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Article

Combining Ability of Sixteen U.S.A. Maize Inbred Lines and Utilization Potential as Hybrids in P.R.C

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Abstract: In China, there are increasing needs for greater genetic diversity of maize (Zea mays L.) germplasm and for hybrids appropriate for machine harvesting. to test and distinguish American maize inbred lines with exceptional combining ability, Four Chinese maize inbred lines (Chang7-2, Zheng 58,four-144 and four-287) were used to judge combining ability and heterosis of 16 U.S.A inbred lines by a NCII genetic mating method. The result showed: Among the American inbred lines, 6M502A,LH208,NL001,LH212Ht,PHW51,FBLA and LH181 showed excellent GCA for yield characteristics; while RS710,PHP76,FBLA,and PHJ89 showed excellent GCA for machine harvesting characteristics. In hybrid combinations, NL001×Chang7-2,LH212Ht×Chang7-2,FBLA×four-144,LH181×four-287,PHK93×four-287 had better SCA for yield characteristics; while NL001×Chang 7-2,6M502A×Chang7-2,LH212Ht×Chang7-2,LH181×four-287,PHW51×Chang7-2 were better than the check for machine harvesting characteristics. NL001×Chang7-2, 6M502A×Chang7-2,LH212Ht×Chang7-2,LH181×four-287,PHW51×Chang7-2 showed excellent total combined advantages compared to the check and potential for future utilization in Inner Mongolia corn production.

Keywords: U.S.A inbred lines; Combining ability; Machine harvesting characteristics; Yield characteristics; control heterosis

1. Introduction

The genetic diversity of maize germplasm in China is decreasing, due to fewer inbred used to produce modern, high-yielding maize hybrids. At the same time, the change of the corn planting pattern in China has greatly increased the demand for full mechanization, which requires the improvement of maize varieties to be suitable for machine harvesting of the grain. However, the lack of maize germplasm suitable for mechanical harvesting that has high combining ability, strong disease and pest resistance, and wide adaptability has become the bottleneck of maize breeding development in China [1-4]. North American germplasm plays an important role in China's corn yield potential, and their genetic contribution to Chinese corn has been increasing [5-6]. Using American maize germplasm is an effective way to improve the diversity of Chinese maize germplasm for identified and screened favorable allele donors due to its clear genealogical origin and abundant genetic variation [7]. Previous studies have shown that the growth period, the silking stage, the ear height, the plant height, and the kernel moisture concentration at the R6 stage could be used to determine a maize germplasm suitable for mechanical harvesting [8]. On this basis, the research used

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16 inbred expired Plant Variety Protection Act (ex-PVP) germplasm adapted to the U.S.A Corn Belt and germplasm currently used in Chinese production as the basic materials. To determine the germplasm suitable for mechanical harvesting, agronomic traits and yield related traits were measured, combining ability was determined, and predominance contrast analyses were performed. So as to clarify its advantage performance and breeding potential in Inner Mongolia region, provides the reference for the rational and effective utilization of U.S.A. germplasm.

2. Materials and Methods

2.1 Germplasm

Through 2014 trail of field adaption, The sixteen U.S.A. ex-PVP inbred germplasms showed excellent adaption characteristic to the weather and soil condition in the two main produce area of Maize in Inner Mongolia-Hohhot(Table1) and Tongliao(Table2).

Table 1. Field characteristic and adaptability of the sixteen U.S.A inbred and four P.R.C inbred in Hohhot

number	inbred	Days to silking	Days to maturity	ASI	Plant Height	Ear height	Seeding potential	Disease resistance （R6）	Anti-lodging	Ear evalution	Overall merit
		d	d	d	cm	cm					
1	RS710	72	118	-2	182	55	†1	‡2	§ 1	¶3	¢7
2	LH191	78	126	-2	260	100	1	2	1	3	7
3	LH192	79	125	-3	200	78	1	2	1	3	7
4	PHN34	76	124	-2	180	79	1	1	1	2	5
5	PHP76	72	117	-3	165	60	1	1	1	3	6
6	PHW51	74	122	-2	198	85	1	2	1	1	5
7	FBLA	74	119	-1	181	79	1	1	1	1	4
8	6F629	75	119	-1	202	87	1	3	1	3	8
9	6M502A	76	118	-3	243	100	1	1	1	1	4
10	NL001	75	111	-3	210	80	1	1	1	1	4
11	LH181	77	122	-2	228	75	1	1	2	1	5
12	LH208	82	118	-2	134	48	1	1	1	1	4
13	LH212Ht	71	122	-2	195	70	1	1	1	1	4
14	Lp215D	81	116	-2	190	70	1	1	1	1	4
15	PHJ89	63	119	-2	120	39	1	2	1	1	5
16	PHK93	79	123	-2	185	50	1	2	1	1	5
17	Zheng58	74	126	-2	175	80	1	1	2	1	5
18	Chang7-2	73	123	0	145	38	2	1	1	1	5
19	Four-144	69	119	-2	178	55	1	1	2	1	5
20	Four-287	68	120	0	156	46	1	2	1	1	5

Sowing date:20140502,Emergence date:20140515.

†means the estimate of the seeding potential, from 1-5 represent the seeding potential from the best to the worst;‡means the estimate of the disease resistance in R6 growth stage, from 1-5 represent the disease resistance from the best to the worst;§means the estimate of the Anti-lodging, from 1-5 represent the Anti-lodging characteristic from the best to the worst;¶means the ear evaluation, from 1-5 represent from the best ear characteristic and yield potential to the worst;¢means the sum of seeding potential, disease resistance, Anti-lodging, and ear evaluation. the lower the amount, the better of the overall merit.

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Table 2. Field Characteristic and adaptability of the sixteen U.S.A inbred and four P.R.C inbred in Tongliao

number	inbred	Days to silking	Days to maturity	ASI	Plant Height	Ear height	Seeding potential	Disease resistance（R6）	Anti-lodging	Ear evaluation	Overall merit
		d	d	d	cm	cm					
1	RS710	51	112	-1	140	34	†1	‡3	§ 1	¶3	¢8
2	LH191	67	123	-1	172	56	1	2	1	2	6
3	LH192	66	120	-2	175	58	1	3	1	2	7
4	PHN34	63	122	-1	210	82	1	2	1	2	6
5	PHP76	55	116	0	171	55	1	2	1	3	7
6	PHW51	63	122	0	205	60	1	2	1	2	6
7	FBLA	58	118	-3	181	45	1	2	1	1	5
8	6F629	58	115	0	206	78	1	1	1	3	6
9	6M502A	63	117	-2	207	73	1	1	1	1	4
10	NL001	62	115	-2	160	63	1	1	1	1	4
11	LH181	61	118	-1	246	72	1	1	1	1	4
12	LH208	65	120	-2	225	75	1	1	1	1	4
13	LH212Ht	64	122	-2	245	100	1	1	1	2	5
14	Lp215D	56	118	0	212	60	1	2	1	1	5
15	PHJ89	53	115	-1	210	63	1	2	1	2	6
16	PHK93	64	115	-1	205	55	1	1	1	2	5
17	Zheng58	66	120	-2	189	81	1	1	2	1	5
18	Chang7-2	65	121	-1	154	47	1	1	1	1	4
19	Four-144	57	116	1	170	52	1	1	2	1	5
20	Four-287	58	115	1	152	43	1	2	1	1	5

Sowing date:20140501,Emergence date:20140514.

†means the estimate of the seeding potential, from 1-5 represent the seeding potential from the best to the worst;‡means the estimate of the disease resistance in R6 growth stage, from 1-5 represent the disease resistance from the best to the worst;§means the estimate of the Anti-lodging, from 1-5 represent the Anti-lodging characteristic from the best to the worst;¶means the ear evaluation, from 1-5 represent from the best ear characteristic and yield potential to the worst;¢means the sum of seeding potential, disease resistance, Anti-lodging, and ear evaluation. the lower the amount, the better of the overall merit.

Sixteen diverse maize expired Plant Variety Protection Act (ex-PVP) inbred germplasms adapted to the U.S.A. Corn Belt were acquired from the North Central Regional Plant Introduction Station (http://www.ars-grin.gov/npgs, verified 24 Aug. 2016), through the Maize Industrial Technology System Construction of Modem Agriculture of China by international communication.

From Table1, it is known that the days to silking of the Sixteen U.S.A inbred was 63d-82d respectively after the emergence, the days to maturity of the sixteen inbred was 111d-126d respectively, the plant height of the sixteen inbred was 120cm-260cm respectively, the ear height was the39cm-100cm respectively, ASI(anthesis - silking interval) was -1 to -3 respectively, and the overall merit of adaptability was 4-8 respectively. From Table2. we can see that the says to silking of the sixteen U.S.A inbred was 51d-67d respectively after the emergence, the days to maturity of the sixteen inbred was 112d-123d respectively, the plant height was 140cm-246cm respectively, the ear height was 34cm-100cm respectively, the ASI(anthesis - silking interval) was 0 to -3 respectively, and the overall merit if adaptability was 4 to 8 respectively. The Field Characteristic of the sixteen U.S.A.

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inbred in Hohhot and Tongliao were suitable to play a hybrid parent together with the four P.R.C inbred, and from the adaptability of the sixteen inbred to the condition of Hohhot and Tongliao, the inbred can adapt to grow in Inner Mongolia Maize produce area, so this study select the sixteen U.S.A ex-PVP inbred germplasms and 4 P.R.C test species as the trial material.

The classification and pedigree sources of the sixteen U.S.A inbred and four P.R.C inbred are shown in Table 3. The P.R.C. heterotic group A is similar to the U.S.A heterotic group of stiff stalk synthetic (SS), while the P.R.C. heterotic group B is similar to the U.S.A heterotic group of non-stiff stalk synthetic (NSSS).

Table 3. Genealogical origin of U.S.A maize inbred lines and P.R.C testers

number	Germpl	Heterotic group¤	Genealogical origin
1	RS 710	NSS	1202 X 1250
2	LH191	SS	LH132 X Pioneer 3184
3	LH192	SS	LHE137 X LHE136
4	PHN34	SS	SC359 X PH157 specifically SC359/PH157)X#4221
5	PHP76	NSS	G50/PHEJ8)X812X
6	PHW51	SS	PHDF2/PHG41)RXB333X
7	FBLA	SS	(B14////Mt42).A656(B14//Mt42)
8	6F629	NSS	88051B/4608H
9	6M502	NSS	MAWU.4913
10	NL001	SS	1089HT x A634HT/B73
11	LH181	NSS	LH58 XL H122
12	LH208	SS	LH74 X CB59G
13	LH212	NSS	LH123Ht X (LH123Ht X LH24)
14	Lp215D	NSS	Mo17 X Lp216D
15	PHJ89	NSS	PHT77 X PHG47
16	PHK93	NSS	PHB72 X PHT60 specifically PHB72/PHT60)6K41K111K211
17	Zheng5	✝A	Ye 478improved line
18	Chang7	B	V59 × Huangzaosi
19	four-	A	VMA724 improved line
20	four-	B	four-444 × 255

¤ A is similar to SS, B to NSS.

2.2 Experimental design

Hybrids were produced using the sixteen U.S.A. maize inbred lines as female parents and the four P.R.C test species as male parents. According to a NC-II genetic mating design, 64 hybrid combinations were produced at Hainan province Ledong county experimental base(18°45′5.38N, 109°10′10.22E) in the winter of 2014.

In 2015, the 64 hybrid combinations and one control hybrid (Zhengdan 958) were planted at two main Maize area in Inner Mongolia of China-Hohhot and Tongliao (table4-5), A randomized block design was used with five replications, 0.6 m row spacing, 0.25 m plant spacing, 40 plants per plot, with a density of 66670 plants/hm2. Two rows plots. All in-crop fertilizer rate of NPK was N: 200 kg/hm2, P2O5: 105 kg/hm2 and K2O: 62 kg/hm2. Phosphate fertilizer and potash fertilizer were applied as basal fertilizer once before planting and nitrogen fertilizer was applied by 30% (60 kg/hm2)atV6 stage(six leaves with collars visible) and 70%(140 kg/hm2) at V12 stage(twelve leaves with collars visible) respectively. Irrigation and other management measures during the whole growth period were similar to local farmer practices.

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Table 4. Weather condition of 2015 in Hohhot and Tongliao

Experimental sites	Latitude	Longitude	Solar radiation	Average temperature	Precipitation
			hour per year	℃	mm per year
Hohhot	40°33′N	110°31′E	1780.5	17.8	275.4
Tongliao	43°42′N	122°32′E	1224.7	20.5	433.2

Table 5. Basis fertilizer of soil in Hohhot and Tongliao

Experimental sites	Organic Matter	Available N	Available P	Available K	Soil type
	g/kg	mg/kg	mg/kg	mg/kg	
Hohhot	18.9	44.8	16.2	120.4	Sandy loam
Tongliao	20.4	55.6	18.2	167.9	Meadow chernozemic soil

2.3 Measurements and Production Indicators

The days from field emergence to 50% silking and to maturity were recorded for each plot. During plant maturation, 10 plants were randomly selected, and their total height and ear height were measured.

Plant stand counts were tallied to confirm plant populations at the R6 plant growth stage. and ear stand counts were tallied to confirm ear number per hm2. The two rows of each plot were manually harvested for determination of grain yield at physiological maturity, Corn ears were tallied and weighed, The grain was removed manually to analyzed for moisture content using seed moisture meter (PM-8188-A,KETT ELECTRIC LABORATORY, Japan), 300 randomly selected kernels were weighed to estimate average individual kernel weight. According to the average weight of the ear, select 10 ear of each plot to assess the number of rows per ear and grain number per row. The kernel weight and the yield were presented at 14% moisture concentration.

2.4 Data statistical analysis

Variance analysis of each trait was conducted by the GLM module of SAS software [9], the General combining ability of each trialed parent and the Special combining ability of the progeny were calculated through the GLM module of SAS software too. The model formula is as follows:

$$Yijk = \mu + mi + fj + (m\times f)ij + eijk \quad (1)$$
[10]

Where Yijk is the k observational value of the progeny of parents i and j, μ is the universal mean, mi is i-th paternity effect, fj is j-th maternal effect, (m×f)ij is the interaction effect, eijk is the error term.

$$TCAi\,j= Gi+Gj+Sij \quad (2)$$

Where TCAij is Total Combining Ability of the progeny of parents i and j, Gi is General Combining Ability of parent i, Gj is General Combining Ability of parent j, Sij is Special Combining Ability of the progeny of parents i and j.

$$CHij = (YFij - YC)/YC\times 100\% \quad (3)$$

Where CHij is the Control Heterosis of the progeny of parents i and j, YFij is the average yield of an individual hybrid combination by parents i and j, YC is the average yield of the control Zhengdan 958.

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3. Results

3.1 The basic statistical analysis of phenotypic and grain yield traits

A basic statistical analysis of the indicators of machine-harvest ability of the hybrids, including days to maturity, days to silking, plant height, ear height and moisture content at harvest time was carried out at the two locations. The results showed that, when averaged over all the hybrids, the machine-harvest characteristics of the maize hybrids in the different locations all varied greatly, such as the maximum and minimum of the value, mean value, standard deviation and coefficient of variation. At Hohhot, the days to maturity between hybrids differed by 13 d, while at Tongliao hybrids matured over 33 d. The days to silking at Hohhot varied by 18 d, but that at Tongliao, by 12 d. Plants were shorter, but with less variability at Hohhot, with a range of 159.5-278.8 cm, compared to that at Tongliao of 202.0-324.0 cm. Correspondingly, ear height of the hybrids at Hohhot was 47.5-116.0 cm, and that in Tongliao was 71.0-158.0 cm. At harvest time in Hohhot, the grain moisture content varied from 18.6% to 38.6%, and at harvest time in Tongliao, from 24.2% to 35.3% (Table 6).

Table 6. Summary of machine-harvesting related trait measurements for 64 maize hybrids grown at Hohhot and TongLiao in 2015.

	Hohhot					Tongliao				
	Days to maturity	Days to silking	Plant height	Ear height	Grain moisture	Days to maturity	Days to silking	Plant height	Ear height	Grain moisture
	d	d	cm	cm	%	d	d	cm	cm	%
minimum	136.0	66.0	159.5	47.5	18.6	105.0	55.0	202.0	71.0	24.2
maximum	149.0	84.0	278.8	116.0	38.6	138.0	67.0	324.0	158.0	35.3
SD	0.65	0.97	7.25	3.05	0.80	0.57	0.83	11.10	4.86	0.96
average	144.7	77.1	225.0	75.4	29.9	121.7	61.4	280.0	110.0	28.6
CV	0.45	1.26	3.22	4.05	2.69	0.47	1.34	3.96	4.42	3.37

A basic statistical analysis of the hybrid yield-based indicators of ear row number, kernel grains per row, 100-kernel weight and grain yield was carried out at Hohhot and Tongliao (Table 7).

Table 7. Summary of yield-related trait measurements for 64 maize hybrids grown at Hohhot and Tongliao in 2015.

	Hohhot				TongLiao			
	Kernels per row	Rows per ear	100-kernel weight	Grain yield	Kernels per row	Rows per ear	100-kernel weight	Grain yield
			g	t/hm^2			g	t/hm^2
minimum	29.5	11.6	23.6	6.5	32.1	12.8	26.7	7.7
maximum	46.5	18.0	39.6	15.3	42.6	18.4	41.0	16.8
SD	0.37	0.27	0.75	0.65	0.56	0.29	0.86	0.88
average	39.3	14.3	30.7	11.0	38.7	15.9	33.5	11.4
CV	0.95	1.93	2.46	5.97	1.43	1.83	2.56	7.74

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The results indicated that the extremes, average, standard deviation and variable coefficient of the measured traits at the different locations were all significantly different. There was a greater range in kernel grains per row at Hohhot from 29.5 to 46.5, compared to 32.1 to 42.6 at Tongliao. At Hohhot, ear row number varied 11.6 to 18.0, with slightly more at Tongliao, from 12.8 to 18.4. At Hohhot, 100-kernel weight of the hybrids was lighter, and varied from 23.6g to 39.6 g, compared to at Tongliao, which was 26.7g to 41.0 g. There was a large variation in grain yield of the hybrids, 6.5 t/hm2-15.7 t/hm2 and 7.7 t/hm2- 16.8 t/hm2 at Hohhot and Tongliao, respectively.

3.2 Analysis of variance of main characteristics

Table 8 shows that the variances of five traits relating to the suitability of harvesting (the days to maturity, days to silking, plant height, ear height and moisture content at harvest) in paternal tester's heterosis, general combining ability (GCA) and specific combining ability (SCA) of maternal lines were all significant or highly significant. The environmental and gene interaction effects of all traits were highly significant.

Table 8. Analysis of variance for the machine-harvesting characteristics of the hybrids derived from American maize inbred lines crossed with Chinese inbred testers grown in two locations in 2015.

Variation source	DF	Days to maturity	days to silking	Plant height	Ear height	Grain moisture at harvest
Environment	1	§50669.1**	§23531.3**	§290554.0**	§115065.8**	§155.3**
Line	15	166.2**	134.8**	3133.8**	801.0**	49.4**
Tester	3	467.4**	158.4**	22005.8**	15824.8**	118.3**
Line*Tester	45	56.6**	12.3**	390.0**	350.8**	22.3**
Line*Environment	15	69.6**	30.1**	516.3**	167.3**	29.3**
Tester*Environment	3	316.5**	2.7*	2255.1**	344.4**	19.6**
Line*Tester*Environment	45	55.3**	8.6**	504.9**	363.0**	30.2**

§ means:* and **in the column represents significance at the 0.05 and 0.01 probability level, respectively.

Table 9 shows that the variance of four grain yield characteristics (kernel grains per row, the ear row number, 100-kernel weight and grain yield) in paternal testers heterosis, general combining ability (GCA) and special combining ability (SCA) of maternal lines were highly significant. The environmental and gene interaction effects of all traits were also highly significant. Therefore, there were genetic and phenotypic differences in all hybrid combinations for the five traits related to suitability for harvesting, and the four grain yield-production traits. Consequently, the utilization potential of the test materials can be evaluated by estimating the GCA, SCA, TCA and control heterosis of the test materials.

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Table 9. Analysis of variance for the yield characteristics of the hybrids derived from U.S.A. maize inbred lines crossed with P.R.C. inbred testers grown in two locations in 2015.

Variation source	DF	Kernel number per row	Kernel row number	100-kernel weight	grain yield
Environment	1	§29.4**	§248.7**	§755.0**	§16.0**
Line	15	60.8**	4.7**	47.8**	14.5**
Tester	3	187.4**	41.6**	279.4**	36.6**
Line*Tester	45	12.6**	1.7**	18.9**	3.7**
Line*Environment	15	16.2**	2.8**	17.3**	4.4**
Tester*Environment	3	32.2**	1.6**	14.6**	2.7**
Line*Tester*Environment	45	6.7**	0.7**	18.0**	2.6**

§means * and ** in the column represents significance at the 0.05 and 0.01 probability level, respectively.

2.3 Analysis on the general combining ability effect of suitable to machine-harvest indexes and grain yield characters

General combining ability (GCA) is determined by the additive effects of genes, and can distinguish the genetic component of an inbred line and reflect its potential for utilization. At the present stage, with the change of the corn planting pattern in China, the breeding of corn varieties is developing in the direction towards suitability for full mechanization. According to the analysis of suitability traits of the U.S.A. inbred lines, the GCA effect values of both days to maturity and days to silking were significantly negative for RS710, PHP76, FBLA, 6F629, NL001, Lp215D and PHJ89, indicating that hybrids derived from these inbred lines had faster development, with shorter days to silking and to maturity (Table 7). Hybrids made from RS710, PHP76, FBLA, or PHJ89 resulted in shorter plants with lower ear heights, displaying lower GCA effect values. Additionally, the negative GCA effect values of grain water content at harvest of RS710, PHP76, FBLA, 6F629, LH208 and PHJ89, indicates that hybrids derived from these inbred lines had a faster grain dehydration rate (Table 10).

Ear row number, kernel number per row and 100-kernel weight are important factors for grain yield composition. Focusing on these parameters can improve the efficiency of using American inbred lines for breeding research. Evaluating of the 100-kernel weight revealed positive and significant GCA values for the U.S.A. inbred lines of LH191, FBLA, LH181, LH212Ht, Lp215D and PHK93. The hybrid combination obtained by above inbred lines would lead to above-average 100-kernel weight; The GCA effect values of row number per ear were positive and significant in the inbred LH191, LH192, and NL001, indicating that hybrid combinations obtained by these inbred lines could increase ow number per ear; The GCA effect values of kernels per row indicated significant increases due to many inbred, including LH192, PHN34, PHP76, 6F629, 6M502A, LH208, PHJ89 and PHK93; hybrid combinations obtained by these inbred lines could increase kernels per row; As for total grain yield, the GCA effect indicated that using 6M502,ALH208, NL001, LH212Ht, PHW51, FBLA, LH181, for hybrids may achieve higher than average grain yield (Table 10).

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Table 10. The general combining ability of U.S.A. inbred lines for machine harvest and yield characteristics.

Line	Days to maturity	Days to silking	Plant height	Ear height	Grain moisture at harvest	Kernels per row	Kernel rows	100-kernel weight	Grain yield
RS710	§-4.96**	§-5.47**	§-34.33**	§-13.96**	§-2.91**	§-4.85**	§-0.04	§-1.47**	§-1.97**
LH191	3.04**	2.57**	-3.72**	-0.85	0.10	-0.77**	0.18**	1.20**	-0.31**
LH192	4.41**	2.73**	4.93**	1.57*	1.89**	0.60**	0.76**	-0.66**	-0.49**
PHN34	3.50**	2.07**	13.54**	11.26**	2.06**	0.67**	-0.09*	0.11	-0.28*
PHP76	-1.88**	-3.35**	-13.09**	-2.13**	-0.86**	0.59**	-0.04	-2.07**	-0.56**
PHW51	1.71**	0.69**	0.14	-0.26	1.32**	0.10	-0.33**	-0.70**	0.48**
FBLA	-1.75**	-1.68**	-2.68*	-5.34**	-2.43**	-0.19**	-0.41**	1.49**	0.42**
6F629	-1.04**	-0.27*	-0.96	-0.37	-1.33**	1.01**	-0.11**	-2.20**	-0.63**
6M502A	-1.25**	2.23**	7.55**	6.57**	1.43**	1.01**	-0.41**	-0.99**	1.47**
NL001	-2.79**	-0.85**	-2.18	0.09	0.25*	-0.61**	0.52**	-0.25*	0.51**
LH181	1.29**	2.19**	9.64**	-0.02	0.48**	-1.57**	-0.37**	2.48**	0.34**
LH208	-1.34**	0.15	3.10*	-1.36*	-0.33*	1.97**	-0.28**	0.01	0.89**
LH212Ht	1.66**	1.19**	11.06**	8.28**	0.77**	-0.01	0.01	1.18**	0.51**
Lp215D	-1.42**	-2.02**	4.17**	1.17*	-0.07	-0.42**	-0.74**	0.85**	-0.07
PHJ89	-1.79**	-1.72**	-4.54**	-5.22**	-0.98**	0.65**	-0.07	-0.93**	-0.11
PHK93	2.62**	1.53**	7.38**	0.57	0.62**	1.83**	0.01	1.95**	-0.19
$LSD_{0.05}$	0.17	0.25	2.58	1.12	0.24	0.13	0.08	0.22	0.21
$LSD_{0.01}$	0.24	0.35	3.66	1.58	0.35	0.18	0.11	0.32	0.30

§ means * and **in the column represents significance at the 0.05 and 0.01 probability level, respectively.

2.4 General combining ability analysis of machine-harvest suitability traits and grain yield traits of test varieties

From table 11 ,we can see that the kernel number per row, row number per ear and grain yield GCA effect values of chang7-2 are positively significant. The results indicated that Chang7-2 was beneficial to be used for hybrid combinations, increasing kernel number per row, row number per ear, and grain yield. The GCA effect of plant height and ear height of Zheng58 was significantly negative, but the GCA effect of 100-kernel weight was positively significant. The results indicate that Zheng58 would be beneficial in hybrids for mechanized harvest, contributing traits of shorter plants, low ears, and high 100-kernel weights.

Table 11. The general combining ability of P.R.C tester lines for machine harvest and yield characteristics.

Line	Days to maturity	Days to silking	Plant height	Ear height	Moisture moisture at harvest	Kernels per row	Kernel rows	100-kernel weight	Grain yield
Zhen58	§1.7**	§0.8**	§-17.1**	§-6.9**	§1.0**	§-1.0**	§-0.3**	§0.2**	§-0.2**
Chang7	2.1**	1.3**	19.8**	19.2**	0.9**	1.8**	0.9**	-0.4**	0.8**
four-144	-1.7**	-0.5**	-0.4	-4.7**	-0.7**	0.5**	-0.03	-2.0**	-0.6**
four-287	-2.1**	-1.6**	-2.3**	-7.6**	-1.2**	-1.2**	-0.6**	2.2**	0.01
$LSD_{0.05}$	0.09	0.09	0.98	0.44	0.07	0.15	0.05	0.15	0.09
$LSD_{0.01}$	0.13	0.12	1.39	0.62	0.10	0.21	0.08	0.21	0.13

§ means * and ** in the column represents significance at the 0.05 and 0.01 probability level, respectively.

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The GCA effect values of days to maturity, days to silking, plant height and grain moisture content at harvest were all negative significant, and GCA effect values of kernel number per row were positive significant in the tester line of four-144, demonstrating its ease of use in hybrid combinations with the characteristic of short growth period and day from emergence to silking, low ear, low grain moisture in harvest time and more kernel number per row. The GCA effect values of days to maturity, days to silking, plant height, ear height and grain moisture content at harvest of four-287 were all significantly negative, and the GCA effect of 100-kernel weight was positively significant. The results showed that the hybridization combination by four-287 was easy to possess the characteristics of earlier maturity, less days to silking, low plant height, low ear, low moisture content at harvest, and high 100-kernel weight.

2.5 Analysis of specific combining ability of hybrid combination

Specific combining ability (SCA) is determined by the non-additive effect of genes, which is easily affected by the environment and cannot be inherited stably. It is used as a reference when sifting through hybrid combinations.

Of the 64 hybrid combinations, there were 16 with significant positive SCA effects for yield (Table 12). The A × A cis-hybrid combinations with good yield included LH191 × Zheng58, PHN34 × Zheng58, LH208 × Zheng58 and FBLA × four-144. The B × B cis-hybrid combinations producing increased yield included 6M502A × Chang 7-2, LH212Ht × Chang 7-2, Lp215D × Chang 7-2, RS710 × four287, LH181 × four-287 and PHK93 × four-287. While the A × B trans-hybrid combinations with yield increases included PHW51 × Chang 7-2, NL001 × Chang 7-2 and LH208 × four-287. The B × A trans-hybrid combinations with yield increases included 6M502A × Zheng 58, PHP76 × four-144 and 6F629 × four-144.

Conversely, the SCA of 18 hybrid combinations indicated decreased yields(Table 12 and Continuation Table 12). The A × A cis-hybrid combination with poor yield included NL001 × Zheng58 and LH208 × four-144. The B × B cis-hybrid combinations that significantly decreased yield included 6F629 × Chang7-2, LH181 × Chang7-2, PHK93 × Chang7-2, PHP76 × four-287, 6M502A × four-287, LH212Ht × four- 287. The A × B trans-hybrid combinations with poor yield includes PHN34 × Chang 7-2, FBLA × Chang7-2, PHN34 × four-287, PHW51 × four-287, FBLA × four-287 and NL001 × four-287. While the poor performers in the B × A trans-hybrid combinations included RS710 × Zheng58, LH181 × Zheng58, Lp215D × four-144 and PHJ89 × four-144.

At the same time, there were 15 of the hybrid combinations with significant negative SCA effect values for both days to maturity and days to silking. The A × A cis-hybrid combinations with faster growth included LH191 × Zheng58, LH192 × Zheng58, PHN34 × four-144 and NL001 × four-144. The B × B cis-hybrid combinations with more rapid development included RS710 × Chang7-2, LH181 × Chang7-2, PHJ89 × Chang7-2, PHP76 × four-287 and LH181 × four-287. The more rapid maturing A × B trans-hybrid combinations included LH212Ht × Zheng58, PHK93 × Zheng58, RS710 × four-144 and 6F629 × four-144. While the B×A trans-hybrid combinations with rapid development included LH192 × four-287 and PHW51 × four-287.

And there were 14 of the hybrid combinations with significant negative SCA effect values for both plant height and ear height. The A × A cis-hybrid combinations with shorter plants and ears included LH192 × Zheng58, NL001 × Zheng58 and LH208 × Zheng58; the B × B cis-hybrid combinations included RS710 × Chang7-2, PHP76 × Chang7-2, PHK93 × Chang7-2, 6M502A × four-287, LH212Ht × four-287 and PHJ89 × four-287; the A × B trans-hybrid combinations included PHN34 × four-287; the B × A trans-hybrid combinations included RS710 × Zheng58, PHJ89 × Zheng58, LH212Ht × four-144 and Lp215D × four-144.

Table 12. Analysis of specific combining ability of hybrid combinations for growth and yield parameters.

hybrid combinations	Hybrid pattern	Days to maturity	Days to silking	Plant height	Ear height	Grain moisture at harvest	Grain yield
RS710×Zheng58	B×A	§-4.25**	§-0.07	§-12.84**	§-7.52**	§0.68*	§-0.47*
LH191×Zheng58	A×A	-2.91**	-0.61**	0.63	-0.09	-0.03	0.57*
LH192×Zheng58	A×A	-1.96**	-1.11**	-8.85**	-5.01**	-0.99**	-0.14
PHN34×Zheng58	A×A	-2.54**	0.06	8.58**	0.55	-2.68**	0.87**
PHP76×Zheng58	B×A	-1.16**	0.64*	2.22	6.94**	-0.28	0.19
PHW51×Zheng58	A×A	5.09**	1.60**	6.86*	3.64**	-1.61**	0.14
FBLA×Zheng58	A×A	1.71**	0.47	6.55*	6.74**	3.13**	0.15
6F629×Zheng58	B×A	2.67**	1.22**	3.62	2.43*	2.59**	-0.27
6M502A×Zheng58	B×A	1.21**	0.89**	7.21*	1.49	0.73**	0.50*
NL001×Zheng58	A×A	0.42*	-1.19**	-10.24**	-7.78**	-3.18**	-1.01**
LH181×Zheng58	B×A	5.34**	1.77**	-1.61	-3.04*	-0.26	-0.95**
LH208×Zheng58	A×A	1.29**	-0.03	-7.31**	-3.99**	0.71**	0.64**
LH212Ht×Zheng58	B×A	-1.21**	-1.57**	7.94**	9.37**	-1.79**	-0.17
Lp215D×Zheng58	B×A	0.71**	-0.03	0.53	-0.02	2.22**	0.12
PHJ89×Zheng58	B×A	-0.08	-0.32	-8.33**	-4.97**	0.99**	0.10
PHK93×Zheng58	B×A	-4.33**	-1.73**	5.03	1.24	-0.25	-0.26
RS710×Chang7-2	B×B	-3.47**	-1.18**	-11.52**	-15.97**	0.59*	-0.32
LH191×Chang7-2	A×B	2.03**	-1.22**	4.87	7.48**	-2.25**	-0.41
LH192×Chang7-2	A×B	3.16**	0.94**	-4.27	9.00**	0.01	0.26
PHN34×Chang7-2	A×B	4.08**	1.11**	-3.19	3.90**	-0.08	-0.66**
PHP76×Chang7-2	B×B	0.95**	0.19	-13.36**	-6.13**	-0.46	-0.22
PHW51×Chang7-2	A×B	-3.47**	-0.18	3.76	-6.91**	1.51**	0.60**
FBLA×Chang7-2	A×B	-1.01**	0.53*	0.83	-5.58**	1.63**	-1.09**
6F629×Chang7-2	B×B	-1.88**	0.94**	1.99	-1.89	1.60**	-0.50*
6M502A×Chang7-2	B×B	-1.84**	-0.06	2.65	10.33**	0.19	0.50*
NL001×Chang7-2	A×B	2.03**	1.03**	10.24**	6.15**	-0.05	1.69**
LH181×Chang7-2	B×B	-4.55**	-1.52**	-4.85	7.68**	0.83**	-0.79**
LH208×Chang7-2	A×B	1.08**	-0.31	3.52	-7.55**	-0.31	-0.04
LH212Ht×Chang7-2	B×B	2.08**	-0.02	5.44*	3.46**	0.02	1.07**
Lp215D×Chang7-2	B×B	-0.34*	0.86**	1.83	0.99	-2.39**	0.52*
PHJ89×Chang7-2	B×B	-0.97**	-0.93**	9.02**	-0.05	-0.91**	0.27
PHK93×Chang7-2	B×B	2.12**	-0.18	-6.98*	-4.92**	0.21	-0.88**
LSD $P \leq 0.05$		0.34	0.50	5.16	2.23	0.49	0.43
LSD $P \leq 0.01$		0.48	0.70	7.31	3.17	0.69	0.60

§ means * and ** in the column represents significance at the 0.05 and 0.01 probability level, respectively.

There were 20 of the hybrid combinations with significant negative SCA values for grain water content at harvest. The A × A cis-hybrid combinations with more rapid grain moisture dry down rate included LH192 × Zheng58, PHN34 × Zheng58, PHW51 × Zheng58, NL001 × Zheng58, FBLA × four-144 and LH208 × four-144. The B × B cis-hybrid combinations with lower grain moisture content included Lp215D × Chang7-2, PHJ89 × Chang7-2, LH181 × four-287 and PHK93 × four-287. The A × B

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trans-hybrid combinations with decreased grain moisture content at harvest included LH191 × Chang7-2, PHN34 × four-287, PHW51 × four-287 and FBLA × four-287. While the B × A trans-hybrid combinations which produced drier grain included LH212Ht × Zheng58, RS710 × four-144, 6F629 × four-144, 6M502A × four-144, Lp215D × four-144 and PHJ89 × four-144.

Continuation Table 12. Analysis of specific combining ability of hybrid combinations for growth and yield parameters.

hybrid combinations	Hybrid pattern	Days to maturity	Days to silking	Plant height	Ear height	Grain moisture at harvest	Grain yield
RS710×four-144	B×A	§-1.05**	§-2.05**	§6.30*	§-3.32**	§-2.05**	§0.06
LH191×four-144	A×A	0.78**	2.74**	-2.85	-4.01**	1.24**	-0.40
LH192×four-144	A×A	1.24**	1.08**	2.20	-3.68**	-0.20	0.03
PHN34×four-144	A×A	-1.67**	-0.59*	8.56**	5.21**	3.56**	0.37
PHP76×four-144	B×A	4.87**	1.99**	8.90**	3.19**	0.67*	0.69**
PHW51×four-144	A×A	1.62**	-0.88**	-8.83**	-0.93	1.71**	0.01
FBLA×four-144	A×A	-0.09	-1.51**	-4.16	-1.93	-4.25**	1.48**
6F629×four-144	B×A	-2.80**	-3.26**	-5.99*	-0.69	-3.81**	0.67**
6M502A×four-144	B×A	0.08	-0.42	-0.58	-4.10**	-1.10**	-0.43*
NL001×four-144	A×A	-3.72**	-1.01**	3.31	-1.55	1.06**	0.09
LH181×four-144	B×A	-0.30	0.79**	-0.33	-1.51	2.41**	-0.10
LH208×four-144	A×A	-2.51**	0.66*	-0.88	6.08**	-0.82**	-1.33**
LH212Ht×four-144	B×A	0.66**	0.95**	-5.34*	-3.97**	0.60*	-0.14
Lp215D×four-144	B×A	-0.42*	-0.17	-6.22*	-2.61*	-0.68*	-0.47*
PHJ89×four-144	B×A	2.78**	1.04**	6.76*	11.94**	-0.68*	-0.59*
PHK93×four-144	B×A	0.53**	0.62*	-0.86	1.90	2.32**	0.08
RS 710*four-287	B×B	8.76**	3.30**	18.06**	26.81**	0.78**	0.73**
LH191*four-287	A×B	0.10	-0.91**	-2.65	-3.38**	1.04**	0.24
LH192×four-287	A×B	-2.45**	-0.91**	10.91**	-0.31	1.19**	-0.15
PHN34×four-287	A×B	0.14	-0.58*	-13.95**	-9.66**	-0.79**	-0.58*
PHP76×four-287	B×B	-4.65**	-2.83**	2.24	-4.00**	0.08	-0.65**
PHW51×four-287	A×B	-3.24**	-0.54*	-1.79	4.20**	-1.60**	-0.74
FBLA×four-287	A×B	-0.61**	0.51*	-3.22	0.78	-0.50*	-0.53*
6F629×four-287	B×B	2.01**	1.09**	0.38	0.14	-0.36	0.10
6M502A×four-287	B×B	0.55**	-0.41	-9.29**	-7.72**	0.16	-0.57*
NL001×four-287	A×B	1.26**	1.17**	-3.31	3.18**	2.17**	-0.76**
LH181×four-287	B×B	-0.49**	-1.04**	6.79*	-3.13*	-2.98**	1.84**
LH208×four-287	A×B	0.14	-0.33	4.66	5.46**	0.43	0.74**
LH212Ht×four-287	B×B	-1.53**	0.63*	-8.05**	-8.86**	1.18**	-0.75**
Lp215D×four-287	B×B	0.05	-0.66*	3.86	1.65	0.85**	-0.18
PHJ89×four2-87	B×B	-1.74**	0.21	-7.45**	-6.93**	0.61*	0.22
PHK93×four-287	B×B	1.68**	1.30**	2.80	1.78	-2.28**	1.05**
LSD $P \leq 0.05$		0.34	0.50	5.16	2.23	0.49	0.43
LSD $P \leq 0.01$		0.48	0.70	7.31	3.17	0.69	0.60

§ means * and ** in the column represents significance at the 0.05 and 0.01 probability level, respectively.

2.6 Total yield combining effect value and control heterosis analysis

The total combining ability (TCA) effect value is determined by the parental inbred GCA and SCA. It can be used as an index to evaluate combined hybrid performance. As can be seen from Table 10, the TCA value of the yield characters in the worst to best hybrid combinations ranged from -2.62

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to 3.03. The TCA effect values of the 30 best-yield and least-yield hybrid combinations were similar to the control heterosis rankings.

Table 13. Analysis of output effect in total combining ability and Control heterosis

hybrid combinations	Hybrid pattern	Female parent GCA effects	Male parent GCA effects	SCA effects	TCA effects	Control heterosis	rank
NL001×Chang7-2	A×B	§0.51**	§0.83**	§1.69**	3.03	21.48	1
6M502A×Chang7-2	B×B	1.47**	0.83**	0.50*	2.80	19.64	2
LH212Ht×Chang7-	B×B	0.51**	0.83**	1.07**	2.41	15.93	3
LH181×four-287	B×B	0.34**	0.01	1.84**	2.19	14.05	4
PHW51×Chang7-2	A×B	0.48**	0.83**	0.60**	1.91	11.60	5
6M502A×Zheng58	B×A	1.47**	-0.18**	0.50*	1.79	11.21	6
LH208×Chang7-2	A×B	0.89**	0.83**	-0.04	1.68	9.79	7
LH208×four-287	A×B	0.89**	0.01	0.74**	1.64	9.50	8
LH208×Zheng58	A×A	0.89**	-0.18**	0.64**	1.35	6.94	9
Lp215D×Chang7-2	B×B	-0.07	0.83**	0.52*	1.28	6.44	10
FBLA×four-144	A×A	0.42**	-0.64**	1.48**	1.26	5.96	11
PHJ89×Chang7-2	B×B	-0.11	0.83**	0.27	0.99	3.86	12
6M502A×four-287	B×B	1.47**	0.01	-0.57*	0.91	3.36	13
PHK93×four-287	B×B	-0.19	0.01	1.05**	0.87	2.96	14
LH192×Chang7-2	A×B	-0.49**	0.83**	0.26	0.60	0.76	15
LH181×Zheng58	B×A	0.34**	-0.18	-0.95**	-0.79	-10.95	50
PHK93×four-144	B×A	-0.19	-0.64**	0.08	-0.75	-11.18	51
LH192×Zheng58	A×A	-0.49**	-0.18**	-0.14	-0.81	-11.61	52
PHN34×four-287	A×B	-0.28*	0.01	-0.58*	-0.85	-11.79	53
LH208×four-144	A×A	0.89**	-0.64**	-1.33**	-1.08	-13.48	54
6F629×Zheng58	B×A	-0.63**	-0.18**	-0.27	-1.08	-13.65	55
LH192×four-144	A×A	-0.49**	-0.64**	0.03	-1.10	-14.19	56
Lp215D×four-144	B×A	-0.07	-0.64**	-0.47*	-1.18	-14.32	57
PHP76×four-287	B×B	-0.56**	0.01	-0.65**	-1.2	-14.59	58
RS 710×four-287	B×B	-1.97**	0.01	0.73**	-1.23	-15.12	59
PHJ89×four-144	B×A	-0.11	-0.64**	-0.59*	-1.34	-16.11	60
LH191×four-144	A×A	-0.31**	-0.64**	-0.40	-1.35	-16.17	61
RS710×Chang7-2	B×B	-1.97**	0.83**	-0.32	-1.46	-16.81	62
RS710×four-144	B×A	-1.97**	-0.64**	0.06	-2.55	-26.35	63
RS710×Zheng58	B×A	-1.97**	-0.18**	-0.47*	-2.62	-26.89	64

§ means * and **in the column represents significance at the 0.05 and 0.01 probability level, respectively.

Of the top fifteen TCA effect values, there were two A × A cis-hybrid combinations, seven B × B cis-hybrid combinations, five A × B trans-hybrid combinations and one B × A trans-hybrid combination. The TCA effect values that increased yield can be divided into the following three categories:

1) Both parental GCA effects and hybrid SCA effects were large, such as hybrid combinations NL001 × Chang7-2, 6M502A × Chang7-2, LH212Ht × Chang7-2, PHW51 × Chang7-2, Lh181 × four-287 and LH208 × four-287.

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2) Complementary parental GCA effects with a positive hybridization combination SCA effect, such as 6M502A × Zheng58, LH208 × Zheng58, Lp215D × Chang7-2, FBLA × four-144, PHJ89 × Chang7-2, PHK93 × four-287 and LH192 × Chang7-2.

3) Parental GCA effect values were large and hybridized SCA effect values were small, such as hybrid combinations LH208 × Chang7-2 and 6M502A × four-287.

On the contrary, the 15hybrids with the lowest TCA effect values can be divided into the following four categories:

1) The complementary value of parental GCA effect value and the large value for the SCA effect of hybrid combination, such as RS 710 × four-287.

2) The complementary value of parental GCA effects and a small value for the SCA effect of hybrid combination, such as LH181 × Zheng58, PHN34 × four-287, LH208 × four-144, PHP76 × four-287, and RS710 × Chang7-2.

3) Both parents with small GCA effect value and hybrid combinations with positive SCA effect value, such as hybrids PHK93 × four-144, LH192 × four-144, and RS710 × four-144.

4) Both parents with small GCA effect value and hybrid combination with low SCA effect value, such as hybrids LH192 × Zheng58, 6F629 × Zheng58, Lp215D × four-144, PHJ89 × four-144, LH191 × four-144, and RS710 × Zheng58.

Control heterosis is considered to be the yield-increasing index for corn varieties in the national standard of China. It is indicated that the best hybrid combination can be selected by analyzing the control heterosis. In table 13, all the control heterosis values were the mean value of two locations, and ranged from -26.89 % to 21.48%. There were 15 hybrid combinations with positive comparative heterosis, 2NL001 × chang7-2, 6M502A × chang7-2, LH212Ht × chang7-2, LH181 × four287, PHW51 × chang7-2, 6M502A × Zheng58, LH208 × chang7-2, LH208 × Zheng58, lh215d × chang7-2, FBLA × four-144, PHJ89 × chang7-2, 6M502A × four287, PHK93 × four287, LH192 × chang7-2 (Table13), indicating that these hybrids yielded better than the standard of Zhengdan 958.

4. Discussion

4.1 Discussion on Improvement and Utilization of U.S.A. Germplasm

The introduction of exotic germplasm was an important way to enrich genetic diversity for P.R.C. maize crop production. The utilization potential of inbred lines can not be judged according to the strengths and weaknesses of the inbred plant growth, but needs to be identified through the analysis of combining ability [11-13]. The North American inbred lines are genetically distinct from the inbred lines of China, and there was a wide regional gap between them. There were significant differences in GCA effect values of the inbred when grown at different locations, which indicates that American inbred lines perform well in comprehensive traits such as yield. In the process of improving, selecting, and matching inbred lines to make improved hybrids, the target traits can be selected according to the inbred GCA, and the characteristic groupings of American inbred lines can be determined. On the basis of plant growth, development, and heterotic patterns, according to the principle of complementary characteristics of the same group, successful maize production populations have been constructed with superior inbred lines, and the frequency of superior alleles has been improved by selective repetitive breeding [14-17].

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4.2 Discussion on the classification of U.S.A. Germplasm

By analyzing the SCA effect value of 64 hybrid combinations, it was found that there were both cis and trans combinations of heterotic groups in which the yield SCA effect value was positive and significant. Heterosis existed between U.S.A. inbred lines SS group and P.R.C. A group, and between U.S.A inbred lines NSS group and P.R.C B group. This is due to differences in the Germplasm Foundation of the P.R.C. A group and the B group, also the SS group and NSS group in the United States. When using the U.S.A. inbred lines, the combining ability of U.S.A. inbred lines must be determined on the basis of local indigenous inbred lines. Identify the taxa of American inbred lines, and the genetic pedigree and heterosis group of U.S.A. inbred lines can be accurately identified. In breeding the second cycle inbred line, the cis hybrid combination is usually used to improve the group.

4.3 Discussion on combining ability and control heterosis of American germplasm

The TCA effect value of a hybrid was the same as its ranking compared to a known hybrid (Control heterosis). The TCA values of hybrid combinations with yields greater than the comparison hybrid were all positive, and the TCA values of hybrid combinations yielding less than the comparison hybrid were all negative. The value of TCA can be used as an index to evaluate heterosis in the evaluation of hybrid combinations [18-19]. In the top 15 TCA value hybrid combinations, the SCA effect value was mostly positive. There were 8 hybrid combinations which their GCA effect values of parental yield were all positive, and 8 hybrid combinations with positive and negative GCA effect values of parental yield, respectively. The results showed that hybrid combinations with high heterosis required higher yield SCA effect value and higher yield GCA effect value of their parents [20]. The selection of GCA effect value of parental yield should be paid attention to in combination with heterotic crossing, so as to ensure that at least one parent yield GCA effect value was positive, and SCA effect value should not be too low.

5. Conclusions

5.1 The materials for the U.S.A. Inbred Lines that have higher combining ability with characteristics suitable for machine harvesting were: RS710, PHP76, FBLA, and PHJ89. These materials have great potential for breeding early maturing, high density tolerant, and suitable to machine harvest hybrids.

5.2 The U.S.A. inbred lines with higher yield combining ability were: 6M502A, LH208, NL001, LH212Ht, PHW51, FBLA, and LH181. Therefore, these materials have great potential in breeding high yield hybrids.

5.3 In the selection of hybrid combinations suitable for high yield and suitable for machine harvesting, it was necessary to determine the combining ability of the two parents, so as to make the characteristics complement each other. Using the parental combining ability information will ease the process of making superior hybrids.

5.4 The test variety Chang7-2 promoted a high-yielding hybrid combination. Meanwhile, the test variety four-287 led to hybrid combinations suitable for machine harvesting.

5.5 In the experiment, the TCA effect value was the same as the control heterosis ranking, and the TCA value could be used as an index to evaluate the heterosis of hybrid combinations without growing the control hybrid for comparison each time. The hybrid combinations were screened by yield SCA effect value, yield TCA effect value and yield control heterosis. NL001 × Chang7-2, 6M502A × Chang7-2, LH212Ht × Chang7-2, LH181 × four-287, PHW51 × Chang7-2, 6M502A × Zheng58, LH208 × Chang7-2, LH208 × four-287, LH208 × Zheng58, Lp215D × Chang7-2, FBLA × four-144 were selected as dominant hybrid combinations in this experiment. Furthermore, these hybrid combinations can be continue further tested.

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