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Research Article

Evaluation of yellow maize inbred lines for maturity and grain yield related traits using line×tester analysis

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Abstract

Thirty yellow maize inbred lines were selected from different source populations and planted in isolation with common male testers (YD-2 and YD-4) in 1:4:1 ratio at Cereal Crop Research Institute (CCRI) Pirsabak, Nowshera during spring-2014 (season–I). On the bases of best seed setting and other important traits, eighteen test-crosses were selected using line × tester approach. The developed 18 test-crosses, nine parental lines and two testers along with two check cultivars (Sarhad Yellow and CS2Y10) were grown in summer season-2014 (July – November) using two replications.Data were collected on various maturities and yield related traits via; days to pollen shedding, silking, ear height, plant height, 100-kernel weight, kernel row ear^{-1} and grain yield. Significant differences were observed among test-crosses for yield related traits mainly 100-kernel weight and grain yield. L-9 using YD-4 as a tester revealed minimum days to pollen shedding (50.5 days) and days to silking (52.5 days). L-3 using YD-2 as a tester recorded maximum plant height while, L-9 using YD-4 as a tester obtained maximum ear height and length. L-9 using YD-4 as a tester revealed high 100-kernel weight, grain yield and high GCA effect, while L-8 using YD-4 as a tester recorded high SCA effect for 100-kernel weight. L-9 exhibited high GCA effect for grain yield while, high SCA effect was obtained for L-2 using tester (YD-2). L-9 using tester YD-4 revealed maximum mid-parent and best-parent heterosis for ear length and grain yield. For maximum traits, L-9 was the best combiner followed by L-3 and L-6 using the same tester (YD-4) under conducted study.

Keywords: General combining ability, Heterosis, Maize, Specific combining ability, Tester analysis

Introduction

Maize (*Zea mays* L.) is grown worldwide and used as a primary staple diet in many developing countries (Morris, 1999). During 2013, total maize production was 950 million tons showing an increase of 9% compared to previous year-2012 reported by Brandt (2013). According to International Institute of Tropical Agriculture, Hahn *et al.* (1989), total world production of maize was 785 million tons. United States contributes 42% to the total maize production worldwide, thus stands for the leading producer. Maize is the 3rd most developed crop after wheat and rice. Maize was cultivated on 1139.4 thousand hectares acreages for production with total yield of 4997.1 thousand tones and 4385.7 kg ha^{-1}, respectively in Pakistan (PBS, 2012-2013). Maize is a consistent crop in the cropping pattern and also used as a primary food for poor resource farmers in Khyber Pakhtunkhwa (Khan *et al.*, 2003).

Yellow maize is more valuable than white maize to feed animals because of containing huge amount of Vitamin-A (Morrison, 1936). The breeding strategies used in maize are normally characterized by increasing of genetic diversity in the pool of germplasm (Lee, 1998). Heterosis is an important phenomenon which leads to the development of hybrids showing desired superiority in maturity, disease resistance and yield contributing traits over the parental inbreed lines (Lippman and Zamir, 2007). Combining ability and heterosis computations are helpful for the development of economical and sustainable maize hybrids and cultivars (Krivanek *et al.*, 2007). Evidence on combining ability and heterosis among maize germplasm are necessary to increase the efficacy of hybrid development. The significance of a "good tester" depends upon the breeders objectives. Breeders study the specific and general combining ability of various lines and also the gene effects by using line × tester analysis. The information about mode of inheritance and genetic arrangement of different characters helps breeders to employ proper breeding techniques for improvement in crops (Kiani *et al.*, 2007). The easiest and most accurate approach towards screening of large number of inbred lines and parental genotypes are line × tester analysis and combining ability (Kempthorne, 1957).

Materials and Methods

Two experiments in two consecutive seasons were conducted at Cereal Crop Research Institute (CCRI) Pirsabak, Nowshera using RCB Design in 2014. During spring season-2014 (February – June), 30 yellow inbred lines from different source populations were planted in isolation with common male testers, YD-2 and YD-4 in 1:4:1 ratio each with a row length of 3m, plant to plant distance of 25cm and 75cm space between the rows to facilitate easy crossing and to manage the breeding material easily and carefully. The developed 18 test-crosses, nine parental lines and two testers along with two check cultivars (Sarhad Yellow and CS2Y10) were grown in summer season-2014 (July – November) using two replications. Each plot consists of two rows having row to row and plant to plant distance of 75cm and 25cm respectively. Data were taken on days to pollen shedding, to silking, ear height, plant height, 100-kernel weight, kernel rows ear^{-1} and

Table 1. Physical and maturity features of the experimental material consisting of nine S_2 lines, two testers and two checks

Genotype	Type	Grain color	Maturity group	Stature
Testers				
YD-2	Flint	Yellow	Intermediate	High
YD-4	Dent	Yellow	Intermediate	High
CCRI experimental yellow lines (CCRI-EYL+1)				
L-1	Dent	Yellow	Intermediate late	High
L-2	Dent	Yellow	Intermediate	Low
L-3	Semi dent	Yellow	Intermediate late	Intermediate tall
L-4	Flint	Yellow	Intermediate late	High
L-5	Dent	Yellow	Intermediate	High
L-6	Dent	Yellow	Intermediate	High
L-7	Dent	Yellow	Intermediate	High
L-8	Semi dent	Yellow	Intermediate late	Low
L-9	Dent	Yellow	Intermediate	Intermediate tall
Checks				
CS2Y10	Dent	Yellow	Intermediate late	High
Sarhad yellow	Dent	Yellow	Intermediate late	Intermediate tall

Note: YD-2 and YD-4 are testers; L-1, L-2, L-3, L-4, L-5, L-6, L-7, L-8, L-9 are nine parental lines; CS2Y10 and Sarhad yellow are checks.

Table 2. Mean squares for maturity and yield related traits of the test-crosses derived from S_2 lines of Yellow maize.

Source of variation	DF	PS days)	S (days)	PH (cm)	EH (cm)	EL (cm)	KR (no)	100 KW (g)	GY (kg ha^{-})
Replication	1	1.3966	1.1034	82.0862	38.0862	0.069	0.069	2.4828	4139
Genotype	28	2.7475**	2.8436**	175.8190**	166.1564**	7.8042^{NS}	2.9310^{NS}	41.3251^{NS}	6927084^{NS}
Cross	17	2.1699^{NS}	1.4248^{NS}	172.0915*	111.9690**	4.3676^{NS}	2.2500^{NS}	15.9886**	4466468^{NS}
Parent	10	1.8273^{NS}	2.8091*	178.0694*	110.3403*	4.1000**	2.0364^{NS}	51.1818^{NS}	2161319**
Line	8	3.2361**	2.3403*	182.3273*	117.2364**	6.8125^{NS}	2.0000^{NS}	22.1944**	4998531^{NS}
Tester	1	0.1111^{NS}	0.4444^{NS}	469.4444**	156.2500^{NS}	8.0278**	3.3611**	0.0278^{NS}	21416841^{NS}
Line × tester	8	1.3611^{NS}	0.6319^{NS}	128.9444^{NS}	108.0625*	1.4653^{NS}	2.3611^{NS}	11.7778**	1815608*
Error	28	1.1466	1.0677	75.3362	41.6219	0.7475	0.2118	3.8399	657244
Cv (%)		2.04	1.89	5.62	9.57	5.02	3.16	6.25	10.25

** = Highly significant at 1% of probability, * = Significant at 5% of probability, NS = Non significant and CV = Coefficient of variation

grain yield. Normal agronomic practices were used to maintain the minimum environmental variations.

Statistical analysis

The recorded data were analyzed using AGRISTAT package developed by Dr. N. Manivannan, TNAU, Coimbatore-3, an appropriate package for line × tester analysis on maturity and yield related traits. GCA and SCA effects were analyzed using (Singh and Chaudhary, 1979).

General combining ability was computed using the formula given below:

$$gi = \frac{Xi...}{t \times r} - \frac{X...}{l \times t \times r}$$

Where:

l, t and r = represents the number of lines, testers and replications, respectively.

Specific combining ability was computed using the formula given below:

$$si = \frac{Xij}{r} - \frac{Xi...}{t \times r} - \frac{Xj...}{l \times r} + \frac{X...}{l \times t \times r}$$

Where:

Xi = total F_1 resulting from all testers crossing with ith lines
Xj = total lines crosses with jth testers
Xij = total F_1 resulting from ith lines with jth testers
X = total test-crosses

Mid-parent heterosis (MP) is an increase or decrease of F_1 hybrid over the average performance of both parents. Mid-parent heterosis (MPH) may be positive or negative and was calculated by the expression:

$$Mid\ \ parent\ heterosis = \frac{F_1 - \overline{MP}}{\overline{MP}} \times 100$$

Best-parent heterosis (BPH) is an increase or decrease of F_1 hybrid over the best parent (BP) in an across combination. BPH may be positive or negative and was calculated by the following expression:

$$Better\ \ parent\ heterosis = \frac{F_1 - \overline{BP}}{\overline{BP}} \times 100$$

Proportional Contribution of lines, Testers, and their interaction to total variance:

Contribution of lines = {ss(l) / ss(crosses)}× 100
Contribution of testers = {ss(t) / ss(crosses)} × 100
Contribution of (lxt) = {ss ($^{(lxt)}$/ss (crosses)} ×100

Results and Discussion

Genetic variance and mean performance

Analysis of variance revealed highly significant differences among genotypes for days to pollen shedding, days to silking, plant height and ear height while, traits like plant height, ear height and grain weight exhibited highly significant differences among crosses. Among parents, highly significant differences were observed for all traits except pollen shedding, kernel rows ear^{-1} and grain weight. While non-significant differences were recorded for traits of ear length, kernel rows ear^{-1} and grain yield among lines. Ear length and kernel rows ear^{-1} and also highly significant differences were recorded for ear height, grain weight and grain yield among Line × testers (Table 2). Mean data of F_1

Table 3. Mean values for maturity and yield related traits of the test-crosses, parental lines and checks.

Genotype	PS (days)	S (days)	PH (cm)	EH (cm)	EL (cm)	KR (no)	100 KW (g)	GY (kg ha^{-1})
L-1 × YD-2	53	55	147.5	59.5	16.45	14.45	30.5	8170
L-1 × YD-4	52.5	55	152.5	75	16.51	15.1	27.8	9148
L-2 × YD-2	51	53.5	160	72	17.34	17.41	33.2	8470
L-2 × YD-4	53	54	145.5	62.5	17.44	14	29.7	7401
L-3 × YD-2	52	54	169.5	84.5	17.79	15	29.3	7947
L-3 × YD-4	53	55	171.5	82	16.75	15.1	25	10506
L-4 × YD-2	51	53.5	151	59.5	18	14.35	30.8	8619
L-4 × YD-4	51.5	54.5	150.5	74.5	17.86	13.9	28.8	9407
L-5 × YD-2	50.5	53.5	148.5	76.5	15.9	16.8	25.9	8000
L-5 × YD-4	51	53.5	166	66	18.66	15	26.5	9009
L-6 × YD-2	54	55.5	148	66.5	20.26	15.5	30.1	9200
L-6 × YD-4	52	54.5	164	80	20.15	15.4	30.1	10683
L-7 × YD-2	53	55	139.5	67	18.48	13.9	29.4	5352
L-7 × YD-4	53.5	55.5	163.5	76.5	19.14	14.45	33.4	9024
L-8 × YD-2	52	53.5	149	63.5	17.92	17.05	23.3	7578
L-8 × YD-4	52	54.5	155.5	72	20.05	14.65	29.3	9861
L-9 × YD-2	51.5	53.5	157.5	75.5	18.25	14	32.5	9973
L-9 × YD-4	50.5	52.5	166.5	73.5	21.05	15.7	33.6	12156
L-1	53.5	56.5	153	52.5	13.9	15.05	26	4501
L-2	53	55	132	52.5	17	11.8	32.2	6573
L-3	54	56.5	150.5	52	12.5	12.95	27.1	4519
L-4	54.5	57.5	155.5	68	14.75	14.25	31.6	6107
L-5	53	54.5	162	73	16.75	14.65	37.5	6849
L-6	54.5	56	157	70	15.75	13.65	36.9	6909
L-7	53.5	56.5	156	63	15.5	14.5	36.3	5883
L-8	53	55	138	52.5	14.9	12.95	34.9	5850
L-9	54	56.5	150	59	15.25	14.35	35.4	6650
YD-2	52	54	159.5	63.5	16.5	12.6	40.1	7184
YD-4	51.5	54	162	62	17.1	14.25	42.5	7833
CS2Y10	53.5	55.5	171.5	87	18.38	16.54	29.7	8461
S. Yellow	52.5	54.5	132.5	65	18.35	14.7	24.2	7432
G. Mean	52.56	54.77	154.4	67.95	17.25	14.64	31.08	7911
LSD	2.3	2.22	18.82	13.72	1.67	0.75	3.99	1676.5

PS−Pollen shedding; S−Silking; PH−plant height; EH−ear height; EL−ear length; KR−kernel rows; 100 KW−100 kernel weight; GY−grain yield; YD-2 and YD-4 −testers; L-1, L-2, L-3, L-4, L-5, L-6, L-7, L-8, L-9 are nine parental lines

Table 4. GCA effects of nine parental lines for maturity and yield related traits in maize

S2 Line	Days to PS	Days to S	PH	EH	EL	KR ear^{-1}	100-KW	GY
1	0.69	0.78	-5.89	-4.22	-1.75	-0.33	-0.11	-257.72
2	-0.06	-0.47	-3.14	-4.22	-1	0.67	1.89	-981.72
3	0.44	0.28	14.61	11.78	-1	-0.08	-2.36	309.53
4	-0.81	-0.22	-5.14	-4.47	-0.25	-1.08	0.39	96.53
5	-1.31	-0.72	1.36	-0.22	-1	0.67	-3.11	-412.22
6	0.94	0.78	0.11	1.78	2	0.42	0.64	1024.53
7	1.19	1.03	-4.39	0.28	0.5	-0.83	1.89	-1729.2
8	-0.06	-0.22	-3.64	-3.72	1	0.92	-2.86	-197.47
9	-1.06	-1.22	6.11	3.03	1.5	-0.33	3.64	2147.78

PS−pollen shedding; PH− plant height; EH−ear height; EL−ear length; KR−kernel row; KW− kernel weight; GY−grain yield

Table 5. SCA effects of 18 test-crosses with two testers derived from S2 lines of Yellow maize for maturity and yield related traits

S2 Line	Days to PS		Days to S		PH		EH		EL		KR ear^{-1}		100-KW		GY	
	YD2	YD-4	YD-2	YD-4	YD-2	YD-4	YD-2	YD-4	YD-2	YD-4	YD-2	YD-4	YD-2	YD-4	YD-2	YD-4
1	0.31	-0.31	0.11	-0.11	1.11	-1.11	-5.67	5.67	0.47	-0.47	-0.56	0.56	1.28	-1.28	282.5	-282.5
2	-0.94	0.94	-0.14	0.14	10.86	-10.9	6.83	-6.83	0.22	-0.22	1.44	-1.44	1.78	-1.78	1306	-1306
3	-0.44	0.44	-0.39	0.39	2.61	-2.61	3.33	-3.33	0.72	-0.72	-0.31	0.31	2.03	-2.03	-507.6	507.6
4	-0.19	0.19	-0.39	0.39	3.86	-3.86	-5.42	5.42	0.47	-0.47	0.19	-0.19	0.78	-0.78	377.3	-377.3
5	-0.19	0.19	0.11	-0.11	-5.14	5.14	7.33	-7.33	-0.78	0.78	0.44	-0.44	-0.22	0.22	266.5	-266.5
6	1.06	-1.06	0.61	-0.61	-4.39	4.39	-4.67	4.67	0.22	-0.22	-0.31	0.31	0.03	-0.03	30.31	-30.31
7	-0.19	0.19	-0.14	0.14	-8.39	8.39	-2.67	2.67	0.22	-0.22	-0.56	0.56	-2.22	2.22	-1064.9	1064.9
8	0.06	-0.06	-0.39	0.39	0.36	-0.36	-2.17	2.17	-0.78	0.78	0.69	-0.69	-2.97	2.97	-370.1	370.1
9	0.56	-0.56	0.61	-0.61	-0.89	0.89	3.08	-3.08	-0.78	0.78	-1.06	1.06	-0.47	0.47	-319.9	319.9

hybrids manifested outstanding performance across maturity and yield traits compared to their parents (Table 3). Lowest days were obtained for pollen shedding (50.5 days) and silking (52.5 days) compared to its parents (53 and 54.5 days). Yield component traits of ear length (21.05 cm), kernel rows (17.41) and grain yield (12156 kg ha^{-1}) revealed that maximum mean performance were higher than those of parents (17 cm, 15.05 and 6909 kg ha^{-1}) (Table 3) as

Table 6. Proportional contribution of lines, testers and line × tester interaction to total variance of testcrosses derived from S2 lines in Yellow maize

Parameters	Contribution (%)		
	Lines	Testers	Line × tester
Days to pollen shedding	70.18	0.3	29.52
Days to silking	77.29	1.83	20.87
Plant height	48.69	16.05	35.05
Ear height	46.37	8.21	45.42
Ear length	73.4	10.81	15.79
Kernel rows ear^{-1}	41.83	8.79	49.38
100-kernel weight	65.32	0.01	34.67
Grain yield	52.66	28.21	19.13

Table 7. Heterosis (%) values over mid-parent (MPH) and best-parent (BPH) for maturity and yield related traits of 18 test-crosses with two testers derived from S2 lines of Yellow maize

Line × Tester		Days to PS		Days to S		PH		EH		EL		KR ear^{-1}		100-KW		GY	
		MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)
1	YD-2	0.47	-0.93	-0.45	-2.65	-5.6	-7.52	2.59	-6.3	8.2	0	5.45	-3.33	-7.58	-23.75**	39.88**	13.73
	YD-4	0	-1.87	-0.45	-2.65	-3.17	-5.86	31.00**	20.97	6.45	-2.94	3.45	0	-18.25**	-34.12**	48.34**	16.79
2	YD-2	-2.86	-3.77	-1.83	-2.73	9.72	0.31	24.14*	13.39	1.49	0	42.86**	40.00**	-8.97	-17.50**	23.14*	17.9
	YD-4	1.44	0	-0.92	-1.82	-1.02	-10.19	9.17	0.81	2.94	2.94	7.69*	0	-21.3**	-30.59**	2.74	-5.52
3	YD-2	-1.89	-3.7	-2.26	-4.4*	9.35	6.27	46.32**	33.07**	20.69**	6.06	17.65**	15.38**	-13.4*	-27.50**	35.82**	10.63
	YD-4	0.47	-1.85	-0.45	-2.65	9.76	5.86	43.86**	32.26**	15.25**	0	11.11**	7.14*	-28.1**	-41.18**	70.10**	34.12**
4	YD-2	-4.23*	-6.4**	-4.1*	-7.1*	-4.13	-5.33	-9.51	-12.5	16.13**	9.09	9.43**	3.57	-14.7**	-23.75**	29.71**	19.9
	YD-4	-2.83	-5.5*	-2.24	-5.2*	-5.2	-7.1	14.62	9.56	14.29**	5.88	-3.57	-3.57	-21.6**	-31.76**	34.98**	20.1
5	YD-2	-3.81*	-4.72*	-1.38	-1.83	-7.62	-8.33	12.09	4.79	-4.48	-5.88	20.00**	10.00**	-32.9**	-35.0**	14.02	11.36
	YD-4	-2.39	-3.77	-1.38	-1.83	2.47	2.47	-2.22	-9.59	8.82	8.82	3.45	0	-33.7**	-37.7**	22.73*	15.02
6	YD-2	1.41	-0.92	0.91	-0.89	-6.48	-7.21	-0.37	-5	23.08**	21.21**	16.98**	10.71**	-22.1**	-25.0**	30.57**	28.00**
	YD-4	-1.89	-4.59*	-0.91	-2.68	2.82	1.23	21.21*	14.29	24.24**	20.59**	10.71**	10.71**	-24.5**	-29.4**	44.93**	36.38**
7	YD-2	0.47	-0.93	-0.45	-2.65	-11.57*	-12.54	5.93	5.51	15.63**	12.12*	3.7	-3.45	-24.2**	-27.5**	-18.09	-25.51*
	YD-4	1.9	0	0.45	-1.77	2.83	0.93	22.40*	21.43*	16.92**	11.76*	1.75	0	-15.2**	-21.2**	31.58**	15.2
8	YD-2	-0.95	-1.89	-1.83	-2.73	0.17	-6.58	9.48	0	14.29**	9.09	33.33**	30.77**	-37.1**	-41.3**	16.28	5.48
	YD-4	-0.48	-1.89	0	-0.91	3.67	-4.01	25.76*	16.13	28.13**	20.59**	11.11**	7.14*	-23.4**	-30.6**	44.13**	25.89*
9	YD-2	-2.83	-4.6*	-3.17	-5.3**	1.78	-1.25	23.27*	18.9	15.63**	12.12*	3.7	-3.45	-14.1*	-18.8**	44.19**	38.83**
	YD-4	-4.3*	-6.5**	-5.1**	-7.1**	6.73	2.78	21.49*	18.55	29.23**	23.53**	8.77**	6.90*	-14.1*	-21.2**	67.87**	55.19**

PS–pollen shedding; PH–plant height; EH–ear height; EL–ear length; KR–kernel row; KW– kernel weight; GY–grain yield; YD-2 and YD-4–testers; MPH–Mid-parent heterosis; BPH–Best-parent heterosis

described by Paterniani *et al.* (2000) while our results are in line with the results of (Desai and Singh 2001), for maturity and yield related different studied traits of the maize crop. Traits like ear length, kernel rows, and grain yield exhibited maximum performance compared to its parents thus, need to be further tested at various locations for consistence performance and released as a hybrid.

General and specific combining abilities study

General combining abilities of parental lines and specific combining abilities of the test-crosses were presented in Table 4 and 5, respectively. Among the evaluated nine parental lines, four parental lines exhibited positive general combining ability effects for days to shedding, days to silking, plant height, ear height and grain yield. However, half of the test-crosses showed negative effects of specific combining abilities (Menkir and Ingelbrecht, 2007). Similarly, five out of nine parental lines revealed positive GCA effects for ear length, kernel rows ear^{-1} and 100-kernel weight however, nine out of 18 test-crosses exhibited positive SCA effects (Rahman *et al.*, 2012).

Proportional Contribution of Lines, Tester and Its Associations among Studied Traits

Proportional contribution of lines, testers and line × tester interactions clearly suggested that sufficient amount of variance present to the total variances for all the studied traits were due to line × tester interaction. Lines manifested much higher contribution to that of testers for almost all the studied traits (Table 6). Results obtained for proportional contribution of lines, testers and line × tester interactions were in similarity with the finds of (Mendoza *et al.*, 2000; Konak *et al.*, 2015) for various traits under study.

Heterosis

Range of mid-parent heterosis and best-parent heterosis are presented in Table 7. Maturity traits such as days to pollen shedding and days to silking revealed negative heterosis of both mid-parents and best-parents for most of the test-crosses. While positive heterosis were observed on yield related traits such as kernel rows ear^{-1} and grain yield for almost all test-crosses. The desired heterosis values for various maturity and yield related traits result in the increase performance of F_1 hybrids over parents. The desired negative heterosis were confirmed by (Dickert and Tracy 2002; Gupta and Nagda 2000; Saleh *et al.*, 2002) who also obtained similar findings for days to pollen shedding.

Maximum values of heterosis effect positively affect plant height among test-crosses. (Misevic 1989; Vasal *et al.*, 1992) also reported that for plant height heterosis effect was positive among test-crosses. Heterosis for plant height among F1 hybrids was found higher compared to parental lines and the same result also reported by (Morrison 1936; de la Rosa *et al.*, 2000), which might be due to epistasis gene action. For yield related traits like ear length, kernel row ear^{-1} and 100- kernel weight alike results were reported by (Gorgulho and Filho 2001; Saleh *et al.*, 2002).

Conclusions

These findings clearly suggested that sufficient amount of genetic variability was observed among the studied test-crosses. Best combining ability was recorded for L-9 using YD-4 as a tester and was also observed as the best hybrid combination for most studied traits. Similarly, the highest mid-parent heterosis was manifested for L-3 with YD-4 tester followed by L-9. L-9 using YD-4 as a tester was a good specific combiner for grain yield, early maturity and ear length among the test-crosses. L-9 followed by L-3 and L-6 using YD-4 as a tester showed good performance in yield contributing traits and is therefore recommended to be included in coming breeding programs for hybrid improvement.

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