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GENE ACTION AND COMBINING ABILITY ASSESSMENT OF FIELD CORN (*Zea mays* L.) USING LINE × TESTER MATING DESIGN

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ABSTRACT

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An elite parental line with good combining ability is mandatory for hybrid-oriented breeding program. In this study, line × tester mating design was used to determine combining ability, type of gene action, genetic variance of yield and yield contributing characters for selecting superior parents of field corn (maize). Ten S_5 lines of commercial hybrid NT 6323 were crossed with 2 testers in a line × tester mating design and the resulting 20 crosses along with the parents and standard checks BHM 9, NK 40 and 900 M GOLD were evaluated in a Randomized Complete Block Design (RCBD) replicated twice, during rabi season, 2015-16 at the experimental field of Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. There were significant differences among the lines for days to 50% silking, plant height, ear height and number of grains per row whereas both testers were insignificant for all the traits though they were from different heterotic group of maize. No significant difference was observed for line × tester interaction except thousand grain weight and yield. Mean squares due to genotype, parents, parents versus crosses and crosses were significant for the most studied traits. Estimation of variance due to GCA, SCA and their ratio revealed intensive non-additive gene effects for all the traits except ear height. Lines NT 6323/S_5-21-1-2 and NT 6323/S_5-49-1 exhibited significant negative GCA effect for both plant height and ear height. Only NT 6323/S_5-50-1line displayed significant negative GCA effect for both of the traits days to 50% tasseling and days to 50% silking. Therefore, lines NT 6323/S_5-21-1-2 and NT 6323/S_5-49-1 could be used to develop dwarf variety and line NT 6323/S_5-50-1for short duration variety. NT 6323/S_5-27-1, NT 6323/S_5-44-1 and NT 6323/S_5-50-1 were good general combiners for grain yield and some of the important yield contributing characters. Cross combinations NT 6323/S_5-50-1 x BIL 79 and NT 6323/S_5-27-1 × BIL 28 showed significant positive SCA effects for grain yield along with high mean performance could be recommended for high yielding commercial hybrid variety development after further advanced maize breeding program.

Key words: *maize, general combining ability (GCA), specific combining ability (SCA), yield*

INTRODUCTION

Maize or corn (*Zea mays* L.) belongs to the family Poaceae, is the third most important cereal crop in the world after rice and wheat due to its versatile use and greater range of adaptability over different agro climatic zones (Koutsika-Sotiriou, 1999). Maize is not only an important source of human nutrition due to enrichment of carbohydrate, proteins, oil, fat, minerals and vitamins but also a basic element of animal feed and raw materials of many industrial products in fermentation and distillation industries including corn starch, corn oil, corn syrup and maltodextrins. In Bangladesh, maize is cultivated over an area of 0.33 million hectares with production of 2.27 million metric tons and an average yield of 6.75 ton per hectare (BBS 2016). There is still some scope to raise maize yield pursuing breeding program to create new superior hybrids. Genetic improvement is a continuous process for forming hybrids and varieties. One of the most crucial criteria for detecting high yielding hybrids is the information about parents' genetic architecture and their combining ability (Ceyhan 2003). The line × tester mating design as suggested by Kempthorne (1957) is an appropriate method to identify superior parents and hybrids based on both general combining ability (GCA) and specific combing ability (SCA). Sprague and Tatum (1942) introduced GCA and SCA theory predominantly in breeding program of several crops. GCA is representable to the additive genes in their effects, whereas SCA attributed to genes of dominance effects or epistasis. The main objective of this study is to find out and assess superior lines of maize, compare the performances of testers to evaluate the inbred lines, to identify the best crosses relative to commercial check hybrid variety on the basis of combining ability of testers, lines and their crosses.

MATERIALS AND METHODS

Ten newly developed phenotypically selected inbred lines of field corn *viz.*, NT 6323/S_5-18-1, NT 6323/S_5-21-1-2, NT 6323/S_5-21-2-2, NT 6323/S_5-23-1, NT 6323/S_5-27-1, NT 6323/S_5-35-1, NT 6323/S_5-44-1, NT 6323/S_5-45-3, NT 6323/S_5-49-1 and NT 6323/S_5-50-1 were crossed with two testers *viz.*, BIL 28 and BIL 79 during rabi season, 2014-15 at the experimental field of Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. The resulting 20 F_1 crosses along with three standard checks (BHM 9, NK 40 and 900 M GOLD) and all the parents (lines and testers) were evaluated in randomized complete block design (RCBD) with two replications in the same location during subsequent rabi season, 2015-16. Two border rows were sown at both side of each replication to minimize the border effect. Each entry was sown in single row of 4m length with a spacing of 60 cm between rows and 25 cm between the plants respectively. One healthy seedling was kept after thinning at 4-5 leaf stage. Fertilizers were applied at 250, 55, 110, 40, 5 and 1 Kg ha^{-1} of N, P, K, S, Zn and B respectively, following recommended procedure. All the necessary agronomic practices were carried out. The

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data on five quantitative characters of plant height (cm), ear height (cm), ear length (cm), number of grains per row and 1000 grain weight (g) were recorded on ten randomly selected competitive plants in each replication, whereas days to 50% tasseling, days to 50% silking and grain yield were recorded on plot basis and yield was then finally converted to ton/ha following the formula defined by Carrangal *et al*. (1971). Combining ability analysis was computed according to the model given by Kempthorne (1957).

RESULTS AND DISCUSSION

Analysis of variance

Analysis of variance for combining ability was carried out for yield and yield contributing traits and the mean sum of squares are presented in Table 1.

Table 1. Mean squares and estimates of variance for some physiological traits, grain yield and yield components in maize

Sources	df	DT (day)	DS (day)	PH (cm)	EH (cm)	EL (cm)	NGPR (no.)	TGW (g)	Y (t ha^{-1})
Genotypes	31	16.6**	3.61	1039**	545**	9.66**	45.4**	3001*	5.05**
Parents (P)	11	15.1**	3.04	801**	275**	8.41**	58.4**	3164	1.60
P vs C	1	213**	33.0*	19828**	10017**	89.4**	468**	454	66.2**
Crosses (C)	19	7.08	2.39	189*	203**	6.19**	15.6	3042	3.82**
Lines	9	5.84	4.47*	329**	325**	8.23	20.7*	1632	4.25
Testers	1	25.6	0.63	156	286	0.9	24.0	10	2.60
L x T	9	6.27	0.51	52.4	71.3	4.73	9.47	4787*	3.53**
Error	31	3.84	4.56	72.2	64.8	2.24	17.1	1595	1.11
Estimate of component of variance									
σ^2g (line)		-0.11	0.99	69.1	63.4	0.88	2.82	-789	0.18
σ^2g (tester)		0.97	0.01	5.18	10.8	-0.19	0.73	-239	-0.05
σ^2gca		0.03	0.06	4.62	4.46	0.05	0.21	-59.3	0.01
σ^2sca		1.21	-2.02	-9.86	3.23	1.25	-3.81	1596	1.21
σ^2gca/σ^2sca		0.02	-.03	-0.47	1.38	0.04	-0.05	-0.04	0.01

* Significant at 5% level, ** Significant at 1% level

DT= Days to 50% tasseling, DS= Days to 50% silking, PH= Plant height, EH= Ear height, EL= Ear length, NGPR= Number of grains per row, TGW= 1000-grain weight, Y= Yield

The analysis of variance revealed that genotypes exhibited highly significant differences among themselves for all the traits studied except days to 50% silking. Significant differences were observed among the parents for the traits days to 50% tasseling, plant height, ear height, ear length and number of grains per row in a cob indicating greater diversity in the parental lines of the traits. The crosses displayed significant differences for plant height, ear height, ear length and yield which denoted varying performance of the cross combinations. The parents vs. crosses showed significance for all the traits except 1000-grain weight, thus considerable amount of average heterosis was reflected in hybrids. When the effects of crosses partitioned into lines, testers and line × tester effects, the interaction effects (line × tester) were found highly significant for 1000-grain weight and yield traits pointed that hybrids differed significantly in their SCA effects. These findings agreed with the report of Amin *et al*. (2014) and Kamara *et al*. (2014). Comparison between the components of variance due to GCA and SCA confirms the gene action in controlling the expression of traits. The ratio of GCA and SCA variance for all the traits in maize were less than one except ear height under study which indicated that all these traits were predominantly governed by non-additive gene effects (Table 1) and could be improved by heterosis breeding. Similar non-additive gene action was mentioned by Kanagarasu *et al.* (2010) and Kumar *et al.* (2014) for grain yield, ear length, plant height, ear height, 100-grain weight, days to 50% tasseling and days to 50% silking, Ali *et al.* (2012) for 100-grain weight; Kumar *et al*. (2012) for plant height, days to 50% tasseling, days to 50% silking, ear length, number of grains per row, 100-grain weight and grain yield in their study.

Proportional contribution of lines, testers and their interaction to total variance

The proportional contributions of lines (female), testers (male) and their interactions (crosses) to total variance for different traits revealed that female lines (maternal) contributed predominantly compare to male lines (paternal) in all studied traits (Table 2). Preeminent maternal influence was found by Begum *et al*. (2016) and Ahmed *et al*. (2016) for both plant height and ear height. Similarly, Amiruzzaman (2010) observed the greater effect of female lines for grain yield, grain weight and grain number. Relatively higher contribution of line × tester interaction than both male and female lines was due to non-additive genetic effect for days to 50% tasseling and1000-grain weight which were also endorsed by Amiruzzaman (2010) and Amin *et al*. (2014) respectively.

Table 2. Proportional contribution of lines, testers and their interactions to total variance in maize

Source	DT (day)	DS (day)	PH (cm)	EH (cm)	EL (cm)	NGPR (no.)	TGW (g)	Y (t ha^{-1})
Line (L)	39.1	88.5	82.5	75.9	63.0	63.1	25.4	52.7
Tester (T)	19.0	1.37	4.35	7.43	0.77	8.12	0.02	3.58
L × T	41.9	10.2	13.2	16.7	36.2	28.8	74.6	43.8

DT= Days to 50% tasseling, DS= Days to 50% silking, PH= Plant height, EH= Ear height, EL= Ear length, NGPR= Number of grains per row, TGW=1000-grain weight, Y= Yield

General combining ability (GCA) effects

General combining ability (GCA) is an efficient genetic tool to assess the genotype frequently. Selection of parents with good GCA is a fundamental prerequisite for successful heterosis breeding program using line × tester mating design. Estimates of general combining ability (GCA) effects for the lines (females) and testers (males) are presented in Table 3. Significant negative GCA effect was recorded in only one female line (*viz*., NT 6323/S_5-50-1) among all the parents for days to 50% tasseling and silking which could be utilized for earliness. EL-Hosary (2014) observed similar phenomenon for days to 50% tasseling, Kamara *et al*. (2014) and Ibrahim *et al*. (2012) for days to 50% silking and Amin *et al*. (2014) for both days to 50% tasseling as well as days to 50% silking. LinesNT 6323/S_5-21-1-2and NT 6323/S_5-49-1showed significant negative GCA effects for both plant and ear height that could be valued for dwarf variety development. In consistence with this finding Chandel *et al*. (2014) and Seyoum *et al*. (2016) reported negative significant GCA value for both plant height and ear height. Ear length, grains per row in an ear and 1000-grain weight are major yield components and directly proportional to yield. Significant positive GCA effects for ear length and grains per row were possessed by line NT 6323/S_5-44-1 only. Three lines (*viz*., NT 6323/S_5-27-1, NT 6323/S_5-44-1 and NT 6323/S_5-50-1) exhibited significant positive GCA effect for grain yield denoted that these inbred lines were good general combiner for that trait. As GCA is associated with additive gene action, these lines could be utilized for hybrid breeding program followed by allelic exploitation. Similar significant positive GCA effect for grain yield in maize was found by by Shah *et al*. (2015), Amin *et al.* (2014), Kumar *et al.* (2014) and Amiruzzaman (2010).

Table 3. General combining ability (GCA) effects and mean of parents for some physiological traits, grain yield and yield components in maize

Parents	DT (day)		DS (day)		PH (cm)		EH (cm)	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
Testers								
1. BIL 28	0.8	94	0.13	95	1.97	143	2.68	60
2. BIL 79	-0.8	91	-0.13	93	-1.97	125	-2.68	57
SE(gi)	0.44		0.48		1.90		1.80	
SE(gi-gj)	0.62		0.68		2.69		2.55	
Lines								
1. NT 6323/S_5-18-1	1.35	91	0.03	93	-3.03	145	-5.18	57
2. NT 6323/S_5-21-1-2	-0.9	96	0.28	95	-9.53*	127	-10.2*	60
3. NT 6323/S_5-21-2-2	1.1	94	0.28	95	-4.78	148	-1.68	65
4. NT 6323/S_5-23-1	-0.4	90	-0.73	92	-1.28	111	3.08	45
5. NT 6323/S_5-27-1	-1.15	90	-0.48	93	9.97*	159	10.8*	75
6. NT 6323/S_5-35-1	-0.4	87	-0.48	92	-0.03	143	1.08	61
7. NT 6323/S_5-44-1	-1.4	88	-0.98	92	17.7**	177	11.8**	86
8. NT 6323/S_5-45-3	-0.15	89	-0.48	92	7.22	154	10.8*	67
9. NT 6323/S_5-49-1	-0.4	95	-0.23	93	-11.0*	109	-10.9*	48
10. NT 6323/S_5-50-1	-2.35*	88	-2.77*	90	-5.28	126	-9.68*	48
SE(gi)	0.98		1.07		4.25		4.03	
SE(gi-gj)	1.39		1.51		6.01		5.69	

* Significant at 5% level, ** Significant at 1% level

DT= Days to 50% tasseling, DS= Days to 50% silking, PH= Plant height, EH= Ear height

Table 3. Cont'd.

Parents	EL (cm)		NGPR (no.)		TGW (g)		Y (t ha^{-1})	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
Testers								
1. BIL 28	-0.15	15	0.77	26	-0.5	290	-0.26	5.15
2. BIL 79	0.15	14	-0.77	23	0.5	250	0.26	4.45
SE(gi)	0.33		0.92		8.93		0.24	
SE(gi-gj)	0.47		1.31		12.6		0.33	
Lines								
1. NT 6323/S_5-18-1	0.85	16	1.88	27	5.5	350	-0.55	5.2
2. NT 6323/S_5-21-1-2	0.35	13	0.13	26	10.5	360	-0.58	4.8
3. NT 6323/S_5-21-2-2	-1.15	13	-2.63	27	5.5	390	-0.05	6.0
4. NT 6323/S_5-23-1	-1.4	10	-0.88	24	20.5	310	-0.45	4.3
5. NT 6323/S_5-27-1	0.85	15	1.13	35	-4.5	330	1.85**	5.6
6. NT 6323/S_5-35-1	-1.9*	12	-1.88	27	0.5	340	-0.68	6.8
7. NT 6323/S_5-44-1	3.1**	16	4.88*	36	15.5	290	1.41**	6.7
8. NT 6323/S_5-45-3	-0.15	15	0.88	34	-44.5*	290	-0.05	6.8
9. NT 6323/S_5-49-1	-0.65	11	-1.63	20	-24.5	350	-1.31*	4.8
10. NT 6323/S_5-50-1	0.1	10	-1.88	20	15.5	290	1.77**	5.8
SE(gi)	0.75		2.07		20.0		0.53	
SE(gi-gj)	1.06		2.92		28.2		0.74	

* Significant at 5% level, ** Significant at 1% level

EL= Ear length, NGPR= Number of grains per row, TGW= 1000-grain weight, Y= Yield

Specific combining ability (SCA) effects

Specific combining ability effects and mean value of 20 crosses and 3 checks are presented in Table 4. In respect of days to 50% tasseling, only NT 6323/S_5-21-1-2 × BIL 79 cross combination recorded significant negative SCA effects with the lowest mean value which is expected to develop early hybrid variety development. Short stature maize plant is desired to minimize the lodging problem. Significant negative SCA effect as well as lower mean values were estimated from the cross NT 6323/S_5-50-1 × BIL 79 for both plant height ear height involving negative GCA value of parents. The results are agreed with the findings of Amin *et al.* (2014) and Amiruzzaman (2010) who reported the non-additive gene action for plant height and ear height in maize.

Table 4. Specific combining ability (SCA) effects and mean of the crosses for some physiological traits, grain yield and yield components in maize

Crosses / hybrids	DT (day)		DS (day)		PH (cm)		EH (cm)	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
1. NT 6323/S_5-18-1 × BIL 28	-0.05	90	-0.13	92	-0.47	174	1.58	86
2. NT 6323/S_5-18-1 × BIL 79	0.05	88	0.13	92	0.47	171	-1.58	77
3. NT 6323/S_5-21-1-2 × BIL 28	3.2*	91	0.13	92	5.03	173	3.58	83
4. NT 6323/S_5-21-1-2 × BIL 79	-3.2*	83	-0.13	92	-5.03	159	-3.58	70
5. NT 6323/S_5-21-2-2 × BI 28	-0.8	89	-0.38	92	-1.22	171	-0.42	87
6. NT 6323/S_5-21-2-2 × BIL 79	0.8	89	0.38	92	1.22	170	0.42	83
7. NT 6323/S_5-23-1 × BIL 28	-0.3	88	-0.38	91	-0.72	175	-1.18	91
8. NT 6323/S_5-23-1 × BIL 79	0.3	87	0.38	91	0.72	173	1.18	88
9. NT 6323/S_5-27-1 × BIL 28	-0.55	87	-0.13	91	-1.97	185	0.58	101
10. NT 6323/S_5-27-1 × BIL 79	0.55	86	0.13	91	1.97	185	-0.58	94
11. NT 6323/S_5-35-1 × BIL 28	0.2	88	0.38	92	3.53	181	5.83*	96
12. NT 6323/S_5-35-1 × BIL 79	-0.2	86	-0.38	91	-3.53	170	-5.83*	79
13. NT 6323/S_5-44-1 × BIL 28	-0.3	87	-0.13	91	0.78	196	-1.93	99
14. NT 6323/S_5-44-1 × BIL 79	0.3	86	0.13	91	-0.78	190	1.93	98
15. NT 6323/S_5-45-3 × BIL 28	0.45	89	0.38	92	4.78	189	4.58	105
16. NT 6323/S_5-45-3 × BIL 79	-0.45	86	-0.38	91	-4.78	176	-4.58	90
17. NT 6323/S_5-49-1 × BIL 28	-0.3	88	0.63	92	-3.47	163	-4.68	74
18. NT 6323/S_5-49-1 × BIL 79	0.3	87	-0.63	91	3.47	166	4.68	78
19. NT 6323/S_5-50-1 × BIL 28	-1.55	89	-0.38	94	6.22*	174	7.93*	82
20. NT 6323/S_5-50-1 × BIL 79	1.55	91	0.38	95	-6.22*	166	-7.93*	72
21. BHM9 (Check 1)		88		91		173		82
22. 900 M Gold (Check 2)		89		92		173		87
23. NK40 (Check 3)		88		91		156		84
$SE_{(Sii)}$	1.39	-	1.51	-	3.01	-	2.84	-
$SE_{(Sij-Skl)}$	1.96	-	2.14	-	4.25	-	4.04	-

* Significant at 5% level, ** Significant at 1% level

DT= Days to 50% tasseling, DS= Days to 50% silking, PH= Plant height, EH= Ear height

Positive SCA effect is expected for some yield contributing traits *viz*. ear length, number of grains per row and 1000-grain weight. Significant positive SCA effects for ear length and 1000-grain weight were observed in four cross combinations for each trait whereas only one cross combination was found for the trait number of grains per row. In case of grain yield, three crosses exhibited significant positive SCA effects *viz.*, NT 6323/S_5-27-1 × BIL 28,NT 6323/S_5-44-1 × BIL 28 and NT 6323/S_5-50-1 × BIL 79 where first two cross combinations showed higher mean value(10.5 t ha^{-1}) compare to the better performing check 900 M Gold (10.2 t ha^{-1}). Ibrahim *et al*. (2012), Seyoum *et al*. (2016) and Chandel and Mankotia (2014) observed similar type of significant positive SCA effect as well as better yield performance than check in maize for five, two and three cross combinations, respectively in their study. In general, crosses involving both good general combiner as well as one good and other poor combiner showed high SCA effects which are due to additive × additive and additive × dominant gene action. These results are in agreement with the earlier findings of Amin *et al.* (2014) in maize.

Table 4. Cont'd.

Crosses / hybrids	EL (cm)		NGPR (no.)		TGW (g)		Y (t ha^{-1})	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
1. NT 6323/S_5-18-1 × BIL 28	-0.1	16	0.48	36	-19.5	300	0.40	7.3
2. NT 6323/S_5-18-1 × BIL 79	0.1	17	-0.48	33	19.5	340	-0.41	6.9
3. NT 6323/S_5-21-1-2 × BIL 28	-0.1	16	0.73	34	-4.5	320	0.63	7.5
4. NT 6323/S_5-21-1-2 × BIL 79	0.1	16	-0.73	31	4.5	330	-0.63	7.1
5. NT 6323/S_5-21-2-2 × BI 28	-1.1*	13	-1.53	29	-9.5	310	-0.52	6.4
6. NT 6323/S_5-21-2-2 × BIL 79	1.1*	16	1.53	31	9.5	330	0.52	8.7
7. NT 6323/S_5-23-1 × BIL 28	-0.35	14	1.23	34	-54.5*	280	-0.25	6.8
8. NT 6323/S_5-23-1 × BIL 79	0.35	15	-1.23	30	54.5*	390	0.25	7.7
9. NT 6323/S_5-27-1 × BIL 28	1.9**	18	0.23	35	70.5*	380	1.46**	10.5
10. NT 6323/S_5-27-1 × BIL 79	-1.9**	15	-0.23	33	-70.5*	240	-1.46**	8.4
11. NT 6323/S_5-35-1 × BIL 28	0.15	14	1.73	33	5.5	320	0.68	8.5
12. NT 6323/S_5-35-1 × BIL 79	-0.15	14	-1.73	28	-5.5	310	-0.68	7.2
13. NT 6323/S_5-44-1 × BIL 28	-0.85	18	-1.53	37	20.5	350	0.95*	10.5
14. NT 6323/S_5-44-1 × BIL 79	0.85	20	1.53	38	-20.5	310	-0.95*	8.6
15. NT 6323/S_5-45-3 × BIL 28	-1.6*	14	-3.03*	31	-9.5	260	0.20	7.5
16. NT 6323/S_5-45-3 × BIL 79	1.6*	17	3.03*	36	9.5	280	-0.21	7.6
17. NT 6323/S_5-49-1 × BIL 28	1.4*	16	1.48	33	30.5*	320	0.21	6.3
18. NT 6323/S_5-49-1 × BIL 79	-1.4*	14	-1.48	29	-30.5*	260	-0.21	7.0
19. NT 6323/S_5-50-1 ×BIL 28	0.65	16	0.23	32	-29.5*	300	-1.87**	8.1
20. NT 6323/S_5-50-1 × BIL 79	-0.65	15	-0.23	30	29.5*	360	1.87**	10.1
21. BHM9 (Check 1)		16		33		330		9.8
22. 900 M Gold (Check 2)		13		29		360		10.2
23. NK40 (Check 3)		14		26		380		10
$SE_{(Sij)}$	0.53	-	1.46	-	14.1	-	0.37	-
$SE_{(Sij-Skl)}$	0.75	-	2.07	-	19.7	-	0.53	-

* Significant at 5% level, ** Significant at 1% level

EL= Ear length, NGPR= Number of grains per row, TGW= 1000-grain weight, Y= Yield

CONCLUSION

This study revealed that good general combining ability effects for some physiological traits, yield and important yield contributing traits were noticed in the lines NT 6323/S_5-27-1, NT 6323/S_5-44-1, NT 6323/S_5-50-1, NT 6323/S_5-21-1-2 and NT 6323/S_5-49-1. These parents can serve the purpose of superior single crosses production. Hence, these inbred lines have the potential application in the crop improvement program. High specific combining ability effects for grain yield and important yield contributing characters were observed in NT 6323/S_5-27-1 × BIL 28, NT 6323/S_5-44-1 × BIL 28 and NT 6323/S_5-50-1 × BIL 79 with high mean value for yield compare to the best check 900 M GOLD. These crosses were selected based on the SCA effects of yield, some yield contributing components with high mean values and overall field performances and could be advanced for commercial hybrid development after verifying the performance in over locations.

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