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ВІННИЦЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

Сільське господарство та лісівництво

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BREEDING AND GENETIC FEATURES OF SOYBEAN VARIETIES BASED ON THE MANIFESTATION OF TRAITS IN F1 HYBRIDS IN TOPCROSSES

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Further increase in gross soybean production requires the introduction of new varieties with an optimal combination of elements of the crop structure. Hybridization in soybeans is the main effective method of creating new varieties. Increasing the efficiency of hybridization in obtaining heterotic offspring is possible when using parental forms with high combinational ability in crosses.

In the study, a two-tester analysis of topcrosses of soybean varieties differing in economically valuable traits was used. Based on the results of the combinational ability assessment, the value of soybean varieties was determined by the elements of the yield structure. Heterotic combinations in first-generation hybrids were identified, from which it is more likely to select highly productive forms in later hybrid populations F2-F4.

The high effects of ZKZ and SCZ on plant height in varieties Medea, Kyivska 97, Sawyer 2-95 and KiVin tester; on the height of lower bean attachment in varieties Sawyer 2-95, Ustia, Kharkivska skoroglya and KiVin tester; on the number of productive nodes - in varieties Kyivska 97 and Goverla tester; by the number of beans per plant - in varieties Sawyer 2-95, Kyivska 97 and tester Goverla; by the number of seeds per plant - in varieties Medea, Kyivska 97 and tester KiVin; by the weight of 1000 seeds - in varieties Sawyer 2-95, Kyivska 97 and tester Goverla; by the weight of grain per plant - in varieties Sawyer 2-95, Kyivska 97 and tester Goverla. It was found that additive effects of genes were predominant in the genetic control of plant height and lower bean attachment, elements of yield structure and grain weight per plant, but there is a smaller influence of non-additive effects.

The manifestation of true heterosis (dominance in 100% of cases) in hybrids (F1) was found in crosses with both testers for the number of productive nodes, number of beans and seeds per plant, and grain weight per plant.

Keywords: traits, tester, combinatorial ability, dominance, additive effects, heterosis.
Table 11. Fig. 7. Lit. 15.

Review of sources of scientific literature. Further growth in soybean seed production requires the availability and introduction of new varieties with an optimal combination of productivity elements [1], early maturity, resistance to diseases and pests [2], to extreme environmental conditions in different growing areas, and with high nutritional and feed properties.

To create such varieties, it is necessary to renew and study the new soybean gene pool, continue the search for sources and donors of economically valuable traits, identify the peculiarities of variability and inheritance of important traits, optimize methods for evaluating and creating new source material [3].

The results of the research indicate high heritability of the weight of 100 seeds, the period from germination to full maturity, from germination to the end of flowering, the period of fruit formation, oil content, the number of cracked beans on plants, seed yield per plant, plant height and protein content. There was a significant positive correlation between the yield and the number of beans per plant. Increasing the value of this trait ultimately increases the yield. Studies have also shown that the maximum direct contribution to the next harvest is made by the duration of the fruit formation period [4]. It is assumed that these traits can be considered as selection criteria for increasing soybean yields [5].

The results of studies conducted in China showed that the variation in the number of beans and seeds per plant is the largest, as well as heritability, so they can create an ideal breeding effect. The yield per plant had a significant genetic correlation with the number of productive nodes per plant. All selection indices that included the trait "number of productive nodes per plant" had a good selection effect, the selection index consisting of the number of productive nodes and the weight of 100 seeds received a selection effect of 226% compared to direct selection. Therefore, for selections for yield, lines with more productive nodes per plant and average seed size should be selected [6].

Research in Louisiana showed that differences in soybean yields were consistently controlled by the number of nodes, productive nodes, beans, and seeds per m2. However, the trait "number of nodes per 1 m2 did not have as direct an impact on the formation of high or low yields of varieties as other yield components. Perhaps, the number of productive nodes per 1 m2 should be used as an additional criterion for yield selection during the development of soybean plants [7].

Hybridization in soybean has been and is the main effective method of creating new varieties [3]. Increasing the effectiveness of hybridization in obtaining heterotic offspring is possible when using parental forms with high combining ability in crosses. Combining value is usually determined in two ways: general combining ability (GCA) and specific combining ability (SCA). The two forms of combining ability - general and specific - differ in their genetic basis. General combinatorial ability is determined by additive hereditary factors, and specific combinatorial ability is based on dominance, superdominance and epistasis [8].

In the topcross system, it is also possible to determine the presence of CCPs and CCSs in genetically different parental forms [9]. Testers with a broad genetic basis should be used for the determination of PBDs, and testers with a narrow genetic basis should be used for SCDs. According to Horner et al. [10], it is effective to use testers that are distant in origin when selecting forms with high SCC.

Combining ability interprets the various actions and interactions of genes. It is expressed as general combining ability (GCA) and specific combining ability (SCA). GCV is used to determine the average value of a variety in hybrid combinations. SCV is used when characterizing individual combinations if they are better or worse than expected based on the average values of the studied varieties [8].

It was found that there is a positive correlation between the amount of heterosis in the first generation, the degree and frequency of transgressions in weight (r = 0.75, r = 0.31) and the number of beans per plant (r = 0.35, r = 0.23), as well as the number of beans on the main stem (r = 0.65, r = 0.42) [14].

It should be noted that it is advisable to select promising plants in those hybrid combinations where heterosis is observed in the first generation. In other generations F2-F4, transgressive forms with a significant excess of traits are selected [8].

However, scientists achieve the maximum effect of heterosis only with specially selected parental pairs for hybridization [3].

Foreign researchers have noted significant contributions of both dominant and additive effects, with a slight predominance of additive effects in F1 and dominant effects in F2 [11]. Other authors have also found a significant contribution of additive and dominant effects with the latter prevailing, and superdominance was noted in inheritance [12].

In the absence of stress (irrigation), dominant effects prevailed in hybrid populations, although additive effects were also significant. Instead, under stressful conditions, additive effects prevailed over dominant ones. Under moisture conditions, the trait was increased by recessive genes, and under stress conditions - by dominant genes. In general, the authors conclude that dominant effects and non-allelic interaction are the most important in the genetic control of a trait for both research conditions. Non-allelic interaction in various combinations with additive and dominant effects has been found by other researchers [13].

Research methods. The research was conducted in the experimental field of Vinnytsia National Agrarian University in 2016-2017. This area is characterized by the distribution of gray forest soils of light medium loamy texture.

The main method of creating source material in soybean breeding was intraspecific hybridization. We studied F1 hybrid combinations from interspecific crosses of soybean varieties of different ecological and geographical origin, which showed heterosis in the first generation.

The crosses were conducted according to the scheme of full topcrosses. Soybean varieties Sawyer 2-95, Ustia, Medea, Kyivska 97 and Kharkivska Skoroglya were used as maternal forms, and testers Hoverla and KiVin were used as paternal forms. Evaluation was carried out according to the following traits: plant height, lower bean attachment height, and elements of the yield structure (number of productive nodes, number of beans per plant, number of seeds per plant, weight of 1000 seeds, weight of grain per plant). The experiment was conducted in quadruplicate.

Four 1 m long row plots with 45 cm row spacing were sown.

To study the nature of inheritance and the level of heterosis, the degree of dominance hp was determined, which was calculated using the formula B. Griffinq [8].

hp = F1-MP/HP-MP, where: hp is an estimate of the degree of dominance; F1 is the arithmetic mean of the trait in plants of the 1st generation hybrid; MP is the arithmetic mean of the trait in both parental forms; HP is the value of the trait in the parent with its maximum manifestation.

The effects of SCZ and SCZ variant were calculated according to the methodological recommendations. To study F1 hybrid plants, true heterosis was calculated [8].

Results of experimental studies.

The analysis of variance for general combining ability (GCA) of maternal and paternal components, as well as specific combining ability (SCA) for valuable economic traits (plant height and lower bean attachment height, number of productive nodes, number of beans and seeds per plant, weight of 1000 seeds and grain yield) obtained as a result of crossing these components is presented in (Tables 1-7).

Significant genotypic differences were found for the listed traits. Significant effects of the general and specific combinational ability of the studied varieties were noted. A significant difference in the variants of the ZKZ and SKZ indicates that, along with the additive effects of genes, non-additive genes also have an important effect. At the same time, the mean squares of the general combinatorial ability varied from 1.29 to 310.6 and exceeded the mean squares of the specific combinatorial ability, which varied from 0.23 to 12.3 (Tables 1-7).

This indicates the dominant role of additive effects of genes in the system of trait control compared to non-additive genes and the possibility of selecting the best forms for their breeding improvement.

To establish the genetic determination of plant height in our studies, we used a two-tester method - topcross, where the varieties Sawyer 2-95, Ustia, Medea, Kyivska 97, Kharkivska skoroglya were taken as maternal forms, and two testers - Goverla and KiVin - as paternal forms.

High significant effects of IPA, which determine the tallness of plants, were noted in varieties Medea (+3.25), Kyivska 97 (+1.85) and Sawyer 2-95 (+0.8). The negative effects of IPM were characterized by varieties Kharkivska skoroglya (-5.4) and Ustia (-0.5) (Table 1).

The KiVin tester was characterized by a positive effect of the PPD (+0.43), and the Goverla tester was negative, which should be taken into account when selecting a parental component for hybridization as a tester. The effects of the testers' CDDs were not significant, indicating that the testers were genetically equivalent for this trait.

The combination Medea × KiVin provided high plant growth due to the additive effect of both the maternal form (+3.25) and the paternal form (+0.43), and this combination also had high effects of non-additive gene interaction (SCC = 2.17).

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Table 1

Combining ability in plant height of soybean varieties

<table>
<tr><td colspan="8">Analysis of variance</td></tr>
<tr><td rowspan="3">Source of variation</td><td rowspan="3">Sum of squares</td><td rowspan="3">Number of degrees of freedom</td><td rowspan="3">Middle square</td><td colspan="4">Criterion F</td></tr>
<tr><td rowspan="2">actual</td><td colspan="3">theoretical</td></tr>
<tr><td colspan="2">0.05</td><td>0.01</td></tr>
<tr><td>Parental forms SCC</td><td>1.85</td><td>1</td><td>1.85</td><td>9.6</td><td colspan="2">4.21</td><td>7.68</td></tr>
<tr><td>MACs of parent forms</td><td>88.1</td><td>4</td><td>22.0</td><td>114.7</td><td colspan="2">2.73</td><td>4.11</td></tr>
<tr><td>SCS</td><td>49.0</td><td>4</td><td>12.3</td><td>63.8</td><td colspan="2">2.73</td><td>4.11</td></tr>
<tr><td>Random deviations</td><td>5.1</td><td>27</td><td>0.19</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">Varieties</td><td colspan="2" rowspan="2">The effect of the SCC varieties</td><td colspan="2">The effect of the SCS</td><td colspan="3" rowspan="2">Constant SCS varieties</td></tr>
<tr><td>Tester 1 Hoverla</td><td>Tester 2 KiVin</td></tr>
<tr><td>Sawyer 2-95</td><td colspan="2">0.8</td><td>-0.12</td><td>0.12</td><td colspan="3">0.03</td></tr>
<tr><td>Ustia</td><td colspan="2">-0.5</td><td>-0.02</td><td>0.02</td><td colspan="3">0.01</td></tr>
<tr><td>Medea</td><td colspan="2">3.25</td><td>-2.17</td><td>2.17</td><td colspan="3">9.41</td></tr>
<tr><td>Kyivska 97</td><td colspan="2">1.85</td><td>-1.77</td><td>1.77</td><td colspan="3">6.26</td></tr>
<tr><td>Kharkiv early ripening</td><td colspan="2">-5.4</td><td>4.08</td><td>-4.08</td><td colspan="3">33.3</td></tr>
<tr><td colspan="3">Effects of the testers' SCC</td><td>-0.43</td><td>0.43</td><td colspan="3"></td></tr>
<tr><td colspan="3">Variants of the SCS testers</td><td>4.80</td><td>4.80</td><td colspan="3"></td></tr>
<tr><td colspan="3">Nir 0.05 PCC of varieties</td><td colspan="2">0.89</td><td colspan="3"></td></tr>
<tr><td colspan="3">Nir 0.05 PCC of testers</td><td colspan="2">0.56</td><td colspan="3"></td></tr>
</table>

the source is formed on the basis of own research results

A similar type of gene interaction was observed in the hybrid combination Kyivska 97 × KiVin, where the increase in plant height was associated with both additive effects of maternal and paternal forms, as well as non-additive effects of gene interaction (Coefficient of Variation = 1.77).

The increase in plant height in the hybrid combination Kharkivska Skoroglya × Hoverla is associated exclusively with the influence of non-additive effects of gene interaction of parental components (SCC = 4.08), since the value of the effects of the crossing components was negative SCC (-5.4) and (-0.43) of the maternal and paternal forms, respectively.

The analysis of the genotypic structure of plant height variability indicates the predominance of additive effects of the genes of the studied varieties compared to the testers. Their contribution was 60.96 and 5.12 %, respectively. The contribution of the non-additive share of genotypic variation was also high - 33.92 % (Fig. 1).

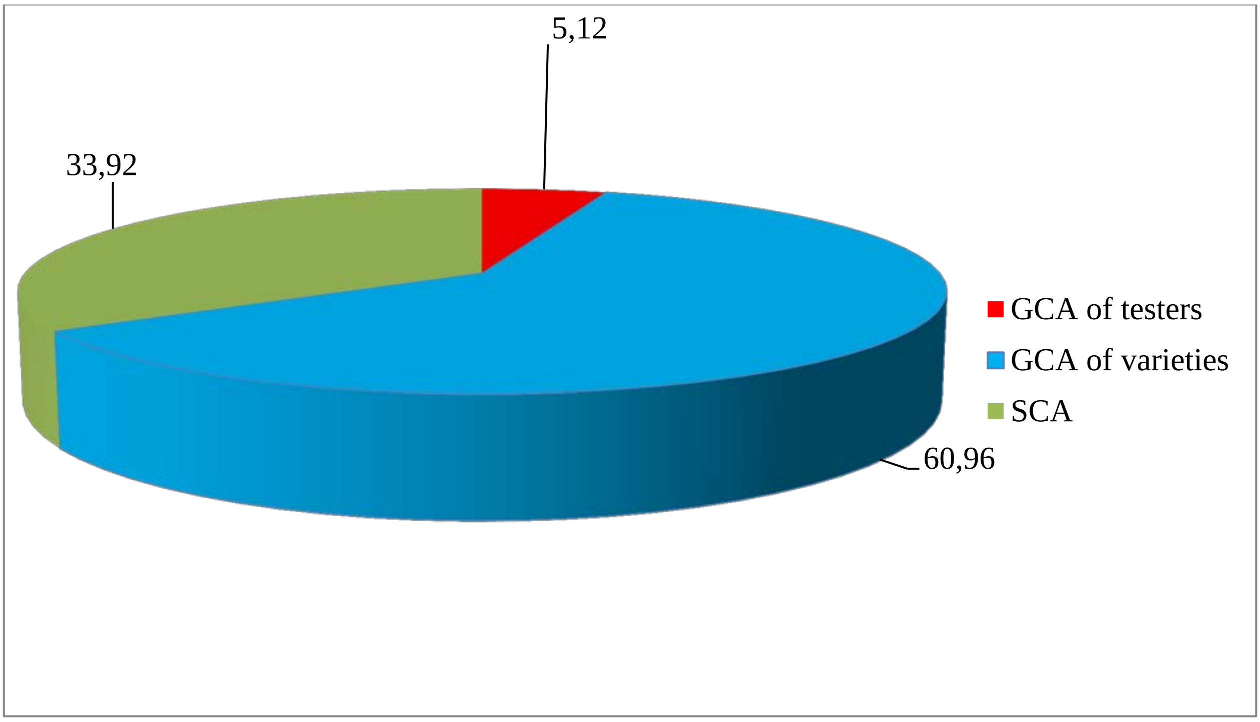

Fig. 1. Share of genotypic variability in plant height, 2017.
the source is formed on the basis of own research results

The height of lower bean attachment is a correlated trait with plant height (Table 2). Therefore, taller genotypes will generally have higher lower bean attachment rates.

However, it should be pointed out that there is a biological dependence of high lower bean attachment with slightly lower grain yield potential. This will be discussed in the following experimental data presented in (Tables 3-7).

The analysis of variance of the general combining ability (GCA) of maternal and paternal components, as well as the specific combining ability (SCA) in pairwise crosses, indicates that the lion's share of the formation of the height of the lower bean attachment is played by the additive effects of the genes of the paternal components, the mean square is 101.7 and a much smaller share of maternal forms is 16.9. At the same time, there is a smaller effect of non-additive interaction genes - 2.8.

The importance of genetic variants allowed us to estimate the combinational ability of the studied varieties. As shown by the effects of combinational ability, the most genetically valuable varieties in terms of the height of lower bean attachment were Kharkivska Skoroglya and Sawyer 2-95 (the effects of the CCA were 0.74 and 0.69). The KiVin tester was characterized by a high positive effect of the SCC (+0.91), and the Goverla tester by a high negative effect, which should be taken into account when hybridizing and selecting a tester.

In the hybrid combinations Kharkivska skoroglya × KiVin and Sawyer 2-95 × KiVin, the increase in the height of lower bean attachment is associated with both additive effects of varieties and tester and non-additive interaction genes (CCR = 0.14 and 0.09).

Table 2

Combining ability for the height of attachment of the lower beans of soybean varieties

Analysis of variance						
Source of variation	Sum of squares	Number of degrees of freedom	Middle square	Criterion F		
				actual	theoretical	
					0.05	0.01
Parental forms SCC	8.28	1	8.28	101.7	4.21	7.68
MACs of parent forms	5.51	4	1.37	16.9	2.73	4.11
SCS	0.91	4	0.23	2.8	2.73	4.11
Random deviations	2.19	27	0.08			

Varieties	The effect of the SCC varieties	The effect of the SCS		Constant SCS varieties
		Tester 1 Hoverla	Tester 2 KiVin	
Sawyer 2-95	0.69	-0.09	0.09	0.02
Ustia	0.24	-0.34	0.34	0.23
Medea	-0.46	0.56	-0.56	0.63
Kyivska 97	-1.21	0.01	-0.01	0.001
Kharkiv early ripening	0.74	-0.14	0.14	0.04
Effects of the testers' SCC		-0.91	0.91	
Variants of the SCS testers		-0.03	-0.03	
Nir 0.05 PCC of varieties		0.58		
Nir 0.05 PCC of testers		0.37		

the source is formed on the basis of own research results

The increase in the height of lower bean attachment was noted in the hybrid combination Ustia × KiVin, which is mostly due to the additive effects of the paternal component and non-additive effects in pair crosses (CCR = 0.34), the influence of the additive effects of the maternal component of the CCR (+0.24) is unreliable.

The analysis of the shares of influence of different gene interactions indicates that the largest contribution (83.74 %) to the formation of the height of lower bean attachment belongs to the additive effects of the paternal component (Fig. 2). The contribution of additive effects of the studied varieties was 13.94 %. The share of non-additive effects was 2.32%.

The results of the analysis of variance of combinational ability by the number of productive nodes showed that the variants associated with the influence of additive effects of the studied varieties were significant, since F fact. = 89.88 > F theoret. = 2.73, TCD - testers' variants, F fact. = 19.03 > F theoret. = 4.21, as well as the

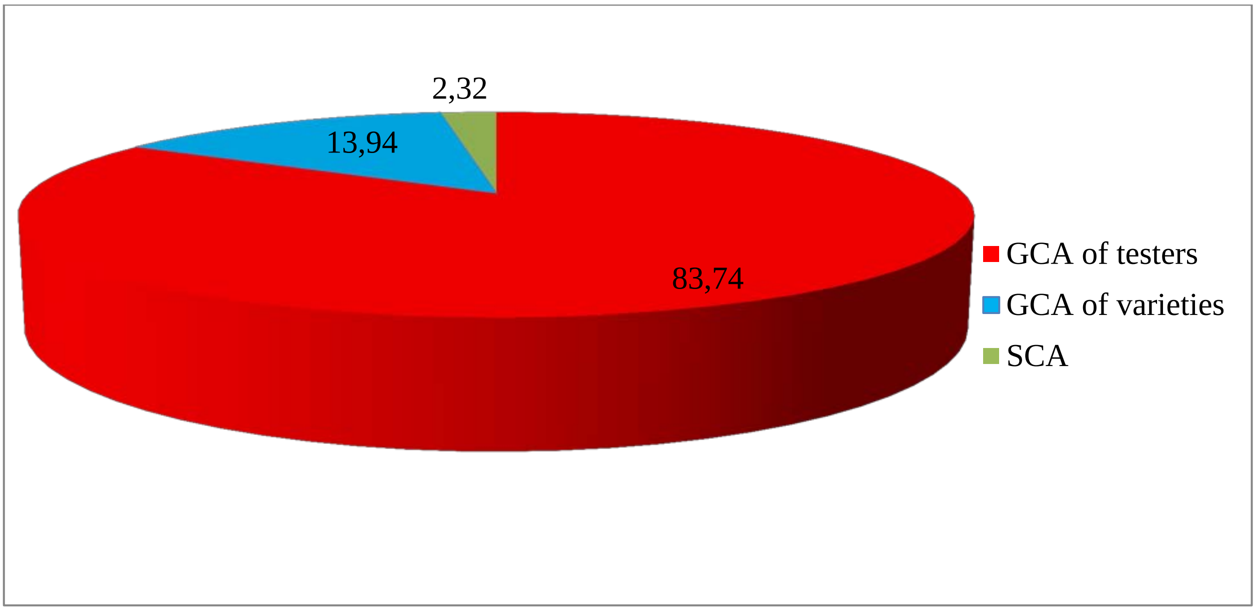

Fig. 2. Share of genotypic variation in the height of lower bean attachment, 2017.

the source is formed on the basis of own research results

variant's SEM for pairwise crosses, F fact. = 5.45 > F theoretical. = 2,73. This allowed us to estimate the combining ability of the studied varieties (Table 3).

Table 3

Combining ability by the number of productive nodes on the main stem of soybean varieties

Analysis of variance						
Source of variation	Sum of squares	Number of degrees of freedom	Middle square	Criterion F actual	Criterion F theoretical 0.05	Criterion F theoretical 0.01
Parental forms SCC	1.29	1	1.29	19.03	4.21	7.68
MACs of parent forms	24.47	4	6.12	89.88	2.73	4.11
SCS	1.48	4	0.37	5.45	2.73	4.11
Random deviations	1.83	27	0.068			
Varieties	The effect of the SCC varieties		The effect of the SCS Tester 1 Hoverla	The effect of the SCS Tester 2 KiVin	Constant SCS varieties	
Sawyer 2-95	0.63		-0.11	0.11	0.02	
Ustia	-2.57		-0.61	0.61	0.74	
Medea	1.28		0.04	-0.04	0.01	
Kyivska 97	1.63		0.59	-0.59	0.69	
Kharkiv early ripening	-0.97		0.09	-0.09	0.02	
Effects of the testers' SCC			0.36	-0.36		
Variants of the SCS testers			0.13	0.13		
Nir 0.05 PCC of varieties			0.53			
Nir 0.05 PCC of testers			0.34			

the source is formed on the basis of own research results

The analysis of the results showed that Kyivska 97 (+1.63), Medea (+1.28) and Sawyer 2-95 (+0.63) varieties were characterized by a significantly high effect of IPM, and Ustia (-2.57) and Kharkivska Skoroglya (-0.97) varieties were characterized by a significantly low effect of IPM.

The Goverla tester was characterized by a significant positive effect of the IPM (+0.36), and the KiVin tester had a significant negative effect, which should be taken into account when hybridizing and selecting a tester.

The effects of the SCZ deviated from the average population values for the Goverla tester in the range of 0.61...+0.59, and for the KiVin tester - 0.59...+0.61. The highest positive values were achieved in the pair combination Kyivska 97 × Hoverla - (SCZ = 0.59) and indicates the importance of both additive and non-additive interaction of parental forms.

The contribution of the additive effects of varietal genes was high (78.59%), and the share of tester variance was lower and amounted to 16.65%. However, the entire genotypic variation of hybrids was 95.24 % dependent on the additive effects of the genes of the studied varieties (Fig. 3). The share of non-additive gene effects was 4.76%.

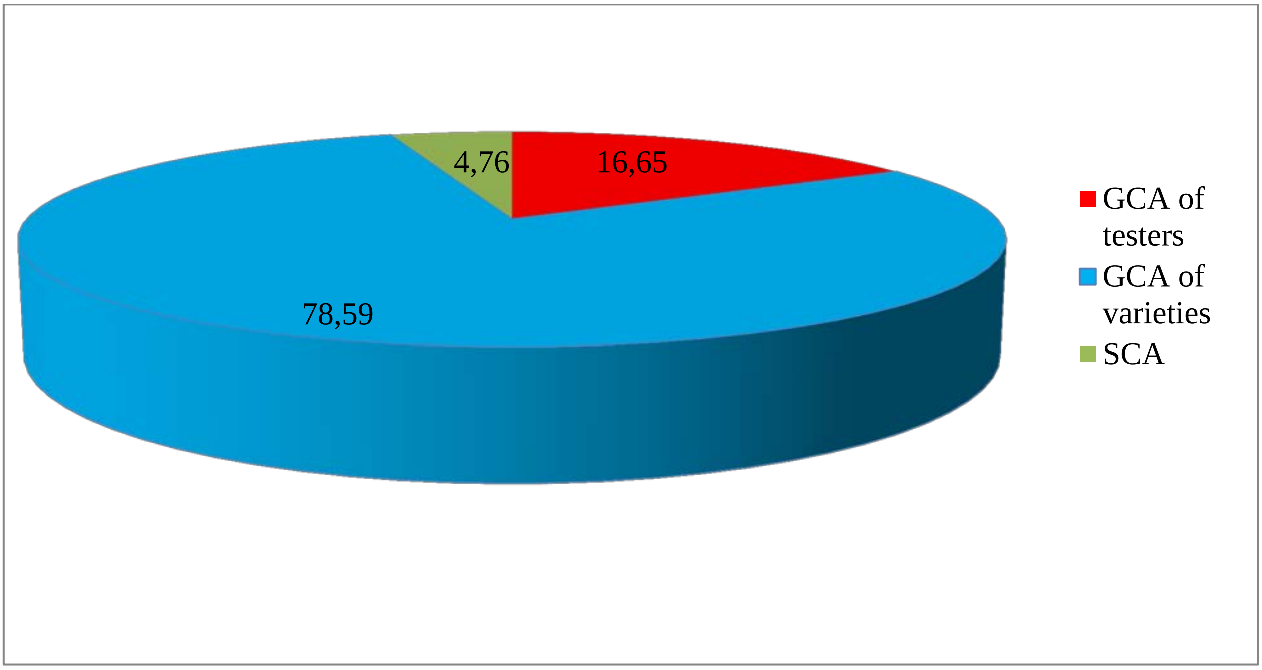

Fig. 3. Share of genotypic variability in the number of productive nodes on the main stem, 2017

the source is formed on the basis of own research results

The analysis of variance for the combinatorial ability of the number of beans per plant showed highly significant differences between the varieties with ZKZ variants, since F fact. = 102.2 > F theoret. = 2.73, ZKZ - testers' variants, F fact. = 121.1 > F theoret. = 4.21, as well as the variant's SEM for pairwise crosses, F fact. = 20.5 > F theoret. = 2.73 (Table 4). Kyivska 97 (+2.81) and Sawyer 2-95 (+1.16) varieties were characterized by high additive effects on the number of beans per plant, while Ustia

Table 4

Combining ability by the number of beans on plants of soybean varieties

Analysis of variance						
Source of variation	Sum of squares	Number of degrees of freedom	Middle square	Criterion F		
				actual	theoretical	
					0.05	0.01
Parental forms SCC	15.6	1	15.6	121.1	4.21	7.68
MACs of paren forms	52.8	4	13.2	102.2	2.73	4.11
SCS	10.6	4	2.6	20.5	2.73	4.11
Random deviations	3.4	27	0.12			

Varieties	The effect of the SCC varieties	The effect of the SCS		Constant SCS varieties
		Tester 1 Hoverla	Tester 2 KiVin	
Sawyer 2-95	1.16	0.4	-0.4	0.32
Ustia	0.5	-1.45	1.45	4.21
Medea	-0.39	-0.75	0.75	1.12
Kyivska 97	2.81	0.25	-0.25	0.12
Kharkiv early ripening	-4.08	1.55	-1.55	4.81
Effects of the testers' SCC		1.25	-1.25	
Variants of the SCS testers		1.08	1.08	
Nir 0.05 PCC of varieties		0.73		
Nir 0.05 PCC of testers		0.46		

the source is formed on the basis of own research results

(+0.5) had a positive effect, and Kharkivska Skoroglya (-4.08) had a significantly low effect. The best tester with high additive effects in terms of the number of beans per plant was the Goverla variety, which had a ZKZ effect of +1.25. That is, the testers differed significantly in their ability to combine in hybrids. The effects of non-additive interaction of varietal genes on the background of the tester Goverla were positive when crossed with the variety Sawyer 2-95 (SCC = 0.4) and the variety Kyivska 97 (SCC = 0.25).

An increase in the number of beans per plant was obtained in the hybrid combination Kharkivska Skoroglya × Hoverla, which is associated with a significant influence of non-additive effects of genes (SCC = 1.55) and additive effects of the tester (+1.25), while the effect of the mother's SCC was significantly negative (-4.08). In the hybrid combination Ustia × KiVin, the increase in the number of beans per plant was associated with non-additive effects (SCR = 1.45), the effect of the maternal component's SCA, although positive, was unreliable - (0.5), and the paternal component's SCA was significantly negative (-1.25).

The analysis of genotypic variability of the number of beans per plant showed that the additive effects of gene interaction play a dominant role (91.6%) in the expression of this trait (Fig. 4). It should be noted that the influence of both maternal (41.9%) and paternal components (49.7%) is almost equal. The share of non-additive effects of genes in pairwise crosses was 8.4%.

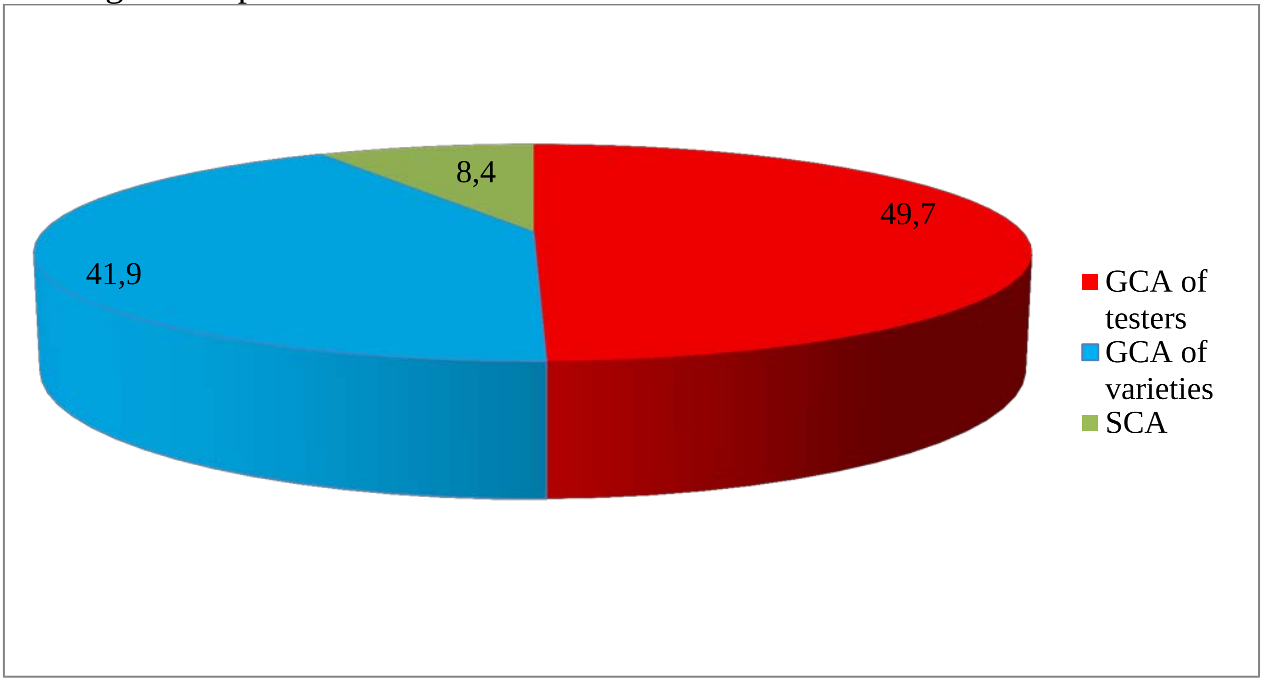

Fig. 4. Share of genotypic variability in the number of beans per plant, 2017.
the source is formed on the basis of own research results

The analysis of variance of the combinatorial ability of the number of seeds per plant indicates highly significant differences between the varieties of the ZPD variants, first of all, F fact. =378.4 > F theoret. = 2.73 and ZKZ - testers' variants, F fact. = 194.1 > F theoret. = 4.21, as well as the SCZ of the variants in pairwise crosses, F fact. = 15.8 > F theoretical. = 2.73 (Table 5).

According to the number of seeds per plant, the varieties Sawyer 2-95 and Kharkivska skoroglaya were combination-capable, which had a negative effect of SCD (-2.52 and -7.51), but the varieties Kyivska 97 and Medea in hybrid combinations increased the value of the trait (SCD effects were +9.87 and +0.98).

Hoverla variety was characterized by high SCC (+2.04). In the pair combinations Sawyer 2-95 × Hoverla and Ustia × Hoverla, the increase in the number of seeds per plant was associated with both non-additive effects of genes (SCC = 2.06 and 0.46) and additive effects of the paternal component of SCC alone (+2.04). In the combination of crosses Kyivska 97 × KiVin, the increase in the number of seeds per plant is associated with the additive effects of the maternal genes (+9.87) and non-additive effects of genes (CCR = 0.84) in pair crosses.

In the pairwise cross Kharkivska skoroglya × KiVin, the increase in the number of seeds is associated exclusively with non-additive effects of genes (SCC = 1.13), the value of SCC of both parental forms is significantly negative.

In the combination of Medea × KiVin crosses, the increase in the number of seeds per plant is associated with non-additive effects of genes (SCC = 0.53), as well as with the value of the maternal form SCC (+0.98), since the paternal form is significantly negative (-2.04).

Table 5

Combining ability by number of seeds on plants of soybean varieties

Analysis of variance						
Source of variation	Sum of squares	Number of degrees of freedom	Middle square	Criterion F actual	Criterion F theoretical 0.05	Criterion F theoretical 0.01
Parental forms SCC	41.5	1	41.5	194.1	4.21	7.68
MACs of parent forms	323.9	4	80.9	378.4	2.73	4.11
SCS	13.5	4	3.4	15.8	2.73	4.11
Random deviations	5.7	27	0.2			
Varieties	The effect of the SCC varieties		The effect of the SCS Tester 1 Hoverla	The effect of the SCS Tester 2 KiVin	Constant SCS varieties	
Sawyer 2-95	-2.52		2.06	-2.06	8.5	
Ustia	-0.82		0.46	-0.46	0.4	
Medea	0.98		-0.53	0.53	0.6	
Kyivska 97	9.87		-0.84	0.84	1.4	
Kharkiv early ripening	-7.51		-1.13	1.13	2.6	
Effects of the testers' SCC			2.04	-2.04		
Variants of the SCS testers			1.45	1.45		
Nir 0.05 PCC of varieties			0.94			
Nir 0.05 PCC of testers			0.59			

the source is formed on the basis of own research results

In the course of testing these varieties, it was found that the contribution of the interaction of additive gene effects was the highest and amounted to 97.31%, while the share of varieties accounted for almost twice as much (64.32%). While the non-additive effects of genes in pair combinations accounted for 2.69% (Fig. 5).

The analysis of variance of the combining ability of 1000 seeds indicates highly significant differences between the ZPD variants, especially between varieties - F fact. = 302.7 > F theoret. = 2.73 and the testers' PKD variants, F fact. = 32.8 > F theoret. = 4.21, as well as the SCZ variants for pairwise crosses, F fact. = 9.1 > F theoretical. = 2.73 (Table 6). High significant effects of IPM, weight of 1000 seeds were observed in varieties Sawyer 2-95 (+8.4), Medea (+10.9) and Kyivska 97 (+4.4). The negative effects of ZKZ were characterized by varieties Kharkivska skoroglya (-20.0) and Ustia (-3.7).

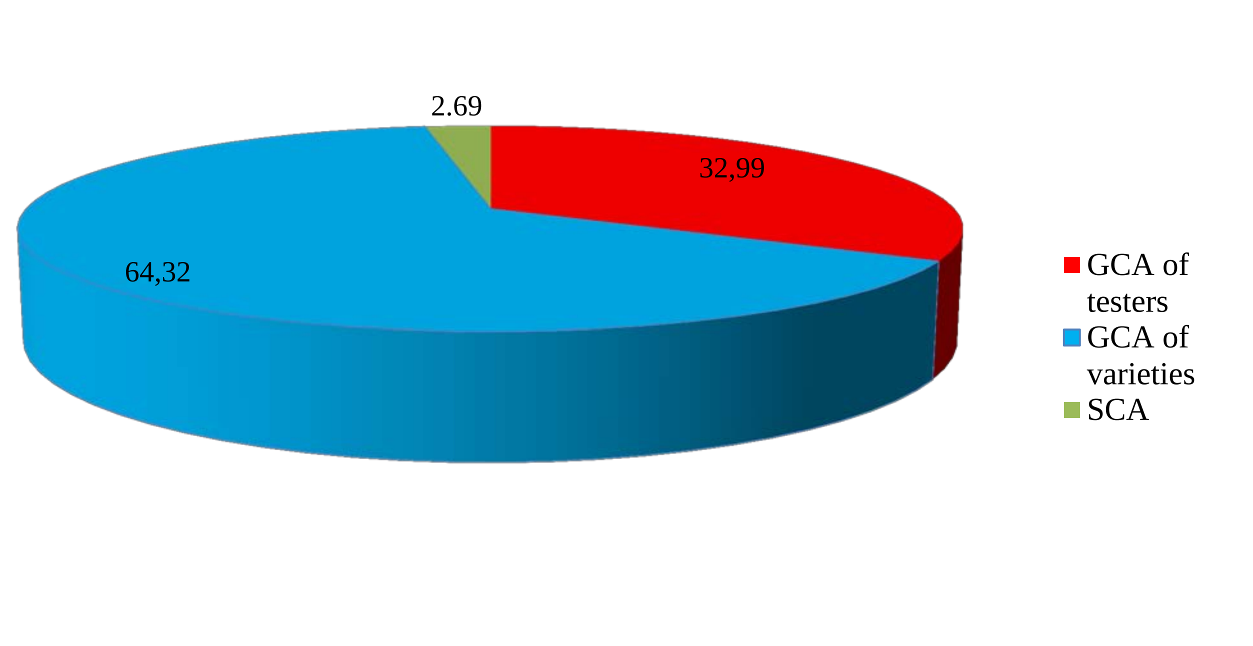

Fig. 5. Share of genotypic variability in the number of seeds per plant, 2017
the source is formed on the basis of own research results

The tester Goverla was characterized by a positive effect of the PPV (+1.83), and the tester KiVin - by a negative one, which should be taken into account when selecting the parental component for hybridization as a tester, the effects of the PPV of the testers were significant.

In the hybrid combination Sawyer × Hoverla, the increase in the weight of 1000 seeds is associated with both additive effects of maternal (+8.4) and paternal (+1.83) genes and non-additive effects of pair crosses (SCC = 1.86). Similarly to the hybrid combination Kyivska 97 × Hoverla, the increase in the weight of 1000 seeds was provided by both additive and non-additive effects of gene interaction (+4.4 and +1.83), and the SCZ for pair crosses was 2.07.

Table 6

Combining ability by weight of 1000 seeds of soybean varieties

Analysis of variance						
Source of variation	Sum of squares	Number of degrees of freedom	Middle square	Criterion F		
				actual	theoretical	
					0.05	0.01
1	2	3	4	5	6	7
Parental forms SCC	33.7	1	33.7	32.8	4.21	7.68
MACs of parent forms	1242.4	4	310.6	302.7	2.73	4.11
SCS	37.2	4	9.3	9.1	2.73	4.11
Random deviations	27.7	27	1.0			

continuation of table 6

1	2	3	4	5
Varieties	The effect of the SCC varieties	The effect of the SCS		Constant SCS varieties
		Tester 1 Hoverla	Tester 2 KiVin	
Sawyer 2-95	8.4	1.86	-1.86	6.9
Ustia	-3.7	-2.71	2.71	14.7
Medea	10.9	-1.78	1.78	6.4
Kyivska 97	4.4	2.07	-2.07	8.6
Kharkiv early ripening	-20.0	0.56	-0.56	0.6
Effects of the testers' SCC		1.83	-1.83	
Variants of the SCS testers		3.08	3.08	
Nir 0.05 PCC of varieties		2.07		
Nir 0.05 PCC of testers		1.3		

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In the pair combination Kharkivska skoroglya × Hoverla, the increase in the weight of 1000 seeds is associated with non-additive effects of genes in pair crosses (SCC = 0.56) and exclusively with additive effects of genes of the SCC tester (+1.83). In the combination Medea × KiVin, the high heterotic effect on the weight of 1000 seeds is due to the total positive effect of both the additive effects of the maternal form (+10.9) and non-additive effects of gene interaction in pairwise crosses (CCR = 1.78).

It should be noted that the dominant contribution of additive effects of genes of varieties (87.83%), and the share of variance of additive effects of testers was lower and amounted to 9.52% in the total genotypic variability of weight of 1000 seeds (Fig. 6). The share of non-additive effects of genes was 2.63%.

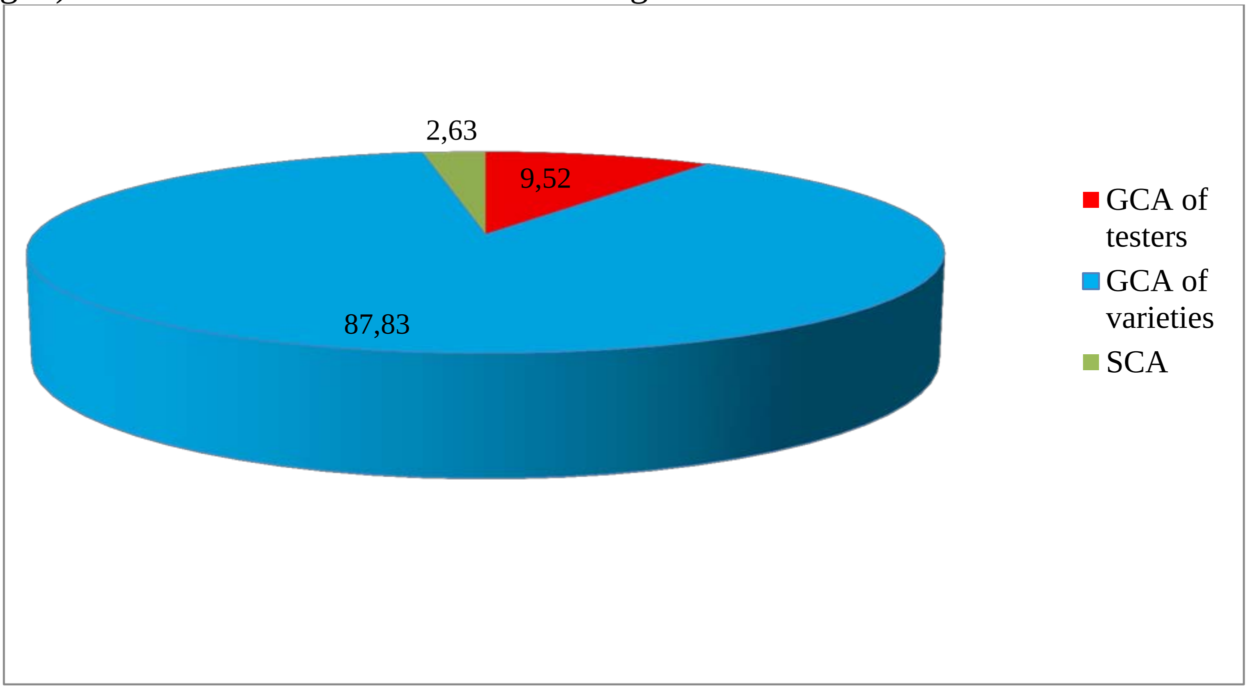

Fig. 6. The share of genotypic variability in the weight of 1000 seeds, 2017

the source is formed on the basis of own research results

Grain weight per plant is a polygenic trait that includes elements of the yield structure of soybean plants. The analysis of variance of combinatorial ability of grain weight from the plant showed the predominant influence of the additive effects of the mother forms, mean square F fact. = 152 > F theoret. = 2.73 and paternal F fact. = 48.2 > F theoretical. = 4,21. The influence of non-additive effects was also significant, but much smaller F fact. = 4.1 > F theoret. = 2.73 (Table 7).

Table 7

Combining ability by grain weight per plant of soybean varieties

Analysis of variance						
Source of variation	Sum of squares	Number of degrees of freedom	Middle square	Criterion F		
				actual	theoretical	
					0,05	0.01
Parental forms SCC	3.6	1	3.6	48.2	4.21	7.68
MACs of parent forms	45.3	4	11.3	152.0	2.73	4.11
SCS	1.2	4	0.3	4.1	2.73	4.11
Random deviations	2.0	27	0.07			
Varieties	The effect of the SCC varieties		The effect of the SCS		Constant SCS varieties	
			Tester 1 Hoverla	Tester 2 KiVin		
Sawyer 2-95	0.59		0.62	-0.62	0.76	
Ustia	-0.63		-0.28	0.28	0.16	
Medea	1.54		-0.31	0.31	0.19	
Kyivska 97	2.3		0.16	-0.16	0.05	
Kharkiv early ripening	-3.8		-0.17	0.17	0.06	
Effects of the testers' SCC			0.59	-0.59		
Variants of the SCS testers			0.07	0.07		
Nir 0.05 PCC of varieties			0.56			
Nir 0.05 PCC of testers			0.35			

the source is formed on the basis of own research results

The high significant effects of the SCC on grain weight per plant were characterized by Sawyer 2-95 (+0.59), Kyivska 97 (+ 2.3) and Medea (+1.54), and significantly low effects were observed in Kharkivska Skoroglya (- 3.8) and Ustia (-0.63).

The Goverla tester was characterized by a significant positive effect of the SCC (+0.59), and the KiVin tester was negative, which should be taken into account when selecting the parental component for hybridization.

The effects of non-additive interaction of varieties' genes on the background of the Hoverla tester were positive when crossed with Sawyer 2-95 (Coefficient of Variation = 0.62) and Kyivska 97 (Coefficient of Variation = 0.16). This indicates that the grain weight per plant of these hybrid combinations was formed by different types of gene interactions, both additive and non-additive gene effects in pairwise crosses.

In the paired combination Medea × KiVin, the increase in grain weight per plant is associated with non-additive effects of genes in paired crosses (Coefficient of Variation = 0.31) and exclusively with additive effects of genes of the mother form of the ZKZ (+1.54). In the hybrid combination Kharkivska skoroglya × KiVin, the increase in grain productivity is associated only with non-additive effects of gene interaction (CCR = 0.17). The effects of the parental forms are significantly negative.

As a result of the studies, it was found that in these hybrid combinations the interaction of additive effects of the genes of the parental forms accounted for 74.4%, and the share of testers accounted for 23.58%. Whereas the non-additive effects of genes of pair combinations accounted for 2.02% (Fig. 7).

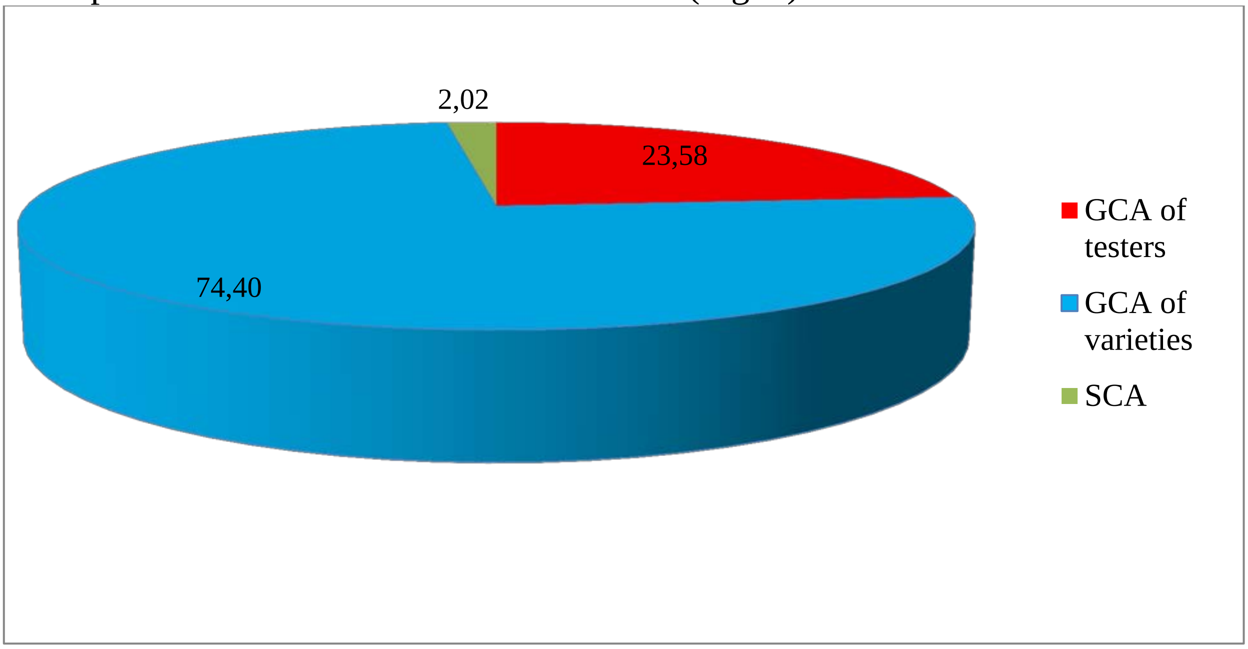

Fig. 7. Share of genotypic variability of grain weight per plant, 2017.
the source is formed on the basis of own research results

In addition to the indicators of combinational ability, the degree of phenotypic dominance (hp) is often used in breeding practice to qualitatively assess the level of trait expression in F1 hybrids [8], which characterizes the level of trait expression in hybrids compared to parental forms.

Positive dominance (hp>+1) in plant height in F1 soybean hybrids was observed in 100% of cases. Positive dominance (hp>+1) for the height of lower bean attachment was observed in 60% of cases, and intermediate inheritance (-0.5≤hp≤+0.5) - 40.0% (Table 8).

However, it is noticeable that in F1 hybrids in which the inheritance of elements of the yield structure (number of productive nodes per plant, number of beans per plant, number of seeds per plant, and grain weight per plant) occurred by the type of positive dominance, the hp index varied quite a bit depending on the crossing combination.

The highest hp values were observed for the number of beans per plant, number of seeds per plant, and grain weight per plant in the hybrid combinations Sawyer 2-95 × Goverla, Ustia × Goverla, and Kharkivska skoroglya × Goverla.

The value of dominance in the hybrid combination Sawyer 2-95 × Hoverla hp for these traits varied within 7.8-22.8.

Table 8

The degree of phenotypic dominance (hp) of valuable economic traits of soybean hybrids (F1), 2017

Features	Crossbreeding combinations				
	Sawyer-2-95 × Hoverla	Ustia × Hoverla	Medea × Hoverla	Kyivska 97 × Hoverla	Kharkivskaya fast ripening × Goverla
Plant height, cm	3.6	1.7	1.35	1.31	1.04
Height of attachment of the lower beans, cm	-0.4	1.4	1.2	-0.4	4.3
Number of productive nodes per plant, pcs.	1.3	1.2	255	5.4	13.8
Number of beans per plant, pcs.	22.8	4.5	1.5	3.4	40.4
Number of seeds per plant, pcs.	10.2	3.6	2.9	7.1	15.6
Weight of 1000 seeds, g	2.2	1.1	81.0	1.3	-3.8
Weight of grain per plant, g	7.8	5.9	3.7	6.1	21.3

the source is formed on the basis of own research results

In the hybrid combination Ustia × Hoverla, the degree of inheritance of elements of the crop structure (number of beans, number of seeds and grain weight per plant), established in the course of hybridization analysis of F1, was related to superdominance (hp>+1) and varied from 3.6 to 5.9. In the hybrid combination Kharkivska skoroglya × Hoverla, hp for the number of beans and seeds and grain weight per plant varied from 15.6-40.4.

Lower values of dominance for these traits were observed in the hybrid combination Kyivska 97 × Hoverla, where hp varied from 3.4 to 7.1. As well as in the hybrid combination Medea × Hoverla, where hp varied from 1.5 to 3.7.

To evaluate F1 hybrids, the degree of true heterosis (Hist) was determined, which shows how much the average value of the hybrid trait exceeds the average value of the best of the parental components expressed as a percentage (Table 9).

The manifestation of true heterosis (dominance in 100% of cases) in hybrids (F1) was found in hybrid combinations by elements of the yield structure (number of productive nodes, number of beans per plant, number of seeds per plant and grain weight per plant).

Table 9

Manifestation of true heterosis in hybrids (F1) for valuable economic traits of soybean plants, 2017

Features	Crossbreeding combinations				
	Sawyer-2-95 × Hoverla	Ustia × Hoverla	Medea × Hoverla	Kyivska 97 × Hoverla	Kharkivskaya fast ripening × Goverla
Plant height, cm	3.0	1.6	3.5	2.3	0.7
Height of attachment of the lower beans, cm	-15.2	1.0	3.1	-10.2	5.0
Number of productive nodes per plant, pcs.	4.9	1.5	55.7	36.2	36.5
Number of beans per plant, pcs.	82.1	43.8	11.2	38.4	80.0
Number of seeds per plant, pcs.	96.2	38.5	31.9	65.5	83.8
Weight of 1000 seeds, g	10.1	0.3	9.4	0.94	-11.9
Weight of grain per plant, g	116.1	53.5	44.6	67.1	70.3

the source is formed on the basis of own research results

According to the height of attachment of the lower beans of hybrid offspring, only two combinations Medea × Goverla and Kharkivska skoroglyha × Goverla inherited them by the type of superdominance (hp>+1). As for the weight of 1000 seeds, superdominance was observed in the hybrid combinations Sawyer 2-95 × Goverla and Medea × Goverla.

Lower rates of phenotypic dominance (hp) of yield structure elements, as well as true heterosis, were observed in these varieties when crossed with the KiVin tester compared to the Goverla tester, indicating a lower general combining ability (GCA) of the KiVin tester (Table 10).

Table 10

The degree of phenotypic dominance (hp) of valuable economic traits of soybean hybrids (F1), 2017

Features	Crossbreeding combinations				
	Sawyer-2-95 × Hoverla	Ustia × Hoverla	Medea × Hoverla	Kyivska 97 × Hoverla	Kharkivskaya fast ripening × Goverla
Plant height, cm	4.6	10.2	2.1	2.1	0.5
Height of attachment of the lower beans, cm	3.0	1.0	0.4	0.1	1.3
Number of productive nodes per plant, pcs.	1.2	3.7	4.6	21.7	2.0
Number of beans per plant, pcs.	10.0	3.7	1.4	2.7	10.4
Number of seeds per plant, pcs.	6.2	3.8	3.1	9.3	8.5
Weight of 1000 seeds, g	1.5	1.1	13.8	-0.2	-6.5
Weight of grain per plant, g	5.0	7.4	4.0	6.7	7.9

the source is formed on the basis of own research results

Only in the hybrid combination Sawyer 2-95 × KiVin the degree of inheritance for all valuable economic traits, which was established during the

hybridization analysis of F1, was related to superdominance (hp>+1) and varied from 1.2 to 10.0. In the hybrid combinations Ustia × KiVin and Medea × KiVin hp, positive dominance (hp>+1) was observed for all valuable economic traits, except for the height of lower bean attachment.

According to the height of attachment of the lower beans in the first hybrid combination, positive dominance (+0.5≤hp≤+1) was noted, and in the second - intermediate inheritance (-0.5≤hp≤+0.5).

In the hybrid combination Kyivska 97 × KyVin, positive superdominance (hp>+1) was observed for the majority of traits, except for the height of the lower beans and the weight of 1000 seeds, where intermediate inheritance was observed (-0.5≤hp≤+0.5). In the hybrid combination Kharkivska skoroglya × KiVin, the degree of inheritance for valuable economic traits, which was established during the hybrid analysis of F1, was related to superdominance (hp>+1), except for plant height, where intermediate inheritance was observed (-0.5≤hp≤+0.5) and weight of 1000 seeds, where negative superdominance (hp<-1) was observed.

A comparative analysis of the proportion of heterotic hybrid combinations from crossing parental forms that differed in valuable economic traits is presented in (Table 11).

Table 11

Manifestation of true heterosis in hybrids (F1) for valuable economic traits of soybean plants, 2017

Features	Crossbreeding combinations				
	Sawyer-2-95 × Hoverla	Ustia × Hoverla	Medea × Hoverla	Kyivska 97 × Hoverla	Kharkivskaya fast ripening × Goverla
Plant height, cm	3.1	2.7	10.2	8.1	-7.3
Height of attachment of the lower beans, cm	0.8	0	-12.9	-14.5	2.4
Number of productive nodes per plant, pcs.	1.8	3.0	26.7	22.5	9.6
Number of beans per plant, pcs.	75.7	44.7	9.5	32.3	63.8
Number of seeds per plant, pcs.	70.2	33.2	28.8	62.7	67.6
Weight of 1000 seeds, g	4.7	0.3	8.2	-3.4	-14.6
Weight of grain per plant, g	78.9	49.1	41.3	57.2	49.6

the source is formed on the basis of own research results

Superdominance in 100% of cases, i.e. the manifestation of true hybrid heterosis (F1) was found in all hybrid combinations when crossed with the KiVin tester in terms of the number of productive nodes, number of beans per plant, number of seeds per plant and grain weight per plant.

Conclusions and prospects for further research.

The high effects of SCC and SCP on plant height in varieties Medea, Kyivska 97, Sawyer 2-95 and KiVin tester; on the height of lower bean attachment in varieties Sawyer 2-95, Ustia, Kharkivska skoroglya and KiVin tester; on the number of productive nodes - in varieties Kyivska 97 and Goverla tester; by the number of beans per plant - in varieties Sawyer 2-95, Kyivska 97 and tester Goverla; by the number of seeds per plant - in varieties Medea, Kyivska 97 and tester KiVin; by the weight of 1000 seeds - in varieties Sawyer 2-95, Kyivska 97 and tester Goverla; by the weight of grain per plant - in varieties Sawyer 2-95, Kyivska 97 and tester Goverla. It was found that additive effects of genes were predominant in the genetic control of plant height and lower bean attachment, elements of yield structure and grain weight per plant, but there is a smaller influence of non-additive effects.

The manifestation of true heterosis (dominance in 100% of cases) in hybrids (F1) was found in crosses with both testers in terms of the number of productive nodes, the number of beans and seeds per plant, and the weight of grain per plant.

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АНОТАЦІЯ
СЕЛЕКЦІЙНО-ГЕНЕТИЧНІ ОСОБЛИВОСТІ СОРТІВ СОЇ ЗА ПРОЯВОМ ОЗНАК У ГІБРИДІВ F1 У ТОПКРОСНИХ СХРЕЩУВАННЯХ

Подальше підвищення валового виробництва сої потребує впровадження нових сортів з оптимальним поєднанням елементів структури врожаю. Гібридизація у сої є основним ефективним методом створення нових сортів. Підвищення ефективності гібридизації в одержанні гетерозисного потомства можливе при використанні в схрещуваннях батьківських форм з високою комбінаційною здатністю.

У дослідженнях використано двотестерний аналіз топкросних схрещувань сортів сої, які відрізняються за господарськоцінними ознаками. За результатами оцінки комбінаційної здатності визначено цінність сортів сої за елементами структури врожаю. Виділено гетерозисні комбінації у гібридів першого покоління, з яких імовірніше відібрати високопродуктивні форми у пізніших гібридних популяціях F2-F4.

Встановлено високі ефекти ЗКЗ і СКЗ за висотою рослин у сортів Медея, Київська 97, Соєр 2-95 і тестера КиВін; висоти прикріплення нижніх бобів у сорту Соєр 2-95, Устя, Харківська скоростигла і тестера КиВін; за кількістю продуктивних вузлів − у сортів Київська 97 і тестера Говерла; за кількістю бобів на рослині − у сортів Соєр 2-95, Київська 97 і тестера Говерла; за кількістю насінин на рослині − у сортів Медея, Київська 97 і тестера КиВін; за масою 1000 насінин – у сортів Соєр 2- 95, Київська 97 і тестера Говерла;

за масою зерна із рослини – у сортів Соєр 2-95, Київська 97 і тестера Говерла. Встановлено, що переважаючими у генетичному контролі висоти рослин і прикріплення нижніх бобів, елементів структури врожаю та маси зерна із рослини були адитивні ефекти генів, проте наявний менший вплив також неадитивних ефектів.

Прояв істинного гетерозису (наддомінування у 100 % випадків) у гібридів (F1) виявлено у схрещуванні з обома тестерами за кількістю продуктивних вузлі, кількістю бобів і насінин на рослині та масою зерна із рослини.

***Ключові слова**: ознаки, тестер, комбінаційна здатність, наддомінування, адитивні ефекти, гетерозис.*

Табл. 11. Рис. 7. Літ. 15.

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