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# COMBINING ABILITY ANALYSIS OF MAIZE INBRED LINES SUITABLE FOR MACHINE HARVEST

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**Abstract**

Using self selected maize inbred lines and hybrid combinations as test materials, the combining ability of maize hybrids suitable for machine harvest was analyzed. Ten maize inbred lines were selected as female parent (P1) and three inbred lines as male parent (P2). The experiment design of incomplete diallel cross was adopted in this study. The combining ability of 10 agronomic characters such as plant height, ear height, ear grain weight, ear length, ear diameter, number of rows per ear, number of grains per row, 100-grain weight, number of branches in male ear and water content at harvest were analyzed. The present findings revealed that in terms of general combining ability, JM39 was the best in ear length, grain number per row, 100-grain weight, branch number of male ear and water content at harvest, followed by JM35, JM26 and JM28. In terms of specific combining ability, the combination with better performance were JM39×JF167, JM39×JF200 and JM35×JF167. Moreover, JM26, JM28, JM35 and JM39 could be used directly, and the other inbred lines could be improved and reused. Plant height, number of rows per ear, number of grains per row and 100-grain weight should be selected in the early generation, while ear height, ear diameter, number of branches in male ear and water content at harvest should be selected in the late generation.

## Introduction

In recent years, China's people's living standards have been continuously improved, in which maize plays an irreplaceable role as a food crop, feed crop and industrial raw material (Yu *et al.* 2018, Wang *et al.* 2019, Jin *et al.* 2021). With the development of land circulation and agriculture, the scale of maize planting is increasing. It is not only necessary to ensure the high yield, high quality, density and disease resistance of maize, but also a major problem in maize variety breeding (Wang *et al.* 2017, Hao *et al.* 2021). Moreover, in order to adapt to the national conditions of China's aging population, mechanization is also the only way which must be passed for modern agriculture (Ma *et al.* 2019). In the present experiment, a complete diallel cross design was used to make 36 hybrid combinations of 10 female parent maize inbred lines and 3 male parent maize inbred lines with some excellent characters suitable for machine harvest, and the combining ability of their correlation with machine harvest was analyzed. The purpose is to provide a useful reference for guiding the combination of maize hybrids and breeding maize varieties suitable for mechanized harvest.

## Materials and Methods

In December 2019, in Hainan breeding base of Jilin Agricultural Science and Technology University (18°35′ N, 109°19′ E), 30 hybrid combinations were prepared according to NC II griffing genetic mating design with 10 newly selected maize inbred lines JM26, JM28, JM31, JM35, JM39, JM43, JM46, JM50, JM54 and JM60 as female parents and 3 maize inbred lines JF156, JF167 and JF200 as male parents.

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In May 2020, the above-mentioned maize breeding combinations were identified in the field breeding base of Jilin Agricultural Science and Technology University (43°57' N, 126°40′ E). A randomized block design was used in the experiment, which was set as three repetitions, four row area, with a length of 4 m, a row spacing of 60 cm. The field management was the same as the land for growing field crops. The specific method of yield measurement in autumn was to continuously measure the plant height and ear position of 10 plants (except the first 3 plants) in the middle row of the plot, and measure the water content at harvest. After harvest and air drying, five representative seeds were selected for indoor test, and the agronomic characters such as ear diameter and ear length were recorded.

Based on the average number of tested varieties of each trait, the preliminary data processing was carried out with Excel 2017 software, and then the data processing and analysis were carried out with DPS 7.1 software (Tang and Feng 2002 and Pei *et al.* 2020)

**Results and Discussion**

Through the variance analysis of combining ability of 10 agronomic characters of 30 hybrid combinations, results of variance analysis of suitable machine harvest characters are listed in Table 1. It can be seen from Table 1 that there was no significant difference among the 10 characters, indicating that the field fertility selected in this test was similar, the difference of soil fertility could be excluded, and the design was reasonable. The traits suitable for machine harvest among different combinations reached a very significant level, indicating that these traits really have genetic differences among hybrid combinations. Except that the differences of general combining ability (GCA) in ear diameter and row number per ear of the tested species (male parent, P2) did not reach a significant level, the differences of other general combining ability (GCA) and all specific combining ability (SCA) reached a very significant or significant level, indicating that there are real differences between parents and combinations in GCA and SCA of most traits.

General combining ability (GCA) refers to the average value of a quantitative trait in the hybrid offspring produced by the hybridization of a parent variety with several other parent varieties, which could be inherited. It is apparent from Table 2 that there were great differences in GCA effect values of different inbred lines on the same trait, and there were also great differences in GCA effect values of the same inbred line on different traits. Therefore, when selecting breeding objectives, it was necessary to select appropriate inbred lines for combination.

In terms of plant height and ear height, the GCA relative effect values of JM31, JM43, JM46, JM50 and JF200 were negative, indicating that the hybrid combination combined with them may effectively reduce the plant height and ear height of hybrid offspring and enhance the lodging resistance to a certain extent. In terms of ear grain weight, the GCA relative effect values of JM26, JM28, JM35, JM39, JM50, JM54, JM60, JF156 and JF167 were all positive, indicating that the hybrid combination can effectively improve the ear grain weight of hybrid offspring and had a great impact on yield, among which JM26 had the highest GCA relative effect value. In terms of ear length, the GCA relative effect values of JM26, JM28, JM31, JM35, JM39, JM50, JM54, JM60, JF156, JF167 and JF200 were positive, indicating that the hybrid combination combined with them may effectively increase the ear length of hybrid offspring, especially JM39. In terms of ear diameter, the GCA relative effect values of JM26, JM28, JM31, JM35, JM43, JM54, JM60, JF156, JF167 and JF200 were all positive, indicating that the hybrid combination combined with them may effectively increase the ear diameter of hybrid offspring. In terms of the number of rows per ear, the GCA relative effect values of JM26, JM28, JM31, JM39, JM50, JM54, JM60, JF167 and JF200 were all positive, indicating that the hybrid combination combined with them may effectively increase the number of rows per ear of hybrid offspring. In terms of the number of grains per row, the GCA relative effect values of JM26, JM28, JM31, JM35, JM39, JM43, JM54, JF156, JF167 and JF200 were positive, indicating that the combination can effectively increase the number of grains per row of hybrid offspring, of which JM39 was the most significant. In terms of 100-grain weight, the GCA relative effect values of JM26, JM28, JM31, JM35, JM39, JM46, JM54, JF156, JF167 and JF200 were positive, indicating that the combination can effectively increase the 100-grain weight of hybrid offspring and had a great impact on yield, among which JM39 had the highest GCA relative effect value. In the aspect of number of branches in male ear, JM39 had the lowest GCA relative effect value, and the fewer number of branches in male ear. On the contrary, the more male ear branches indicate that the combination of JM39 can effectively reduce the number of male ear branches of hybrid offspring. In terms of water content at harvest, JM39 had the largest GCA relative effect value, indicating that the combination of JM39 could effectively increase the water content at harvest of hybrid offspring. In conclusion, it may be inferred that JM39 had the best performance in ear length, grain number per row, 100-grain weight, number of branches in male ear and water content at harvest.

Specific combining ability (SCA) refers to the special effect that deviates from the average performance of parents in the performance of hybrid generation characters produced by the hybridization of two parental inbred lines in a specific combination. It depends on the dominant and epistatic effects in the genotype (Li *et al.* 2014, Jiang *et al.* 2019). Usually, based on the determination of general combining ability, the inbred line with high general combining ability is selected, and then its specific combining ability was further determined. In Table 3 the number of positive and negative combinations, the variation range of effect value and the number of hybrid combinations with the largest positive and negative effect value were summarized. It can be seen from Table 3 that the SCA effect value varied greatly among different combinations of various characters. The combination with the best plant height performance was JM46×JF200, the combination with the best performance in ear height was JM43×JF200, the combination with the best performance of ear grain weight was JM26×JF156, the combination with the best ear length performance was JM35×JF167, the combination with the best ear diameter performance was JM35×JF200, the best combination of the number of rows per ear and water content at harvest was JM39×JF200, the combination with the best performance in the number of grains per row, 100-grain weight and the number of male ear branches was JM39×JF167. In the process of maize inbred line breeding, one should not only pay attention to the screening of general combining ability, but also pay attention to the screening of specific combining ability. The following combinations, namely JM46×JF200, JM43×JF200, JM26×JF156, JM35×JF167, JM35×JF200, JM39×JF200 and JM39×JF167 were relatively in line with the machine harvest standard. It was necessary to further determine, analyze and identify the variety adaptability on the basis of their dehydration rate, grain filling rate, bract and other characters, so as to screen out the suitable machine harvest maize combination.

Generalized heritability refers to the percentage of genetic variance in phenotype variance, and narrow heritability refers to the percentage of additive variance in phenotype variance. The numerical value reflects the ability of parents' traits to be transmitted to their offspring. The greater the value, the stronger the genetic stability, and vice versa (Hao *et al.* 2021). From Table 4 it is apparent that the GCA variance of plant height, rows per ear, grains per row and 100-grain weight were much greater than the SCA variance, indicating that these traits were mainly affected by additive genes. On the other hand, the GCA variance of ear height was much smaller than SCA variance, indicating that it was mainly affected by non additive genes. Last but not the least the GCA variance of ear grain weight, ear length, ear diameter, the number of male ear branches and

**Table 1. F value of variance analysis of 8 agronomic traits.**

| Source of variation | DF | Plant height | Ear height | Grain weight | Ear length | Ear diameter | Rows per ear | Number of grains per row | 100-grainweight | Tassel branch | Water content at harvesting |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Block group | 2 | 0.284 | 0.438 | 0.575 | 0.617 | 0.378 | 0.179 | 0.231 | 0.167 | 0.585 | 2.335 |
| Combinations | 29 | 8.698** | 6.761** | 9.439** | 7.289** | 4.782** | 2.552** | 8.261** | 6.525** | -0.709** | -0.512** |
| P1 | 9 | 5.976** | 5.222** | 7.465** | 6.561** | 3.282** | 4.372** | 7.445** | 4.859** | -0.833** | 0.242** |
| P2 | 2 | 3.172* | 3.861* | 5.282* | 4.299* | 0.948 | 0.271 | 3.337* | 2.789* | 0.640* | -1.867* |
| P1×P2 | 18 | 6.090** | 5.119** | 5.289** | 4.959** | 2.956** | 3.868** | 6.788 | 2.979** | 1.8337** | 1.269** |
| Error | 58 | 22.304 | 29.049 | 2.436 | 0.589 | 1.931 | 0.409 | 1.481 | 1.327 | 0.3499 | 0.3193 |

*Means the difference was significant at 0.05 level and ** was extremely significant at 0.01 level.

**Table 2. GCA relative effect values of main agronomic traits of 10 corn inbred lines.**

| Inbred lines | Plant height | Ear height | Grain weight | Ear length | Ear diameter | Rows per ear | Number of grains per row | 100-grain weight | Tassel branch | Water content at harvesting |
|---|---|---|---|---|---|---|---|---|---|---|
| JM26 | 5.77 | 2.30 | 5.63 | 4.73 | 0.06 | 1.13 | 2.33 | 2.16 | -0.24 | 0.21 |
| JM28 | 4.30 | 1.41 | 2.85 | 5.28 | 0.17 | 2.16 | 3.18 | 2.58 | -2.24 | 1.16 |
| JM31 | -2.31 | -1.61 | -3.95 | 3.51 | 0.10 | 0.70 | 2.10 | 1.89 | 0.73 | -0.49 |
| JM35 | 2.69 | 0.24 | 4.94 | 5.44 | 0.13 | 0.02 | 3.39 | 3.21 | -1.86 | 1.33 |
| JM39 | 3.97 | 1.87 | 3.60 | 8.09 | -0.05 | 1.91 | 5.27 | 4.94 | -0.82 | 1.50 |
| JM43 | -3.26 | -2.75 | -2.54 | -1.84 | 0.05 | -0.07 | 0.76 | -1.02 | -2.10 | 0.29 |
| JM46 | -6.73 | -3.17 | -2.31 | -2.79 | -0.10 | -1.35 | -0.86 | 0.73 | 1.19 | -0.85 |
| JM50 | -2.09 | -2.03 | 1.10 | 3.13 | -0.06 | 1.18 | -0.73 | -2.55 | -2.24 | 0.26 |
| JM54 | 3.66 | 2.87 | 1.79 | 4.74 | 0.15 | 0.28 | 2.09 | 3.18 | -1.81 | 1.29 |
| JM60 | 2.51 | 1.13 | 2.61 | 2.98 | 0.07 | 0.20 | -1.60 | -1.04 | 0.69 | -0.22 |
| JF156 | 2.83 | 1.80 | 4.20 | 3.49 | 0.06 | -0.05 | 2.70 | 2.79 | 0.91 | -0.19 |
| JF167 | 0.98 | 0.26 | 3.35 | 6.26 | 0.08 | 0.15 | 4.95 | 3.44 | -0.14 | 0.34 |
| JF200 | -1.75 | -1.04 | -2.47 | 2.90 | 0.10 | 0.26 | 1.23 | 1.13 | 0.10 | 0.09 |

**Table 3. Results of SCA effect analysis of characters in different combinations.**

| Characters | Positive combinations | Negative combinations | Amplitude of effect value | The largest positive effect value of combinations | The largest negative effect value combinations |
|---|---|---|---|---|---|
| Plant height | 16 | 14 | -13.28～11.60 | JM26×JF167 | JM46×JF200 |
| Ear height | 15 | 15 | -9.49～7.41 | JM54×JF156 | JM43× JF200 |
| Grain weight | 17 | 13 | -17.98～19.44 | JM26×JF156 | JM31× JF200 |
| Ear length | 15 | 15 | -3.59～7.40 | JM35×JF167 | JM46×JF156 |
| Ear diameter | 14 | 16 | -0.30～0.33 | JM35×JF200 | JM46×JF167 |
| Rows per ear | 15 | 15 | -1.26～2.19 | JM39×JF200 | JM46×JF156 |
| Number of grains per row | 16 | 14 | -3.76～6.85 | JM39×JF167 | JM50×JF200 |
| 100-grainweight | 15 | 15 | -3.21～5.15 | JM39×JF167 | JM60×JF200 |
| Tassel branch | 15 | 15 | -14.48～20.87 | JM39×JF167 | JM60×JF156 |
| Water content at harvesting | 16 | 14 | -0.65～0.81 | JM39×JF200 | JM31×JF156 |

**Table 4. Estimation of genetic parameters of each character.**

| Genetic parameters | Plant height | Ear height | Grain weight | Ear length | Ear diam. | Rows per ear | Number of grains per row | 100-grainweight | Tassel branch | Water content at harvesting |
|---|---|---|---|---|---|---|---|---|---|---|
| GCA variance | 61.51 | 32.12 | 55.82 | 58.68 | 60.46 | 75.65 | 69.84 | 71.40 | 75.67 | 65.80 |
| SCA variance | 38.55 | 67.94 | 44.24 | 41.38 | 39.60 | 24.41 | 30.22 | 28.66 | 24.39 | 34.26 |
| Broad sense heritability | 81.33 | 55.59 | 84.37 | 64.55 | 51.46 | 71.46 | 58.85 | 91.29 | 53.79 | 97.33 |
| Narrow sens heritability | 49.62 | 17.86 | 47.31 | 37.87 | 31.18 | 54.04 | 41.09 | 69.06 | 31.55 | 64.02 |

water content at the time of receiving was slightly greater than the SCA variance, indicating that these traits were affected by both additive and non additive genes, and additive genes had a greater impact.

To sum up, firstly, the broad heritability of plant height, rows per ear, grains per row and 100-grain weight were high, which was mainly affected by additive genes, so it was suitable for selection in early generations. Secondly, the broad heritability of ear height, ear diameter, branch number of male ear and water content at harvest were high, but the narrow heritability was low, so it was suitable for selection in late generations.

China is a large agricultural country in China, where maize plays an important role in the development of national economy and national food security. As the most basic means of agricultural production, maize seeds are not only the basis of increasing corn production and income, but also the foundation of industrial growth. At present, China's agriculture has entered the stage of modern development, from human and livestock as the main force to a new level of mechanization. It is a strategic choice and urgent task to accelerate the breeding and popularization of new varieties of corn suitable for machine harvest grain, promote the technology of early sowing and late harvest of corn, and achieve the integrated development of agricultural machinery and agronomy, and the matching of improved varieties, opportunities and methods (Wang *et al.* 2017).

Through the analysis of combining ability of 10 inbred lines and 3 test inbred lines, it was found that the GCA effect value of plant height and ear height of maize inbred line JM46 was the lowest, which could be used to reduce the plant height and ear height of offspring. JM35 had high GCA effect values on ear grain weight, ear length and 100-grain weight, and could form many groups of excellent combinations. It was an inbred line with high breeding value. JM26 had the highest general combining ability in ear grain weight, which could be used to increase the ear grain weight of hybrid offspring, but its general combining ability of grain number per row and 100-grain weight was low, so it needs to be cross bred after improvement to improve it. JM28 had the highest combining ability in ear length and rows per ear, but it was general in other aspects. It could increase the yield of hybrid offspring through improvement. JM39 had the best performance in ear length, number of grains per row, 100-grain weight, number of branches of male ear and water content at harvest, but generally in plant height, ear height, ear grain weight and ear diameter. Several outstanding excellent character combinations were also related to JM28, indicating that the parental inbred line had strong general combining ability and specific combining ability, and was a parental inbred line with great breeding value. In the next step, JM28 could be used as a parent to increase the ear length, grain number per row and 100-grain weight of hybrid offspring, so as to selecting breeding objectives and carry out the breeding of new maize varieties. When selecting maize varieties suitable for machine harvest, one should focus on the traits such as low water content at harvest, small number of male ear branches, moderate and neat plant and ear position.

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