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GENETIC EVALUATION OF IODENT HARD KERNEL MAIZE INBRED LINES

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Abstract

In the present study, 12 introduced Iodent hard kernel maize inbred lines were used as test materials, and four backbone maize inbred lines (JM005, JM006, JF003 and JF004) selected by the present team were tested. Incomplete diallel design was used for combining ability determination and genetic analysis. Results showed that the yield general combining ability effect of test varieties JM005 and JM006 were excellent. Among the Iodent hard maize inbred lines tested, I215, I308, I130, I102, I120, I209 and I401 showed excellent effect of yield general combining ability (GCA). Hybrid combination I215 × JM005, I130×JM005, I598×JM005, I102×JM006, I120×JM005, I215×JF004 had a strong super parent advantage in yield, which can be further tested.

Introduction

In China, maize is an indispensable and important crop. With the continuous improvement of social demand, maize germplasm with high yield, high quality, good seed adaptability and suitable for mechanized harvest has become the mainstream demand of the current market (Li and Wang, 2017, Zhang *et al.* 2020, Zheng and Wang, 2021). However, at present, China's maize germplasm resources are scarce, the genetic basis is narrow, and there are few germplasm suitable for machine harvest, resulting in the deadlock in the development of maize breeding industry (Pan 2016, Liu 2021). Based on this, breeders are adjusting new breeding directions according to the needs of the industry and breeding new varieties more suitable for mechanized harvest (Dai *et al.* 2015, Wu 2020). In the present study of germplasm renewal, many experiments show that Iodent hard maize germplasm has the characteristics of early maturity, suitable for machine harvest, good stem flexibility and good stress resistance (Zhang *et al.* 2018, Song *et al.* 2022). At present, there have been many studies on improving and breeding new maize varieties with this germplasm, and the results show good high yield, density tolerance and strong heterosis. The indexes to evaluate the suitable mechanical harvest characteristics of maize usually include growth period, silking stage, plant height, ear height, lodging rate, empty stem rate, stem puncture intensity and water content at harvest (Zhou *et al.* 2017, Xu *et al.* 2018, Jia *et al.* 2019). Therefore, in this study, 12 Iodent hard maize inbred lines and two backbone maize inbred lines of "group G" and "group H" in our research group were used as materials to evaluate the combining ability and analyze the super parent advantage from the aspects of yield traits and relevant traits suitable for machine harvest.

Materials and Methods

In 2021, the maize breeding team of Jilin Agricultural Science and Technology University introduced 12 Iodent hard kernel maize inbred lines named I102, I120, I130, I189, I209, I215, I217, I276, I277, I308, I401 and I598. Incomplete diallel design was adopted, and 48 combinations were prepared in Hainan Nanbin breeding base in the winter of 2021 with the back-

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bone inbred lines JM005 and JM006 of "group G" and the backbone inbred lines JF003 and JF004 of "group H", which were created by our team as test species. The experiment was carried out in two maize planting bases, Jiuzhan in Jilin City (E126°28', N43°57') and Gongzhuling in Changchun City (E125°13', N43°44') in 2022. A randomized block design was used in the experiment, which was set as three repetitions, four row areas, with a length of 5 m, a row spacing of 65 cm. Xianyu 335 was used as the control variety. The density was 67500 plants per hectare. Two seeds were sown in each hole and one plant was retained after emergence. Field management was the same as general field production.

The growth stages such as seedling emergence stage, tasseling stage and silking stage were recorded. The plant height, ear height, lodging number and empty stalk number of the plot were investigated at the mature stage of maize, and the stem puncture strength of the third stem node above the ground was measured by stem strength instrument (YYD-1). The actual number of plants in the plot was investigated during the maize harvest period, and the yield of the whole area was measured. At the time of harvest, 5 ears were randomly taken and 300g seeds were peeled. Then the water content of maize seeds at harvest was measured with PM-8188, and the yield was calculated according to the standard water content of 14%. The general combining ability (GCA) and special combining ability effect value (SCA) were estimated according to the fixed model of Griffin method IV. The analysis of variance and combining ability were estimated with SAS9.0 data processing software. The total combining force was calculated according to the formula $t_{ij} = g_i + g_j + s_{ij}$. Super parent advantage (%) = (F1 - CK) / CK × 100, where F1 represents the yield of hybrid combination and CK represents the yield of control (Hang *et al.* 1980, Zhang *et al.* 2022).

Results and Discussion

The four yield related agronomic characters of Jiuzhan and Gongzhuling were statistically analyzed, including yield, single panicle weight, 100-grain weight and kernel rate. Results showed that due to ecological differences, there were great variations in the extreme value, average value, standard deviation and coefficient of variation of the same yield related traits in different locations. The overall performance of yield traits in the Jiuzhan was better than that in Gongzhuling, except for the kernel rate. The output range of Jiuzhan was 8.26 - 18.48 t / hm^2, and that of Gongzhuling was 6.86 - 13.47 t / hm^2. The variation range of single panicle weight in Jiuzhan station was 96.25 - 234.25 g, and that in Gongzhuling was 72.26 - 187.5 g. The variation range of 100-grain weight in Jiuzhan station was 22.55 - 40.42 g, and that in Gongzhuling was 21.55 - 37.7g. The variation range of kernel rate of Jiuzhan was 82 - 90.26%, and that of Gongzhuling was 84.04 - 96.52% (Table 1).

Table 1. Basic statistics of yield related traits.

Traits	Output (t/hm^2)		Single panicle weight (g)		100 grain weight (g)		Kernel rate (%)	
Place	Jiuzhan	Gongzhuling	Jiuzhan	Gongzhuling	Jiuzhan	Gongzhuling	Jiuzhan	Gongzhuling
Maximum	18.48	13.47	234.25	187.50	40.42	37.70	90.26	96.52
Minimum	8.26	6.86	96.25	72.26	22.55	21.55	82.00	84.04
Standard deviation	3.16	2.71	29.96	23.10	5.56	5.32	2.85	3.62
Average value	13.23	9.90	167.45	122.35	31.19	29.32	87.15	89.37
Coefficient of variation	17.21	18.17	18.53	19.46	15.63	15.65	3.11	3.94

At the same time, the basic statistical analysis was carried out on the correlation of suitable machine harvest at Jiuzhan and Gongzhuling. Results showed that there was no significant difference between the two places in the silking stage (The variation amplitude at Jiuzhan was 79d - 69d and that at Gongzhuling was 75d - 65d). There was no significant difference in plant height between the two place (The variation amplitude of Jiuzhan was 203.8 - 295.6 cm and that of Gongzhuling was 209.2-284.5 cm), indicating that the plant height is less affected by the environment. Ear height, lodging rate, empty stem rate, stem puncture intensity and water content at harvest were significantly different in the two places, and the Jiuzhan were better than Gongzhuling in general. The variation range of ear height in Jiuzhan was 67.8 - 110.9 cm, and that in Gongzhuling was 71.8 - 118.9 cm. The lodging rate of Jiuzhan ranged from 0 to 5.66%, and that of Gongzhuling ranged from 0 to 82.53%. The range of empty stalk rate of Jiuzhan was from 0 to 14.73%, and that of Gongzhuling from 0 to 26.4%. The stem puncture intensity of Jiuzhan was 35.38 - 74.22, and that of Gongzhuling was 40.64 - 72.4. The variation range of water content at harvest of Jiuzhan was 17.1 - 31.15%, and that of Gongzhuling was 24.5 - 33.70% (Table 2).

Table 2. The basic statistics of mechanical harvesting related traits.

Traits	Place	Maximum	Minimum	Standard deviation	Average value	Coefficient of variation
Silking stage (d)	Jiuzhan	79	69	4.25	88.83	3.51
	Gongzhuling	75	65	3.92	88.65	3.73
Plant height (cm)	Jiuzhan	295.6	203.8	17.01	249.1	7.7
	Gongzhuling	284.5	209.2	17.72	250	7.97
Ear height (cm)	Jiuzhan	110.9	67.8	11.42	87.34	13.06
	Gongzhuling	118.9	71.8	14.38	96.25	15.08
Lodging rate (%)	Jiuzhan	5.66	0.0	2.05	1.57	380.9
	Gongzhuling	82.53	0.0	20.55	17.95	117.2
Empty stem rate（%）	Jiuzhan	14.73	0.0	4.45	4.7	93.57
	Gongzhuling	26.4	0.0	7.55	6.17	130.4
Stem puncture intensity	Jiuzhan	74.22	35.38	7.64	58.7	12.3
	Gongzhuling	72.4	40.64	8.75	55.81	14.91
Water content at harvest (%)	Jiuzhan	31.15	17.1	4.73	25.03	15.5
	Gongzhuling	33.7	24.5	3.6	29.68	9.17

The joint analysis of variance showed that the mean square of yield, single panicle weight, 100 grain weight and seed yield reached a very significant level among sites, and the variance of GCA, variance of SCA and test species and tested lines × location and tested system × location and test type × system under test × the mean square of site interaction reached a very significant level (Table 3). The variance of GCA of yield related traits was greater than that of SCA, which showed that yield related traits are mainly controlled by additive genetic effects. It showed that except that the mean square difference of plant height between locations was not significant, the mean square of other relevant traits suitable for machine harvest reached a very significant level among locations (Table 4). Variance test of GCA, variance test of SCA and correlation of combining ability of tested lines × location and tested system × location and test type × system under test × the mean square of site interaction reached a very significant level, except for the test species of stem puncture intensity, the variance of GCA was not significant. Except for the empty stalk rate, the variance of GCA of other traits suitable for mechanized harvest was greater than that of SCA, indicating that these traits suitable for mechanized harvest are mainly controlled by additive gene effects. The variance of GCA of empty stem rate was less than that of SCA, which indicates that empty stem rate was mainly determined by non additive gene effect and cannot be inherited stably.

Table 3. Combined variance analysis of yield characters of Iodent flint maize inbred lines.

Source of variation	F	Output	Single panicle weight	100 grain weight	Kernel rate
Place	1	531.51**	97561.73**	136.24**	236.83**
Test species	3	36.35**	5942.31**	108.71**	19.91**
System under test	11	10.45**	3176.85**	91.7**	23.72**
System under test × test species	33	5.77**	896.76**	31.51**	5.8**
Test species × place	3	4.99**	2191.87**	20.78**	16.79**
System under test × place	11	5.59**	428.76**	26.78**	10.72**
System under test × test species × place	33	5.04**	716.47**	17.17**	5.64**

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.

Table 4. Combined variance analysis of mechanical harvesting related traits of Iodent flint maize inbred lines.

Source of variation	F	Silking period	Plant height	Ear height	Lodging rate	Empty stem rate	Stem puncture intensity	Water content at harvest
Place	1	77483.66**	41.84	3814.92**	12873.33**	104.57**	402.47**	1040.96**
Test species	3	11.7**	1366.32**	600.57**	973.17**	15.87**	20.63	17.5**
System under test	11	14.55**	919.69**	369.86**	534.94**	47.2**	210.07**	16.99**
System under test × test species	33	8**	260.7**	194.99**	265.95**	52.31**	48.6**	14.51**
Test species × place	3	7.59**	707.65**	658.19**	963.19**	34.62**	50.98**	8.52**
System under test × place	11	21.51**	1039.05**	380.13**	523.61**	28.82**	88.45**	34.41**
System under test ×test species × place	33	8.07**	241.17**	178.18**	267.5**	47.47**	74.76**	14.12**

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.

The general combining ability is determined by the additive genetic effect of genes and can be stably inherited to offspring (Su *et al.* 2021). The yield of 12 Iodent hard maize inbred lines and their combining ability of 10 agronomic characters were analyzed. Results showed that I215, I308 and I130 had positive and significant GCA effect values, and their effect values were 1.26, 1.01 and 0.85, respectively, indicating that the hybrid combinations with the above inbred lines would show strong advantages in yield. The GCA effect values of single ear weight and 100-grain weight of maize inbred lines I130, I215 and I308 were positive and significant on the whole, indicating that the above inbred lines can be used to form hybrid combinations with high single ear weight and 100-grain weight, which can promote the increase of yield (Table 5). The GCA effect values of seed yield of inbred lines I189, I308, I217, I598 and I277 were positive and significant, and their values were 1.69, 1.29, 1.17 and 1.07, respectively, indicating that the hybrid combination composed of the above four inbred lines can ensure the kernel rate, improve the rate of emergence, and meet the requirements of high-quality inbred lines (Table 5). Silking stage is an important period in maize growth period. Effectively shortening the silking stage can reduce the days of growth period and promote maize maturity. The GCA effect values of inbred lines I217, I189 and I276 were negative and significant at the silking stage, indicating that the above maize inbred lines may shorten the growth period of their hybrid combinations (Table 5). The maize inbred lines with negative and significant GCA effect on plant height were I598, I217, I401 and I209, indicating that using the above maize inbred lines may reduce the plant height of their hybrid combinations (Table 5). The maize inbred lines with negative GCA effect value of ear height were I401, I189, I598 and I276, which indicates that the use of the above maize inbred lines may reduce the ear height of the hybrid combinations (Table 5). The maize inbred lines with negative and significant GCA effect value of lodging rate were I189, I401, I217 and I102, indicating that the lodging rate of their hybrid combinations may be reduced by using the above maize inbred lines. The maize inbred lines with negative and significant GCA effect value of empty stalk rate were I189, I102, I276 and I217, which indicates that the empty stalk rate of the hybrid combination may be reduced by using the above maize inbred lines. I277 and I401 were inbred lines with positive and significant GCA effect value of stem puncture intensity, indicating that these two maize inbred lines may be used to form a hybrid combination with good lodging resistance. The maize inbred lines with significant negative GCA effect value of water content at harvest were I102, I209, I189 and I401, indicating that the use of the above maize inbred lines may reduce the water content at harvest of their hybrid combinations.

Table 5. GCA effects for yield releated traits and mechanical harvesting related traits among American maize inbred lines.

System under test	Output	Single panicle weight	100 grain weight	Kernel rate	Silking stage	Plant height	Ear height	Lodging rate	Empty stem rate	Stem puncture intensity	Water content at harvest
I102	0.37	6.4*	-0.33	-0.69**	-0.36	-1.57	6.19**	-4.01**	-1.65*	-7.98**	-1.35**
I120	0.12	5.28	2.5**	-1.61**	1.39**	-3.96	8.13**	0.11	1.87*	-3.27*	0.57
I130	0.85**	22.59**	1.19*	-1.79**	1.45**	7.73**	2.96*	2.58**	1.59*	2.08	-0.19
I189	-0.78**	-17.97**	-3.32**	1.69**	-0.99**	4	-6.34**	-7.14**	-1.86**	1.14	-1.06**
I209	0.07	1.97	1.63**	-0.67**	0.2	-6.05*	-1.53	4.79**	-0.07	2.2	-1.18**
I215	1.26**	16.84**	3.00**	-0.08	-0.24	5.16*	-0.02	13.42**	-1.11	-0.83	0.99*
I217	-1.22**	-22.35**	-4.01**	1.17**	-0.99	-9.37**	2.14	-4.67**	-1.44*	-3.02*	-0.21
I276	-0.66**	-11.28**	0.41	-0.18	-0.92*	8.76**	-2.67*	4.2**	-1.56*	-0.5	1.03*
I277	-0.16	-3.22	-3.24**	1.02**	0.64	13.01**	2.48	-2.47**	1.46	4.5**	1.22**
I308	1.01**	14.28**	1.89**	1.29**	0.76	-0.98	1.48	2.07**	2.46**	2.62	0.49
I401	0.05	0.28	1.11*	-0.74**	0.2	-6.31**	-6.87**	-5.73**	1.91*	4.49**	-0.83*
I598	-0.43*	-12.35**	-0.35	1.07**	-0.67	-10.04**	-5.47**	-2.66**	-1.12	-0.95	1.03*
$LSD_{0.05}$	0.4	5.709	0.96	0.46	0.90	4.78	2.74	0.4	1.47	2.71	0.82
$LSD_{0.01}$	0.52	7.545	1.26	0.6	1.18	6.31	3.61	0.52	1.93	3.57	1.08

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.

According to the general combining ability analysis of four test crosses, it can be seen that the GCA effects of JM005 on yield, single panicle weight and 100-grain weight were positive and significant, indicating that JM005 can be used to form hybrid combinations with high yield, single panicle weight and 100-grain weight. The GCA effect of lodging rate of JM005 were negative and the stem puncture intensity were positive, both of which were significant, indicating that JM005 can be used to form a hybrid combination with strong lodging resistance. The GCA effects of JF003 on silking stage, plant height, ear height and lodging rate were negative and significant, indicating that JF003 can be used to form hybrid combinations with short silking stage and strong lodging resistance. The GCA effect values of yield, single panicle weight and 100-grain weight of JF003 were negative and significant, indicating that this test species have an inhibitory effect on yield. JM006 had a significant negative GCA effect on ear height and lodging rate, indicating that it can be used to form a hybrid combination with low ear height and strong lodging resistance. The GCA effect of single panicle weight and 100-grain weight of JM006 were positive and significant, indicating that JM006 can be used to form a hybrid combination with high single panicle weight and 100-grain weight. The GCA effect value of kernel rate of JF004 was positive and significant, indicating that hybrid combinations with high kernel rate can be prepared by using JF004 (Table 6).

Table 6. GCA effects for yield related traits and mechanical harvesting related traits among testers.

System under test	Output	Single panicle weight	100 grain weight	Kernel rate	Water content at harvest	Silking stage	Plant height	Ear height	Lodging rate	Empty stem rate	Stem puncture intensity
JM005	2.15**	12.16**	2.78**	-0.90**	-0.28	-0.38	7.44**	3.5**	-3.38**	-0.42	1.97
JF003	-1.32**	-15.28**	-1.13**	1.31	-0.52	-0.72*	-6.97**	-3.03**	-1.55**	-0.89	1.27
JM006	1.33	5.99**	1.76*	-0.41	1.95**	1.42	-0.55	-3.51**	-2.48**	1.77	-0.61
JF004	-0.35	-1.17	-0.61	1.89**	-0.75*	1.58	1.88	4.83**	7.8**	1.35	-0.84
$LSD_{0.05}$	1.36	4.423	1.68	1.39	1.6	1.65	3.88	2.71	1.36	1.98	2.69
$LSD_{0.01}$	1.43	5.483	1.85	1.47	1.75	1.81	4.77	3.21	1.43	2.24	3.19

* and ** indicated significant at 0.05 and 0.01 probability levels, respectively.

The different phenotypes produced by inbred lines of the same genotype in different environments are called response norms. The yield GCA of maize inbred lines varies greatly at different locations, indicating that the reaction specifications of different maize inbred lines are very different (Fig.1). The yield GCA responses of JM005, JF003, JM006 and JF004 in Jiuzhan and Gongzhuling were consistent, indicating that environmental factors has little effect on the genotypes of these four maize inbred lines and has strong adaptability to the environment. The yield GCA response specifications of Iodent hard maize inbred lines I189, I215, I217, I276, I308 and I598 were consistent at the two sites, indicating that the yield of the above maize inbred lines generally has little interaction effect with the environment and has good ecological adaptability. However, the yield GCA changes of I102, I120, I130, I209, I277 and I401 at the two sites were inconsistent, indicating that the yield general combining ability of the above maize inbred lines is easy to be affected by environmental factors and the ecological adaptability isn’t strong.

Taking Xianyu 335 as the control, the analysis of super parent heterosis was carried out. Results showed that the variation range of yield TCA of hybrid combinations with yield in the top 10 and the bottom 10 was -4.02 to 2.34 (Table 7). The ranking of TCA effect value in 20 hybrid combinations was consistent with that of super parent heterosis. The greater the TCA effect value, the greater the super parent heterosis, and vice versa. Table 7 showed that the super parent heterosis was the average of two points. The variation range of super parent heterosis of yield traits in hybrid combinations was -45.61 to 8.26%. There were 6 hybrid combinations with positive super parent heterosis, and the order from strong to weak were I215 × JM005 ＞ I130 × JM005 ＞ I598 × JM005 ＞ I102 × JM006 ＞ I120 × JM005 ＞ I215 × JF004, their super parent advantages were 8.26, 4.93, 4.49, 3.5, 2.99 and 1.04%, respectively (Table 7).

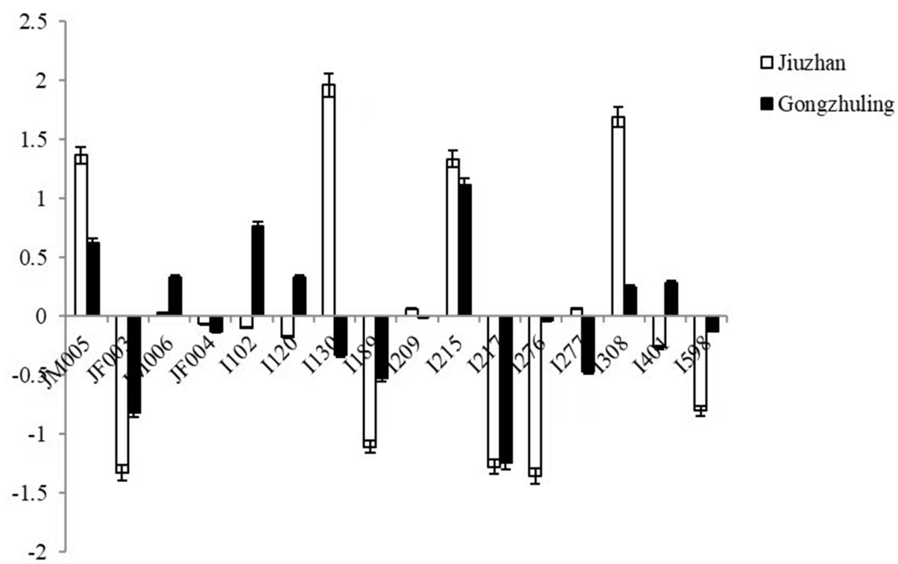

Fig.1. Change of yield GCA in different locations.

From the results of the present experiment, the yield GCA effect of I215, I308, I130, I102, I120, I209 and I401 in the tested Iodent hard maize inbred lines was excellent. In the Iodent hard maize inbred lines tested, I215, I308 and I130 had higher GCA of yield, single ear weight, 100 grain weight and kernel rate, indicating that the hybrid combination combined with these three inbred lines are easier to achieve the purpose of high yield.

The GCA effects of yield, single panicle weight and 100 grain weight of test variety JM005 were positive and significant, and its combination can effectively improve the yield. The GCA effects of silk drawing stage, plant height, ear position height and lodging rate of JF003 were negative and significant. The combination with JF003 had strong lodging resistance and early maturing potential, which is suitable for mechanized harvest. The GCA effect values of yield, single panicle weight and 100 grain weight of JM006 were positive, while plant height, ear height and lodging rate were negative, but the performance was not significant. The GCA effect values of all tested traits of JF004 were positive, but the performance was not significant. Therefore, the main analysis materials JM005 and JF003 showed that the general combining ability response specifications of JM005 and JF003 were consistent in the changes of combining ability under two different environments of Jiuzhan and Gongzhuling, indicating that the two inbred lines had less interaction effect with environment and strong ecological adaptability. Hybrid combination I215 × JM005, I130 × JM005, I598 × JM005, I102 × JM006, I120 × JM005, I215 × JF004 had a strong yield super parent advantage, of which four combination parents with strong super parent advantage contain JM005, which further shows that JM005 can be combined with combinations with strong super parent advantage as a parent, and the potential of JM005 germplasm as a parent can be affirmed.

Table 7. Total yield combining effect value and comparative advantage analysis.

Hybrid combination	GCA effect value of the tested system	GCA effect value of test species	SCA effect value	TCA effect value	Super parent advantage /%	Ranking
I215×JM005	1.08	0.86	0.12	2.34	8.26	1
I130×JM005	0.67	0.86	0.14	1.94	4.93	2
I598×JM005	-0.61	0.86	1.36	1.89	4.49	3
I102×JM006	0.19	0.04	1.26	1.77	3.5	4
I120×JM005	0.06	0.86	0.64	1.71	2.99	5
I215×JF004	1.08	-0.24	0.36	1.49	1.04	6
I215×JM006	1.08	0.04	-0.19	1.22	-1.22	7
I102×JF004	0.19	-0.24	0.89	1.12	-2.06	8
I308×JM006	0.83	0.04	-0.08	1.07	-2.47	9
I308×JM005	0.83	0.86	-0.91	1.05	-2.62	10
I277×JM006	-0.34	0.04	-1.02	-1.05	-20.4	39
I209×JM006	0.01	0.04	-1.41	-1.2	-21.7	40
I276×JF003	-0.84	-1.21	0.55	-1.22	-21.91	41
I189×JF003	-0.96	-1.21	0.6	-1.29	-22.51	42
I189×JF004	-0.96	-0.24	-0.51	-1.43	-23.63	43
I120×JF003	0.06	-1.21	-0.99	-1.99	-28.4	44
I217×JF004	-1.4	-0.24	-0.79	-2.15	-29.75	45
I102×JF003	0.19	-1.21	-2.08	-2.82	-35.47	46
I598×JF003	-0.61	-1.21	-1.93	-3.47	-40.96	47
I217×JF003	-1.4	-1.21	-1.69	-4.02	-45.61	48

Results showed that JM005 and JF003 not only have strong ecological adaptability, but also have traits suitable for mechanized harvest and high super parent advantages. They are suitable for the combination and breeding of new varieties in Jilin. On the basis of retaining the characteristics of Iodent hard maize germplasm and combining with local backbone inbred lines, they provide a basis for the breeding of new varieties suitable for machine harvest in Jilin Province. Taking JF003 as the parent, the present research group cultivated the first new maize variety Jikeyu 518 (KA103×JF003) suitable for mechanized grain harvest in Jilin Province and taking JM005 as parent, new maize varieties approved by the province such as Jikeyu 917 (JM005×KB024) and Jikeyu 916 were cultivated. Therefore, JM005 and JF003 (JM005×KB074) have the potential to cultivate new varieties suitable for machine harvest, which should be used in the future.

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