Heterosis Analysis of Yield Characters of Waxy Maize Hybrid Jinuo 3

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Abstract. The heterosis of high yield maize variety Jinuo3 was analysed. The results showed that Jinuo3 had significant yield increasing effect, which was 1.76% and 9.58% higher than Jingkenuo2000 and Wannuo2000, respectively. The relative heterosis of yield traits ranged from 6.57% to 68.41%, with an average of 30.73%. The mid parent heterosis ranged from 7.03% to 216.55%, with an average of 57.83%. And the heterosis index was between 107.03% and 316.55%, with an average of 157.84%. Among the traits, the heterosis of yield was the largest, with relative heterosis, mid parent heterosis and heterosis index were 68.41%, 216.55% and 316.55%, respectively. The other characters ranked from high to low were yield per plant, ear height, and number of grains per row, ear length, plant height, and axis diameter, and ear diameter, row per ear, 100 grain weight, seed yield and threshing water content.

1. Introduction
Heterosis utilization was an effective way to increase crop yield and stress resistance, and that was the greatest contribution of plant genetics to agricultural production in the last century [1, 2]. Maize was the earliest and most successful crop to utilize heterosis, which greatly promoted the production and development of maize in China [3, 4]. For the yield of maize hybrids, previous studies had been carried out from yield components and cultivation techniques, different planting densities and single seed sowing, but the heterosis of maize yield had not been analyzed [5, 6]. Therefore, the heterosis of Jinuo3 was analyzed in order to provide theoretical basis for revealing the mechanism of high yield.

2. Materials and methods

2.1. Test materials
The test materials were maize variety Jinuo3 and its parent inbred line (female parent J100, male parent J28), which were provided by maize breeding research group of Jilin Agricultural Science and Technology University. The control varieties were Jingkenuo2000 and Wannuo2000, which were the main varieties of this maturity group, and were purchased from Hongze brand seed store and Meibang brand seed store.
2.2. Field test
The experiment was conducted in maize breeding base of Jilin Agricultural Science and Technology University in 2020.

2.2.1. Comparative experiment on yield characters of different maize varieties. The test varieties Jinuo3, Jingkenuo2000 and Wannuo2000 were randomly divided into 10 rows, 4 meters in length, 0.625 meters in row spacing and 60000 plants·hm⁻² in density. After ripening, all the six rows in the middle of the plot were harvested, and the grain moisture content was measured. After the ears were air dried, 10 representative ears were selected for the determination of yield traits, including ear length, ear diameter, and ear row number, grain number per row, axis diameter, seed rate, 100 grain weight and grain weight. The grain yield and 100 grain weight were converted into the weight under the condition of uniform water content (14%), and the yield of 667m² was converted to calculate the seed rate according to the ear weight and grain weight.

2.2.2. Heterosis analysis of yield characters in Jinuo3. Jinuo3 and its parent inbred lines were used in this study. They were randomized block design, 6 rows, 4 meters in length, 0.625 meters in row spacing, and 60000 plants·hm⁻² in density. Field management was carried out according to conventional production conditions. Plant height and ear height were investigated in the field. After ripening, all the four rows in the middle of the plot were harvested.

2.3. Statistical analysis of data
The average value of each character was used for statistical analysis. DPS v14.1 software was used to analyze the basic statistics and variance. Heterosis analysis is based on absolute heterosis, relative heterosis, mid parent heterosis, super parent heterosis and heterosis index.

\[
\text{Absolute heterosis (Kg·667m⁻²)} = F₁-MP, MP = (P₁+P₂)/2; \quad (1)
\]

\[
\text{Relative heterosis} (\%) = [(F₁-MP)/F₁]×100; \quad (2)
\]

\[
\text{Heterosis} (\%) = (F₁-MP)/MP×100; \quad (3)
\]

The super parent advantage was divided into super high parent advantage and ultra-low parent advantage

\[
\text{Super high parent heterosis} (\%) = [(F₁-HP)/HP] ×100; \quad (4)
\]

\[
\text{Ultra-low parent heterosis} (\%) = [(F₁-LP)/LP] ×100; \quad (5)
\]

\[
\text{Heterosis index} (\%) = F₁/MP×100. \quad (6)
\]

Among them, F₁ was the hybrid, P₁ and P₂ were parents, HP was the high value parent, LP was the low value parent, and MP was the average value of both parents.

3. Results and Analysis

3.1. Comparison of yield traits of different maize varieties
In table1, analysis of variance was carried out on yield traits of Jinuo3, Jingkenuo2000 and Wannuo2000. The results showed that there were significant or extremely significant differences in yield and related traits. The yield of Jinuo3 was the highest, 1.76% and 9.58% higher than that of Wannuo2000 and Jingkenuo2000, respectively. Compared with Jingkenuo2000, Jinuo3 had obvious advantages in axis diameter, 100 grain weight, and ear diameter, row number per ear, ear length and water content at harvest.
The first five characters were 4.92%, 5.05%, 2.53%, 1.47% and 6.02% higher than Jingkenuo2000. The water content at harvest was 7.09% lower and only the seed yield was 1.21% lower. Compared with Wannuo2000, Jinuo3 had advantages in axial diameter, 100 grain weight and ear diameter, which were 3.26%, 0.75% and 0.87% higher respectively, but the number of grains per row and ear length were 1.66% and 1.64%.

Table 1. Comparison on yield of different maize varieties

| Variety      | Yield kg·667m⁻² | Ear length cm | Ear diameter cm | Ear row | Kernel number per ear | Cob diameter cm | Kernel ratio % | 100-kernel weight g | Grain moisture content % |
|--------------|-----------------|---------------|-----------------|---------|-----------------------|-----------------|-----------------|---------------------|-------------------------|
| Jingkenuo2000 | 784.16B         | 18.92B        | 5.54Bb          | 15.8b   | 40.8b                 | 3.49Aa          | 87.42Aa         | 47.45Bc             | 34.72Aa                |
| Jinuo3       | 859.29Aa        | 19.85Bba      | 5.82Aa          | 16.2a   | 41.4b                 | 3.13Bc          | 86.36Bba        | 50.31Aa             | 32.26Bb                |
| Wannuo2000   | 844.42Bb        | 20.18Aa       | 5.77AAb         | 16.4a   | 42.1a                 | 3.37Bb          | 85.72Bb         | 48.72Bb             | 32.87Bb                |

Notes: Different small letters after the numbers in the same column indicated significant differences at the level of 0.05, and different capital letters indicated significant differences at the level of 0.01.

3.2. Heterosis analysis of yield characters of Jinuo3

3.2.1. Phenotypic analysis. In table 2, the analysis of variance showed that the yield related traits all reached extremely significant difference, Jinuo3 and its parents all reached extremely significant difference, except the seed rate and water content at threshing were lower than J28, and other traits were significantly higher than the parent inbred line.

The phenotypic and yield characters of the two inbred lines were quite different. The grain of J100 was hard grain type with good quality. It was highly resistant to maize leaf spot, gray leaf spot, stem rot, head smut and rust. J28 grain was semi dentate, resistant to maize leaf spot, stem rot, corn borer, good quality of rhizome, strong lodging resistance. There were significant differences in yield, yield per plant, ear length, and number of grains per row, axis diameter, seed rate, 100 grain weight, plant height and ear height.

Table 2. Comparison on yield of different among Jinuo3 and parents

| Variety | Yield kg·667m⁻² | Yield per plant g | Ear length cm | Ear diameter cm | Ear row | Kernel number per ear | Cob diameter cm | Kernel ratio % | 100-kernel weight g | Grain moisture content % | Plant height cm | Ear height cm |
|---------|-----------------|-------------------|---------------|-----------------|---------|-----------------------|-----------------|----------------|---------------------|------------------------|----------------|-------------|
| J100    | 327.62C         | 68.43C            | 11.38C        | 4.93B           | 12.42B  | 19.84C                | 3.26B           | 72.95C         | 39.53B              | 18.64B                 | 187.52C        | 62.56C       |
| J28     | 557.72B         | 111.5B            | 14.95B        | 4.88B           | 13.27B  | 29.42B                | 2.49C           | 87.36A         | 42.64C              | 17.58C                 | 248.41B        | 89.53B       |
| Jinuo3  | 924.29A         | 284.85A           | 19.56A        | 5.71A           | 16.13A  | 42.12A                | 3.96A           | 85.79B         | 54.20A              | 19.43A                 | 312.54A        | 136.64A      |
3.2.2. _Heterosis analysis of yield traits_. In table 3, the heterosis of yield related traits in Jinuo3 were analyzed. The results showed that all characters had high absolute heterosis. The relative heterosis was between 6.57% and 68.41%, with an average of 30.73%; the mid parent heterosis was between 7.03% and 216.55%, with an average of 57.83%. And the heterosis index was between 107.03% and 316.55%, with an average of 155.84%. The relative heterosis, mid parent heterosis and heterosis index were 68.41%, 216.55% and 316.55%, respectively. The other characters ranked from high to low were yield per plant, ear height, and number of grains per row, ear length, plant height, and axis diameter, and ear diameter, row per ear, 100 grain weight, seed yield and threshing water content.

Jinuo3 also had higher super parent heterosis, which ranged from -1.80% to 155.38%, with an average of 41.63%. The super high parent advantage of yield was the largest. The sequence of characters from high to low was yield, yield per plant, ear height, grain number per row, ear length, plant height, 100 grain weight, ear diameter, axis diameter, ear row, seed rate and threshing water content. There was no super high parent advantage. The heterosis of ultra-low parent ranged from 10.52% to 316.26%, with an average of 157.83%. The super low parent heterosis of yield was the largest. The sequence of characters from high to low was yield, yield per plant, and grain number per row, ear height, ear length, plant height, axis diameter, ear row, ear diameter, 100 grain weight, seed rate and threshing water content.

| Trait            | Absolute heterosis | Relative heterosis | Mid-parent heterosis | Ultra-high-parent heterosis | Ultra-low-parent heterosis | Heterosis indexes |
|------------------|--------------------|--------------------|----------------------|-----------------------------|-----------------------------|-------------------|
| Plant height     | 94.58              | 30.26              | 43.39                | 25.82                       | 66.67                       | 143.39            |
| Ear height       | 60.60              | 44.35              | 79.68                | 52.62                       | 118.41                      | 179.68            |
| Ear length       | 6.40               | 32.69              | 48.58                | 30.84                       | 71.88                       | 148.58            |
| Ear thickness    | 0.81               | 14.10              | 37.74                | 15.82                       | 17.01                       | 116.41            |
| Ear row          | 3.29               | 20.37              | 25.57                | 21.55                       | 29.87                       | 125.57            |
| Number of grains | 17.49              | 41.52              | 71.01                | 43.17                       | 112.30                      | 171.01            |
| per row          | 1.09               | 27.40              | 37.73                | 59.04                       | 21.47                       | 137.74            |
| Shaft thickness  | 5.64               | 6.57               | 7.03                 | -1.80                       | 17.60                       | 107.03            |
| Seed yield       | 13.12              | 24.20              | 31.92                | 27.11                       | 37.11                       | 131.92            |
| 100 grain weight | 1.32               | 6.79               | 7.29                 | 4.24                        | 10.52                       | 107.29            |
| Water content of | 194.87             | 68.41              | 216.55               | 155.38                      | 316.26                      | 316.55            |
| threshing       |                    |                    | 65.73                | 182.12                      | 208.80                      |                   |
| Yield            | 481.62             | 52.11              | 108.80               | 65.73                       | 182.12                      | 208.80            |

4. Conclusion and discussion

Jinuo3 has been widely used for its high yield, high quality, disease resistance and other excellent traits, especially its high yield potential. It has achieved a new breakthrough in the comprehensive production capacity of mid late maturing maize single cross in Jilin province, and a new breakthrough in the coordinated development of yield, quality and resistance in the application fields of similar products and technologies. The results showed that Jinuo3 had a high level of heterosis in yield and other traits. The relative heterosis (52.11%) of Jinuo3 was 6.72-23.42 percentage points higher than that under two densities (45000 plants·hm⁻² and 75000 plants·hm⁻²), mid parent heterosis (216.55%) and heterosis index (316.55%) 42.14-114.32 percentage points higher.

According to the pedigree analysis, the parental inbred lines J100 and J28 belonged to PA and Lancaster groups, and their heterosis model was PA group Lancaster group. The inbred lines of PA
group have strong heterosis with the inbred lines of Tangsipingtou and Ludahonggu groups in China, which is a relatively independent and new heterosis group [7].

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