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COMBINING ABILITY OF SOME AGRONOMIC CHARACTERS OF SWEET-WAXY DOUBLE RECESSIVE MAIZE INBRED LINES

MEIQI RONG, LONG JIANG*, HAIYAN YU AND JIANMING LI

College of Agronomy, Jilin Agricultural Science and Technology University, Jilin, Jilin 132101, Jilin Province, P. R. China

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Abstract

The present study was undertaken to explore more excellent sweet-waxy maize germplasm resources and provide a theoretical basis for the rational application of sweet-waxy maize inbred lines. Eight sweet-waxy maize inbred lines VB. RN1621, RN1423, RN1432, RN1636, RN1441, RN1443, RN1457 and RN1669 were selected as female parents (P1) and three sweet-waxy maize inbred lines e. g. LN505, LN506 and LN515 were taken as male parents (P2). Using incomplete diallel cross NCII design, 24 combinations were configured to analyze the combining ability of eight agronomic characters such as plant height, ear height, ear grain weight, ear length, number of grains per row, hundred-grain weight, peel residue rate and amylopectin content. It was obaerved that the order of general combining ability was RN1669, RN1636 and LN506. The combination with the highest effective value of special combining ability was RN1641 × LN506, RN1621 × LN506 followed by RN1657 × LN506 which ranked third. Plant height, panicle grain weight and bark residue rate should be selected in the early generation. The ear height, ear length, 100-grain weight and amylopectin content may be selected in the late generation, which can be used for sweet-waxy maize breeding.

Introduction

Sweet-waxy maize refers to a new type of fresh corn with both waxy and sweet grains on the same corn ear, the sweet and waxy corn are arranged randomly, which balance the matching degree of sweet and waxy corn in the past. It integrates fragrance, sweet and waxy (Shen *et al.* 2021). It has rich grain color, fresh and tender taste like fruit, and nutrients necessary for human body. So it is favored by more and more consumers (Zhang *et al.* 2021). Therefore, the breeding of sweet-waxy maize inbred lines has become a research hotspot. The breeding of sweet-waxy maize varieties is to select sweet waxy double recessive inbred line (wxwxsh2sh2) through sweet waxy hybridization, and then hybridize with waxy maize inbred line (wxwxsh2sh2), 25% of the seeds (wxwxsh2sh2) were sweet and 75% (wxwxsh2sh2 or wxwxsh2sh2) were waxy (Tao *et al.* 2020). Using conventional breeding methods, the process is cumbersome and time-consuming, so a new breeding method is adopted instead, that is, haploid breeding. By inducing haploid and doubling haploid chromosomes, pure lines (DH lines) can be obtained in only two generations, which shortens the breeding years of inbred lines and accelerates the process of variety improvement (*Zhang et al.* 2021*).* At present, few studies are done on haploid breeding of sweet-waxy maize. In the present investigation, the combining ability of some agronomic characters of sweet-waxy maize inbred lines was studied and analyzed by incomplete diallel cross NC II design to broaden the germplasm resources of sweet-waxy maize breeding and provide reference ideas for the efficient breeding of new sweet-waxy maize varieties.

*Author for correspondence: <jlnykjxyjl@163.com>.

Materials and Methods

Eight sweet-waxy maize inbred lines (RN1621, RN1623, RN1632, RN1636, RN1641, RN1643, RN1657 and RN1669) were used as female parents (P1), and three sweet-waxy maize inbred lines (LN505, LN506 and LN515) were used as male parents (P2). According to the incomplete diallel cross NC II design, 24 hybrid combinations were composed. The experiment was carried out in the maize breeding base of Jilin Agricultural Science and Technology University (43°57' N, 126°40′ E) in China in the spring of 2021. A randomized block design was used in the experiment, which was set as three replications. The seeds were sown in double row area, with a length of 5 m, a row spacing of 65 cm and a plant spacing of 25 cm. The field management was done uniformly. The yield was measured 25 days after pollination. Ten consecutive samples of each plot (except the first 3 plants) were collected for seed test, and the plant height and panicle height were measured. Five representative fresh fruit panicles were selected to measure the panicle grain weight, panicle length, number of grains per row, 100-grain weight and residue ratio. The ears were harvested at the maturity stage to determine the amylopectin content. The residue rate and amylopectin content were measured according to the previous methods (Zeng *et al*. 2010).

Based on the average number of test species of each trait, the data were studied by Excel 2013, DPS 7.05 software and analysis of variance (Pei *et al.* 2020). The combining ability of characters with significant difference among combinations was analyzed by incomplete diallel cross model.

Results and Discussion

Results of eight personality traits of 24 combinations analyzed by variance, presented in Table 1 showed that the F values of different groups of characters have little difference, and there is no significant difference between them, indicating that the design of this experiment is reasonable. By analyzing the main agronomic characters and genetic correlation, the difference of each character between combinations reached a very significant level, indicating that there were real differences between parents and combinations in general combining ability (GCA) and special combining ability (SCA). The combining ability effects of these eight agronomic characters can be further compared and analyzed.

Table 1. F value of variance analysis of eight agronomic characters.

Source of variation	DF	Plant height (cm)	Ear height (cm)	Grain weight (g)	Ear length (cm)	Number of grains/ row	100 grain weight (g)	Residue ratio	Amylopectin content
Block group	2	0.251	0.492	0.508	0.634	0.332	0.124	0.653	0.592
Combinations	23	8.681**	6.648**	9.325**	6.786**	7.898**	6.482**	10.817**	6.502**
P1	7	6.133**	4.745**	6.886**	7.814**	7.542**	4.816**	9.336**	2.327**
P2	2	2.936*	4.216*	5.433**	4.896*	3.931*	2.746*	3.886*	2.973*
P1×P2	14	5.927**	4.536**	6.133**	4.634**	7.608	2.936**	4.712**	3.651**
Error	46	23.381	28.286	3.072	0.391	2.417	1.284	1.036	1.991

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

Table 2 reveals that the GCA effect values of the same trait were quite different among different parents, and the GCA effect values of different traits were also significantly different among the same parents. It showed that the additive effects of different traits of different parents are different, and there are great differences in the inheritance of different traits of the same parent and the same trait in different parents (Zhang *et al*. 2020). Therefore, the research and analysis of these eight inbred lines are very important for the breeding of new sweet-waxy maize varieties.

Among the female parent materials RN1632, RN1657 and RN1669 and the male parent materials LN506 and LN512 showed negative values in plant height and panicle height, indicating that their hybrid offspring have advantages in lodging resistance. RN1621 had the highest GCA effect on panicle grain weight, and the female parent materials RN1621, RN1623, RN1636, RN1641 and RN1669 and male parent materials LN505 and LN506 showed positive values on panicle grain weight. The hybrid combination can effectively improve the panicle grain weight of hybrid offspring and achieve effective increase in yield. The female parent materials RN1621, RN1623, RN1632, RN1636, RN1641 and RN1669 and the male parent materials LN505, LN506 and LN515 showed positive values in panicle length which indicate that using of the offspring of hybrid combinations is easy to grow longer panicles. Furthermore, all except LN1657 were positive, indicating that the number of grains in each row can be increased by other cross combinations except RN1657. The GCA effect values of female parent materials, RN1621, RN1623, RN1632, RN1636, RN1641 and RN1657 and male parent materials LN505 and LN515 were positive, and RN1641 was the highest, indicating that it is easy to use these eight inbred lines to produce offspring with higher 100-grain weight, which is conducive to improving yield. Except for RN1657, LN505 and LN515, the GCA effect values of the skin residue rates of the other nine inbred lines were negative, indicating that the ears of the offspring of their hybrid combinations had better edible taste. The amylopectin contents of RN1621, RN1623, RN1636, RN1641, RN1643, RN1669 and LN506 were positive, so it is easy to obtain varieties with better taste value.

Combining the general combining ability effect values of all agronomic characters of tested plants, it can be determined that the comprehensive performance of inbred lines of RN1669, RN1636 and LN506 are found to be the best. Selection of their combinations as parents can produce high-yield, lodging resistant and good taste varieties.

Table 2. GCA relative effect values of main agronomic traits of eight waxy maize inbred lines.

Inbred lines	Plant height (cm)	Ear height (cm)	Grain weight (g)	Ear length (cm)	Rows per ear	100-grain weight (g)	Residue ratio	Amylopectin content
RN1621	6.27	3.52	5.93	5.00	3.11	2.10	-1.53	0.11
RN1623	4.45	1.60	3.47	4.69	2.93	2.52	-0.79	0.30
RN1632	-0.49	-3.47	-4.24	1.91	1.48	1.83	-0.88	-0.71
RN1636	1.54	0.19	2.84	3.93	4.04	3.15	-0.90	0.60
RN1641	3.43	0.60	4.83	7.47	6.23	4.88	-1.59	0.65
RN1643	-2.05	-3.83	-1.58	-0.58	1.01	-1.00	-1.55	1.49
RN1657	-4.87	-4.04	-3.55	-3.43	-1.05	0.67	1.01	-1.04
RN1669	-3.95	-1.72	1.23	2.43	1.20	-2.53	-1.00	0.78
LN505	3.68	0.23	5.63	4.57	3.47	3.12	0.09	-0.71
LN506	-0.20	-0.31	2.93	4.78	6.03	-1.02	-0.60	0.77
LN515	1.20	-2.04	-1.94	1.51	0.94	2.73	0.98	-0.23

Special combining ability (SCA) refers to the special effect different from the average performance of two parents in a specific combination produced by parental hybridization (Song *et al*. 2020, Zhang *et al*. 2020).

Table 3 revealed that the SCA effect value varied greatly among different combinations of various characters, and the hybrid combination with the best plant height performance was RN1657 × LN506. RN1657 × LN515 was the best hybrid combination with high panicle position. The best hybrid combination of panicle and grain weight was RN1621 × LN505. The highest of 100-grain weight was found in the hybrid combination of RN1641 × LN506. Due to the high effect value of special combining ability, it showed that the hybrid offspring had a strong increasing trend in a certain trait (Yao *et al*. 2019). Therefore, the offspring of hybrid combination RN1621× LN505 will have dominant expression in yield. The hybrid combination with the highest panicle length was in RN1621 × LN506. The hybrid combination with the maximum grain number per row was RN1641 × LN506. RN1641 × LN506 was the best hybrid combination with the highest skin residue rate. The hybrid combination with the maximum amylopectin content was obtained in RN1643 × LN506. Hybrid combination RN1641 × LN506 and hybrid combination RN1643 × LN506 are easy to breed and export sensitive sweet-waxy variety with high nutritional value.

Total combining ability (GCA) is the comprehensive expression of general combining ability and special combining ability of hybrid parents (Yao *et al*. 2019). When selecting parents, in addition to selecting parents with high general combining ability effect value, the special combining ability effect value of parent combination is also an important factor that can not be ignored (Zhou *et al*. 2020).

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	13	11	-11.17～10.94	RN1621×LN505	JRN1657×LN505
Ear height	12	12	-8.34～6.92	RN1621×LN505	RN1657×LN505
Grain weight	14	10	-15.63～13.77	RN1621× LN505	RN632× LN515
Ear length	12	12	-5.61～9.84	RN1621× LN506	RN1657× LN515
Number of grains per row	12	12	-2.55～5.38	RN1641× LN506	RN1657× LN515
100 grain weight	15	15	-2.09～3.53	RN1641× LN505	RN1669×LN506
Residue ratio	14	10	-13.61～19.17	RN1657× LN515	RN1641× LN506
Amylopectin content	13	11	-0.75～0.86	RN143× LN506	RN1657×LN505

Estimation of broad heritability and narrow heritability of different traits showed that the GCA variance of ear length, number of grains per row, 100-grain weight and amylopectin content was much greater than the SCA variance, and the GCA variance of ear height was much less than the SCA variance (Table 4). Results also showed that the genetic effects of these traits were mainly affected by additive genes. The GCA variance of plant height, panicle grain weight and bark residue rate were slightly greater than the SCA variance. It is appropriate to combine the early and late generations when selecting plant height, panicle grain weight and residue rate. Moreover, it was found that the broad heritability of plant height and panicle grain weight was greater than 70%. The narrow heritability of panicle height and amylose content were less than 30%, indicating that these traits are greatly affected by the external environment. Based on the analysis of the experimental data and the characteristics of genetic effects of different traits of maize described by predecessors, different traits need to be selected by early generation selection, late generation selection and the combination of early and late bands in the process of inbred line trait selection (Chen *et al*. 2018).

Table 4. Estimation of genetic parameters of each character.

Genetic parameters	Plant height (cm)	Ear height (cm)	Grain weight (g)	Ear length (cm)	Number of grains per row	100-grain weight (g)	Residue ratio	Amylopectin content
GCA variance	58.34	34.03	59.58	60.69	68.73	71.37	59.68	62.71
SCA variance	41.59	65.89	40.34	39.23	31.19	28.63	40.24	37.21
Broad sense heritability	79.42	61.33	74.42	67.28	61.33	66.18	57.45	38.09
Narrow sense heritability	51.34	22.90	48.91	35.80	40.15	47.26	35.37	22.53

The demand for corn in China is huge. With the improvement of people's living standards, the requirements for corn are also improving. This situation has promoted the development of fresh corn industry. Therefore, the varieties with both sweet and waxy fresh corn in the market have become an urgent need, and the problem of corn breeding needs to be solved urgently. Combining ability is the material basis of maize breeding. The utilization of germplasm in breeding finally comes down to the selection of character combining ability (Qiu *et al*. 2021, Yao *et al*. 2021). In the present experiment, eight agronomic characters of inbred lines were studied by using incomplete diallel cross NCII design, so as to select breeding objectives and carry out the breeding of new sweet-waxy maize varieties.

Through the analysis of combining ability of eight sweet-waxy maize inbred lines and 3 test species, the following results were determined. In terms of crop agricultural yield, the hybrid combination of RN1641 × LN506 had the best performance in 100-grain weight, inbred lines RN1641 and LN506 showed the best comprehensive performance, which will be produced high-yield, lodging resistant and good taste sweet-waxy maize. For edible purpose, RN1643 × LN506 was found to be the best hybrid combination with amylopectin content. So the hybrid combination RN1641 × LN506 and hybrid combination RN1643 × LN506 were found easy to breed and export sensitive sweet-waxy variety with high nutritional value. RN1641 and LN505 had the highest general combining ability and both RN1621 × LN505 and RN1641 × LN506 showed the highest special combining ability. It can be seen that the compatibility of two inbred lines with high general combining ability is not necessarily high. Moreover, there must be one or two inbred lines with high general combining ability in the hybrid combination with high special combining ability.

In the process of character selection of inbred lines, early generation breeding should be carried out for ear position weight, ear length, number of grains per row, 100-grain weight and amylopectin content, while early and late generation breeding should be combined for plant height, ear grain weight and skin residue rate. Results of this study on ear length, row number per ear, grain number per row and 100-grain weight are found to be consistent with the findings of Jin *et al*. (2021). However, the present study only focused on specific inbred lines. More experimental materials need to be used to study various agronomic characters of sweet-waxy double recessive maize seeds under different environmental conditions and in order to use these indexes for predicting the most suitable harvest time of sweet-waxy double recessive inbred line maize.

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