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ANALYSIS OF AGRONOMIC TRAITS COMBINING ABILITY OF SWEET-WAXY DOUBLE RECESSIVE CORN INBRED LINES

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Abstract

Sweet-waxy corn is a kind of fresh corn which is harvested, processed and eaten in the milk ripening period. It is one of the most popular special corns in the fresh corn market. In order to screen and evaluate the breeding value of sweet-waxy corn inbred lines, 10 selected sweet waxy double recessive corn inbred lines i.e JT111, JT113, JT116, JT120, JT124, JT128, JT131, JT135, JT139 and JT145 were used as female parents (P1), and 3 waxy corn inbred lines namely JN44, JN55 and JN88 were used as male parents (P2), and NC II design of incomplete diallel cross was used to analyze combining ability of 10 agronomic characters, including plant height, ear height, grain weight per ear, ear length, ear diameter, rows per ear, grains per row, 100-grain weight, skin residue rate and amylopectin content. Results showed that in general combining ability, JT124 had the best performance in ear length, grain number per row, 100-grain weight, skin residue rate and amylopectin content, and the better inbred lines were JT120, JT111 and JT113. In the special combining ability, JT124×JN55, JT124×JN88 and JT120×JN55 were the best crossing combinations. JT124, JT120, JT111 and JT113 could be used directly, and other inbred lines could be improved and reused. Plant height, row number per ear, grain number per row and 100-grain weight should be selected in early generation, while ear height, ear diameter, skin residue rate and amylopectin content should be selected in late generation. According to this, one can select the breeding target and the suitable parent inbred line.

Introduction

Since the reform and opening up, Chinese people's living standards have been continuously improved, fresh sweet and waxy corn is also loved by people, and consumers have higher and higher demand for the quality of fresh sweet and waxy corn. It has promoted the rapid development of breeding, breeding and popularization of fresh sweet and waxy corn in China (Wu 2003, Zeng *et al*. 2020, Zhao *et al*. 2020). In recent years, sweet and waxy fresh corn is gradually coming into people's field of vision. Waxy corn forms a paste with high viscosity after cooking, which is not hard after cooling, and the entrance is smooth. Sweet corn contains plenty of water-soluble polysaccharides in the endosperm and is sticky in taste as well as taste excellent (Tu 1990, Su *et al*. 2012). On the other hand, sweet and waxy corn takes into account the excellent characteristics of the above two kinds of corn and becomes the new favorite of fresh corn (Li *et al*. 2021). In order to broaden the germplasm resources of waxy maize breeding and maximize the value of inbred lines in production, the combining ability of 10 sweet and waxy double recessive maize inbred lines was studied by incomplete diallel cross NC II design, and the combining ability of the main characters was determined and analyzed, in order to provide theoretical basis for sweet waxy maize breeding.

Materials and Methods

In May 2020, 10 sweet and waxy double recessive maize inbred lines i.e; JT111, JT113, JT116, JT120, JT124, JT128, JT131, JT135, JT139 and JT145 were selected as female parents and 3 waxy maize inbred lines namely, JN44, JN55 and JN88 as male parents. According to the design

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of incomplete diallel NC II, 30 hybrid combinations were planted in the maize breeding base of Changchun.

The field identification experiment was carried out in 2021 at the maize breeding base of Changchun. The experiment adopted randomized block design, ridging planting, 3 repeats, double row area, length 5 meters, row spacing 60 cm, plant spacing 25 cm, planting 21 plants per row. Sowing on May 1, field management and fresh corn production in the field. The yield of each experimental material was measured 25 days after pollination. The specific method was to measure continuously the plant height and ear height of 10 plants (except the first 3 plants) in the middle row of the plot, and harvest their effective ears for indoor seed examination. Five representative fresh ears were selected to measure agronomic traits such as ear grain weight, ear length, ear diameter, ear row number, row grain number, 100-grain weight, skin residue rate and amylopectin content.

Determination of skin residue rate was conducted according to the method of Feng *et al*. (2022), all the three fresh fruit ears harvested at milk maturity were threshed, then the grains were mixed evenly and divided into two equal parts, 100 g each. One part is dried in a blast oven at 70ºC to a constant weight, and the dry weight (m_1) is accurately recorded. The other part is put into the weaving net cover of the soymilk machine by adding appropriate amount of water according to the method of grinding soybean milk, and beat at a high speed for 15 s each time with an interval of 15 s. The accurate dry weight (m_2) of the 60-mesh sample sieve in advance was weighed, and at the same time, the ground corn husk residue was poured in the net cover of the soybean milk machine into the 60-mesh screen, and the net cover was rinsed continuously with water flow until all the residue on the screen was transferred to the screen. The corn husk residue in the sampling screen was continuously washed with fine water flow to prevent the corn husk residue from overflowing from the sampling sieve until the washed water becomes clear. The washed sample sieve and corn dregs were dried in a blast oven at 80℃ to a constant weight, removed and cooled in a dryer and weighed (m_3). Percentage of husk residue in fresh sweet and waxy corn was calculated using formula: husk residue % = $(m_3\text{-}m_2) / m_1 \times 100\%$.

Determination of amylopectin content was carried out according to the method of Tian *et al*. (2017), 3 fresh ears were threshed, and the fresh grains were killed in a drying box at 110°C. Then the temperature was changed to 65-70°C and dried to constant weight. Before weighing, the fresh grains were crushed with a micro-injection grinder, then sifted through 100 mesh, 0.2 g was accurately weighed by electronic balance, and the amylopectin content was determined by anthrone colorimetry for 3 times, and the average value was taken as the sample observation value.

Based on the average number of tested species of each character, the data were processed initially by Excel 2013 software, and then processed and analyzed by DPS7.1 software (Tang *et al*. 2002).

Results and Discussion

Results of the analysis of variance of combining ability of 10 agronomic characters of 30 hybrid combinations presented in Table 1 showed that there is no significant difference among the 10 characteristic groups, indicating that the soil fertility of the selected fields in this experiment is similar, which can rule out the difference of soil fertility and the design is reasonable. The differences of each character among the combinations reached a very significant level, indicating that there were real genetic differences in these traits among the hybrid combinations. Except for the general combining ability (GCA) of ear diameter and the number of rows per ear of the tested species (male parent, P2), the differences of GCA and all special combining ability (SCA) were extremely significant or significant, indicating that there were real differences in GCA and SCA of most traits between parents and combinations.

General combining ability (GCA) refers to the average value of a certain quantitative character in the offspring of a parent variety crossed with several other parent varieties, which is heritable. It can be seen from Table 2 that the GCA effect values of different inbred lines on the same character are very different, while the GCA effect values of the same inbred line on different characters are also very different. No inbred line can take into account all the excellent characters, so it is necessary to select suitable inbred lines for combination when selecting breeding objectives.

In terms of plant height and ear height, the GCA relative effect values of JT116, JT128, JT131, JT135 and JN88 were all negative, indicating that the hybrid combinations may effectively reduce the plant height and ear height of hybrid progenies, and enhance lodging resistance to a certain extent. In terms of grain weight per ear, the GCA relative effect values of JT111, JT113, JT120, JT124, JT135, JT139, JT145, JN44 and JN55 were all positive, indicating that the hybrid combination could effectively increase the grain weight per ear and had a great effect on yield, and the GCA relative effect value of JT111 was the highest. In terms of panicle length, the GCA relative effect values of JT111, JT113, JT116, JT120, JT124, JT135, JT139, JT145, JN44, JN55 and JN88 were all positive which indicates that the hybrid combinations might effectively increase the panicle length of hybrid offspring, especially JT124. In terms of ear diameter, the GCA relative effect values of JT111, JT113, JT116, JT120, JT128, JT139, JT145, JN44, JN55 and JN88 were all positive, indicating that the hybrid combinations may effectively increase the ear diameter of hybrid progenies. In terms of the number of rows per ear, the GCA relative effect values of JT111, JT113, JT116, JT124, JT135, JT139, JT145, JN55 and JN88 were all positive; this result indicate that the hybrid combinations may effectively increase the number of rows per ear of hybrid progenies. In terms of the number of grains per row, the GCA relative effect values of JT111, JT113, JT116, JT120, JT124, JT128, JT139, JN44, JN55 and JN88 were all positive, indicating that their combinations could effectively increase the number of grains per row of hybrid offspring, among which JT124 was the most significant. In terms of 100-grain weight, the GCA relative effect values of JT111, JT113, JT116, JT120, JT124, JT131, JT139, JN44, JN55 and JN88 were all positive. This result indicated that their combinations could effectively increase the 100-grain weight of hybrid offspring and had a great effect on yield, among which the GCA relative effect value of JT124 was the highest. In terms of skin residue rate, the GCA relative effect value of JT124 was the lowest, the less the skin residue was, and vice versa, indicating that the combination of JT124 can effectively reduce the skin residue of hybrid offspring and enhance the taste, while in terms of amylopectin content, the GCA relative effect value of JT124 was the highest, indicating that the combination of JT124 can effectively increase the amylopectin content of hybrid offspring, which is the same as reducing the skin residue rate. Generally speaking, JT124 has the best performance in ear length, number of grains per row, 100-grain weight, skin residue rate and amylopectin content. The inbred line has a good application prospect as a parent.

Special combining ability (SCA) refers to the special effect that deviates from the average performance of parents in the first generation of hybrids produced by the crossing of two parent inbred lines in a particular combination. It depends on the dominant and epistatic effects in the genotype (Li *et al*. 2014, Jiang *et al*. 2019). Usually, on the basis of measuring the general combining ability, the inbred lines with high general combining ability are selected, and its special combining ability is further determined.

Table 3 showed that the SCA effect values varied greatly among different combinations of different traits, the combination with the best plant height was JT131 × JN88, the combination with the best ear height was JT128 × JN88, the combination with the best ear grain weight was

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-grain weight	Residue ratio	Amylopectin content
Block group	2	0.281	0.435	0.572	0.614	0.375	0.176	0.228	0.164	0.743	0.571
Combinations	29	8.695**	6.758**	9.436**	7.286**	4.779**	2.549**	8.258**	6.522**	10.276**	5.654**
P1	9	5.973**	5.219**	7.462**	6.558**	3.279**	4.369**	7.442**	4.856**	8.615**	2.108**
P2	2	3.169*	3.858*	5.279**	4.296*	0.945	0.268	3.334*	2.786*	2.943*	2.845*
P1×P2	18	6.087**	5.116**	5.286**	4.956**	2.953**	3.865**	6.785	2.976**	4.538**	3.246**
Error	58	22.301	29.046	2.433	0.586	1.928	0.406	1.478	1.324	2.016	1.942

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

Table 2. GCA relative effect values of main agronomic traits of 10 sweet-waxy double recessive 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	Residue ratio	Amylopectin content
JT111	5.75	2.28	5.61	4.71	0.04	1.11	2.31	2.14	-0.34	0.31
JT113	4.28	1.39	2.83	5.26	0.15	2.14	3.16	2.56	-0.27	0.24
JT116	-2.33	-1.63	-3.97	3.49	0.08	0.68	2.08	1.87	0.10	-0.28
JT120	2.67	0.22	4.92	5.42	0.11	0	3.37	3.19	-0.20	0.18
JT124	3.95	1.85	3.58	8.07	-0.07	1.89	5.25	4.92	-0.42	0.37
JT128	-3.28	-2.77	-2.56	-1.86	0.03	-0.09	0.74	-1.04	-0.26	0.24
JT131	-6.75	-3.19	-2.33	-2.81	-0.12	-1.37	-0.88	0.71	0.15	-0.18
JT135	-2.11	-2.05	1.08	3.11	-0.08	1.16	-0.75	-2.57	-0.14	0.15
JT139	3.64	2.85	1.77	4.72	0.13	0.26	2.07	3.16	-0.33	0.35
JT145	2.49	1.11	2.59	2.96	0.05	0.18	-1.62	-1.06	0.17	-0.16
JN44	2.81	1.78	4.18	3.47	0.04	-0.07	2.68	2.77	0.31	-0.35
JN55	0.96	0.24	3.33	6.24	0.06	0.13	4.93	3.42	-0.16	0.10
JN88	-1.77	-1.06	-2.49	2.88	0.08	0.24	1.21	1.11	0.08	0.07

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	-13.16~11.48	JY111×JN55	JT131×JN88
Ear height	15	15	-9.37~7.29	JT139×JN44	JT128×JN88
Grain weight	17	13	-17.86~19.32	JT111×JN44	JT116×JN88
Ear length	15	15	-3.47~7.28	JT120×JN55	JT131×JN44
Ear diameter	14	16 ~	-0.18~0.21	JT120×JN88	JT131×JN55
Rows per ear	15	15	-1.14~2.07	JT124×JN88	JT131×JN44
Number of grains per row	16	14	-3.64~6.98	JT124×JN55	JT135×JN88
100 grain weight	15	15	-3.09~5.03	JT124×JN55	JT145×JN88
Residue ratio	15	15	-14.36~20.78	JT124×JN55	JT145×JN44
Amylopectin content	16	14	-0.53~0.74	JT124×JN88	JT116×JN44

Table 4. Estimation of genetic parameters of each character.

Genetic parameters	Plant height	Ear height	Grain weight	Ear length	Ear diameter	Rows per ear	Number of grains per row	100 grain weight	Residue ratio	Amylopectin content
GCA variance	61.48	32.09	55.79	58.65	60.43	75.62	69.81	71.37	58.73	60.44
SCA variance	38.52	67.91	44.21	41.35	39.57	24.38	30.19	28.63	41.27	39.56
Broad sense heritability	81.30	55.56	84.34	64.52	51.43	71.43	58.82	66.18	53.76	33.81
Narrow sense heritability	49.59	17.83	47.28	37.84	31.15	54.01	41.06	47.26	31.52	20.49

JT111 × JN44, the combination with the best ear length was JT120 × JN55, the combination with the best ear diameter was JT120 × JN88, the combination with the best row number per ear and amylopectin content was JT124 × JN88, and the combination with the best row number per row, 100-grain weight and dregs was JT124 × JN55. Thus, it can be seen that the special combining ability of parents with high general combining ability is not necessarily high, on the contrary, the general combining ability of parents with high special combining ability is not necessarily high. In the process of breeding maize inbred lines, attention should be paid not only to the screening of general combining ability, but also to the screening of special combining ability (Zhang *et al.* 2008).

Broad heritability refers to the percentage of genetic variance in phenotypic variance, narrow heritability refers to the percentage of additive variance in phenotypic variance, and its magnitude reflects the ability of parental traits to be inherited to offspring (Tian *et al.* 2017). Table 4 showed that the GCA variance of plant height, ear rows, grains per row and 100-grain weight was much larger than the SCA variance, indicating that these traits are mainly affected by additive genes, while the GCA variance of ear height was much smaller than the SCA variance, indicating that it is mainly affected by non-additive genes. The GCA variance of ear grain weight, ear length, ear diameter, skin residue rate and amylopectin content were slightly larger than the SCA variance, indicating that these traits were affected by both additive genes and non-additive genes. Except that the broad heritability of amylopectin content was less than 0.42, the broad heritability of other traits was more than 0.42. However, the narrow heritability of ear height, ear diameter, skin residue rate and amylopectin content were lower than 0.32.

To sum up, the broad heritability of plant height, number of rows per ear, number of grains per row and 100-grain weight were higher, and were mainly affected by additive genes, so they were suitable for selection in the early generation, while the broad heritability of ear height, ear diameter, skin residue rate and amylopectin content were higher, but the narrow heritability was lower, so it was suitable for selection in later generations.

China is a large agricultural country. As the largest food crop in China, corn plays an important role in the development of national economy and national food security. With the continuous decline of cultivated land and the improvement of people's living standards, the demand for fresh corn has soared (Li *et al.* 2021, Xu *et al*. 2020, Wang 2020). This requires breeders to select varieties with high yield and high quality, and the key link of maize breeding with heterosis is to select excellent inbred lines. Combining ability is not only the "vitality" of inbred lines, but also the basis for breeding excellent new varieties. Having a number of good inbred lines can not only accurately formulate breeding objectives, but also speed up the breeding process.

In the present study, through the analysis of combining ability of 10 sweet-waxy double recessive inbred lines and 3 test inbred lines, it was found that sweet-waxy double recessive inbred lines JT131 had the lowest GCA effect values of plant height and ear height, which could be used to reduce plant height and ear height of offspring, while JT120 had higher GCA effect values of panicle grain weight, ear length and 100-grain weight, and could produce many groups of excellent combinations, so it was an inbred line with high breeding value. JT111 has the highest general combining ability in grain weight per ear, which can be used to increase the grain weight per ear of hybrid offspring, but its general combining ability of grains per row and 100-grain weight was low, so it can be improved to breed new varieties, while JT113 has the highest general combining ability in ear length and row number per ear, but it is average in other aspects, so it can increase the yield of hybrid offspring through improvement. JT124 performed best in ear length, number of grains per row, 100-grain weight, skin residue rate and amylopectin content, but not in plant height, ear height, ear grain weight and ear diameter. Several outstanding excellent character combinations were also related to the inbred line, indicating that the parent inbred line had strong general combining ability and special combining ability, and it was a parent inbred line with great breeding value. In the next step, the inbred line can increase the ear length, the number of grains per row and 100-grain weight for the parents, so as to select the breeding objectives and carry out the breeding of new sweet and waxy maize varieties.

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