Genetic control of parameters of harvest structure elements in the corn diallel complex

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Abstract. The article discusses the results of the use of diallel analysis in the study of self-pollinated maize lines. The average values of the elements of the structure of the grain yield in self-pollinated lines, as well as the average group indicators of hybrids, are noted. The effects of the general and dispersion of the specific combinative ability of lines are revealed. The ranking of the average group values of hybrids by the weight of the cob was carried out, which made it possible to arrange the lines in the following sequence: CL 7 < X 46 < SE 19 < Od 28 < KS 25 < LV 32 < Bg 1266 < Om 255 < Uk12 D 2 < RSK 25 < Om 232 < Mk 130 U < RSK 3 < RSK 7 < RN 26 < Mk 11. In 2016-2019 A significant influence on the manifestation of the weight of the cob, the weight of the grain from the cob, the yield of grain, the number of grains in a row and the grains on the cob of the paratypical component of the dispersion (E) was noted.

1. Introduction
One of the directions in the study of maize breeding material is the study of the combinational ability of lines and the determination of the components of the genetic control of economically valuable parameters [3-4]. The use of a diallel crossing scheme, unlike other methods for studying combinational ability (topcross, polycross, free cross-pollination), is more laborious [9;13;15]. However, this method allows obtaining the most accurate information about the general and specific combinational ability [4;7;11]. The most convenient for diallel analysis are quantitative indicators, which, with a relatively simple measurement, are an important component in the formation of an integral indicator of plant yield [1;6]. Determining the overall combining ability by the weight of the cob, grain yield, the number of grains on the cob is an important part of the work that helps to identify promising lines that can produce high-yielding hybrids [5].

2. Materials and methods
The studies were carried out in 2016–2019 on the experimental field of the FGBNU RosNIISK "Rossorgo" in accordance with the methodology [2]. The climate of the region is characterized as sharply continental. The HThC amounted to 0.48 in 2016, -1.05 in 2017, 0.61 in 2018, and 0.56 in 2019. The soil of the experimental plot is southern low-humus, medium-thick, heavy loamy chernozem. The experiment included simple hybrids (120 combinations) obtained according to the diallel scheme of 16 homozygous lines (method 2, Griffing model 1). Repetition - three times. The accounting area of the plot is 7.7 m²; plot length 5.5 m. Plant density (45 thousand plants/ha).
Agrotechnics in the experiment - zonal, developed at the Federal State Scientific Institution RosNIISK "Rossorgo". Appropriate methods were used to carry out counts and observations [10;14]. The combination ability of the samples was determined according to the II method of B. Griffing [16]. Genetic analysis of the components of the genetic dispersion was carried out according to B.I. Hayman [17]. Data processing was carried out using the computer program Agros-2.09.

3. Results and Discussion

To increase the productivity potential of corn hybrids, it is necessary to analyze quantitative traits that affect grain yield and other economically valuable traits. In this case, special attention should be paid to the elements of productivity. The elements of the yield structure are correlated with grain yield, although they make an unequal contribution to the formation of plant productivity (table 1). A similar conclusion is given in other studies [8]. Correlation analysis of averaged data for 2016–2019 revealed a close relationship between grain yield and cob weight (r = 0.96), and grain weight per cob (r = 0.99).

Table 1. Statistical parameters and correlation coefficients between grain yield and plant productivity elements in corn hybrids (2016-2019).

| feature                                      | Correlation coefficient | Mean  | Error | Dispersion | Standard deviation | The coefficient of variation, % |
|----------------------------------------------|-------------------------|-------|-------|------------|--------------------|---------------------------------|
| The mass of the cob, g                       | 0.96**                  | 128.8 | 1.23  | 182.1      | 13.5               | 10.5                            |
| Weight of grain from the cob, g              | 0.99**                  | 100.5 | 0.94  | 106.2      | 10.31              | 10.3                            |
| Grain output, %                              | 0.06                    | 77.5  | 0.24  | 6.63       | 2.58               | 3.3                             |
| Number of grains in a row, th.               | 0.33**                  | 30.1  | 0.26  | 7.82       | 2.80               | 9.3                             |
| Number of grains per cob, th.                | 0.57**                  | 397.0 | 4.08  | 1994.1     | 44.7               | 11.2                            |

For 2016-2019 the weight of 1 cob in self-pollinated lines varied from 50.1 g to 91.5 g (table 1). The average group values of hybrids varied from 118.1 g to 142.9 g. The weight of grain per cob varied within the limits: 35.8-71.6 g for lines, 92.3-110.4 g according to the average group values of hybrids. Ranking according to the average values of the cob mass made it possible to arrange the lines depending on the following sequence: CL 7 < RSK 25 < RN26 < Uk12D2 < MK 130 U < Om 255 < X46 < RSK 7 < LV32 < MK 11 < YuV 19 < Bg1266 < KS 25 < Om232 < Od 28 < RSK 3. The distribution of the average group indicators of hybrids revealed a shift in the location of the lines: CL 7 < X 46 < YuV 19 < Od 28 < KS 25 < LV 32 < Bg 1266 < Om 255 < Uk12 D 2 < RSK 25 < Om 232 < Mk 130 U < RSK 3 < RSK 7 < PH 26 < Mk 11. Ranking according to the average values of grain weight from the cob in the lines and according to the average group values of hybrids revealed minor deviations in a similar sequence.

In terms of grain yield from the cob, the parameter varied from 66.5% to 79.4% for the lines and from 76.7% to 79.4% for the average group values of hybrids. The hybrids with the participation of lines RSK 7, YuV 19, RSK 25, RSK 3, Uk 12 D 2 showed the highest percentage of grain yield.

On average, over the years of the study, differences were noted between the lines in the number of grains in a row and the number of grains on the cob. The largest number of grains in the row was noted in the lines Uk 12 D 2, YuV 19, LV 32, Om 255, RSK 7. The hybrids with these forms also showed the largest number of grains in the row.

The results of the analysis of the combinational ability of self-pollinated maize lines, carried out according to the diallel scheme, indicate a low value of the effects of GCA on the traits "cob weight" and "grain weight per cob" in line CL 7. A high effect of GCA was noted in line Mk11. (table 2). The remaining forms according to these parameters were characterized by the average value of the GCA
effect in varying degrees. Relatively high dispersion of SCA by the weight of the cob and grain from the cob was recorded in the lines RN 26, Bg 1266, Mk 11, and RSK 7.

Relatively high effects of SCA on the mass of the cob were revealed in combinations: RN 26 / Bg 1266 (24.3), X 46 / KS 25 (30.0), RSK / Bg 1266 (36.4), YuV 19 / Bg 1266 (24.6).

Lines Uk 12 D 2, KS 25, YuV 19, and RSK 3 were characterized by positive and high GCA effects on grain yield from the cob.

The sign "number of grains in a row" positively correlates with grain yield. As a component of yield, it to some extent determines the level of grain yield per plant and grain yield per unit area. Evaluation of the material for this trait made it possible to reveal high GCA effects in the lines RN 26, RSK 7 and low values of the GCA effect in the lines KS 25, RSK 3, Bg 1266, and Om 232. The indicator of the number of grains on the cob is also important. High values of the GCA effect were noted in the lines Mk 130 U, RSK 7, Bg 1266, and low values in the lines X 46, CL 7, KS 25, and Om 232.

Using the method of diallel crosses, one can also establish the nature of the inheritance of quantitative traits and obtain information about other genetic properties of the analyzed forms (about the additive effects of genes, the degree and direction of dominance of genes that control the development of traits, about the ratio of frequencies of dominant and recessive genes in a certain locus) [8]. In the experiment, there is a negative correlation between the value of the trait and dominance in parental lines in terms of: cob weight $r = -0.60$ (df=10), grain weight from the cob $r = -0.51$ (df=11), grain yield from the cob $r = -0.73$ (df=13), the number of grains in the row $r = -0.24$ (df=10). A positive correlation was noted between the number of grains on the cob and dominance.

### Table 2. Elements of the yield structure of self-pollinated corn lines (L*) and average group values of hybrids (G*), average 2016-2019, %.

| Line    | The mass of the cob, g | Weight of grain from the cob, g | Grain output, % | Number of grains in a row, th. | Number of grains per cob, th. |
|---------|------------------------|---------------------------------|-----------------|-------------------------------|-------------------------------|
|         | $L^*$  | $G^*$ | $L^*$ | $G^*$ | $L^*$  | $G^*$ | $L^*$  | $G^*$ |
| RN26    | 67.4  | 134.8 | 50.6  | 104.9 | 75.0  | 77.9 | 22.5  | 28.9 |
| MK 130 U| 69.5  | 132.1 | 46.2  | 102.1 | 66.5  | 77.1 | 22.4  | 29.7 |
| MK 11   | 78.5  | 142.9 | 54.8  | 110.4 | 69.8  | 77.2 | 19.9  | 29.5 |
| UK12D2  | 68.1  | 128.3 | 48.8  | 101.2 | 78.9  | 78.8 | 26.3  | 31.0 |
| RSK 25  | 66.6  | 128.6 | 50.1  | 101.5 | 74.6  | 78.9 | 22.1  | 30.2 |
| Om 255  | 71.2  | 127.8 | 54.1  | 98.4  | 75.8  | 77.5 | 26.1  | 29.8 |
| X46     | 71.3  | 123.2 | 55.1  | 95.8  | 78.1  | 76.9 | 21.7  | 29.6 |
| RSK 7   | 73.2  | 134.6 | 55.3  | 105.1 | 74.9  | 79.4 | 25.9  | 31.3 |
| CL 7    | 50.1  | 118.1 | 35.8  | 92.3  | 72.4  | 78.4 | 23.3  | 30.6 |
| KS 25   | 85.4  | 125.9 | 67.6  | 99.8  | 78.9  | 78.7 | 24.2  | 28.9 |
| YuV19   | 78.7  | 123.6 | 63.0  | 98.2  | 79.4  | 79.2 | 26.3  | 31.1 |
| RSK 3   | 91.5  | 133.1 | 71.6  | 104.8 | 78.0  | 78.8 | 20.1  | 27.9 |
| Bg 1266 | 82.9  | 126.5 | 63.6  | 98.0  | 76.9  | 77.3 | 23.3  | 27.0 |
| LV32    | 77.1  | 126.0 | 59.3  | 98.8  | 76.8  | 78.2 | 25.4  | 30.4 |
| Od 28   | 88.4  | 124.3 | 68.8  | 97.4  | 77.7  | 78.3 | 23.2  | 29.9 |
| Om 232  | 88.0  | 130.0 | 67.5  | 99.4  | 76.6  | 76.7 | 23.9  | 28.0 |
| Mean    | 75.5  | 128.7 | 57.0  | 100.5 | 75.6  | 78.1 | 23.5  | 30.1 |
| F       | 3.50* | 4.25* | 4.5*  | 3.56* | 4.1*  | 2.29* | 1.37  | 5.17* |
| LSD$_{0.05}$ | 16.04 | 8.08  | 13.0  | 6.52  | 4.29  | 1.63  | 2.15  | 1.66 |

Significantly significant indicators of the components of dominance (H$_1$, H$_2$). By the weight of the cob and grain, as well as by the number of grains in a row, in absolute value exceed the values of the
D component (table 4). The ratio $\sqrt{H_i/D}$ according to these parameters is greater than one (1.35-9.40), which indicates a positive effect of overdominance. The obtained data confirm the conclusions of other researchers [12].

According to the yield of grain from the cob, significant indicators of the component characterizing the additive effect of genes (D) and insignificant values of the dominance components were noted. The value of the $\sqrt{H_i/D}$ component (0.78) indicates the effect of incomplete dominance.

**Table 3.** Combining ability of self-pollinated maize lines by crop structure elements, average 2016-2019, %.

| Line    | The mass of the cob, g | Weight of grain from the cob, g | Grain output, % | Number of grains in a row, th. | Number of grains per cob, th. |
|---------|------------------------|---------------------------------|-----------------|-------------------------------|-------------------------------|
|         | OKC | CKC | OKC | CKC | OKC | CKC | OKC | CKC | OKC | CKC | OKC | CKC |
| RN26    | 4.3 | 230.8 | 3.0 | 138.4 | -0.3 | 3.6 | 1.8 | 4.6 | 16.2 | 1689.1 |
| MK 130 U | 2.1 | 112.4 | 0.1 | 72.4 | -1.6 | 4.7 | 0.6 | 3.5 | 33.5 | 1075.7 |
| MK 11   | 12.2 | 193.7 | 8.0 | 140.5 | -1.4 | 3.7 | -0.2 | 6.2 | 3.3 | 1246.8 |
| UK12D2 | -1.2 | 92.2 | -0.3 | 62.6 | 1.1 | 1.9 | 1.0 | 3.7 | 0.3 | 552.1 |
| RSK 25  | -1.1 | 116.0 | 0.0 | 69.6 | 0.8 | 2.8 | 0.3 | 3.2 | 18.3 | 917.0 |
| Om 255  | -1.3 | 85.1 | -2.0 | 41.4 | -0.7 | 1.6 | 0.2 | 3.2 | 3.9 | 889.8 |
| X46     | -5.1 | 141.1 | -4.1 | 93.5 | -0.2 | 2.2 | -0.8 | 4.1 | -24.6 | 1102.4 |
| RSK 7   | 4.6 | 211.7 | -3.7 | 105.9 | -0.2 | 2.3 | 1.3 | 5.7 | 26.5 | 1560.5 |
| CL 7    | -11.7 | 183.3 | -9.2 | 112.2 | -0.6 | 1.9 | 0.4 | 8.3 | -44.1 | 1367.7 |
| KS 25   | -1.3 | 186.9 | 0.2 | 118.1 | 0.9 | 1.4 | -1.3 | 4.2 | -22.9 | 1261.1 |
| YuV19  | -3.9 | 93.7 | -1.2 | 73.7 | 1.5 | 2.7 | 1.0 | 6.2 | 0.5 | 805.9 |
| RSK 3   | 5.2 | 182.1 | 5.3 | 124.7 | 1.1 | 2.2 | -1.6 | 5.0 | -6.2 | 735.2 |
| Bg 1266 | -1.0 | 282.3 | -1.3 | 181.7 | -0.3 | 2.5 | -2.4 | 7.6 | 26.5 | 1220.3 |
| LV32    | -2.1 | 128.5 | -1.1 | 89.8 | 0.4 | 1.7 | 0.8 | 3.3 | 4.0 | 1221.3 |
| Od 28   | -2.2 | 90.6 | -1.3 | 52.8 | 0.6 | 2.5 | -0.1 | 5.0 | -13.4 | 1393.3 |
| Om 232  | 2.4 | 151.9 | 0.2 | 75.4 | -1.0 | 3.0 | -1.3 | 6.6 | -21.7 | 917.2 |
| F       | 2.02* | 1.87* | 1.63 | 1.83* | 4.65* | 1.07* | 4.75* | 1.95* | 4.97* | 1.38* |
| LSD_{0.05} | 14.6 | 11.9 | 1.73 | 2.12 | 37.82 |

The difference between the overall average trait in all offspring (ml1) and the average parental forms (ml0) for the studied traits is positive, which indicates that dominance in all parameters is directed towards parental forms with a greater severity of the trait, which is confirmed by $h > D$.

The values of the $H_2/4H_1$ ratio for the studied traits are significantly less than the theoretical value (0.25), which indicates an uneven distribution of alleles with positive and negative effects. Analysis of the components indicates that 9-11 genes or groups of genes influence the manifestation of the cob mass and grain mass, and the manifestation of the number of grains in a row is controlled by 7 genes. Insignificant values of the $H_2$ component in terms of grain yield and the number of grains on the cob do not allow one to reliably determine the number of genes that affect the manifestation of traits.

In 2016-2019 The paratypical component of the dispersion (E) had a significant effect on the elements of the yield structure.

The relative contribution of genes with additive and dominant effects in the development of a trait characterizes the significance of the genetic component Fr. Negative and significant indicators of the $fr$ component were noted by: the weight of the cob in the lines MK 130 U ($fr = -839.7$), CL-7 ($fr = -1208.0$); the mass of grain from the cob CL-7 ($fr = -691.4$); the number of grains in a row for line Bg 1266 ($fr = -28.8$); the number of grains on the cob at line RSC 7 ($fr = -1272.9$), Bg 1266 ($fr = -8371.9$). Positive and significant values of the $fr$ component were identified on the basis of "grain yield" in lines X46 ($fr = 28.6$), CL-7 ($fr = 27.6$), KS 25 ($fr = 31.3$), YuV 19 ($fr = 20.7$), RSK 3 ($fr = 27.8$), LV 32 ($fr = 19.4$), Od 28 ($fr = 23.7$), Om 232 ($fr = 17.6$).
4. Conclusion
The use of diallel analysis makes it possible to determine the components of genetic dispersion and evaluate the self-pollinated maize lines included in the working collection. As a result of the assessment of self-pollinated maize lines for combination ability by elements of the grain yield structure, high effects of GCA and SCA dispersion were noted in the following cross components: RN 26, Bg 1266, Mk 11, RSK 7. These lines can be used to identify promising hybrid combinations and obtain synthetic populations. It is expedient to use the CL 7 lines with low GCA when highlighting individual valuable combinations. A significant influence of the components of dominance (H₁, H₂) was established, and also that dominance is directed towards parental forms with a greater severity of the trait.

References
[1] Goncharenko A A, Krakhmalev S V, Makarov A V and Ernakov S A 2015 Genetic analysis of quantitative traits in inbred lines of winter rye (Secale cereale L.) in diallel crosses. *Agricultural Biology* 1 75-84
[2] Dospekhov D A 1985 *Methods of field experience* (Moscow: Agropromizdat) 351
[3] Dragavtsev V A, Litun P P, Shkel N M and Nechiporenko N N 1984 Model of ecological-genetic control of quantitative traits of plants. *Doklady AN SSSR* 3 720-723
[4] Zhuzhukin V I, Zaitsev S A, Volkov D P and Gudova L A 2018 Evaluation of the combination ability of maize lines in diallel crosses according to the height of attachment of the cob. *Successes of modern natural science* 10 50-55
[5] Zaitsev S A 2020 The use of diallel analysis in the study of the combination ability of corn. *Agrarian scientific journal* 8 16-19
[6] Kibalnik O P 2016 Combining ability of CMS lines of grain sorghum by yield elements. *Corn and sorghum* 3 10-13
[7] Koretskaya L S 2012 Diallel analysis of soybean resistance to fusarium. *Fruit growing and berry growing in Russia* 1 356-371
[8] Krivosheev G Ya and Ignatiev A S 2018 Development of model values of elements of productivity of corn hybrids created for arid conditions. *Tauride Bulletin of Agrarian Science* 4(16) 96-75
[9] Novichikhin A P, Lemeshev N A and Gulnyashkin A V 2019 The study of the combination ability of new early ripe maize lines. *Risovodstvo* 1(42) 54-57

**Table 4.** Estimation of the components of genetic dispersion by crop structure elements of self-pollinated maize lines, 2016-2019. %

| Component | The mass of the cob value | Weight of grain from the cob value | Grain output value | Number of grains in a row value | Number of grains per cob value |
|-----------|---------------------------|-----------------------------------|-------------------|-------------------------------|-------------------------------|
| D         | -201.1                    | -127.6                            | 13.4              | 0.3                           | 300.5                         |
| F         | -423.1                    | -263.7                            | 17.4*             | -2.4                          | -2675.8                       |
| H₁        | 824.9*                    | 550.6*                            | 8.3               | 26.6*                         | 550.2                         |
| H₂        | 985.4*                    | 638.1*                            | 1.2               | 21.3*                         | 1347.1                        |
| h         | 9347.8*                   | 6729.6*                           | 14.1*             | 149.6*                        | 23971.8*                      |
| E         | 407.8*                    | 279.2*                            | 9.3*              | 13.4*                         | 3949.8*                       |
| m11-m10   | 48.7                      | 41.3                              | 2.0               | 6.2                           | 79.5                          |
| √H₁/D    | 2.02                      | 2.08                              | 0.78              | 9.4                           | 1.35                          |
| H₂/4H₁    | 0.29                      | 0.29                              | 0.04              | 0.20                          | 0.61                          |
| √(4DΗ₁)+F/√(4DΗ₁)-F | 1.00  | 1.00                             | 1.04              | 0.93                          | 1.00                          |
| h/ H₂     | 9.5                       | 10.5                              | 11.8              | 7.0                           | 17.8                          |
| r =       | -0.60 (df = 10)           | -0.51 (df = 11)                   | -0.73 (df = 13)   | -0.24 (df = 10)               | 0.68 (df = 10)                |

\[ r = \sqrt{\frac{1}{n-1} \sum (x_i - \bar{x})^2} \]
[10] **Methodology of state variety testing of agricultural crops. Issue. 2. Cereals, cereals, legumes, corn and fodder crops** 1989 (Moscow: Gosagroprom USSR) 194

[11] Obydalo N D 2016 The study of hybrid combinations of confectionery sunflower, obtained on the basis of ox estimates, by the method of diallel analysis and top cross. *Oil cultures* 1(165) 22-28

[12] Paritov A Yu, Aishaeva Z M and Aloeva B A 2015 Evaluation of the components of genetic variation based on data from diallel crosses. *Modern Problems of Science and Education* 3 575

[13] Turbin N V, Khotyleva L V and Tarutina L A 1974 *Diallel analysis in plant breeding* (Minsk) 184

[14] Fedin M A, Silis D Ya and Smiryaev A V 1980 *Statistical methods of genetic analysis* (Moscow: Kolos) 208

[15] Khotyleva L V, Mishin L A and Tarutina L A 1996 Analysis of various cross-breeding schemes for assessing the overall combination ability of the initial material in terms of early ripeness and total yield. *Vegetable growing* 9 38

[16] Griffing B 1956 Concept of general and combining ability in relation to diallel crossing systems. *J. Biol. sci.* 9 463-493

[17] Hayman B I 1954 The theory and analysis of diallel crosses. *Genetics* 10 235–244