein, oil, and the sum of protein and oil) can be evaluated by the traits of the intensity of their formation (Kobyzieva et al., 2007), which allows identifying the variety potential. The use of these traits has made it possible to reveal significant differences between varieties and groups of varieties in the ability to synthesize protein and oil.

The analysis of results showed that the samples of the early group showed a significantly higher ability to form protein and oil in the seeds than the samples of the mid-early and mid-ripening groups, with almost the same economic and biological indicators in the samples of both maturity groups (Riabukha et al., 2018). This is explained by the fact that at the same levels of productivity, the content of protein, oil, and their sum in the seeds, the accumulation of the main components of the seeds in samples of the early group occurs at a faster rate.

Varieties with a higher level of adaptability reduce yield and seed quality less, quickly restore physiological processes after the stress of air and soil droughts. For the varieties intended for arid conditions, a developed root system, a large number of beans and seeds per plant, and the optimal diameter of the stem at its base are important. Drought resistance is determined by several mechanisms (lead size, total leaf surface, features of the leaf placement on the plant, and water-holding capacity) (Biliavska, 1998; Mazur V. et al., 2023).

Insufficient plasticity can negatively affect seed productivity and product quality (Biliavska et al., 2013). Scientists have proven that the maximum accumulation of protein and fat in soybean seeds is possible under conditions of favorable plant growth and development (Norman, 1963–1967).

The purpose of the research was to conduct a comparative assessment of soybean varieties by the content and output of oil and protein, the intensity of oil and protein formation in the seed, taking into account their ontogenetic adaptation.

2 Material and methods

The research was carried out in different soil and climatic conditions of Ukraine, during 2010–2021, which were contrasting in terms of temperature changes, temperature conditions and amount of precipitation. This contributed to the objective evaluation of varieties based on their response to the variability of hydrothermal and edaphic conditions. Soil types were different, and in Vinnytsia region they were represented by gray forest soils, in Kyiv region by typical chernozems, and in Poltava region by podzolized chernozems.

Low HTC were recorded in the conditions of 2015, when HTC varied from 0.4 to 0.7 (very arid), 2019 when HTC varied from 0.8 to 1.0 (dry), and 2020 when HTC varied from 0.8 to 1.0 (dry). The mean long-term values of HTC ranged from 1.1–1.3 (slightly arid), which was reflected in the content of oil and protein, the yield of oil and protein, the intensity of oil and protein formation in the seed of soybean varieties under contrasting soil conditions where the studies were conducted (Figure 1).

The object of research was soybean varieties included in the State Register of Varieties suitable for distribution in Ukraine, namely Amethyst, Hoverla, Artemida, Femida, Zolotysta, Vezha, and Oriana. The breeder of three varieties Amethyst, Artemida and Vezha is Liudmyla Biliavska (Biliavska et al., 2013).

Analysis of the crude protein content were carried out by the Kjeldahl method, and the oil content in the seed was determined by the Rushkovsky method (Rushkovskii, 1954).

According to the qualitative characteristics, i.e. the content of oil and protein, the output of oil and protein, the intensity of formation of oil and protein in the seeds, homeostatic indicators were determined using the Khangildin method (Petrychenko et al., 2018; Volkodav, 2001) using the following formulas (1, 2):

$$\text{Hom1} = X2/\sigma \qquad (1)$$

$$Hom2 = X2/\sigma\ (Xopt - Xlim) \qquad (2)$$

where: Hom1 and Hom2 are indicators of homeostaticity; *X*, *Xopt*, *Xlim* – respectively, the arithmetic average, optimal and limited values of the trait averaged by genotype; σ – mean square deviation; *Xlim* – taken as the lowest value of the trait in the years of research, while *Xopt* – the highest

The response of varieties to the variability of growing conditions was determined by the linear regression coefficients *bi* of protein content, oil content, output of protein and oil, the intensity of oil and protein formation in seeds according to the Eberhart and Russell methodology (Eberhart and Russell, 1966).

The coefficient of regression of the trait of each sample on the change of conditions was calculated according to the following formula (3):

$$bi = \sum(Xij \times Ij)/\sum Ij \qquad (3)$$

where: *bi* – the regression coefficient of the yield (protein content, oil content, protein output, and oil output) of each (ith) variety in the environment with improving or deteriorating conditions; *Xij* – productivity (protein content, oil content, output of protein and oil) of the ith variety in any *j*-conditions; *Ij* – the index of the jth conditions, which is the difference between the average yield (content of protein and oil, output of protein and oil) of all varieties under these conditions and the total average yield (content of protein and oil, output of protein and oil) among all experiments

When *bi* is equal to one, the indicator of the variety changes similarly to the variability of the average indicator of this experimental sample of varieties when growing conditions change. If *bi* is significantly higher than unity, then this variety has a stronger response than the average of the entire set of varieties. In the case when *bi* is less than unity, the variety responds to a change in conditions less than the sample average. According to the numerical value of the regression coefficient (coefficient of ecological plasticity) *bi*, genotypes of soybean varieties can be divided into categories with low, medium, and high ecological plasticity.

The intensity of protein formation (IPF) was calculated according to the method proposed by Kobyzeva et al. (2007) by the formula (4):

$$IPF = (Y \times P)/D \qquad (4)$$

where: *IPF* – intensity of protein formation per day of vegetation $(kg.ha^{-1}).day^{-1}$; *Y* – yield of the variety (sample), $kg.ha^{-1}$; *P* – protein content in the seeds of the variety (sample), %; *D* – duration of the vegetation period of the variety (sample), days

The intensity of oil formation was calculated similarly.

Determination of homeostaticity and coefficient of agronomic stability (As) was calculated according to the developed methodology (Petrychenko et al., 2018).

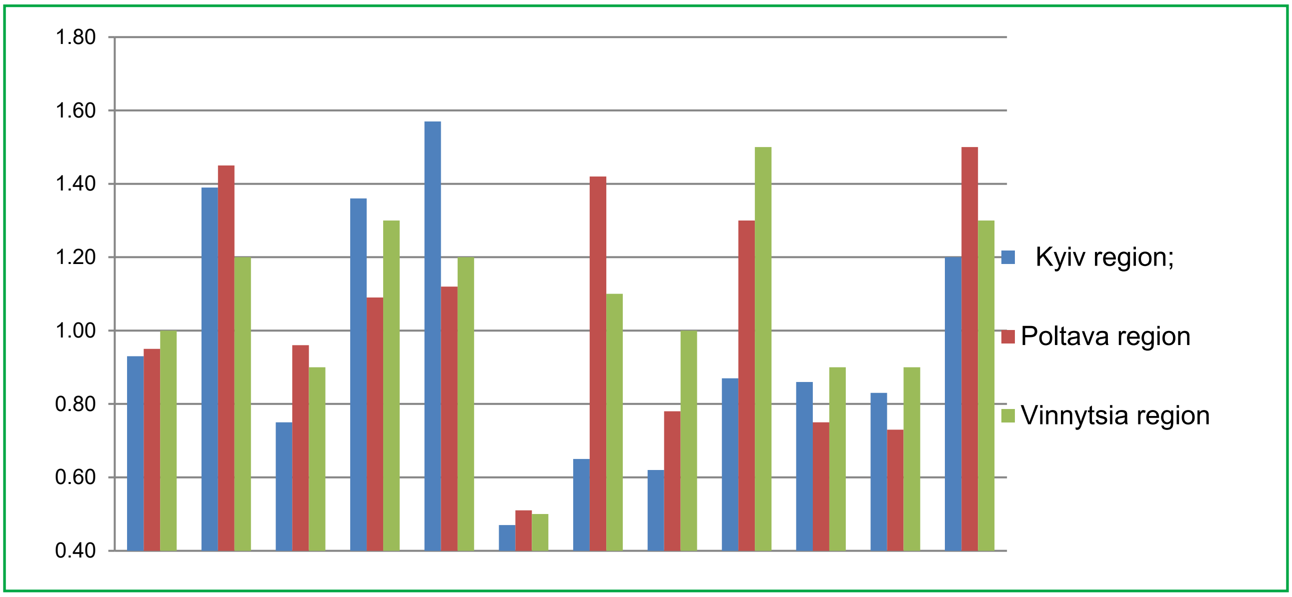

Figure 1 Hydrothermal coefficients for the growing season (BBCH-10-99) (May–September) 2010–2021

3 Results and discussion

The results of hydrothermal conditions during the research period were reflected in the influence of conditions of the trial sites in terms of research years and the interaction of varieties and conditions in terms of oil formation in the seed of soybean varieties (Table 1). In particular, the significance (according to the Fisher criterion) of the interaction of varieties and conditions of trial sites throughout research years, as well as conditions of trial sites throughout research years in the variance of the dispersion treatment of the results on oil content in seeds, was established. This, in turn, made it possible to evaluate soybean varieties using various methods of assessing environmental plasticity and stability.

The highest oil content in the seed was recorded in Hoverla – 22.2%, Artemida – 21.1, and Zolotysta – 20.7%. Lower oil content in the seed was recorded in Femida – 17.9, Oriana – 18.0, Vezha – 18.9, and Amethyst – 19.3%.

It should be noted that varieties with both the highest oil content in the seed like Hoverla and the lowest oil content in the seed like Femida were classified as highly plastic (*bi* >1). The coefficient of agronomic stability in these varieties was quite high and amounted to 98.1% in Hoverla and 96.7% in Femida.

The following varieties showed a more conservative response to changes in the hydrothermal regime: Vezha with a coefficient of ecological plasticity of 0.69, Amethyst – 0.86, Oriana – 0.95, Zolotysta and Artemida – 0.97.

It should be emphasized that according to the Eberhard-Russell interpretation, genotypes with a coefficient *bi* >1 are classified as highly plastic (relative to the group average), and those with 1> *bi* = 0 are classified as relatively low plastic.

Based on this assessment, Hoverla and Femida should be classified as highly plastic with high stability while Vezha, Amethyst, Oriana, Zolotysta, and Artemida are regarded as low-plastic with high stability.

All presented soybean varieties were classified as stable according to the variance of stability since Si^2 was as close to zero as possible. Therefore, the deviation from the direction of the coefficient of ecological plasticity is minimal. As already noted, soybean varieties presented by the oil content in the seed belong to the stable ones, the coefficient of agronomic stability (As) varied from 96.7 to 98.3%. This is confirmed by the similar sequence of distribution of varieties according to homeostaticity of the first (Hom1) and second (Hom2) types. The highest indicators of homeostaticity of the first (Hom1)

Table 1 Parameters of ecological plasticity and stability of soybean varieties by oil content in the seed (%), 2010–2021

Variety	Mean	Coefficient		Variance of stability (Si^2)	Homeostaticity		Components			
	oil content in the seed (%)	ecological plasticity (*bi*)	agronomic stability (As) (%)		Hom1	Hom2	S′	S″	a_i	λ_i
Amethyst	19.3	0.86	98.2	0.13	54.7	42.1	-0.016	0.024	-0.014	0.094
Hoverla	22.2	1.06	98.1	0.03	51.5	34.3	0.012	0.032	0.011	0.124
Artemida	21.1	0.97	98.1	0.02	53.9	33.7	-0.0013	0.029	-0.001	0.113
Femida	17.9	1.49	96.7	0.04	30.1	13.1	0.073	0.083	0.062	0.319
Zolotysta	20.7	0.97	98.2	0.01	55.0	36.7	0.0001	0.011	0.00002	0.043
Vezha	18.9	0.69	98.3	0.04	58.5	45.0	-0.039	0.048	-0.034	0.188
Oriana	18.0	0.95	97.9	0.01	48.8	34.8	-0.0031	0.011	-0.003	0.045

Two-factor variance analysis					
Variance	sum of squares	number of degrees of freedom	average square	criterion F 0.05	
				actual	actual
Total	2,492.4	1,007			
Replication	1.129	3			
Variety	137.43	6	22.9	747.6	2.19
Conditions	2300.91	35	65.7	2145.7	1.54
Interaction variety – conditions	29.89	210	0.142	4.64	1.39
Random deviations	23.07	753	0.031		

and second (Hom2) types were recorded in Vezha – 58.5 and 45.0, as well as the coefficient of agronomic stability – 98.3%; almost at the same level were Amethyst variety– 54.7, 42.1 and Zolotysta – 55.0, 36.7, with the coefficient of agronomic stability of 98.2%. Lower indicators were recorded in Hoverla – 51.5, 34.3 and Artemida – 53.9, 33.7, the coefficient of agronomic stability (As) – 98.1%. The lowest indicators of homeostaticity were recorded in Oriana – 48.8, 34.8 and Femida – 30.1, 13.1, the coefficient of agronomic stability – 97.9, 96.7%. Graphic supplementation of full analysis of the assessment of ecological plasticity and stability confirmed that the varieties of the first zone belong to the forms with a high response to the improvement of the hydrothermal regime of cultivation (Figure 2). Hence, Femida and Hoverla must be cultivated under a high agro-background of cultivation, while deterioration of the farming culture results in sharp decrease in oil content. Ecological plasticity of varieties that are located in the second zone by their coordinates are characterized by medium plasticity, namely Zolotysta, Artemida, and Oriana. Varieties, located by coordinates in the third zone, are characterized by a conservative response to changes in the hydrothermal regime, including Vezha and Amethyst.

In addition, the results of hydrothermal conditions during the research period were reflected in the influence of conditions at the trial sites within the years of research and the interaction of varieties and conditions in terms of forming protein content in the seed of soybean varieties (Table 2).

In particular, the significance (according to the Fisher criterion) of the interaction of varieties and conditions of the trial sites throughout the research years and conditions of the trial sites throughout the research years in the variance of dispersion processing of the results on protein content in seeds was established. This, in turn, made it possible to evaluate soybean varieties using various methods of assessing environmental plasticity and stability.

The highest protein content was recorded in Artemida (39.2), Zolotysta (39.3), and Vezha (38.6), these varieties were distinguished by a conservative response to changes in the hydrothermal regime *bi* <1. In addition, these varieties had the highest indicators of agronomic stability (As), which amounted to 99.2, 99.0, and 99.1%, as well as the sequence of distribution of varieties according to homeostaticity of the first type (Hom1) and the second type (Hom2), namely Artemida – 131.4 and 109.5,

Table 2 Parameters of ecological plasticity and stability of soybean varieties by protein content in the seed (%), 2010–2021

Variety	Mean	Coefficient		Variance of stability (Si^2)	Homeostaticity		Components			
	protein content in seed (%)	ecological plasticity (*bi*)	agronomic stability (As) (%)		Hom1	Hom2	S′	S″	a_i	λ_i
Amethyst	37.9	1.23	98.2	0.46	56.8	23.7	0.06	0.16	0.05	0.635
Hoverla	37.4	0.78	98.9	0.04	92.8	58.0	-0.04	0.05	-0.03	0.2
Artemida	39.2	0.54	99.2	0.03	131.4	109.5	-0.08	0.07	-0.07	0.279
Femida	37.3	1.76	97.5	0.25	39.7	11.7	0.17	0.40	0.14	1.528
Zolotysta	39.3	0.84	99.0	0.01	99.2	62.0	-0.02	0.02	-0.02	0.062
Vezha	38.6	0.58	99.1	0.06	110.5	85.0	-0.08	0.09	-0.07	0.34
Oriana										

Two-factor variance analysis					
Variance	variance	variance	variance	variance	
				actual	theoretical
Total	1,018.9	1,007			
Replication	0.89	3			
Variety	200.47	6	33.41	480.0	2.19
Conditions	655.74	35	18.73	269.2	1.54
Interaction of the variety and conditions	109.39	210	0.52	7.5	1.39
Random deviations	52.4	753	0.07		

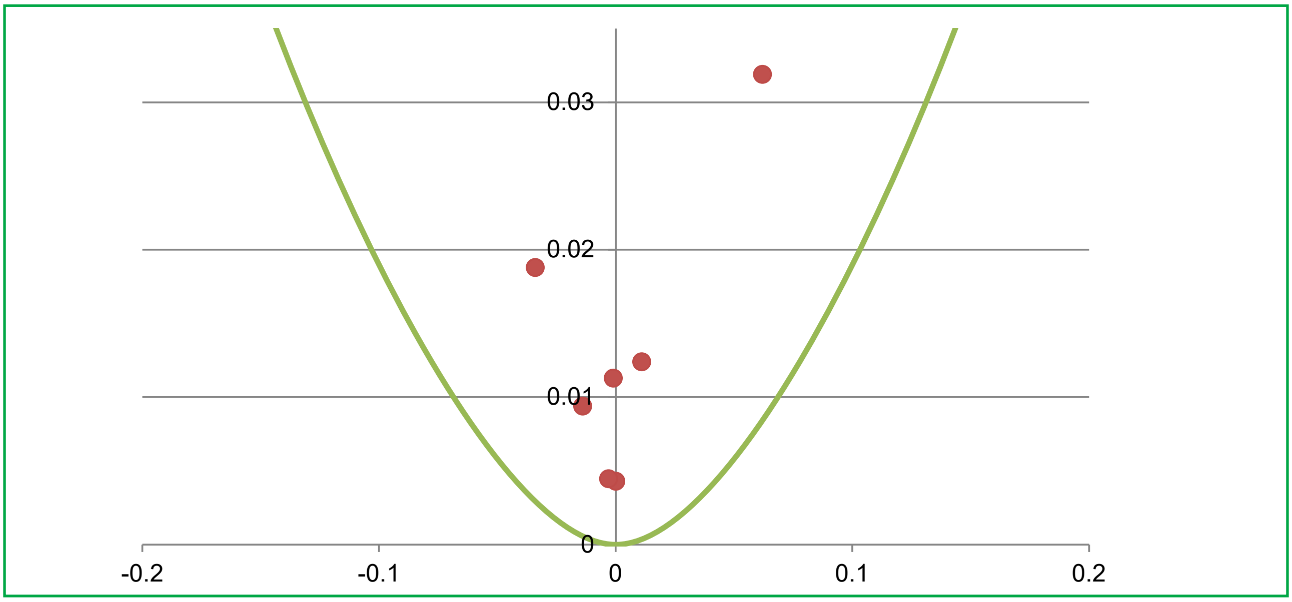

Figure 2 Distribution of soybean varieties into classes by plasticity (a_i) and stability (λ) according to oil content in the soybean seed

Zolotysta – 99.2 and 62.0, and Vezha – 110.5 and 85.0. The stability variance of these varieties was as close as possible to zero. A lower protein content in seeds was recorded in Amethyst (37.9%). Oriana (37.6%), Hoverla (37.4%), and Femida (37.3%). Among these varieties, Femida, Oriana and Amethyst were characterized by their high response to the change in the hydrothermal regime of cultivation, with the coefficient of ecological

Table 3 Parameters of ecological plasticity and stability of soybean varieties by oil output from the seed (t.ha^{-1}), 2010–2021

Variety	Mean	Coefficient		Variance of stability (Si^2)	Homeostaticity		Components			
	oil output from the seed (t.ha^{-1})	ecological plasticity (bi)	agronomic stability (As) (%)		Hom1	Hom2	S′	S″	a_i	λ_i
Amethyst	0.38	0.97	84.6	0.004	6.5	25.7	0.00004	0.00040	0.004	0.157
Hoverla	0.48	1.51	80.9	0.001	5.2	15.3	0.00177	0.00216	0.015	0.84
Artemida	0.43	1.06	85.3	0.0004	6.8	24.9	0.00033	0.00053	0.029	0.209
Femida	0.34	0.88	84.6	0.0002	6.5	32.2	-0.00025	0.00039	-0.022	0.154
Zolotysta	0.38	0.94	85.4	0.0002	6.9	30.1	-0.0001	0.00029	-0.005	0.114
Vezha	0.36	0.80	86.9	0.0002	7.7	37.0	-0.00052	0.00041	-0.045	0.16
Oriana	0.32	0.83	84.7	0.0002	6.5	34.7	-0.00042	0.00041	-0.037	0.16

Two-factor variance analysis					
Variance	sum of squares	number of degrees of freedom	average square	criterion F 0.05	
				actual	actual
Total	126,343.8	1,007			
Replication	340.5	3			
Variety	4,404.4	6	734.1	10.1	2.19
Conditions	20,723.4	35	592.1	8.2	1.54
Interaction of the variety and conditions	46,353.8	210	220.7	3.1	1.39
Random deviations	54,521.8	753	72.4		

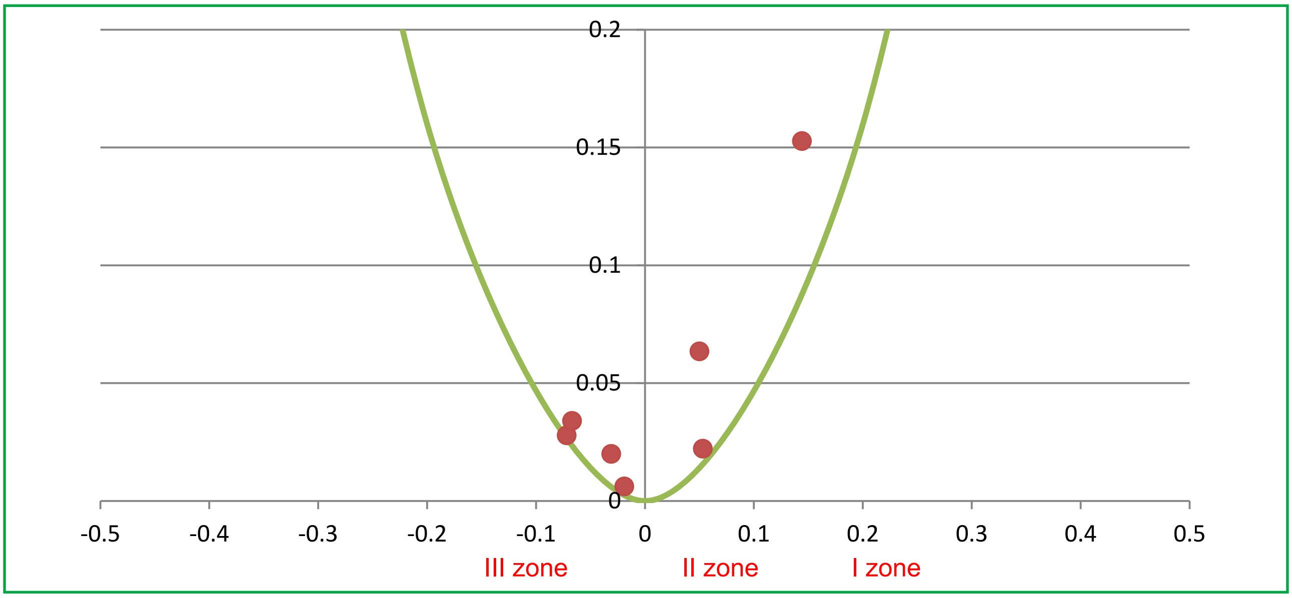

Figure 3 Distribution of soybean varieties into classes by plasticity (a_i) and stability (λ) according to protein content in the soybean seed

plasticity (*bi*) >1. coefficients of agronomic stability (As) were quite high and varied from 97.5 to 98.4%, with the corresponding distribution of varieties according to homeostaticity of the first type (Hom1) and the second type (Hom2) types, in particular, Oriana – 62.6, 26.1; Amethyst – 56.8, 23.7; Femida – 39.7; 11.7.

Supplementing a full analysis of assessing ecological plasticity and stability in the form of a graph confirmed that the varieties of the first zone belong to genotypes with an increased response to the improvement of the agro-background of cultivation (Figure 3).

Femida, Amethyst, and Oriana must be grown under high farming culture, and the deterioration of the agro-background will lead to a decrease in the protein content in the seed. Varieties located by coordinates in the second zone are characterized by medium plasticity, namely Zolotysta. Varieties, the coordinates of which are located in the third zone, are characterized by a low response to changes in the agro-background of cultivation, including Hoverla, Artemida, and Vezha.

A two-factor variance analysis conducted during the research period confirmed the significance of the influence of conditions of the trial sites in terms of the years of research and the interaction of varieties and conditions expressed as oil output from the seeds of soybean varieties, which in turn made it possible

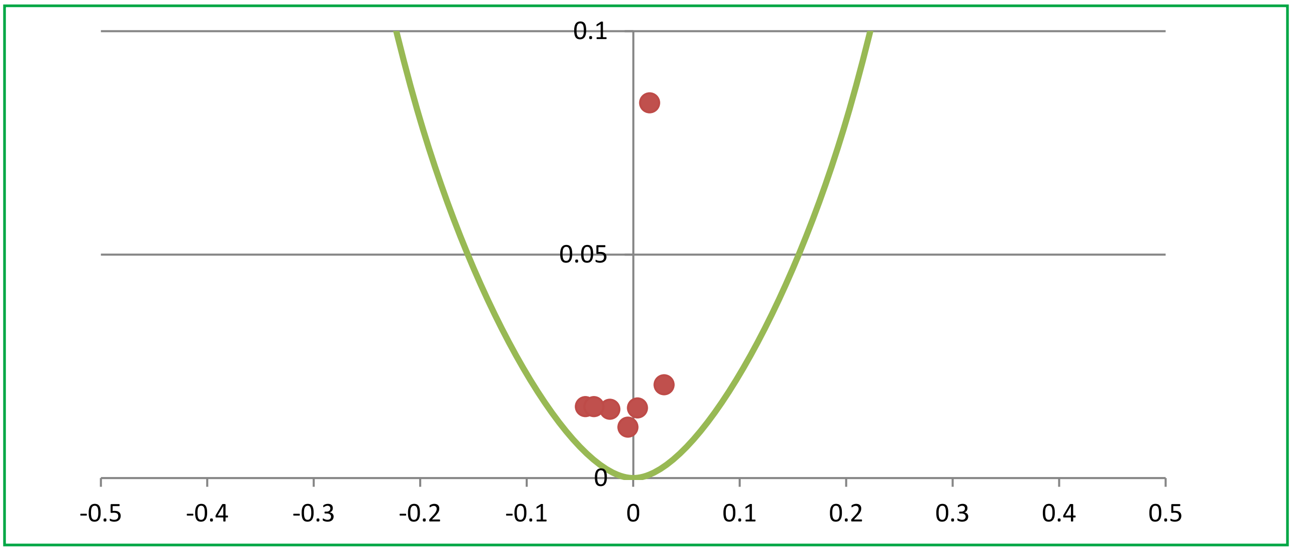

Figure 4 Distribution of soybean varieties into classes by plasticity (a_i) and stability (λ) according to the oil output from the soybean seed

Table 4 Parameters of ecological plasticity and stability of soybean varieties by the seed protein output (t.ha^{-1}), 2010–2021

Variety	Mean	Coefficient		Variance of stability (Si^2)	Homeostaticity		Components			
	seed protein output (t.ha^{-1})	ecological plasticity (*bi*)	agronomic stability (As) (%)		Hom1	Hom2	S′	S″	a_i	λ_i
Amethyst	0.739	0.99	87.4	0.009	7.91	20.0	0.0002	0.001	0.002	0.005
Hoverla	0.805	1.41	83.5	0.003	6.05	13.53	0.003	0.004	0.03	0.017
Artemida	0.803	1.08	87.5	0.001	8.01	19.04	0.001	0.001	0.01	0.0055
Femida	0.700	0.79	89.4	0.001	9.43	34.08	-0.001	0.001	-0.01	0.005
Zolotysta	0.715	0.94	88.0	0.001	8.34	23.62	-0.0001	0.001	-0.001	0.003
Vezha	0.739	0.91	88.9	0.001	8.99	25.24	-0.0004	0.001	-0.003	0.003
Oriana	0.662	0.87	88.0	0.001	8.31	27.5	-0.0001	0.001	-0.01	0.005

Two-factor variance analysis					
Variance	sum of squares	number of degrees of freedom	average square	criterion F 0.05	
				actual	actual
Total	11.15	1,007			
Replication	0.00038	3			
Variety	7.47	6	1.24	37,405	2.19
Conditions	2.369	35	0.067	2,032.9	1.54
Interaction of the variety and conditions	1.28	210	0.0061	183.3	1.39
Random deviations	0.025	753	0.00003		

to carry out various methods of assessing ecological plasticity and stability.

Oil output from the seed primarily depended on the oil content and yield level. The results of the variety yield assessment were presented in our previous studies (Mazur O. et al., 2023b). The highest oil output from the seed was observed in Hoverla (0.48 t.ha^{-1}) and Artemida (0.43 t.ha^{-1}). According to the response to changes in the hydrothermal regime, these varieties were classified as highly plastic, with the coefficient of ecological plasticity (*bi*) >1. When the hydrothermal regime improves, there is an increase in the level of yield and oil content in the seed, which ultimately leads to an increase in the oil output per hectare. A lower oil output from soybean seeds was recorded in Amethyst and Zolotysta 0.38 t.ha^{-1}). According to the response to changes in the hydrothermal regime, these varieties were classified as medium-plastic, with the coefficient of environmental plasticity (*bi*) of 0.97 and 0.94. A lower oil output was recorded in Vezha (0.36 t.ha^{-1}), however, this variety provided the highest index of agronomic stability (As) – 86.9%, with the corresponding distribution of varieties according to homeostaticity of the first type (Hom1) – 7.7 and the second type (Hom2) – 37.0. All presented varieties had high indicators of agronomic stability (As), which varied from 80.9 to 86.9%, and indicators of homeostaticity of the first (Hom1) and second (Hom2) types: from 5.2 and 15.3 to 7.7 and 37.0. The variance of stability (Si^2) in the presented soybean varieties was as close as possible to zero. Thus, these varieties were characterized by minimal deviation from the direction of the coefficient of ecological plasticity.

Supplementing the conducted analysis of ecological plasticity and stability assessment by the oil output from the seed in the form of a graph (Figure 4) additionally confirmed that the varieties located by their coordinates in the first zone belong to the forms with an increased response to the improved agro background of cultivation.

Therefore, it is necessary to grow Hoverla and Artemida under a high level of farming culture, however, if the agro-background of cultivation is reduced, the oil output from the seed will deteriorate. Varieties located by coordinates in the second zone are characterized by medium plasticity, namely Amethyst and Zolotysta. Varieties located by coordinates in the third zone are characterized by a low response to changes in

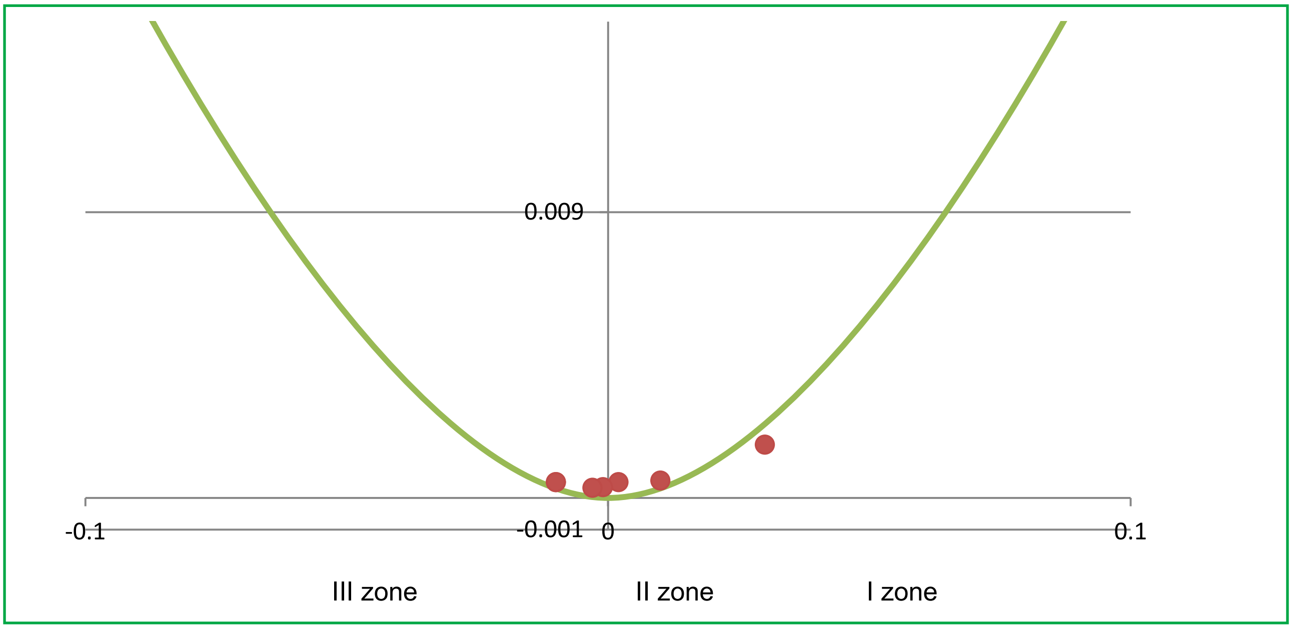

Figure 5 Distribution of soybean varieties into classes by plasticity (a_i) and stability (λ) according to protein output in soybean seeds

the hydrothermal regime, including Oriana, Femida, and Vezha.

High seed protein output in soybean varieties can be ensured both due to high protein content in the seed and high yield of soybean varieties. Thus, two soybean varieties provided the highest protein output from seeds, namely Hoverla – 0.805 $t.ha^{-1}$ and Artemida – 0.803 $t.ha^{-1}$ (Table 4). The first variety provided the highest seed protein output not due to high protein content (Table 2), which was 37.4%, but due to higher yield (Mazur O. et al., 2023b). In contrast, Artemida provided a higher seed protein output, to a greater extent due to its high content in the seed, which amounted to 39.2%. It should be noted that these varieties are highly plastic in response to the improved hydrothermal regime with the coefficient of environmental plasticity (*bi*) >1. A lower seed protein output (0.739 $t.ha^{-1}$) was observed in soybean varieties, in particular, Amethyst and Vezha, which are medium plastic according to the response to the improved hydrothermal regime, with the coefficient of environmental plasticity of 0.99 and 0.91. The lowest seed protein output was observed in soybean varieties, which were characterized by a conservative response to changes in the hydrothermal regime, in particular, Oriana (0.662 $t.ha^{-1}$), Femida (0.700 $t.ha^{-1}$), and Zolotysta (0.715 $t.ha^{-1}$), with the coefficient of environmental plasticity (*bi*) <1. The coefficient of agronomic stability (As) by the seed protein output was quite high and varied from 83.5% in Hoverla to 89.4% in Femida, with the corresponding distribution of varieties according to the homeostaticity of the first type (Hom1) – 6.05 and the second type (Hom2) – 13.53 in Hoverla variety to 9.43 and in Femida to 34.08. High indicators of agronomic stability (As) were observed in Vezha (88.9%), Zolotysta and Oriana (88.0%), with the corresponding distribution of varieties according to the homeostaticity of the first type (Hom1) – 8.31 and the second type (Hom2) – 27.5 in Oriana variety to 8.99 and in Vezha to 25.24.

The stability variance of the specified varieties was as close to zero as possible. Thus, the deviation from the direction of the ecological plasticity coefficient was minimal.

Supplementing a full analysis of assessing ecological plasticity and stability in the form of a graph confirmed that the varieties of the first zone belong to forms with an increased response to the improvement of the agro-background of cultivation.

Hoverla and Artemida must be grown under a high agro-background of cultivation, and the deterioration of the farming culture will lead to a decrease in the seed protein output (Figure 5). Varieties with coordinates located in the second zone are characterized by medium plasticity, namely Amethyst and Zolotysta. Varieties, the coordinates of which are located in the third zone, are characterized by a low response to changes in the agro-background of cultivation, including Femida, Vezha, and Oriana.

Variety's ability to synthesize the main components of the biochemical composition of seeds (protein, oil, and sum of protein and oil) can be evaluated by the intensity of their formation, which reveals the potential of the variety. The use of this trait made it possible to reveal significant differences between varieties and groups of varieties by the ability to synthesize protein and oil (Kobyzieva et al., 2007).

The influence of conditions of the trial sites in terms of research years and their interaction with the variety expressed by the intensity of oil formation in the seed of soybean varieties is shown (Table 5). In particular, the significance of varietal features (according to the Fisher criterion), their interaction with the conditions of the trial sites in terms of the research years, and the conditions of the trial sites in terms of research years of the variance were established using a two-factor variance analysis of the intensity of oil formation in the seed of soybean varieties. This made it possible to evaluate soybean varieties according to this indicator having applied various methods for assessing ecological plasticity and stability.

The results of assessing the duration of the growing season of the specified soybean varieties were presented in our previous studies (Mazur O. et al., 2023a).

The highest intensity of oil formation in the seed was observed in Hoverla – 4.25 kg.ha^{-1} per day, relatively high traits were provided by Artemida – 3.8 and Amethyst – 3.43 kg.ha^{-1} per day. It should be noted that these varieties are highly plastic by their response to changes in the hydrothermal regime with the coefficient of environmental plasticity (*bi*) >1.

Varieties that belong to conservative ones according to the response to the change in the hydrothermal regime, with the coefficient of ecological plasticity (*bi* <1), were characterized by a lower intensity of oil formation in the seed. They included the following ones: Oriana – 2.75, Femida – 2.79, Vezha – 3.12, and Zolotysta – 3.19 kg.ha^{-1} per day.

According to indicators of agronomic stability (As), the presented varieties belonged to the stable ones As >70% by the intensity of oil formation in the seed.

The coefficient of agronomic stability varied in varieties from 79.8 to 85.6%.

With the corresponding distribution of varieties by the homeostaticity of the first type (Hom1) and the second type (Hom2), the highest indicators of agronomic stability were observed in Vezha – 85.6%, as well as

Table 5 Parameters of ecological plasticity and stability of soybean varieties by the intensity of oil formation in the seed (kg.ha^{-1}) per day, 2010–2021

Variety	Mean	Coefficient		Variance of stability (Si^2)	Homeostaticity		Components			
	oil formation in the seed (kg.ha^{-1} per day)	ecological plasticity (*bi*)	agronomic stability (As) (%)		Hom1	Hom2	S′	S″	a_i	λ_i
Amethyst	3.43	1.06	82.5	0.37	5.71	2.44	0.018	0.042	0.015	0.164
Hoverla	4.25	1.49	79.8	0.097	4.96	1.64	0.142	0.166	0.122	0.641
Artemida	3.8	1.09	83.7	0.047	6.13	2.42	0.026	0.047	0.023	0.185
Femida	2.79	0.83	82.9	0.032	5.84	3.52	-0.048	0.041	-0.041	0.159
Zolotysta	3.19	0.9	84.2	0.022	6.33	3.56	-0.027	0.025	-0.024	0.096
Vezha	3.12	0.8	85.6	0.019	6.93	4.1	-0.055	0.03	-0.048	0.115
Oriana	2.75	0.81	83.7	0.014	6.12	3.93	-0.053	0.025	-0.046	0.096

Two-factor variance analysis					
Variance	sum of squares	number of degrees of freedom	average square	criterion F 0.05	
				actual	actual
Total	587.3	1007			
Replication	0.016	3			
Variety	279.1	6	46.51	31860.1	2.19
Conditions	254.7	35	7.27	4984.2	1.54
Interaction of the variety and conditions	52.4	210	0.249	170.9	1.39
Random deviations	1.099	753	0.00146		

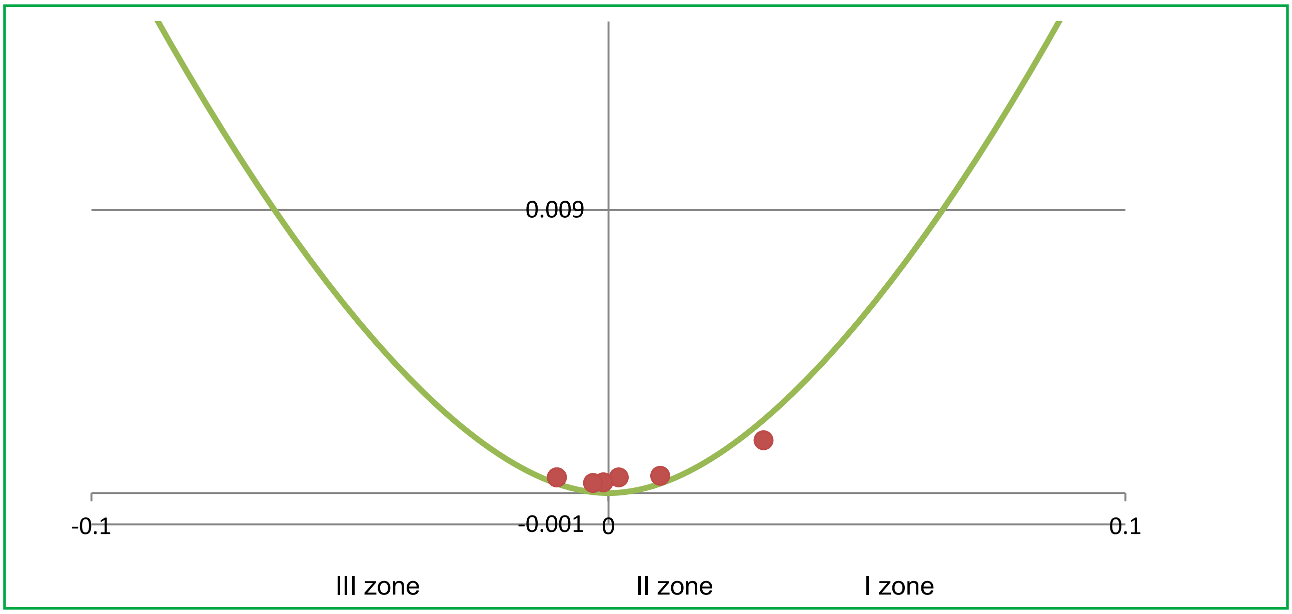

Figure 6 Distribution of soybean varieties into classes by plasticity (ai) and stability (λ) according to the intensity of oil formation in soybean seeds

the highest indicators of homeostaticity of the first type (Hom1) – 6.93 and the second type (Hom2) – 4.1. High indicators of agronomic stability were also observed in Zolotysta – 84.2% with the corresponding distribution of homeostaticity of the first type (Hom1) – 6.33 and the second type (Hom2) – 3.56, similar to Artemida, despite its belonging to the plastic group by its response to the change in the hydrothermal regime. Its coefficient of agronomic stability was 83.7%, homeostatisity of the first type (Hom1) was 6.13 and the second type (Hom2) was 2.42. At the same level, indicators of agronomic stability were observed in Oriana – 83.7%, and the homeostatisity of the first type (Hom1) – 6.12 and the second type (Hom2) – 3.93. According to the variance of stability, all the presented varieties belong to stable ones, the variance of stability (Si^2) is maximally close to zero. The presented analysis of the assessment of ecological plasticity and stability, which was supplemented with a graph, confirmed that the varieties of the first zone belong to forms with an increased response to the improvement of the agro-background of cultivation (Figure 6).

Thus, Hoverla, Artemida, and Amethyst must be grown under favorable hydrothermal conditions, and the intensity of oil formation in soybean seeds will decrease if the agro-background of cultivation deteriorates. Varieties located coordinately in the second zone are characterized by medium plasticity, namely Zolotysta and Femida. Varieties with the coordinates located in the third zone are characterized by a low response to changes in the agro-background of cultivation, including Vezha and Oriana.

The conducted two-factor variance analysis during the research period confirmed the significance of the influence of conditions of the trial sites in terms of the years of research and the interaction of variety and conditions expressed by the protein formation in seeds, kg.ha^{-1} per day (Table 6).

By the intensity of protein formation in seeds, the highest figures were observed in Hoverla – 7.12, Artemida – 7.06, and Amethyst – 6.72 kg.ha^{-1} per day. It should be noted that these varieties belonged to the highly plastic varieties (*bi* >1) by their response to the change in the hydrothermal regime. So, a higher intensity of protein formation in seeds is associated with a high protein content (Table 2), this applies to a greater extent to Artemida with protein content of 39.2%. As for Hoverla (37.4%) and Amethyst variety (37.9%), the intensity of protein formation in seeds, i.e. protein output and the intensity of its formation in soybean seeds depended predominantly on the level of productivity, which was researched in our previous studies (Mazur O. et al., 2023b).

A lower intensity of protein formation in seeds was recorded in the following varieties: Oriana – 5.72, Femida – 5.79, Zolotysta – 6.04, Vezha – 6.37 kg.ha^{-1} per day. According to the response to the hydrothermal regime change, the specified varieties can be ranked as having low plasticity with the coefficient of ecological plasticity of (*bi*) <1. However, the coefficient of agronomic stability (As) was the highest in the presented varieties and amounted to 87.26 in Vezha, 86.53 in Femida, 86.52 in Oriana, and 86.39% in Zolotysta. The distribution

Table 6 Parameters of ecological plasticity and stability of soybean varieties by the intensity of protein formation in seeds (kg.ha^{-1} per day), 2010–2021

Variety	Mean	Coefficient		Variance of stability (Si^2)	Homeostaticity		Components			
	protein formation in seeds (kg.ha^{-1} per day)	ecological plasticity (*bi*)	agronomic stability (As) (%)		Hom1	Hom2	S′	S″	a_i	λ_i
Amethyst	6.72	1.08	84.94	1.05	6.64	1.62	0.06	0.168	0.052	0.652
Hoverla	7.12	1.34	82.38	0.25	5.67	1.28	0.254	0.331	0.218	1.27
Artemida	7.06	1.08	85.84	0.143	7.07	1.79	0.061	0.143	0.052	0.556
Femida	5.79	0.81	86.53	0.124	7.43	2.65	-0.137	0.147	-0.12	0.566
Zolotysta	6.04	0.91	86.39	0.073	7.35	2.46	-0.068	0.077	-0.058	0.3
Vezha	6.37	0.91	87.26	0.052	7.85	2.63	-0.068	0.057	-0.058	0.222
Oriana	5.72	0.86	86.52	0.047	7.42	2.77	-0.100	0.059	-0.086	0.229

Two-factor variance analysis					
Variance	sum of squares	number of degrees of freedom	average square	criterion F 0.05	
				actual	actual
Total	1,187.36	1,007			
Replication	0.0897	3			
Variety	735.13	6	122.5	6,458.75	2.19
Conditions	287.86	35	8.22	433.6	1.54
Interaction of the variety and conditions	149.98	210	0.714	37.65	1.39
Random deviations	14.28	753	0.0189		

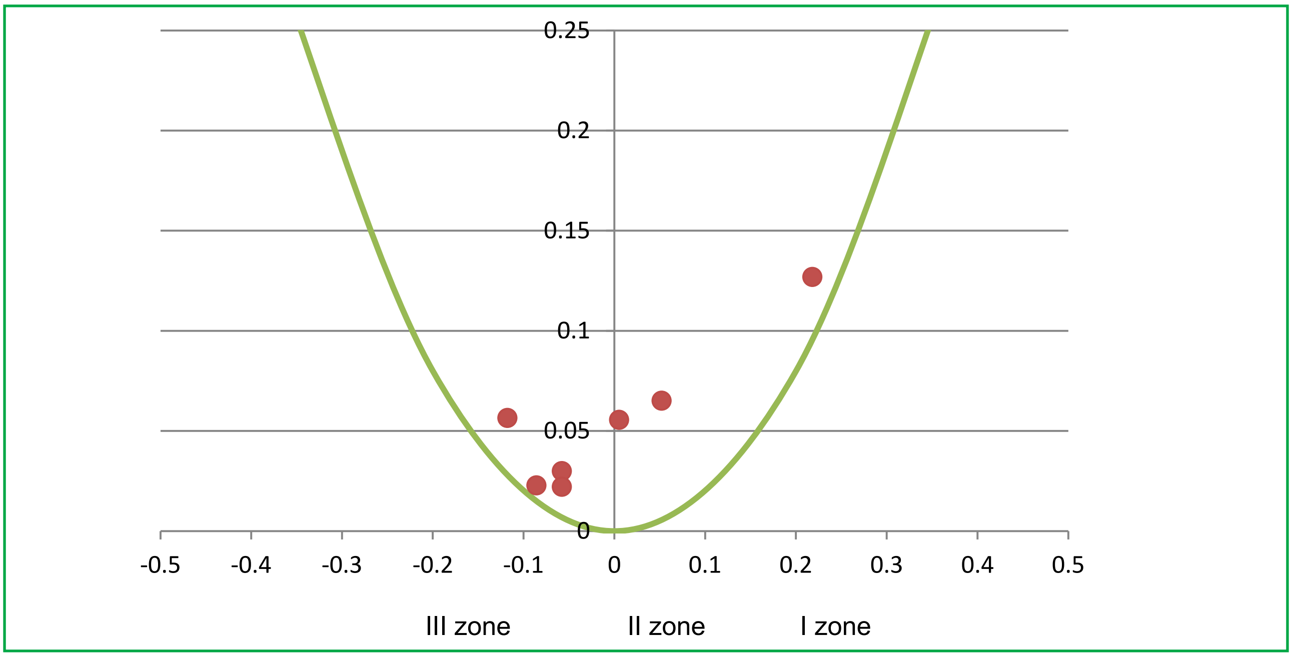

Figure 7 Distribution of soybean varieties into classes according to plasticity (ai) and stability (λ) by the intensity of protein formation in soybean seeds

of figures was similar in Vezha by homeostaticity of the first type (Hom1) – 7.85 and the second type (Hom2) – 2.63, in Femida by homeostaticity of the first type (Hom1) – 7.43 and the second type (Hom2) – 2.65, in Oriana by homeostaticity of the first type (Hom1) – 7.42 and the second type (Hom2) – 2.77, in Zolotysta by homeostaticity of the first type (Hom1) – 7.35 and the second type (Hom2) – 2.46.

By the variance of stability, all soybean varieties, except for Amethyst, provided the maximum approximation of this indicator to zero (Figure 7).

This indicates that there is no deviation of this indicator from the direction of the coefficient of ecological plasticity. Supplementing the analysis of the assessment of ecological plasticity and stability in the form of a graph confirmed that the varieties of the first zone belong to forms with an increased response to the improvement of the agro-background of cultivation. Hoverla and Amethyst must be grown under a high agro-background of cultivation, and deterioration of the farming culture will lead to a decrease in the intensity of protein formation in soybean seeds. Varieties located by their coordinates in the second zone are characterized by medium plasticity, namely Artemida. Varieties, the coordinates of which are located in the third zone, are characterized by a low response to changes in the agro-background of cultivation, they include Femida, Zolotysta, Vezha, and Oriana.

4 Conclusions

As a result of calculating adaptability indicators, namely plasticity (*bi*) and stability (Si^2) of the oil content in soybean seeds, it is necessary to single out Artemida and Zolotysta, which belonged to the 2nd rank, in which the indicators *bi* <1, $Si^2 = 0$ provide higher indicators under worse conditions, and are stable, as well as Hoverla, which belongs to the 5th rank, with indicators *bi* > 1, Si^2 = 0 – have higher indicators under better conditions and are stable, having provided the highest oil content in seeds – 21.1, 20.7 and 22.2%.

By the protein content, the following soybean varieties appeared to be better, namely Artemida – 39.2% and Zolotysta – 39.3%, which according to the indicators of plasticity (*bi*) and stability (Si^2) belonged to the 2nd rank, i.e. they provided higher indicators under worse conditions and were stable.

The highest output of oil and protein from seeds was observed in soybean varieties Hoverla – 0.48 and 0.805 t.ha^{-1}, Artemida – 0.43 and 0.803 t.ha^{-1}, which belong to the 5th rank in terms of plasticity (*bi*) and stability (Si^2) with the indicators *bi* >1, $Si^2 = 0$ – have higher indicators under better conditions and are stable.

However, the combination of high yield of oil and protein, which by these traits are biologically inversely dependent, became possible for Hoverla due to its high yield, especially in terms of protein content. As for Artemida, these traits are at the level above the mean values.

The highest intensity of oil and protein formation in seeds was observed in Hoverla – 4.25 and 7.12, Artemida – 3.8 and 7.06, Amethyst – 3.43 and 6.72 kg.ha^{-1} per day, which belong to the 5th rank in terms of plasticity (*bi*) and stability (Si^2), with the indicators *bi* > 1, $Si^2 = 0$ have higher indicators under better conditions and are stable.

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