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RESEARCH ARTICLE

# Analysis of strategies for combining productivity with disease and pest resistance in the genotype of base breeding lines of maize in the system of diallele crosses

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## Abstract

According to the comparative results of the obtained values of GCA effects of self-pollinated lines by the resistance to pest damage and disease affection with the values of GCA effects by grain production, it is reasonable to mention such self-pollinated lines as UH 405, F 502 and SM 5-1-1. These lines combine the negative values of GCA effects by pest damage and disease affection with high positive GCA effects by grain productivity in conditions of monoculture.

Line UHK 409, despite the negative values of GCA effects by productivity, is still important as a form resistant to diseases and pests; this line can be used in saturating crosses to transfer valuable traits resistant to pathogens to different efficient patterns.

**Keywords:** Diallele crosses, base breeding lines, breeding pair, general combining ability (GCA), specific combining ability (SCA), boil and head smut, European corn borer, *Oscinella*

## Introduction

Maize is one of the dominant crops in Ukraine and the world. Food, processing, medical, microbiological, brewing industries as well as fuel and energy sectors of the country are interested in its grain production, as it is a high-energy raw material for the industrial production of bioethanol and other fuel materials. The research was aimed at developing and identifying the self-pollinated lines resistant to main diseases and pests; finding out the determinative sig ns for the development of principles of the breeding pair selection when creating the maize hybrids resistant to the complex of entomopathogens and phytopathogens adapted to the conditions of the Right-Bank Forest-Steppe of Ukraine (Palamarchuk 2018; Tanchik 2009).

## Materials and Methods

The field methods were used for individual selection in the breeding nursery, phenological observations, and sampling; the laboratory methods for the analysis of plants by morphological signs, genetic for the identification of the breeding and genetic modifications of maize lines in the creation of hybrids of different ripeness groups when using monoculture in combination with valuable economic characters resistant to diseases and pests; statistical for the establishment of regularities of variability of signs and the degree of reliability between the variants of research; comparative calculating for the determination of economic efficiency.

On the territory of the Vinnytsia region, where the research area is located, the climate is moderately warm. Winter begins in the second or third decade of

November. Snow cover occurs on average in the third decade of December and melts in the third decade of March. Its height in the western and southern parts of the zone ranges from 13 to 20 cm, and in the eastern part from 26 to 35 cm. The average monthly air temperature in January and February varies from -4 to -8°C. This zone is characterized by long thaw periods, during which the air temperature in some years rises to +12 to +14°C.

Spring lasts from 65 to 75 days. The rise of air temperature over +5°C is observed in the first decade of April. Summer is characterized by high and stable temperatures. In July, the average monthly air temperature varies from +10°C in the west to + 20°C in the east. The absolute peak temperature reaches +39 to +49°C. The duration of vegetation period is 150-170 days. Moreover, dry periods and hot winds are often observed.

According to the average long-term data, the maize in the research area undergoes the main stages of its development on the following calendar dates: sprouting stage-May 20; the third leaf appearance stage-May 26; panicle appearance stage-July 14; cob flowering stage July 20; kernel milk stage-August 22; kernel dough stage September 11 (Kolisnyk 2016; Dospekhov 1985).

Thus, the first two research years were most favorable for the maize growth and development by weather indicators. They have contributed to the maize resistance to disease and pests and the intensive growth and development of plants. In the third subsequent year, there was a significant deterioration in climatic conditions due to a long dry period, which fell on the stages of panicle and cob flowering and the kernel development.

## Results and Discussion

Genetic aspects of the manifestation of valuable economic features and properties, in particular, grain yield and resistance to pests, can be more closely analyzed by means of diallel crosses. Crosses of the self-pollinated lines, which differ by the performance indicator being studied, guarantee the determination of their combining ability, that is, the genotypic possibility of the implementation of heterosis effect.

The analysis of the genetic structure of General Combining Ability (GCA) and specific combining ability (SCA) foresees that, in the absence of epistasis, GCA is stipulated by the additive and mid-dominant type of genetic activity, whereas SCA by overdominance. In the presence of epistasis, it can be expected that both types of combining abilities contain the epistatic part: GCA includes the average epistatic effect, and SCA - the epistatic effect associated with individual hybrid combinations (Turbin 1974; Tsiuk 2013; Butenko 2019).

The above-listed authors state that GCA expresses the average variability of the genotype in hybrid combinations, whereas SCA is used to characterize some certain combinations when they are better or worse than the average index of the breeding pairs.

Thus, as a result of the comparison of GCA and SCA indices, it is possible to determine the type of genetic interactions that control certain characters making it possible to choose the baseline for the selection of hybrid combinations with desired properties.

To ensure the essentiality of the genetic study of combining value of a baseline, the analysis of the combining ability should include the evaluation of self-pollinated maize lines with contrasting indicators. According to Method 1 of the first Griffing model, the breeding system included, according to the results of the previous sections, 8 self-pollinated maize lines (F 502, UH 405, SM 5-1-1, MA 22, UHC 409, SO 255, KL 17, SO 108), which were characterized by different indicators of grain productivity, resistance to pests and duration of growing season (Turbin 1974; Kolisnyk 2016; Tsyhanskyi 2019).

The disperse analysis determining the resistance of hybrid combinations to pests and diseases (Tab. 1) demonstrated that in this group there are significant genotype differences according to the indicators being studied. The obtained results make it possible to analyze GCA and SCA in the self-pollinated lines used in crosses (Palamarchuk 2009; Scherner 2016; Radchenko 2018).

The data analysis of mean squares of GCA and SCA for the diseases of hybrid combinations has demonstrated that there are significant genotype differences in this group according to the indicators being studied. The obtained results make it possible to analyze GCA and SCA in the self-pollinated lines used in the crosses (Tab. 2).

The data of mean squares of general and specific combining ability by resistance to pests that were taken into account according to the assessing technique of maize General Combining Ability (GCA) and Specific Combining Ability (SCA) (Kolisnyk 2010; Mazur 2016).

Thus, the total genotype variability was subdivided into the components due to general and specific combining ability as well as reciprocal effects.

Chuchmii I. P. (Chuchmii 1997) states that the resistance to the European corn borer, Boil smut and Head smut is inherited at a polygenic level on conditions that genes act in additive and non-additive ways, which is confirmed by the data obtained by us.

The reliability of the reciprocal effect on all properties being studied emphasizes the necessity for reciprocal analysis in the selection of breeding pairs for hybridization.

We have established that the lines with a positive GCA value are characterized by low resistance to disease and pest damage, whereas the lines with a negative value by high resistance (Kolisnyk 2010; Palamarchuk 2010; Kolisnyk 2019).

Assessment of the effects of general and variance specific

**Table 1.** Disperse analysis of the maize hybrids damaged by pests and affected by diseases (2006-2016).

| Year | Source of variation | SS (sum of squares) | Number of degrees of freedom | Mean square | Criterion F | | |
|---|---|---|---|---|---|---|---|
| | | | | | Actual | Tabular | |
| | | | | | | 0.05 | 0.01 |
| European corn borer | | | | | | | |
| 2006 2016 | Common | 13140.59 13797.33 | 255 255 | – | – | – | – |
| 2006 2016 | Hybrids | 12762.51 12807.01 | 63 63 | 202.57 203.28 | 103.35 39.47 | 1.38 1.38 | 1.48 1.48 |
| 2006 2016 | Repetition | 6.22 16.75 | 3 3 | 2.07 5.58 | 1.05 1.08 | 2.65 2.65 | 2.70 2.70 |
| 2006 2016 | Accidental deviations | 371.86 973.57 | 189 189 | 1.96 5.15 | – | – | – |
| *Oscinella* | | | | | | | |
| 2006 2016 | Common | 22055.14 24673.90 | 255 255 | – | – | – | – |
| 2006 2016 | Hybrids | 21506.98 23825.96 | 63 63 | 341.38 378.18 | 120.33 85.56 | 1.38 1.38 | 1.48 1.48 |
| 2006 2016 | Repetition | 11.92 11.60 | 3 3 | 3.97 3.86 | 1.40 0.87 | 2.65 2.65 | 2.70 2.70 |
| 2006 2016 | Accidental deviations | 536.24 836.34 | 189 189 | 2.84 4.42 | – | – | – |
| Year | Source of variation | SS (sum of squares) | Number of degrees of freedom | Mean square | Criterion F | | |
| | | | | | Actual | Tabular | |
| | | | | | | 0.05 | 0.01 |
| Boil smut | | | | | | | |
| 2006 2016 | Common | 8736.87 20369.70 | 255 255 | – | – | – | – |
| 2006 2016 | Hybrids | 8198.24 19643.90 | 63 63 | 130.13 311.80 | 45.82 82.26 | 1.38 1.38 | 1.48 1.48 |
| 2006 2016 | Repetition | 2.38 8.59 | 3 3 | 0.79 2.86 | 0.27 0.75 | 2.65 2.65 | 2.70 2.70 |
| 2006 2016 | Accidental deviations | 536.25 717.22 | 189 189 | 2.84 3.79 | – | – | – |
| Head smut | | | | | | | |
| 2006 2016 | Common | 5028.74 5007.55 | 255 255 | – | – | – | – |
| 2006 2016 | Hybrids | 4674.19 4589.95 | 63 63 | 73.19 72.85 | 39.88 33.47 | 1.38 1.38 | 1.48 1.48 |
| 2006 2016 | Repetition | 7.65 6.26 | 3 3 | 2.55 2.08 | 1.38 0.95 | 2.65 2.65 | 2.70 2.70 |
| 2006 2016 | Accidental deviations | 346.90 411.34 | 189 189 | 1.84 2.18 | – | – | – |

**Table 2.** Diallel analysis of the maize self-pollinated lines damaged by pests and affected by diseases (2006-2016).

| Year | Source of variation | SS (sum of squares) | Number of degrees of freedom | Mean square | Criterion F | | |
|---|---|---|---|---|---|---|---|
| | | | | | Actual | Tabular | |
| | | | | | | 0,05 | 0,01 |
| | | | European corn borer | | | | |
| 2006 2016 | GCA | 2778.95 2809.44 | 7 7 | 396.99 401.34 | 807.10 311.65 | 2.07 2.07 | 2.82 2.82 |
| 2006 2016 | SCA | 208.82 204.19 | 28 28 | 7.45 7.29 | 15.16 5.66 | 1.56 1.56 | 1.98 1.98 |
| 2006 2016 | Reciprocal distinctions | 202.86 188.12 | 28 28 | 7.24 6.71 | 14.72 5.21 | 1.56 1.56 | 1.98 1.98 |
| | | | *Oscinella* | | | | |
| 2006 2016 | GCA | 4432.77 4806.79 | 7 7 | 633.25 686.68 | 892.77 620.72 | 2.07 2.07 | 2.82 2.82 |
| 2006 2016 | SCA | 333.85 347.12 | 28 28 | 11.92 12.39 | 16.80 11.20 | 1.56 1.56 | 1.98 1.98 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2006<br>2016 | Reciprocal distinctions | 610.12 802.58 | 28<br>28 | 21.79 28.66 | 30.72<br>25.91 | 1.56<br>1.56 | 1.98<br>1.98 |
| | | | Boil smut | | | | |
| 2006<br>2016 | GCA | 1584.38 4008.12 | 7<br>7 | 226.33<br>572.58 | 319.08 603.54 | 2.07<br>2.07 | 2.82<br>2.82 |
| 2006<br>2016 | SCA | 222.54 449.52 | 28<br>28 | 7.94<br>16.05 | 11.20<br>16.92 | 1.56<br>1.56 | 1.98<br>1.98 |
| 2006<br>2016 | Reciprocal distinctions | 242.64 453.34 | 28<br>28 | 8.66<br>16.19 | 12.21<br>17.06 | 1.56<br>1.56 | 1.98<br>1.98 |
| | | | Head smut | | | | |
| 2006<br>2016 | GCA | 749.94 685.11 | 7<br>7 | 107.13 97.87 | 233.47<br>5.58 | 2.07<br>2.07 | 2.82<br>2.82 |
| 2006<br>2016 | SCA | 71.73<br>84.77 | 28<br>28 | 2.56<br>3.03 | 179.87<br>5.56 | 1.56<br>1.56 | 1.98<br>1.98 |
| 2006<br>2016 | Reciprocal distinctions | 346.87 377.61 | 28<br>28 | 12.38 13.48 | 26.99<br>24.78 | 1.56<br>1.56 | 1.98<br>1.98 |

combining ability according to the indicators being studied are given in Tab. 3 and 4.

It should be mentioned that the stability of resistance to the damage caused by both pests and diseases (according to the difference in ranks) is, on the one hand, present in some self-pollinated lines, but is variable on the other hand. This points out the different effects of liability to diseases and damage by pests of the breeding pairs and the hybrid breed, depending on fluctuations in weather conditions over the years of research.

In general, the interaction of genotype with environment from the standpoint of realization of signs resistant to pests and diseases is the most vulnerable indicator of reliability in search of self-pollinated lines as donors resistant to diseases and pests, since phytophages and phytopathogens have a close connection with both hydrothermal environmental conditions and special features of phenological development of lines themselves and maize hybrids, the fact that has already been proved in section 4 of the thesis.

Therefore, from the standpoint of creation of hybrids resistant to pests and diseases, in breeding practice, it's urgent to maximize the separation of properties of the genotype itself from its reaction to changes in the growing conditions for the separation of resistant and adapted donors of such resistance.

Analyzing the data given in Tab. 3 it should be noted that the better combining ability to resist the damage caused by the European corn borer has been determined in lines F502, SM 5-1-1, UH 405 and UHC 409, which were characterized by negative values of GCA effects.

Self-pollinated lines SO 108, KL 17, SO 255 and MA 22 were characterized by high positive values of SCA effects, therefore, the resistance to damage by the European corn borer of simple hybrids obtained with the participation of these lines was low.

Lines SM 5-1-1 and UH 405, that were characterized by negative GCA effects and slight SCA variance by the resistance to damage caused by this pest, are most appropriate to be used to create hybrids with high resistance to the European corn borer.

High SCA rates of the damage caused by the European corn borer in self-pollinated lines F 502 and UHK 409 have been determined. The use of these lines in crosses provides for hybrid combinations of both high and low stability.

As for resistance to damage caused by *Oscinella*, it is necessary to mention lines KL 17, MA 22, UHK 409, F 502 and UH 405, which were characterized by high combining ability by this indicator. In their turn, self-pollinated lines SO 255, SO 108 and SM 5-1-1had low GCA indices over the years of research.

Such lines as MA 22, F 502 and UH 405, which were distinguished by negative values of GCA effects and insignificant SCA variance by the resistance to damage caused by *Oscinella*, are most expedient to be used to create hybrids with high resistance to this pest. The self-pollinated lines with high negative GCA values-KL 17 and UHK 409 had high SCA variance. Just for that reason, in crosses with their participation, the defining factor in the formation of resistance to *Oscinella*, along with high GCA values, is also its specific combining manifestation, that is, its greater or lesser value in individual hybrid combinations.

According to our research, such lines as UHK 409, SO 108, MA 22 and F 502, which had negative values of GCA effects over the years of research were noted for their combining ability to better resist boil smut (Tab. 4).

Self-pollinated line SO 255 was characterized by positive values of GCA effects, therefore, the resistance to boil smut of the hybrids obtained with the participation of this line was low.

Lines UHK 409 and SO 108 are characterized by negative values of GCA effects and insignificant SCA variance by the resistance to damage caused by boil smut, therefore, it's expedient to use them to create hybrids resistant to this disease.

According to the results of our research, the self-pollinated lines with high negative values of GCA effects-

**Table 3.** Assessment of the effects of general (gi) and v y pest damage (2006-2016).

| Self-pollinated lines | GCA | | | | | | | | SCA | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | | | | 2016 | | | | 2006 | | | | 2016 | | | |
| | European corn borer | | *Oscinella* | | European corn borer | | *Oscinella* | | European corn borer | | *Oscinella* | | European corn borer | | *Oscinella* | |
| | gi | rank | gi | rank | gi | rank | gi | rank | $\sigma^2_{si}$ | rank | $\sigma^2_{si}$ | rank | $\sigma^2_{si}$ | rank | $\sigma^2_{si}$ | rank |
| F502 | -4.682 | 1 | -3.869 | 4 | -3.949 | 3 | -5.023 | 1 | 4.703 | 2 | 3.956 | 5 | 5.771 | 1 | 2.694 | 7 |
| UH 405 | -4.139 | 3 | -1.525 | 5 | -4.734 | 1 | -1.620 | 5 | 2.673 | 6 | 1.639 | 8 | 1.056 | 6 | 0.463 | 8 |
| SM 5-1-1 | -4.516 | 2 | 0.056 | 6 | -4.623 | 2 | -0.175 | 6 | 2.225 | 7 | 2.479 | 7 | 0.120 | 8 | 3.839 | 4 |
| MA 22 | 1.964 | 5 | -4.281 | 2 | 1.968 | 6 | -3.272 | 4 | 1.165 | 8 | 4.361 | 4 | 0.712 | 7 | 3.004 | 6 |
| UHC 409 | -3.836 | 4 | -4.075 | 3 | -3.571 | 4 | -4.117 | 3 | 4.816 | 1 | 5.591 | 2 | 4.512 | 2 | 4.728 | 2 |
| SO 255 | 2.048 | 6 | 13.259 | 8 | 1.774 | 5 | 14.07 | 8 | 3.497 | 4 | 16.436 | 1 | 3.334 | 3 | 18.901 | 1 |
| KL17 | 5.023 | 7 | -4.728 | 1 | 4.310 | 7 | -4.773 | 2 | 3.175 | 5 | 5.397 | 3 | 2.627 | 4 | 4.668 | 3 |
| SO 108 | 8.139 | 8 | 5.163 | 7 | 8.824 | 8 | 4.911 | 7 | 4.204 | 3 | 2.970 | 6 | 2.207 | 5 | 3.707 | 5 |
| $HIP_{0,05}$ | 0.32 | | 0.38 | | 0.52 | | 0.48 | | | | | | | | | |
| $HIP_{0,01}$ | 0.42 | | 0.51 | | 0.68 | | 0.63 | | | | | | | | | |
| $\sigma^2_{si}$ | | | | | | | | | 3.31 | | 5.35 | | 2.54 | | 5.25 | |

**Table 4.** Assessment of the effects of general (gi) and variance specific (σ2si) combining ability of self-pollinated lines by disease affection (2006-2016).

| Self-pollinated lines | GCA | | | | | | | | SCA | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | | | | 2016 | | | | 2006 | | | | 2016 | | | |
| | Boil smut | | Head smut | | Boil smut | | Head smut | | Boil smut | | Head smut | | Boil smut | | Head smut | |
| | gi | rank | gi | rank | gi | rank | gi | rank | $\sigma^2_{si}$ | rank | $\sigma^2_{si}$ | rank | $\sigma^2_{si}$ | rank | $\sigma^2_{si}$ | rank |
| F502 | -0.888 | 4 | -0.522 | 6 | -1.218 | 5 | -0.416 | 6 | 3.817 | 4 | 0.614 | 5 | 10.460 | 2 | 0.987 | 5 |
| UH 405 | 0.059 | 7 | -0.560 | 5 | -0.903 | 7 | -0.904 | 4 | 1.576 | 7 | 0.496 | 7 | 3.029 | 7 | 0.547 | 6 |
| SM 5-1-1 | -0.213 | 6 | -1.739 | 2 | -1.042 | 6 | -1.744 | 1 | 1.222 | 8 | 0.005 | 8 | 1.568 | 8 | 0.010 | 8 |
| MA 22 | -1.418 | 3 | -0.577 | 4 | -2.396 | 2 | -0.660 | 5 | 4.328 | 2 | 1.551 | 1 | 5.833 | 4 | 1.868 | 1 |
| UHK 409 | -4.227 | 1 | -1.077 | 3 | -5.445 | 1 | -1.477 | 2 | 3.685 | 5 | 1.199 | 4 | 3.524 | 6 | 1.569 | 3 |
| SO 255 | 8.679 | 8 | 0.704 | 7 | 14.350 | 8 | 0.717 | 7 | 5.806 | 1 | 1.348 | 2 | 20.941 | 1 | 1.822 | 2 |
| KL17 | -0.288 | 5 | 6.018 | 8 | -1.682 | 3 | 5.820 | 8 | 2.626 | 6 | 1.278 | 3 | 5.433 | 5 | 1.075 | 4 |
| SO 108 | -1.702 | 2 | -2.247 | 1 | -1.670 | 4 | -1.336 | 3 | 3.866 | 3 | 0.609 | 6 | 6.911 | 3 | 0.501 | 7 |
| $HIP_{0.05}$ | 0.39 | | 0.31 | | 0.45 | | 0.34 | | | | | | | | | |
| $HIP_{0.01}$ | 0.51 | | 0.40 | | 0.59 | | 0.45 | | | | | | | | | |
| $\sigma^2_{si}$ | | | | | | | | | 3.36 | | 0.88 | | 7.21 | | 1.04 | |

SM 5-1-1, SO 108, UHK 409, MA22, F 502 and UH 405-were distinguished by the resistance to damage caused by head smut.

Self-pollinated lines SO 255 and KL 17 were characterized by positive values of GCA effects, therefore, the resistance to damage caused by head smut in hybrids obtained with the participation of these lines was average.

Lines SM 5-1-1, SO 108, F 502 and UH 405 were mentioned by negative values of GCA effects and insignificant SCA variance by the resistance to damage caused by head smut, which ensures their use in creation of hybrids resistant to this disease.

Thus, over the years of research, such self-pollinated lines as UH 405, F 502 and UHK 409 were distinguished by their complex resistance to pest damage and disease affection and were marked by high GCA effects to the pathogens being studied.

By the resistance to the European corn borer and head smut, self-pollinated line SM 5-1-1 is also worth mentioning, but by the resistance to *Oscinella*, boil smut and head smut line 22.

## Conclusion

Thus, despite the significant loss of grain yield due to the negative effects caused by pests, the proportion of genotypic conditionality of grain productivity for each particular breeding form did not go beyond the parameters of the range of values of breeding patterns over the years of research.

It is expedient to pay attention once more to the important influence of the specific combining ability on the effects of grain productivity of the breeding material under study since its role in the manifestation of this property is significant and exceeds GCA variance for all patterns.

Thus, the study of the combining ability of the maize baseline resistant to diseases and pests has enabled us to identify the breeding patterns which combine the indicated features required for practical breeding in the best possible way.

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