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SHORT COMMUNICATION

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RESEARCH PAPER

Evaluation of the performance of maize hybrids under natural and artificial infestation against pink stem borer (*Sesamia cretica* Lederer)

Mohammad Reda Ismail[1,2] · Tamer Talat El-Mouslhy[2]

Abstract: Maize (*Zea mays* L.) is the third most important staple crop in Egypt. *Sesamia cretica* Lederer (*S. cretica*) is the most prevalent corn borer in Egypt, which attacks young maize plants after emergence. *S. cretica* causes dead hearts and is capable of damaging older plants causing drastic yield losses. This study was carried out at the Experimental Research Station of Moshtohor, Benha University, Al-Qalyubiyah Governorate, Egypt during the two successive seasons 2014 and 2015. A half diallel cross between nine yellow inbred lines of maize (*Zea mays* L.) was evaluated under two environments *i.e.* (under borer artificial infestation conditions and normal conditions) in Randomized Complete Block Design (RCBD) with three replications to estimate the mean performance and the interaction of hybrids under the artificial infestation. Artificial infestation was done with newly hatched larvae of *S. cretica*. Highly significant crosses mean squares were detected for all the traits tested, indicating the wide diversity between the parental materials used in this study. Six crosses ($P_1 \times P_6$, $P_1 \times P_7$, $P_2 \times P_4$, $P_3 \times P_5$, $P_5 \times P_7$, and $P_8 \times P_9$) had high mean performance for grain yield and out-yielded significantly the check hybrid SC.166. Therefore, these crosses could be utilized for future breeding work as well as for direct release after confirming the stability of their performances across different environments. Hopefully the information from this study could be useful for researchers who would like to develop high yield potential hybrids of maize tolerance to borer attack.

Keywords: Borer · Combining ability · *Sesamia cretica* · *Zea mays*

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Introduction

Maize (*Zea mays* L.) is one of the most important cereals in Egypt as well as worldwide due to its vast grown area, total production and economic value. It is used for human and livestock consumption and industrial purposes such as manufacturing starch and cooking oils. Increasing its productivity through genetic improvement is the ultimate goal of most of the breeding programs. In Egypt, maize plants are severely attacked by different species of Lepidopteran pests, referred to as corn borers, viz., pink stem borer *Sesamia cretica* Led. (Noctuidae), European corn borer (ECB) *Ostrinia nubilalis* Hubn (pyroustidae) and purple-lined corn borer *Chilo Agamemnon* Bles. (Crambidae). *Sesamia cretica* (*S. cretica*), the most prevalent corn borer in Egypt attacks young maize plants after emergence, causing death of these plants (dead hearts) and its capable of damaging older plants causing drastic yield losses (Simeada, 1985). These losses are mainly attributed to decrease in number of plants population at harvest because of the large number of dead hearts, increase in plant lodging, ear drops and predisposing infested plants to disease organisms.

One of key methods for controlling insect pests in the context of integrated pest control is to grow insect-resistant cultivars (Pathak, 1991). The first step in designing an efficient program for insect resistance breeding is to identify sources of resistance and to determine how resistance traits are transmitted from the original parents to the improved cultivars (Pathak and Othieno, 1992). Considerable efforts have been devoted to identify and develop corn germplasm with resistance to damage by the pink stem borer (Al-Naggar *et al*., 2000; Saafan, 2003 and Soliman, 2003). The objectives of the present work were to identify superior maize genotypes with *S. cretica* resistance and high yielding ability. The present study could help maize breeders to generate new hybrid cultivars having high yield potential as well as tolerance to borer.

Materials and methods

This study was carried out at the Experimental Research Station of Moshtohor, Benha University, Al-Qalyubiyah Governorate, Egypt during the two successive seasons 2014 and 2015. Nine maize inbred lines with diverging resistance levels to corn borer were used in this study. These lines were selected based on clear differences in their reaction to corn borer *S. cretica* and other desirable plant aspects. The designation, pedigree and origin of these inbred lines are presented in (Table 1).

In the first early summer season of 2014, inbred lines were planted. All possible cross combinations (without reciprocals) were made between the nine inbred lines by hand pollination, yielding a total of 36 crosses seeds.

Table 1. The Designation, pedigree and origin of inbred lines studied

Designation	Pedigree	Origin
P_1	TL07A-1903-144	Mexico
P_2	TL07A-1903-145	Mexico
P_3	TL07A-1903-146	Mexico
P_4	TL07A-1903-166	Mexico
P_5	TL07A-1903-167	Mexico
P_6	TL07A-1903-238	Mexico
P_7	TL07A-1903-141	Mexico
P_8	203	Prof. Dr Ali EL-Hosary Egypt
P_9	TL05B-6903-144	Mexico

In the following summer season of 2015, two experiments were conducted in two environments *i.e.* (under artificial infestation and natural conditions).

In each experiment, nine inbred lines, their 36 crosses and a check single cross hybrid 166 (SC.166) were tested in three replications under randomized complete block design. Each plot consisted of two ridges of 6.0 m. length, 0.7 m inter-ridge distance and 0.25 m spacing between hills. Two seeds were planted per hill and later thinned out to one plant per hill before the first irrigation. The recommended agronomic packages of agronomic practices were followed to achieve a good growth.

In the experiment under artificial infestation, all plants were artificially infested at the early whorl stage of plant development (after 25 days of sowing) with neonates of the pink stem borer. The culture was reared artificially in the corn Borer Research Lab., Maize Research Department, Agricultural Research Center. Infestation was done using the mechanical dispenser 'Bazooka' such that each plant received approximately 6-8 larvae. Data were collected on parameters viz., days to 50% tasseling, number of days to silk emergence (DTS), plant height (PH), ear height (EH), ear length (cm), ear diameter (cm), number of rows/ear, number of kernels/ear and grain yield per feddan (GYPF) (1 Feddan= 4200 m^2) was estimated and adjusted at 15.5% grain moisture and expressed kilo gram (kg) per feddan of maize grains. The analysis of variance for RCBD was performed according to (Snedecor and Cochran, 1989).

Results and discussion

Analysis of variance

The analysis of variance for the studied traits in two environments and their pooled mean are presented in (Table 2).

Environment mean squares were significant for all the studied traits with mean values in normal condition being higher than those in artificial infestation of borer for all the studied traits except for tasselling and silking date traits. The earliness of these traits at normal condition may be due to the desirable condition for growing corn and the late of flowering in infested plants may be due to more energy were needed by plant for making recovery. Crosses mean squares were significant for all the studied traits at both environments as well as the combined analysis. This indicates the wide diversity between the parental materials used in this study. Significant interaction mean squares between Crosses and environments were detected for all studied traits except for number of rows per ear indicating that, these crosses behaved somewhat differently from environment to another. Insignificant interaction mean squares between crosses and environment for number of rows per ear revealing the performance of Crosses responded similarly to environmental changes.

Mean performance

The mean performances of the tested 36 Crosses and the check hybrid SC.166 at each environment as well as the combined over the environments are presented in (Table 3).

For days to 50% tasselling, the earliness of tasselling was manifested by $P_7 \times P_9$ under artificial infestation

Table 2. Analysis of variance for all the studied traits under artificial infestation, normal environments and their pooled mean

Traits	d.f		Tasseling date (d)			Silking date (d)			Plant height (cm)		
S.O.V	S.	C.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
Environment (E)		1			27.09 **			43.11 **			23115.7**
blocks/E.	2	4	0.02	2.53	1.27	0.60	2.40	1.50	176.64	60.73	118.68
crosses	35	35	6.00**	7.90**	10.73**	11.49 **	7.18 **	9.37 **	1109.0 **	1069.4 **	1950.6 **
Crosses x E.		35			3.17*			9.30 **			227.88 *
Error/E.	70	140	2.29	1.57	1.93	2.20	1.26	1.73	150.80	124.60	137.70

Table 2 contd.....

Traits	d.f		Ear height (cm)			Ear length (cm)			Ear diameter (cm)		
S.O.V	S.	C.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
Environment (E)		1			22759.1 **			24.13 **			1.33 **
blocks/E.	2	4	625.54 **	19.43	322.48 **	0.10	3.41	1.75	0.01	0.16 *	0.08
crosses	35	35	214.80 **	279.32 **	396.12 **	11.9 **	6.31 **	14.72 **	0.32 **	0.13 **	0.31 **
Crosses x E.		35			98.00 *			3.58 **			0.14 **
Error/E.	70	140	81.09	45.13	63.11	2.33	1.36	1.85	0.08	0.04	0.06

Table 2 contd.....

Traits	d.f		Number of Rows/ Ear			Number of Kernels / Rows			Yield (kg/feddan)		
S.O.V	S.	C.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
Environment (E)		1			7.15 **			516.1 **			60819.8**
blocks/E.	2	4	0.31	1.10	0.71	7.03	15.71	11.37	67.21	98.70	82.95
crosses	35	35	8.46 **	5.71 **	12.82 **	71.57 **	32.9 **	70.22 **	980.14 **	1306.4 **	1605.43 **
Crosses x E.		35			1.34			34.32 **			681.06 **
Error/E.	70	140	1.00	0.97	0.98	9.20	10.19	9.69	44.75	47.79	46.27

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.

Table 3. Mean performance for all the studied traits under artificial infestation, normal environments and their pooled mean

Traits	Tasselling date			Silking date			Plant height (cm)			Ear height (cm)		
Crosses	Infest.	Normal	Comb.	Infest	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P1xP2	66.5	65.7	66.1	72.5	64.3	68.4	146	165	156	75	97	86
P1xP3	62.0	62.0	62.0	63.7	67.3	65.5	194	228	211	99	117	108
P1xP4	63.7	64.3	64.0	66.0	64.3	65.2	218	242	230	104	121	113
P1xP5	65.3	62.3	63.8	69.0	63.3	66.2	176	221	198	88	120	104
P1xP6	61.3	62.7	62.0	63.0	65.3	64.2	228	242	235	108	123	116
P1xP7	63.3	63.0	63.2	66.3	66.0	66.2	217	217	217	91	117	104
P1xP8	62.3	63.3	62.8	65.7	65.3	65.5	236	236	236	104	115	109
P1xP9	62.3	62.3	62.3	63.0	65.3	64.2	215	229	222	94	118	106
P2xP3	62.7	63.0	62.8	67.3	65.7	66.5	196	210	203	96	103	99
P2xP4	65.0	64.3	64.7	66.0	65.7	65.8	197	245	221	95	122	109
P2xP5	63.7	64.0	63.8	65.7	63.7	64.7	189	217	203	97	116	106
P2xP6	62.0	62.0	62.0	65.3	65.3	65.3	206	237	221	100	130	115
P2xP7	62.7	62.3	62.5	63.3	63.3	63.3	199	225	212	97	118	108
P2xP8	62.3	61.0	61.7	65.0	67.3	66.2	224	262	243	103	131	117
P2xP9	61.7	63.0	62.3	65.3	67.0	66.2	214	217	216	106	118	112
P3xP4	63.0	62.7	62.8	66.7	63.3	65.0	225	246	235	106	128	117
P3xP5	62.0	60.3	61.2	64.7	64.7	64.7	198	223	210	92	115	103
P3xP6	61.3	60.7	61.0	64.7	66.3	65.5	220	230	225	107	120	113
P3xP7	61.0	63.0	62.0	64.7	64.0	64.3	204	203	203	93	94	94
P3xP8	61.3	59.0	60.2	64.3	64.7	64.5	223	231	227	98	120	109
P3xP9	60.7	61.3	61.0	65.0	64.7	64.8	210	233	222	97	128	113
P4xP5	63.7	62.0	62.8	66.0	63.7	64.8	208	237	222	113	129	121
P4xP6	63.7	61.0	62.3	65.3	65.0	65.2	242	255	249	118	129	124
P4xP7	63.0	63.0	63.0	66.3	63.0	64.7	214	228	221	104	109	107
P4xP8	62.0	60.0	61.0	63.7	64.7	64.2	243	256	249	118	131	124
P4xP9	63.3	60.3	61.8	66.3	65.0	65.7	235	259	247	108	139	124
P5xP6	62.7	63.3	63.0	65.0	62.3	63.7	201	217	209	101	117	109
P5xP7	63.3	60.0	61.7	65.7	64.7	65.2	183	206	194	91	113	102
P5xP8	61.7	62.7	62.2	63.7	64.7	64.2	207	213	210	97	111	104
P5xP9	62.0	61.0	61.5	65.7	63.7	64.7	197	215	206	93	114	103
P6xP7	64.7	61.7	63.2	67.0	63.3	65.2	223	239	231	104	124	114
P6xP8	61.3	60.3	60.8	64.3	62.0	63.2	200	241	221	100	129	114
P6xP9	61.0	60.0	60.5	62.3	64.0	63.2	212	249	231	100	134	117
P7xP8	62.7	59.0	60.8	67.3	62.3	64.8	205	236	220	90	118	104
P7xP9	60.0	59.7	59.8	62.3	63.7	63.0	202	221	211	93	119	106
P8xP9	60.3	59.7	60.0	62.7	59.7	61.2	231	251	241	100	129	115
SC.166	62.3	63.0	62.7	63.3	63.0	63.2	205	229	217	95	118	106
Mean	62.5	61.9	62.2	65.3	64.4	64.8	209	230	220	99	120	110
LSD5%	2.5	2.0	1.6	2.4	1.8	1.5	20	18	13	15	11	9

Table 3 contd.

Traits	Ear length (cm)			Ear diameter (cm)			No of rows/ ear			No of kernels/ row			Grain Yield (kg/feddan)		
Crosses	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P1xP2	10.7	12.0	11.3	2.9	3.4	3.2	12.3	13.7	13.0	17.3	28.3	22.8	870	2470	1670
P1xP3	13.0	13.3	13.2	3.5	3.5	3.5	13.5	14.1	13.8	30.3	28.3	29.3	1810	1760	1780
P1xP4	13.2	13.0	13.1	2.9	3.1	3.0	11.3	12.5	11.9	23.0	27.5	25.3	1350	1960	1660
P1xP5	10.0	13.1	11.6	3.2	3.6	3.4	15.1	14.9	15.0	28.6	27.8	28.2	1430	2140	1790
P1xP6	15.4	15.8	15.6	3.8	3.8	3.8	15.3	13.7	14.5	34.7	39.5	37.1	2560	3600	3080
P1xP7	12.8	14.1	13.5	3.4	3.3	3.3	13.5	13.5	13.5	27.1	31.6	29.4	1360	2360	1860
P1xP8	14.5	15.2	14.9	3.1	3.9	3.5	15.2	15.5	15.4	24.5	30.8	27.7	1320	2180	1750
P1xP9	12.7	13.0	12.9	3.4	3.2	3.3	15.7	15.3	15.5	26.3	24.9	25.6	1830	1890	1860
P2xP3	12.0	14.3	13.1	3.3	3.9	3.6	13.8	15.7	14.8	23.3	32.0	27.6	1490	3070	2280
P2xP4	18.3	15.3	16.8	3.5	3.6	3.5	11.3	13.2	12.3	17.0	28.6	22.8	1640	2820	2230
P2xP5	14.0	12.7	13.3	3.6	3.6	3.6	14.7	15.2	14.9	29.5	29.3	29.4	1700	2340	2020
P2xP6	12.1	15.6	13.9	3.3	3.8	3.5	12.3	14.9	13.6	27.0	32.6	29.8	1800	3570	2690
P2xP7	14.1	13.1	13.6	3.4	3.6	3.5	12.2	13.5	12.9	21.3	26.3	23.8	1310	2160	1730
P2xP8	17.2	17.3	17.2	3.9	3.8	3.9	16.7	16.6	16.6	33.5	31.2	32.4	1660	2490	2070
P2xP9	15.4	14.6	15.0	3.7	3.4	3.6	14.8	15.5	15.2	27.2	26.2	26.7	2300	1980	2140
P3xP4	12.4	14.5	13.5	3.2	3.5	3.4	11.5	11.7	11.6	26.5	32.7	29.6	1580	2450	2020
P3xP5	12.5	13.5	13.0	3.7	3.7	3.7	13.5	15.2	14.4	28.3	31.2	29.8	2290	3000	2640
P3xP6	14.8	13.3	14.1	3.7	3.6	3.7	13.8	13.6	13.7	33.9	29.3	31.6	2240	2250	2240
P3xP7	11.3	11.6	11.5	3.5	3.4	3.4	13.7	12.5	13.1	23.0	25.7	24.4	1100	2090	1590
P3xP8	13.0	13.1	13.1	3.7	3.6	3.7	14.8	14.5	14.7	37.5	30.3	33.9	2490	2250	2370
P3xP9	13.5	14.9	14.2	3.6	3.8	3.7	14.5	15.0	14.7	30.6	32.2	31.4	2040	2870	2460
P4xP5	12.0	15.4	13.7	2.7	3.7	3.2	12.7	13.1	12.9	24.2	33.7	28.9	1520	2540	2030
P4xP6	15.0	15.1	15.1	3.7	3.6	3.7	11.7	11.8	11.8	33.3	31.9	32.6	2040	2860	2450
P4xP7	15.0	14.4	14.7	3.3	3.4	3.4	11.7	11.8	11.8	24.2	29.2	26.7	1330	2210	1770
P4xP8	15.3	15.7	15.5	3.5	3.6	3.6	14.3	14.2	14.3	30.8	33.9	32.4	1550	2920	2240
P4xP9	15.5	15.4	15.5	3.6	3.6	3.6	13.5	14.5	14.0	30.3	31.9	31.1	1650	3030	2340
P5xP6	11.7	12.3	12.0	3.8	3.7	3.8	14.5	13.3	13.9	26.6	25.7	26.2	1930	2420	2170
P5xP7	11.6	13.2	12.4	3.2	3.7	3.5	13.2	14.3	13.8	24.4	31.6	28.0	1470	2730	2100
P5xP8	12.6	12.0	12.3	3.7	3.5	3.6	15.1	15.4	15.2	28.1	26.5	27.3	1680	2310	2000
P5xP9	14.7	12.5	13.6	3.9	3.9	3.9	16.1	16.3	16.2	32.2	27.6	29.9	2320	2250	2290
P6xP7	11.7	13.6	12.6	2.9	3.8	3.3	12.0	13.1	12.6	24.2	31.3	27.8	1570	2690	2130
P6xP8	13.0	15.7	14.4	3.8	3.9	3.9	16.3	16.4	16.4	26.0	36.8	31.4	1940	3330	2640
P6xP9	14.4	15.8	15.1	3.9	3.9	3.9	15.8	16.2	16.0	28.1	35.1	31.6	2340	3130	2740
P7xP8	9.6	11.9	10.7	3.0	3.3	3.2	14.1	14.2	14.2	18.1	26.4	22.2	1210	1780	1500
P7xP9	10.4	13.3	11.8	3.4	3.7	3.6	15.1	15.6	15.4	23.9	28.5	26.2	1780	2750	2260
P8xP9	16.3	16.5	16.4	4.0	3.8	3.9	18.3	16.5	17.4	33.9	33.4	33.6	2650	3500	3080
SC.166	17.0	15.0	16.0	3.7	3.7	3.7	14.0	15.1	14.6	34.3	28.3	31.3	1150	2460	1800
Mean	13.5	14.1	13.8	3.5	3.6	3.6	14.0	14.4	14.2	27.4	30.2	28.8	1740	2560	2150
LSD 5%	2.47	1.89	1.54	0.47	0.32	0.28	1.62	1.60	1.12	4.92	5.18	3.52	10.85	11.21	7.70

condition, while $P_3 \times P_8$, $P_4 \times P_8$, $P_6 \times P_8$, $P_6 \times P_9$, $P_7 \times P_8$, $P_7 \times P_9$ and $P_8 \times P_9$ were the earliest hybrid at normal condition as well as at the combined analysis compared with SC.166, whereas data showed that the Crosses varied significantly in number of days to 50 % silking, whereas the check variety SC.166 was the earliest hybrid (63.33 day) at artificial infestation condition. While, the hybrid $P_1 \times P_2$ was the latest one (72.5 day) at the same environment. The hybrid $P_8 \times P_9$ was the earliest hybrid at normal condition as well as combined analysis (59.67 day), (61.17 day) respectively. Earliness in maize is favourable to escape from destructive injuries caused by *S. cretica*. The cross $P_1 \times P_2$ solely gave the lowest values in both environments as well as the combined analysis for plant and ear heights. None of the crosses surpassed superiority over the check hybrid SC.166 for ear length at both environments as well as the combined analysis, except the cross $P_2 \times P_8$ at normal condition. While, the crosses $P_2 \times P_4$, $P_2 \times P_8$ and $P_8 \times P_9$ under artificial infestation and the combined analysis showed insignificant deference from the check hybrid SC.166. None of the Crosses showed superiority over the check hybrid SC.166 for ear diameter in both environments as well as the combined analysis. However, the crosses $P_1 \times P_6$, $P_2 \times P_8$, $P_5 \times P_6$, $P_5 \times P_9$, $P_6 \times P_8$, $P_6 \times P_9$ and $P_8 \times P_9$ in both environments and the combined analysis showed higher mean value than the check hybrid. For number of rows per ear six, zero and five crosses showed significant high mean values than the check hybrid SC.166 under artificial infestation condition, normal condition and the combined analysis, respectively. The highest mean value for this trait were detected by the hybrid $P_8 \times P_9$ under the artificial infestation condition as well as the combined analysis. None of the Crosses showed superiority over the check hybrid SC.166 for number of kernels per row under artificial infestation condition. While, the crosses $P_1 \times P_6$, $P_4 \times P_5$, $P_4 \times P_8$, $P_6 \times P_8$ and $P_6 \times P_9$ showed superiority over the check hybrid SC.166 for this trait in normal condition and the cross $P_1 \times P_6$ in the combined analysis.

Concerning grain yield (kg/fed), thirty five, seventeen and twenty seven Crosses had significant superiority over the check hybrid SC.166 under the artificial infestation condition, normal condition as well as the combined analysis, respectively. The crosses $P_1 \times P_6$, $P_2 \times P_6$, $P_3 \times P_5$, $P_6 \times P_8$, $P_6 \times P_9$ and $P_8 \times P_9$ were the best crosses at both environment as well as the combined over them. These Crosses exhibited significant increase of one or more of traits contributing to grain yield (Table 3).

Superiority

Superiority expressed as the percentage deviation of F_1 mean performance from SC.166 values for grain yield trait is presented in Table 4.

Table 4. Superiority for all the studied traits in both environments and the combined over the two environments

Traits	Yield/ton		
Crosses	Infest.	Normal	Comb.
P1xP2	-63.11*	0.73	-12.29
P1xP3	145.8**	-39.66**	-1.85
P1xP4	45.48	-28.46**	-13.38
P1xP5	62.06*	-17.76*	-1.48
P1xP6	313.9**	65.30**	115.9**
P1xP7	45.78	-5.28	5.13
P1xP8	37.78	-15.62*	-4.73
P1xP9	151.6**	-32.47**	5.06
P2xP3	76.00*	34.79**	43.19**
P2xP4	109.3**	20.54**	38.64**
P2xP5	123.2**	-6.51	19.95*
P2xP6	143.8**	63.62**	79.97**
P2xP7	36.14	-17.12*	-6.26
P2xP8	112.6**	1.73	24.34**
P2xP9	254.8**	-27.37**	30.17**
P3xP4	94.95**	-0.14	19.25*
P3xP5	252.4**	30.87**	76.06**
P3xP6	242.5**	-11.93	39.95**
P3xP7	-11.11	-21.08**	-19.05*
P3xP8	298.5**	-11.75	51.52**
P3xP9	198.7**	23.54**	59.25**
P4xP5	81.92**	4.92	20.62*
P4xP6	198.5**	23.18**	58.93**
P4xP7	40.28	-14.16	-3.06
P4xP8	88.73**	26.41**	39.12**
P4xP9	112.0**	32.47**	48.69**
P5xP6	173.5**	-2.19	33.65**
P5xP7	70.67*	15.44*	26.70**
P5xP8	117.7**	-8.20	17.49*
P5xP9	260.0**	-11.52	43.85**
P6xP7	92.9**	13.11	29.38**
P6xP8	175.8**	49.77**	75.48**
P6xP9	265.2**	38.34**	84.60**
P7xP8	13.78	-38.57**	-27.90**
P7xP9	139.1**	16.67*	41.63**
P8xP9	334.2**	59.61**	115.61**

* and ** significant at 0.05 and 0.01 levels of probability, respectively.

The useful superiority effects for grain yield (ton/feddan) relative to SC.166 ranged from 17.49 to 115.99% in the combined analysis. However, most desirable superiority effects were detected from the crosses $P_8 \times P_9$, $P_1 \times P_6$, $P_2 \times P_6$, $P_6 \times P_8$ and $P_6 \times P_9$ at both environments and across them. Hence, it could be concluded that the previous top crosses offer possibility for improving grain yield in maize. Many investigators reported useful superiority for yield in maize (El-Ghonemy, 2015), (Ismail *et al.*, 2018) and (Hassan *et al.*, 2016).

Conclusion

High mean performance for grain yield were obtained by the six crosses ($P_1 \times P_6$, $P_1 \times P_7$, $P_2 \times P_4$, $P_3 \times P_5$, $P_5 \times P_7$, and $P_8 \times P_9$) which had out-yielded significantly the check hybrid SC.166. These crosses could be utilized for future breeding work as well as for direct release after confirming the stability of their performances across different environments. Hence, the information from this study may possibly be useful for researchers who would like to develop high yielding hybrids of maize tolerance to borer attack.

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RESEARCH PAPER

Field efficacy of biopesticides against spotted stem borer *Chilo partellus* (Swinhoe) in maize

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Abstract: Field experiments were conducted to evaluate the bio-efficacy of biopesticides against stem borer *Chilo partellus* (Swinhoe) on maize at Maize Research Centre, PJTSAU, Hyderabad, Telangana during *kharif* 2016 and 2017. The observations based on leaf injury rating, grain yield and cost benefit ratio showed that, among the different biopesticides tested, *Azadirachtin* 1500 ppm (Neem formulation) @ 5 ml followed by *Beauveria bassiana isolate* Bb-23 @ 10 ml/l of water proved effective in reducing *C. partellus* damage. However, chemical control with monocrotophos @ 1.6 ml/l of water was found to be superior among all the treatments in reducing the *C. partellus* damage. Maximum benefit-cost ratio was recorded in monocrotophos 36 SL (13.3) followed by *Azadirachtin* 1500 ppm (Neem formulation) (5.3). Hence, two sprays of Azadirachtin 1500 ppm (neem formulation) @ 5 ml/l of water at 12-15 days after germination followed by 10 days after first spray respectively, can be recommended for the management of stem borer *C. partellus* in maize.

Keywords: Bio-pesticides · *Chilo partellus* · Evaluation · Leaf injury rating · Maize · Spotted stem borer

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Introduction

Maize (*Zea mays* L.) is the most widely grown cereal crop in India after rice and wheat which is grown for various purposes including fodder, food and as a basic raw material for industrial products. The productivity of maize is challenged by various biotic and abiotic factors. Among biotic factors, over 130 insect pests cause varying degree of damage from seedling to maturity stage of maize crop. Out of these insect pests, stem borers cause yield losses ranging from 25.7 to 78.9 percent (Chatterjee *et al.*, 1969). The spotted stem borer, *Chilo partellus* (Swinhoe) is the key pest throughout India during rainy season (Siddiqui and Marwaha, 1993) and has a wide host range in cultivated and wild species (Khan *et al.*, 1997: Van den Berg *et al.*, 2001).

Adult moth of stem borer lay 20-25 creamy white oval scale like eggs in clusters at night. Fecundity is around 250-300. Immediately after hatching, dirty greyish white neontes with black head crawl over the leaf for about 15-30 minutes and then feed on the surface of tender leaves and bore downwards through the whorl and reach the growing point of the plant. As the whorl opens, pin holes or shot holes (occur in a parallel fashion) are seen on the leaf surface. The larvae cut the growing point resulting in drying up of the central shoot and subsequent formation of "dead heart" which on pulling comes out easily. Larvae feed on the tissues (pith) inside the stem and tunnels are formed due to which not only plant vigour is lost but also reduction in grain yield. This pest causes heavy damage to maize crop resulting in 26 to 80% yield losses in different agro climatic regions (Panwar, 2005). The shift from synthetic insecticides to bio-pesticides is necessary for the management of *C. partellus* due to environmental concerns and insecticide resistance. Keeping in view of the importance of maize crop, and the economic losses caused by the spotted stem borer during *kharif* season, the present study aimed to test the efficacy of biopesticides against *C. partellus* for its management.

Materials and methods

Raising crop

A field experiment was laid out during *Kharif* 2016 and 2017 with single cross maize hybrid DHM-117 at Maize Research Centre, ARI, Rajendranagar, Hyderabad, Telangana. The trial was laid out in a randomized block design with 9 treatments, each replicated thrice with a plot size of 9 m^2 (4 rows of 3 meter length). A spacing of 0.75 and 0.20 m between row to row and plant to plant was followed respectively. Also a distance of 0.75 and 1 m was kept between treatments and replications. Recommended agronomical practices were followed in raising the crop and the details of the treatments are given in Table 1.

Biopesticides

The biopesticides viz., *Beauveria bassiana isolates* Bb-5a, Bb-23, Bb-45 and *Metarhizium anisopliae* isolate Ma-35 were obtained from NBAIR, Bangalore. *Bacillus thuringiensis* var. *kurstaki* (Bt formulation), *Azadirachtin* 1500 ppm (Neem formulation) and monocrotophos 36 SL (state recommended) were obtained locally. The standard check used was monocrotophos 36 SL.

Infestation and data recording

All the treatments were imposed two times as per protocol given by ICAR-Indian Institute of Maize Research, Ludhiana, Punjab (Anonymous 2016). The middle two rows of each treatment were artificially infested with ten second generation neonate larvae per plant at 12 days after germination (DAG). Two days after infestation of neonates first spray was imposed and second spray was done at 10 days after first spray. Leaf injury rating was recorded on 1-9 scale (Sarup *et al*., 1979) on middle infested 2 rows plants at 25 days after infestation. In control, spray was done with water. The grain yield from individual treatment was recorded separately during harvest and expressed as q/ha. The moisture content was 15%. While comparing the yield from different treatments, the percent increase in yield over control was calculated using the following formula (Pradhan 1969).

Increase in yield over control (%) = T-C/C × 100

where, T=Yield from treated plot C=Yield from control plot

Data analysis

Data were subjected to statistical analysis by using ANOVA. Economics of different insecticides were worked out as per the market price of the commodities. The benefit cost ratio was also calculated by dividing net profit over control by the total cost.

Results and discussion

Leaf injury rating

Infestation of stem borer was recorded on 1-9 scale at 25 days after infestation and results were presented (two years pooled data). A significant reduction in the stem borer damage (Damage Score recorded on 1-9 scale) was observed in all the treatments except *Metarrhizium* isolate Ma-35 (6.4) when compared to the untreated check (7.1) (Table 1). The results showed that, *Azadirachtin* 1500 ppm (Neem formulation), *B. thuringiensis* (*Bt* formulation), *B. bassiana* (Bb-5a isolate) were at par and have recorded mean leaf injury rating of 5.1, 5.5 and 5.6 respectively. But there was no significant difference in mean injury rating, among the *Beauveria* isolates, Bb-5a (T1), Bb-45 (T3) and Bb-23 (T2) and which recorded 5.6, 6.0 and 6.1 respectively. Monocrotophos 36% SL (state recommended) was found to be superior among all the treatments in reducing the stem borer damage and recorded mean leaf injury rating of 4.3 on 1-9 scale. *Metarhizium* isolate (Ma-35) was ineffective in reducing the stem borer damage and was on par with that of the untreated check.

In the present study, the efficacy of monocrotophos 36% SL @ 1.6 ml (state recommended) was in agreement with Ramesh *et al.,* (2012) who also found effective for the management of stem borer. Among the biopesticides the efficacy of *Azadirachtin* 1500 ppm (Neem formulation) and *B. thurningiensis* (*Bt formulation*) has been confirmed with the report of several workers (Bhanu Kiran and Panwar, 2005; Shekharappa and Kulkarni, 2006 and Deepthi *et al.,* 2008). The entomopathogenic fungi *B. bassiana* isolates were found to provide satisfactory control of stem borer was also in agreement with the results reported by Shekharappa (2001). However, selection of potential isolate of entomopathogenic fungi seems to be a prerequisite to achieve a satisfactory control.

Table 1. Efficacy of Bio-pesticides against the stem borer *Chilo partellus* on maize (Pooled analysis of two years data)

T.No.	Treatment	Dose / lit of water	Leaf injury at 25 DAI (1-9 scale)	Grain Yield (q ha^{-1}) at 15% moisture	Increased grain yield over control q ha^{-1}	Per cent increase in grain yield over control (%)	Total Monitory value over control (Rs. ha^{-1})	Tota cost of the treatment (Rs. ha^{-1}) insecticide + Labour charges	Net monitory returns over control (Rs. ha^{-1})	Net cost benefit ratio (1:↓)
T1	*Beauveria bassiana* (Bb-5a isolate, 10^8 spores / ml)	10 ml	5.6	24.8	3.90	18.66	5557.5	3900	1658	0.4
T2	*Beauveria bassiana* (Bb-23 isolate, 10^8 spores / ml)	10 ml	6.1	29.8	8.90	42.58	12682.5	3900	8783	2.3
T3	Beauveria *bassiana* (Bb-45 isolate, 10^8 spores / ml)	10 ml	6.0	27.3	6.40	30.62	9120.0	3900	5220	1.3
T4	*Metarhizium anisopliae* (Ma-35 isolate, 10^8 spores/ ml)	10 ml	6.4	25.9	5.00	23.92	7125.0	3900	3225	0.8
T5	*Bacillus thurningiensis* (Bt formulation Delffin 5 % WG)	5 g	5.5	27.3	6.40	30.62	9120.0	9500	-380	0.0
T6	*Azadirachtin* (Neem formulation, 1500 ppm)	5 ml	5.1	29.8	8.90	42.58	12682.5	2000	10683	5.3
T7	Monocrotophos 36% SL (State recommendation)	1.6 ml	4.3	34.1	13.20	63.16	18810.0	1320	17490	13.3
T8	Untreated check (control)		7.1	20.9						
	Over all Mean		5.8	27.5						
	S.Ed		0.36	2.95						
	CD @ 5%		0.78	6.33						

Monitory value @Rs.1425/q prevailing during 2017-18; DAI: Days after infestation

Grain yield (q/ha)

The grain yield data also revealed that monocrotophos (1.6 ml) (state recommended) has recorded the highest grain yield of 34.1 q ha^{-1} (Table 1), while the untreated check recorded the lowest grain yield of 20.9 q ha^{-1}. However, all the treatments have recorded significantly increased grain yield over untreated check (Table 1). There was no significant yield difference among bio-pesticide treatments and it ranged from 24.8 and 29.8 q ha^{-1}. The percent increase in grain yield over untreated check amongst the treatments, ranged from 18.66 to 63.16. Monocrotophos 36% SL (1.6 ml/l), *Azadirachtin* 1500 ppm (5 ml/l) and *Beauveria* isolate, Bb-23 (10 ml/l) were most effective against stem borer which reflected in significantly higher grain yield (34.1 and 29.8 q ha^{-1}) resulting in 63.16 and 42.58 percent increase over untreated check respectively. The present studies are also in close agreement with Bhanukiran and Panwar (2005) who reported that neemazal (Azadirachtin) as the best treatment with respect to yield. Singh and Sajjan (1982) reported increase in LIR (from 2 to 9 scale) resulting in increased loss of grain yield of maize. Teki *et al.* (2006) reported that application of neem seed powder @ 3g/ plant and 10% aqueous neem seed extract provide adequate protection against stem borer comparable to conventional insecticide and also reduced yield loss.

Economic estimation of different insecticides against C. partellus

The benefit-cost ratio of different treatments has been worked out aiming at economical and equally effective treatment against stem borer to obtain maximum profit ha^{-1} (Table 1). The data revealed that, benefit-cost ratio was highest with monocrotophos 36 SL (13.3) followed by *Azadirachtin* 1500 ppm (5.3) and *Beauveria* isolate, Bb-23 (2.3) respectively.

Even though, Monocrotophos 36% SL (state recommended) @ 1.6 ml/l of water (Chemical control) was found to be effective and also attained highest benefit-cost ratio among all the treatments, the concern over the adverse effect of pesticides on the environment warrant eco- friendly approaches in pest management programs. Keeping in view the above fact, two sprays of Azadirachtin 1500 ppm (Neem formulation) @ 5 ml/l of water, first spray at 12-15 days after germination followed by second spray at 10 days after first spray can be recommended for the management of stem borer in maize and more detailed studies are necessary to identify the best isolate of *B. bassiana* for use in field control of stem borer.

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RESEARCH PAPER

Acetate utilization pathways in *Mycobacterium tuberculosis*, a potential pathogen in maize silage

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Abstract: Acetic acid is an important component of maize silage, which imparts stability to silage against damage by aerobic conditions. Inoculation of maize fodder with heterofermentative lactic acid bacteria results in formation of acetic acid. The drop in pH that results in ensiled fodder inhibits growth of undesirable organisms. However, certain organisms have developed mechanisms to survive in hostile conditions. Of particular interest is the notorious human pathogen, *Mycobacterium tuberculosis* which had been implicated as a potential pathogen of maize silage. The conditions in silage like availability of magnesium confer advantage to many species of the *Mycobacterium tuberculosis* complex by stabilizing certain proteins, enabling the organism to survive under the otherwise harsh conditions. In this article, the possible routes of acetate conversion in ten strains of *M. tuberculosis*, to acetyl-Coenzyme A, an important intermediate in energy metabolism have been deciphered from a curated metabolic pathway repository. The results implicate that metabolic flexibility in *M. tuberculosis* strains constitutes a strategy for enhanced pathogen survival under adverse conditions. The diversity in utilization of acetate and other carbon sources necessitate an investigation of mycobacterial survival strategies for a more informed Quality Control of maize silage for applications in dairy industry.

Keywords: Acetate · Maize · Metabolic flexibility · Mycobacterium tuberculosis · Silage

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Introduction

Maize is an important feed crop that can supplement dairy industry for increased efficiency and remuneration. Processing of maize in the form of silage provides a rich source of energy to the cattle and results in enhanced milk yields (Khan *et al.*, 2015). Maize silage is considered to be a solution to scientific livestock management. The low productivity of cattle in India, which is due to improper nutrition, can be solved through increased use of silage in dairy industry. Silage making involves a process of ensiling, whereby the green fodder is preserved and becomes suitably available for cattle for a long time. During ensiling, the maize fodder is compressed and is subsequently kept under anaerobic conditions. The ensiled fodder may be left to ferment on its own or actively fermented by addition of lactic acid bacteria. The use of inoculants results in a high-quality silage. The pH of the ensiled fodder drops soon and prevents growth of spoilage-causing microbiota. When the silos are opened for taking silage, air enters and results in oxidation of fermentation via growth of acid-tolerant microorganisms (Danner *et al.*, 2003). The difference in stability of fodder inoculated by homofermentative or heterofermentative lactic acid bacteria, towards aerobic deterioration had been observed previously (Weinberg and Muck, 1996). It has been noticed that inoculation with heterofermentative lactic acid bacteria like *Lactobacillus brevis* or *Lactobacillus buchneri* is stable against deterioration caused by aerobic conditions (Danner *et al.*, 2003). Acetic acid has been reported to be responsible for higher stability in the above silages.

The drop in pH that results in maize silage inhibits growth of non-desirable microbes. Spoilage organisms like *Clostridia* result in butyric acid formation and conversion of proteins to ammonia. While this reduces the quality of silage, it also poses challenges for downstream processing of dairy products. The presence of *Clostridia* spores results in diminished cheese quality, leading to economic losses (Garde *et al.*, 2013). Another potential pathogen group is the *Mycobacterium tuberculosis* complex species. Its presence in maize silage has already been reported earlier (Garnett *et al.*, 2003). A pathogen of high concern in the complex is *Mycobacterium tuberculosis*, which infects humans and can also infect other animals (Grange, 2001 and Hlokwe *et al.*, 2017). Reports of *M. tuberculosis* and *M. bovis* presence in cattle herd settings (Cezar *et al.*, 2016a) and also in end-products like cheese have been obtained (Cezar *et al.*, 2016b). This necessitates investigation of factors that may lead to mycobacterial survival in ensiled conditions and development of intervention strategies to control the same. *M. tuberculosis* is known to survive in low pH also. The growth disadvantage of *M. tuberculosis* is partially rescued by the presence of high magnesium content (Piddington *et al.*, 2000). *M. tuberculosis* is also known to utilize acetate as a carbon source (Rücker *et al.*, 2015). In view of the above, it becomes imperative to understand the ability of acetate utilization of different *M. tuberculosis* strains. We have used a comprehensive metabolic pathway repository for *in vitro* analysis of metabolic flexibility for acetate utilization in ten *M. tuberculosis* strains.

Materials and methods

Database used for selection of M. tuberculosis strains

BioCyc collection of genome databases was used to retrieve data of *M. tuberculosis* strains (Karp *et al.*, 2019). A total of 10 *M. tuberculosis* strains, *viz.*, *M. tuberculosis* 02_1987, *M. tuberculosis* 7199-99, *M. tuberculosis* Beijing, *M. tuberculosis* CDC1551 (TIGR 2014), *M. tuberculosis* H37Rv, *M. tuberculosis* Haarlem, *M. tuberculosis* KZN 605, *M. tuberculosis* M0002959-6, *M. tuberculosis* SCAID 252.0 and *M. tuberculosis* SUMu008 were taken for the analysis. BioCyc platform allows analysis, storage and sharing of data after logging in the server.

Determination of metabolic pathways of acetate utilization

The above ten strains of *M. tuberculosis* were analyzed in the Metabolic Route Search module of BioCyc program. The parameters used involved acetate as 'Start Compound' and Acetyl-CoA as 'Goal Compound'. The metabolic route was searched by setting 'Switching Organisms' in penalty mode. Amongst other parameters, the number of routes (reaction) and maximum route length were kept as 5 and 9, respectively, in the BioCyc program.

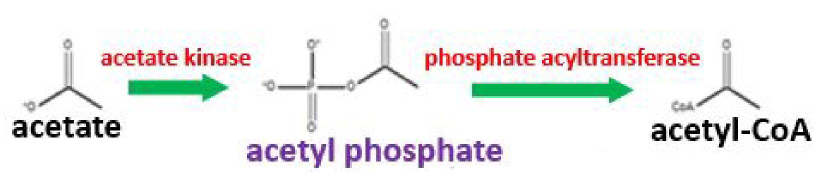
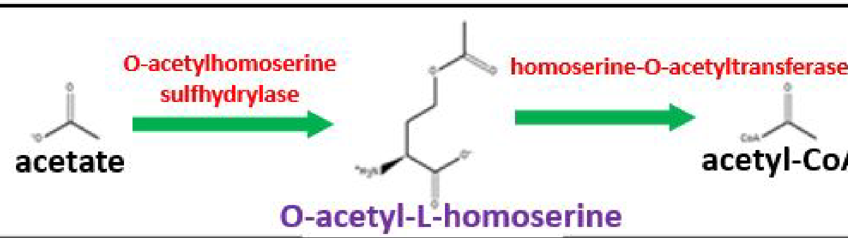
Results and discussion

We have used the information in BioCyc program to understand the inherent diversity of acetate utilization in *M. tuberculosis* strains through *in vitro* analysis (Karp *et al.*, 2019). A total of 10 *M. tuberculosis* strains, *viz.*, *M. tuberculosis* 02_1987, *M. tuberculosis* 7199-99, *M. tuberculosis* Beijing, *M. tuberculosis* CDC1551 (TIGR, 2014), *M. tuberculosis* H37Rv, *M. tuberculosis* Haarlem, *M. tuberculosis* KZN 605, *M. tuberculosis* M0002959-6, *M. tuberculosis* SCAID 252.0 and *M. tuberculosis* SUMu008 were taken for the analysis of metabolic routes that convert acetate to acetyl-CoA in the above strains. *M. tuberculosis* Beijing genotype is associated with high virulence and multiple drug resistance, although its global frequency is not precisely known (Lillebaek *et al.*, 2003). *M. tuberculosis* Haarlem genotype is ubiquitously present and is thought to be linked to post-Columbus European colonization (Kremer *et al.*, 1999). *M. tuberculosis* H37Rv is the laboratory strain (Bifnai *et al.*, 2000), while *M. tuberculosis* CDC1551 is the clinical isolate that induces a rapid response in host (Manca *et al.*, 1999). The above ten strains of *M. tuberculosis* were analyzed in the Metabolic Route Search module of BioCyc program for conversion of acetate as 'Start Compound' to Acetyl-CoA as 'Goal Compound'. Acetyl-Coenzyme A (Acetyl-CoA) is an important molecule, which determines the cellular fate. Acetyl-CoA plays role in carbohydrate, protein and lipid metabolism. Due to its involvement in diverse metabolic processes, it is a key indicator of cellular health (Shi and Tu, 2015). Under 'fed' state, Acetyl-CoA participates in lipid metabolism, while under 'starved' state, it mobilizes to mitochondria for energy production (Shi and Tu, 2015). In *M. tuberculosis*, Acetyl-CoA activates Isocitrate lyase 2, which regulates carbon flux and plays an essential role in bacterial growth as well as virulence (Bhusal *et al.*, 2019). Analysis of top five least-cost routes from acetate to acetyl-CoA showed that the *M. tuberculosis* strains utilize acetate via different routes. Table 1 depicted the top four routes preferred by mycobacterium for conversion of acetate to acetyl-CoA. The reactions occur at comparable metabolic cost, indicating that any of the routes may be taken by the cell, depending on circumstances. The theoretical metabolic cost ranges from 105-110, as mentioned by the BioCyc program. The enzymes acetate CoA-transferase, acetyl-CoA synthetase, acetate kinase, phosphate acetyltransferase, O-acetyl homoserine sulphydrylase and O-homoserine acetyltransferase are present in all the 10 strains analyzed. The above analysis shows metabolic flexibility for acetate utilization exist in different *M. tuberculosis* strains. This indicates that the enzymes revealed in the present analysis may, under the adverse conditions of maize silage, play a role in acetate utilization as well, besides fulfilling other functions. Gene expression of the deciphered enzymes in different mycobacterial strains can be used to assess relative acetate utilization in different species and the contribution of an individual strain to overall mycobacterial load and its persistence under the acidic conditions of silage.

In addition to this, however, a fifth reaction at a comparable metabolic cost of 115, occurs in *M. tuberculosis* H37Rv and *M. tuberculosis* CDC1551. Figure 1 represents the route from acetate to acetyl-CoA mediated via two intermediates N-acetyl-L-ornithine and N-acetyl-L-glutamate. This reaction occurs only in the above two, out of the ten, *M. tuberculosis* strains analyzed.

The comparable metabolic cost of the conversion of acetate to acetyl-CoA via N-acetyl intermediates indicates the inherent diversity in mycobacterial species to utilize different substrates as carbon sources. The above results were obtained with a high penalty imposed to ‘Switching organisms cost’ in the BioCyc program. ‘Switching organisms’ refers to the condition where metabolites can be shared amongst the different organisms or species, leading to desired goal molecules in any organism. *M. tuberculosis* is known to share metabolites. For example, it extracts nicotinamide from host during infection (Young *et al.*, 2015). In scenarios, where multiple mycobacterial strains may be capable of supporting each other by sharing of metabolites, the survival range of the otherwise susceptible species would also enhance.

Table 1. Analysis of the top four routes (reactions) converting acetate to acetyl-CoA in the ten *M. tuberculosis* strains. The reactions occur at comparable metabolic cost

S. No.	Metabolic Cost	Reaction
1.	105	
2.	105	
3.	110	
4.	110	

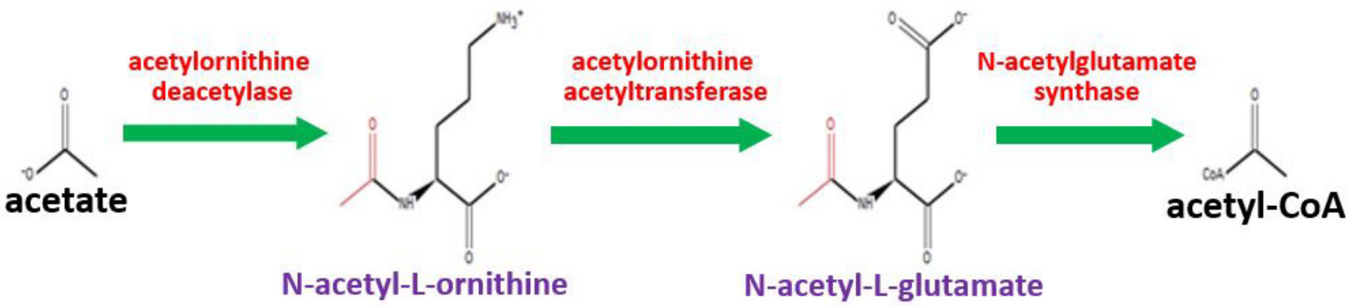


Figure 1. Conversion of acetate to acetyl-CoA via N-acetyl intermediates. Acetate is converted to N-acetyl-L-ornithine, N-acetyl-L-glutamate and acetyl-CoA by enzymes acetylornithine deacetylase, acetylornithine acetyltransferase and N-acetylglutamate synthase.

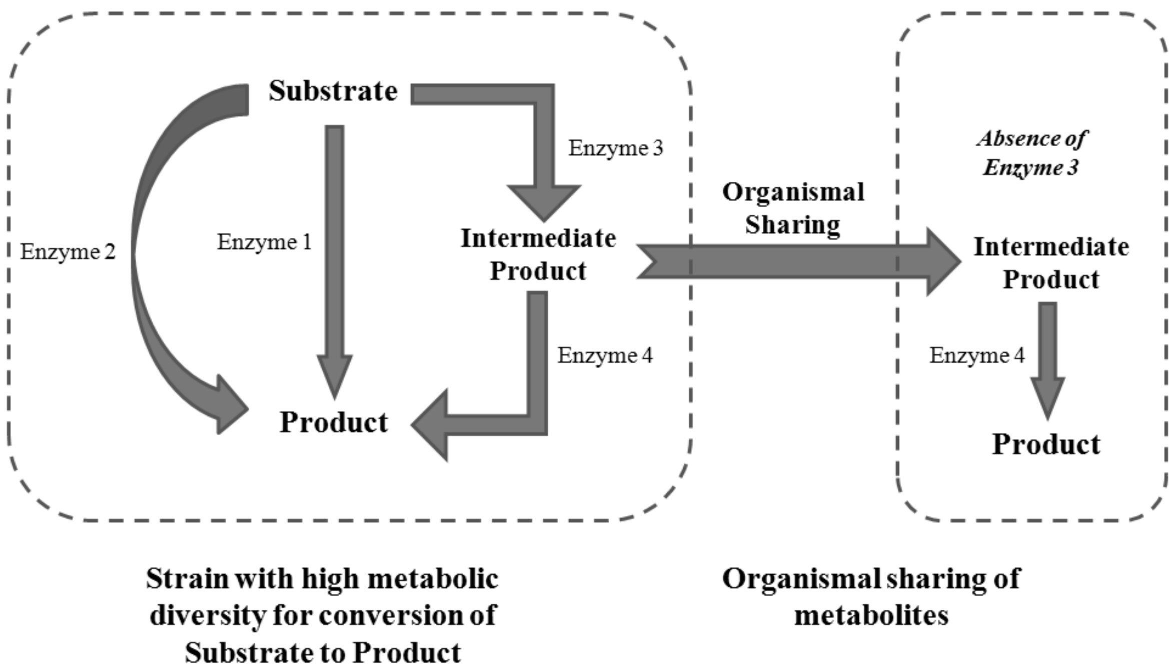


Figure 2. A model of enhanced pathogen survival under adverse conditions by metabolic flexibility and organismal sharing. Metabolic flexibility and organismal sharing of metabolites are two mechanisms whereby enhanced pathogen survival in hostile conditions may be mediated. The strain on the left has enzyme diversity for substrate conversion. Organismal sharing of a key metabolite (Intermediate Product) allows propagation of the strain on the right, which otherwise lacks enzyme diversity for substrate conversion.

The diversity of routes leading to molecules of energy metabolism is important, as under environmental conditions, many confounding factors may be present, all of which may together influence the outcome of bacterial growth towards active division, sporulation or inhibition. The acidity of silage is not a favourable environment for mycobacteria to grow. However, with the availability of different enzymes to utilize energy sources and the possibilities of sharing of metabolites amongst the different strains, enhanced mycobacterial survival under the adverse conditions of maize silage is possible. Figure 2 presents a conceptual model, whereby an interplay of metabolic flexibility and organismal sharing increases the energy source options available to mycobacteria. This may explain the presence of *M. tuberculosis* in cattle herd settings and their end-products, being primarily transmitted from maize silage used as feed.

The availability of more options in the form of increased number of enzymes is obviously to the advantage of microorganism. Evolutionary processes whereby different microbes may get involved via metabolite sharing is another factor that must be considered, when Quality Control parameters for maize silage are reviewed. Mycobacteria also associate with each other in the form of biofilms. In case of *M. smegmatis*, horizontal transfer of DNA occurs between organisms in the biofilm (Nguyen *et al.*, 2010). The above model provides a framework to understand enhanced mycobacterial survival through an increased repertoire of enzymes for substrate utilization and sharing of metabolic products.

Conclusion

Metabolic flexibility and organismal sharing of metabolites, together with the biofilm habitat, have the potential to allow diverse mycobacterial strains to survive in the adverse acidic conditions of maize silage. It is necessary to estimate the survival potential of strains with diverse molecular functions, under natural conditions as well as artificially low pH, high magnesium conditions of maize silage to determine the likely salvage points, which may be utilized by the microorganism to grow. An understanding of the survival mechanism will help in designing effective strategies to prevent the spread of tubercle bacilli in maize silage.

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RESEARCH PAPER

Evaluation of stress tolerance indices and their association with grain yield of maize (*Zea mays* L.) under drought and optimal moisture conditions

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Abstract: Selection for drought tolerance typically involves evaluating genotypes for either high yield potential or stable performance under drought stress. Fifty maize hybrids which were procured from the pool of CIMMYT maize germplasm were evaluated under two different moisture regimes *i.e.* drought and optimal moisture conditions during the cropping season *rabi* 2017-18. Twelve drought tolerance/resistance indices including stress susceptibility index (SSI), relative drought index (RDI), stress tolerance index (STI), geometric mean production (GMP), stress tolerance index (TOL), mean production (MP), yield index (YI), drought resistance index (DRI), yield stability index (YSI), stress susceptibility percentage index (SSPI) and modified stress tolerance (K_1STI and K_2STI) were calculated based on grain yield under drought (Y_p) and optimal moisture (Y_s) conditions. The genotypes with low fluctuations in yield stability under different stress environments were considered as drought resistant genotypes. Kernel yield in stress and non-stress conditions were significantly and positively associated with RDI, STI, GMP, MP, YI, DRI, YSI, K_1STI and K_2STI where as yield in stress is negatively significant with SSI, TOL and SSPI. Screening drought tolerant genotypes using ranking method include mean rank ($\bar{R}$), standard deviation of ranks (SDR) and rank sum (RS) distinguished the genotypes *viz*, VH123021, 900 MG, ZH161529, VH131167, VH12264, Hytech 5106 and ZH161529 as drought tolerant.

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Introduction

Drought and excess moisture stress are the two major abiotic stresses limiting maize production in large part of South and South-East Asia, and many other parts of the world. Losses due to drought in lowland tropics averaged 17% (Edmeades *et al*., 1992), and it reached up to 60% in severely drought-affected regions/seasons (Rosen and Scott, 1992). In India, approximately 2.4 m ha (~ 32.4%) of total maize growing areas is prone to face drought or excess moisture stress. Occasional exposure to both the stresses during same crop cycle, *i.e.* excess moisture at vegetative stage and drought during flowering and grain filling stage, is common.

Productivity of maize drastically decreases under water scarcity conditions due to affect of photosynthesis. In countries like India, the major maize growing season is *kharif*, which accounts for about 85% of the total area in the country. Whereas as in *rabi* and delayed *rabi*, crop has to face the uneven soil moisture at all the critical growth stages. Both the season faces a common problem of water stress. Drought resistant and drought tolerant genotypes are required to overcome this moisture scarcity condition in the maize production. Selecting maize genotypes based on their yield performance under drought conditions is a common approach. However, various drought stress indices have been reported as efficient selection criteria (Naghavi, 2013; Zahra and Jahad, 2011; Masoud, 2013).

Selection for drought tolerance is not easy due to the existing of strong interactions between genotypes and the environment and less knowledge about the function and role of tolerance mech-anisms. Various researchers have used different methods to evaluate genetic associations and environmental interactions towards expressing drought tolerance. Rosielle and Hamb-lin (1981) demonstrated that lower stress tolerance index (STI), hybrid yield in normal irrigation and drought con-dition is close to each other or plant is resistant to drought. Stress Tolerance Index (STI) was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). Blum (1988) defined one more index *i.e.* drought resistance index (DI), which was commonly accepted to identify genotypes producing high yield under both stress and non-stress conditions. So, Ros-ielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between stress and irrigated environments and mean productivity (MP) as the aver-age yield of genotypes under stress and non-stress condi-tions. The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years (Fernandez, 1992). Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measure-ment of yield stability that apprehended the changes in both potential and actual yields in variable environments. The yield index (YI; suggested by Gavuzzi *et al.,* 1997) and yield stability index (YSI) suggested by Bouslama and Schapaugh (1984) in order to evaluation the stability of genotypes in the both stress and non-stress conditions. Stress Tolerance Index (STI) was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). To improve the efficiency of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002) which cor-rects the STI as a weight. Moosavi *et al.* (2008) introduced stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stress condi-tions. Correlations among all the indices and association of yield in stress and non stress with studied indices were helpful in identifying precise indices to screen the resistant or tolerant genotypes. Naghavi *et al*. (2013) studied the effect of drought stress on eight cultivars corn with twelve drought tolerance/resistance indices and recorded a positive significant correlation of yield in stress and non stress with TOL, MP, STI, SSI, YI, DI, SSPI, K_1STI and K_2STI. Kumar *et al*., 2015 evaluated thirteen maize hybrids under stress and non- stress conditions by using eighteen drought tolerant indices and found grain yield under irrigated conditions was significantly and positively correlated with TOL and K_1STI. Madhav *et al.* (2017) evaluated a total of 100 maize genotypes and observations were recorded for 10 morphological characters including per day productivity and eleven stress indices were estimated following standard formulae. All the genotypes were ranked for morphological traits and stress indices for their good performance to poor performance. Based on mean ranks and standard deviation of rank, eight genotypes were identified as drought tolerant. This study was carried out in order to evaluate maize hybrids reaction to drought stress and determine the best measures for increase and improvement of yield in stress and non-stress condition. Also, this experiment was conducted to assess the selection criteria for identifying drought tolerance in corn hybrids.

Materials and methods

Fifty medium duration maize hybrids listed in Table 1 were procured from the CIMMYT Asia, Hyderabad, India. The experimental hybrids developed by biparental crosses, procured from a pool of CIMMYT maize germplasm (600 lines) crossed with two testers *viz.*, CML451 and CL02450 which were screened under optimal moisture, drought and waterlogging condition. They were evaluated using alpha lattice design with two replications under two soil moisture conditions *viz*., managed drought stress and optimal moisture conditions during late *rabi* 2017-18 at Agricultural Research Farm, Banaras Hindu University, Varanasi, India (25.26' N, 82.99' E and 82 m above mean sea level). The experimental site was sandy loam with pH 7.4. Sowing was done by hand with 3 m in length and two in row number. Trials were planted with 0.60 m inter-row spacing and 0.20 m in-row spacing and with two border rows. The experimental trials were sown in the last week of December 2017. In moisture stress experimental plots, drought was imposed based on growing degree days (GDD) by withdrawal of irrigation. The flowering stage of the trial was exposed to severe moisture stress by withdrawing and resuming irrigation at 550 and 1000 GDD respectively. Maximum and minimum temperatures along with cumulative GDD values for the crop season were shown graphically in Figure 1. Total rainfall, 15.4 mm was recorded in the entire crop season, but not in the stress period imposed on the experimental field by withholding irrigation. At harvest time, yield potential in optimal moisture condition (Yp) and stress yield (Ys) were measured. Twelve drought tolerance indices including stress susceptibility index (SSI), relative drought index (RDI), stress tolerance index (STI), geometric mean production (GMP), stress tolerance index (TOL), mean production (MP), yield index (YI), drought resistance index (DRI), yield stability index (YSI), stress susceptibility percentage index (SSPI) and modified stress

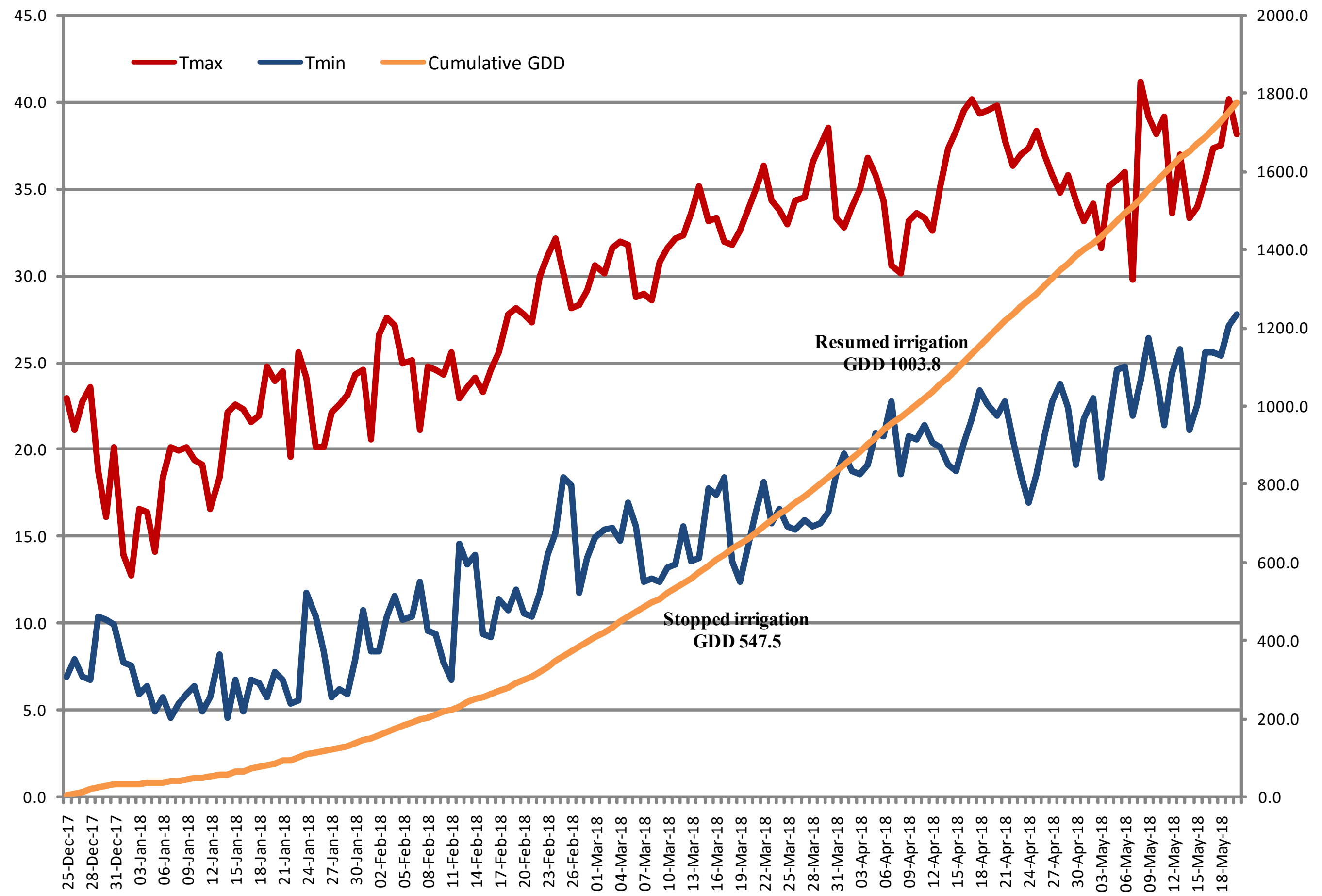

Figure 1. Graph showing maximum temperature (Tmax), minimum temperature (Tmin) and cumulative GDD values during crop season

tolerance (K_1STI and K_2STI) were calculated using the following relationships.

- Stress susceptibility index (SSI) (Fisher & Maurer, 1978):

  SSI = 1 – (Ys / Yp) / SI, while SI = 1 – ($\hat{y}$s / $\hat{y}$p)

- Tolerance index (TOL) and mean productivity (MP) as done by Rosielle and Hamblin (1981):

  TOL = (Yp – Ys) and MP = (Ys + Yp) / 2

- Relative drought index (RDI) (Fischer *et al.,* 1998):

  (Ys / Yp)/ ($\hat{y}$s / $\hat{y}$p)

- Geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992; Kristin *et al.*, 1997):

  GMP = $(Yp * Ys)^{½}$ and STI = (Yp * Ys) / $(\hat{y}p)^2$

- Yield Index (YI) (Gavuzzi *et al.*, 1997; Lin *et al.*, 1986): YI = Ys / vs

- Yield Stability Index (YSI) (Bouslama & Schapaugh, 1984): YSI = Ys / Yp

- Modified stress tolerance index (MSTI) as reported by Farshadfar & Sutka (2002):

  MSTI = kiSTI while $K_1 = (\hat{y}p^2) / (\hat{y}p^2)$ and $K_2 = (Ys^2) / (\hat{y}s^2)$

where, ki is the correction coefficient.

In the above formulas, Ys, Yp $\hat{y}$s and $\hat{y}$p represent yield under stress, yield non-stress for each cultivar, yield mean in stress and non-stress conditions for all cultivars, respec-tively.

For screening drought tolerant genotypes a rank sum (RS) was calculated by the following relationship:

Rank sum (RS) = Rank mean ($\bar{R}$) + Standard deviation of rank (SDR) and SDR= $(S^2i)^{0.5}$

Statistical analysis

Correlation among various stress indices and grain yield in two conditions and ranking matrix were performed by IBM SPSS Statistics version 25 software.

Results and discussion

Screening of maize hybrids based on the stress tolerance indices

To investigate suitable stress resistance indices for screening of cultivars under drought condition, grain yield of cultivars under both non-stress and stress conditions were measured for calculating different sensitivity and tolerance indices (Table 1). Based on the stress indices STI, GMP, MP and K_1STI grain yield in two conditions, maize hybrids *viz*., Hytech 5106, VH123021, 900 MG, ZH161529 and ZH16929 were found drought tolerance with highest STI and grain yield under irrigation (non-stressed) and stress condi-tion, while VH12263, VH12316 and ZH16105 displayed the lowest amount of for these indices under both condition. Other cultivars were identified as semi-tolerance or semi-sensitive to drought stress (Table 1). Also, according to SSI, RDI, TOL, YSI and SSPI indices selected the ZH161035, ZH137998, 900MG and VH123021 as the most relatively tolerant genotypes while for these indices the hybrids VH11129, VH12316 and VH12132 were the least relative tolerant. So, according to SSI and TOL indices selected the ZH161035 and ZH137998 as the most relatively tolerant hybrids. Yield in non-stress condition (Yp) showed highest in genotypes CAH153, VH123021 and ZH16929 whereas genotypes VH123021, 900 MG and Hytech 5106 recorded highest yield under optimal moisture conditions. The genotypes *viz*, ZH164035 followed by ZH137998, 900MG, VH123021, ZH161529, ZH161035, ZH116105 and VH1230 recorded more kernel yield in drought plots than optimal plots. Maximum decrease in the yield was observed in genotypes VH121132 followed by VH11129 and ZH144435. Javed *et al*. (2011) concluded that greater the value of TOL, larger the yield reduction under stress conditions and higher the drought sensitivity and negative value of TOL showed more yield in stress than irrigated conditions. Poppy *et al*. (2017) selected adaptive maize hybrids in drought stress based on stress tolerance index (STI) and drought tolerant maize hybrids based on stress susceptibility index (SSI). Naghavi *et al*. (2013) concluded that the drought tolerance indices STI, YI, SSPI, K1STI, and K2STI can be used as the most suitable indicators for screening drought tolerant cultivars. Majid and Roza (2010) identified drought resistance cultivars among fifteen corn genotypes by evaluating under a variety of environmental conditions with seven drought tolerant indices.

Correlation analysis

To determine the most desirable drought tolerant criteria, the correlation coefficients between Yp, Ys and other quantitative indices of drought tolerance were cal-culated as described by Naghavi *et al*. (2013). Correlation analysis between kernel yield and drought tolerance indices can be a good criterion for screening the best genotypes and indices used in the study (Table 2). A suitable index must have a significant correlation with grain yield under both the conditions (Mitra, 2001). Kernel yield in optimal moisture condition (Yp) showed maximum significant positive correlation with K_1STI while negative correlation with RDI and SSPI, whereas kernel yield in drought condition (Ys) showed maximum positive association with YI and negative significant correlation with SSI, TOL and SSPI. Yield in stress con-dition (Ys) was significantly and positively corrected with RDI, STI, GMP, MP, YI, DRI, YSI, K_1STI and K_2STI. Also, yield in non-stress condition (Yp) was signifi-cant and positively correlated with STI, GMP, MP, YI, DRI, YSI, K_1STI and K_2STI indicating that these criteria

Table 1. Different stress tolerance indices of maize hybrids under stress and non-stress condition

S.No	Genotype	Yp	Ys	SSI	RDI	STI	GMP	TOL	MP	YI	DRI	YSI	SSPI	K_1STI	K_2STI
1	VH12148	8.14	7.23	0.725	1.050	0.897	7.671	0.904	7.685	1.054	0.937	0.889	5.578	1.009	1.112
2	ZH161032	8.77	7.13	1.224	0.960	0.953	7.909	1.644	7.952	1.039	0.845	0.813	10.146	1.173	1.080
3	VH113014	8.97	6.02	2.147	0.793	0.824	7.351	2.950	7.497	0.878	0.589	0.671	18.207	1.227	0.771
4	VH11130	8.25	6.30	1.544	0.902	0.792	7.206	1.949	7.272	0.918	0.701	0.764	12.031	1.037	0.843
5	ZH17191	9.11	7.08	1.453	0.918	0.983	8.029	2.025	8.093	1.032	0.803	0.778	12.501	1.264	1.065
6	VH131167	8.57	8.54	0.018	1.177	1.116	8.556	0.024	8.556	1.245	1.242	0.997	0.148	1.119	1.551
7	ZH161531	7.96	7.64	0.257	1.134	0.927	7.799	0.313	7.800	1.114	1.070	0.961	1.930	0.965	1.242
8	ZH114233	6.60	5.86	0.734	1.048	0.590	6.221	0.742	6.232	0.854	0.758	0.888	4.579	0.665	0.730
9	VH12186	7.95	6.22	1.425	0.923	0.753	7.030	1.735	7.084	0.906	0.708	0.782	10.709	0.964	0.821

Table 1 contd.......

S.No	Genotype	Yp	Ys	SSI	RDI	STI	GMP	TOL	MP	YI	DRI	YSI	SSPI	K_1STI	K_2STI
10	VH12148	6.96	6.27	0.651	1.063	0.665	6.604	0.694	6.613	0.913	0.822	0.900	4.281	0.738	0.834
11	ZH161532	8.02	6.66	1.104	0.981	0.814	7.309	1.356	7.341	0.971	0.807	0.831	8.369	0.980	0.943
12	VH11129	8.14	4.15	3.204	0.602	0.515	5.811	3.993	6.145	0.605	0.308	0.510	24.649	1.010	0.366
13	ZH17192	8.19	6.22	1.574	0.896	0.776	7.135	1.974	7.203	0.906	0.688	0.759	12.185	1.022	0.821
14	VH112926	9.12	6.23	2.070	0.807	0.865	7.534	2.890	7.671	0.908	0.620	0.683	17.836	1.267	0.824
15	VH112733	7.59	5.87	1.481	0.913	0.679	6.674	1.721	6.730	0.856	0.662	0.773	10.623	0.878	0.732
16	VH123021	9.72	10.28	-0.379	1.249	1.522	9.994	-0.564	9.998	1.499	1.585	1.058	-3.481	1.439	2.246
17	VH123045	7.99	7.70	0.237	1.138	0.937	7.839	0.290	7.841	1.122	1.081	0.964	1.789	0.972	1.258
18	ZH161530	7.43	6.10	1.168	0.970	0.692	6.736	1.329	6.769	0.890	0.731	0.821	8.201	0.842	0.792
19	VH112967	7.36	6.19	1.036	0.993	0.694	6.750	1.167	6.775	0.903	0.759	0.841	7.206	0.825	0.815
20	VH12316	7.31	4.44	2.566	0.717	0.494	5.692	2.870	5.871	0.647	0.393	0.607	17.714	0.813	0.418
21	ZH114250	8.41	6.66	1.358	0.935	0.854	7.487	1.749	7.538	0.971	0.769	0.792	10.798	1.079	0.943
22	VH12264	9.04	8.04	0.723	1.050	1.108	8.525	1.000	8.540	1.172	1.042	0.889	6.173	1.245	1.373
23	VH1230	5.81	5.85	-0.040	1.188	0.518	5.829	-0.036	5.829	0.852	0.858	1.006	-0.220	0.515	0.727
24	ZH14435	8.17	5.19	2.380	0.751	0.646	6.511	2.975	6.678	0.757	0.481	0.636	18.364	1.016	0.573
25	VH12229	7.94	6.15	1.477	0.914	0.744	6.986	1.796	7.043	0.896	0.693	0.774	11.086	0.961	0.802
26	VH12263	5.85	4.67	1.317	0.943	0.417	5.230	1.180	5.263	0.681	0.544	0.798	7.283	0.522	0.464
27	VH1253	7.95	6.10	1.521	0.906	0.740	6.966	1.851	7.027	0.889	0.682	0.767	11.427	0.964	0.791
28	VH12132	8.62	4.99	2.752	0.683	0.656	6.560	3.633	6.806	0.727	0.421	0.579	22.427	1.133	0.529
29	ZH161529	8.94	9.43	-0.362	1.246	1.286	9.184	-0.495	9.187	1.375	1.451	1.055	-3.056	1.218	1.892
30	VH112563	7.55	7.50	0.043	1.173	0.864	7.527	0.050	7.527	1.094	1.086	0.993	0.310	0.869	1.196
31	ZH16929	9.40	7.94	1.020	0.996	1.137	8.639	1.469	8.670	1.157	0.976	0.844	9.067	1.348	1.338
32	ZH161035	6.96	8.96	-1.882	1.521	0.950	7.894	-2.004	7.958	1.306	1.682	1.288	-12.372	0.737	1.706
33	ZH16929	9.21	6.98	1.576	0.896	0.980	8.019	2.221	8.095	1.018	0.772	0.759	13.712	1.292	1.037
34	ZH137998	7.56	9.01	-1.253	1.407	1.038	8.251	-1.450	8.282	1.313	1.565	1.192	-8.949	0.871	1.724
35	ZH161034	8.72	7.38	1.003	0.999	0.980	8.018	1.338	8.046	1.075	0.910	0.846	8.261	1.158	1.156
36	VH112986	8.36	6.82	1.203	0.963	0.870	7.555	1.540	7.594	0.995	0.812	0.816	9.507	1.066	0.990
37	VH112744	7.19	5.46	1.572	0.897	0.599	6.267	1.731	6.327	0.796	0.604	0.759	10.688	0.788	0.634
38	VH121082	8.27	6.68	1.256	0.954	0.841	7.428	1.590	7.471	0.973	0.786	0.808	9.812	1.041	0.947
39	ZH116105	5.44	5.63	-0.218	1.220	0.467	5.534	-0.181	5.535	0.820	0.847	1.033	-1.120	0.452	0.672
40	VH112888	8.67	6.35	1.748	0.865	0.840	7.423	2.321	7.513	0.926	0.678	0.732	14.327	1.147	0.858
41	VH112732	7.14	4.61	2.320	0.761	0.502	5.737	2.537	5.876	0.672	0.433	0.645	15.663	0.778	0.451
42	VH121043	7.92	6.67	1.031	0.994	0.805	7.265	1.249	7.292	0.972	0.819	0.842	7.711	0.955	0.945
43	VH12254	6.89	5.64	1.181	0.967	0.593	6.235	1.245	6.266	0.823	0.674	0.819	7.686	0.723	0.677
44	ZH161529	7.99	8.16	-0.145	1.207	0.993	8.074	-0.177	8.074	1.190	1.216	1.022	-1.095	0.972	1.416
45	ZH161035	7.77	8.09	-0.264	1.228	0.958	7.927	-0.314	7.928	1.179	1.226	1.040	-1.938	0.920	1.389
46	CAH 153	8.19	7.15	0.827	1.031	0.893	7.654	1.037	7.671	1.043	0.911	0.873	6.400	1.022	1.087
47	CAH 1511	9.40	7.38	1.404	0.927	1.056	8.325	2.019	8.386	1.075	0.844	0.785	12.464	1.346	1.156
48	900 MG	9.14	9.99	-0.611	1.291	1.391	9.554	-0.855	9.564	1.456	1.593	1.094	-5.277	1.272	2.121
49	P 3502	9.26	7.79	1.033	0.994	1.100	8.495	1.464	8.526	1.136	0.957	0.842	9.034	1.306	1.291
50	Hytech 5106	11.08	9.82	0.745	1.046	1.658	10.429	1.265	10.448	1.431	1.268	0.886	7.806	1.871	2.048

Table 2. Correlation coefficient between Yp, Ys and resistance/tolerance indices

Indices	Yp	Ys	SSI	RDI	STI	GMP	TOL	MP	YI	DRI	YSI	SSPI	K_1STI	K_2STI
Yp	1													
Ys	0.540**	1												
SSI	0.134	-0.757**	1											
RDI	-0.135	0.756**	-1.000**	1										
STI	0.800**	0.929**	-0.469**	0.469**	1									
GMP	0.809**	0.930**	-0.468**	0.467**	0.995**	1								
TOL	0.216	-0.705**	0.990**	-0.990**	-0.404**	-0.397**	1							
MP	0.833**	0.915**	-0.433**	0.433**	0.993**	0.998**	-0.361*	1						
YI	0.540**	1.000**	-0.756**	0.756**	0.929**	0.930**	-0.705**	0.915**	1					
DRI	0.248	0.943**	-0.916**	0.916**	0.763**	0.759**	-0.885**	0.738**	0.943**	1				
YSI	-0.134	0.757**	-1.000**	1.000**	0.470**	0.468**	-0.990**	0.434**	0.757**	0.917**	1			
SSPI	0.216	-0.705**	0.991**	-0.990**	-0.404**	-0.397**	1.000**	-0.361*	-0.705**	-0.885**	-0.990**	1		
K_1STI	0.994**	0.552**	0.113	-0.114	0.815**	0.816**	0.197	0.838**	0.552**	0.263	-0.113	0.197	1	
K_2STI	0.537**	0.992**	-0.743**	0.743**	0.930**	0.920**	-0.698**	0.909**	0.992**	0.944**	0.743**	-0.698**	0.554**	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

were more effective in identifying high yield-ing cultivars under different soil moisture regimes. SSI, TOL, DRI, SSPI showed non-significant positive correlation with yield in non-stress condition whereas RDI, and YSI showed non-significant negative association. Jafari *et al.* (2009) observed that STI, GMP indices which showed the highest correlation with kernel yield under both optimal and stress conditions, can be used as the best indices for maize breeding programs to screen drought tolerant hybrids. Poppy *et al*. (2017) concluded as SSI, GMP, STI, YSI, K1ST1 and K2ST2 were showed positive significant association with grain yield in both stress and non-stress conditions. The strong positive correlation of kernel yield with SSI, GMP and STI was observed in Salih *et al*. (2015). Similar results were found by Ceccarelli *et al*. (1992) and Mevlüt and Sait (2011). Majid and Roza (2010) observed significant and positive correlation between yield means and stress tolerance indices *viz*., MP, GMP and STI under normal and moisture stress conditions.

Ranking method

The estimated indicators of drought tolerance (Table 3) indicated that the identification of drought tolerant hybrids based on a single criterion may be contradictory. To determine the most desirable drought tolerant genotypes according to the corn hybrids, mean rank, and standard de-viation of ranks of all drought tolerance criteria were cal-culated and based on these two criteria the most desirable drought tolerant cultivars were identified. In consider-ation to all indices, genotypes VH123021 (RS 3.79 and $\bar{R}$ 2.57) followed by 900MG (RS=4.92 and $\bar{R}$ =3.29), ZH161529 (RS=8.34 and $\bar{R}$ =5.58), VH131167 (RS=12.95 and $\bar{R}$ =9.29) and VH12264 (RS=15.27 and $\bar{R}$ =11.64) exhibited the lowest rank sum, best mean rank and almost low standard deviation of rank, hence they were identified as the most drought tolerant hybrids, while cultivars VH11129 (RS=54.37 and $\bar{R}$ =45.50) followed by VH12132 (RS=52.86 and $\bar{R}$ =41.36), VH12263 (RS=51.59 and $\bar{R}$ =40.36), ZH16105 (RS=50.64 and $\bar{R}$ =30.79) and ZH14435 (RS=50.06 and $\bar{R}$ =42.00) as the most sensitive (Table 3). Our findings are in conformity with Naghavi *et al*. (2013); Farshadfar *et al.* (2012 a, b); Khalili *et al.* (2012). The ranks of the genotypes for MP, GMP and STI were almost identical (Javed et *al*., 2011; Richard, 1996; Ramirez and Kelly, 1998; Saba *et al*., 2001).

Conclusion

The genotypes with minimum fluctuations under different stress environments *i.e.* uniform performance with stable yielding can be considered as drought resistance genotypes. Stress indices *viz*, RDI, STI, GMP, MP, YI, DRI and K_2STI can be used to screen "drought resistant" genotypes as they are strongly associated with YSI (yield stability index). Whereas, drought tolerant maize hybrids can be screen by

Table 3. Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of drought resistance/tolerance indices

S.No.	Genotype	Yp	Ys	SSI	RDI	STI	GMP	TOL	MP	YI	DRI	YSI	SSPI	K_1	K_2	R	SDR	RS
1	VH12148	26	18	16	16	20	20	16	20	18	16	16	16	26	18	18.71	3.47	22.19
2	ZH161032	13	20	29	29	16	16	31	16	20	21	29	31	13	20	21.71	6.74	28.46
3	VH113014	11	38	45	45	28	28	47	27	38	44	45	47	11	38	35.14	12.43	47.58
4	VH11130	21	29	39	39	31	31	38	31	29	35	39	38	21	29	32.14	6.20	38.34
5	ZH17191	9	21	35	35	12	12	41	12	21	27	35	41	9	21	23.64	11.95	35.60
6	VH131167	17	7	10	10	6	6	10	6	7	7	10	10	17	7	9.29	3.67	12.95
7	ZH161531	30	14	13	13	19	19	13	19	14	12	13	13	30	14	16.86	6.09	22.94
8	ZH114233	47	40	17	17	44	44	15	44	40	32	17	15	47	40	32.79	13.35	46.14
9	VH12186	32	32	34	34	33	33	34	33	32	34	34	34	32	32	33.07	0.92	33.99
10	VH12148	44	30	14	14	39	39	14	41	30	23	14	14	44	30	27.86	12.22	40.07
11	ZH161532	27	27	25	25	29	29	26	29	27	26	25	26	27	27	26.79	1.42	28.21
12	VH11129	25	50	50	50	46	46	50	45	50	50	50	50	25	50	45.50	8.87	54.37
13	ZH17192	23	33	41	41	32	32	39	32	33	37	41	39	23	33	34.21	5.96	40.18
14	VH112926	8	31	44	44	23	23	46	21	31	42	44	46	8	31	31.57	13.47	45.04
15	VH112733	36	39	37	37	38	38	32	39	39	41	37	32	36	39	37.14	2.57	39.71
16	VH123021	2	1	4	4	2	2	4	2	1	3	4	4	2	1	2.57	1.22	3.79
17	VH123045	28	13	12	12	18	18	12	18	13	11	12	12	28	13	15.71	5.76	21.47
18	ZH161530	39	36	26	26	37	37	24	38	36	33	26	24	39	36	32.64	5.97	38.61
19	VH112967	40	34	24	24	36	36	19	37	34	31	24	19	40	34	30.86	7.39	38.25
20	VH12316	41	49	48	48	48	48	45	47	49	49	48	45	41	49	46.79	2.78	49.56
21	ZH114250	18	26	32	32	25	25	35	24	26	30	32	35	18	26	27.43	5.49	32.92
22	VH12264	10	10	15	15	7	7	17	7	10	13	15	17	10	10	11.64	3.63	15.27
23	VH1230	49	41	9	9	45	45	9	48	41	19	9	9	49	41	30.21	17.94	48.16
24	ZH14435	24	45	47	47	41	41	48	40	45	46	47	48	24	45	42.00	8.06	50.06
25	VH12229	33	35	36	36	34	34	36	34	35	36	36	36	33	35	34.93	1.14	36.07
26	VH12263	48	47	31	31	50	50	20	50	47	45	31	20	48	47	40.36	11.24	51.59
27	VH1253	31	37	38	38	35	35	37	35	37	38	38	37	31	37	36.00	2.39	38.39
28	VH12132	16	46	49	49	40	40	49	36	46	48	49	49	16	46	41.36	11.50	52.86

Table 3 contd....

S.No.	Genotype	Yp	Ys	SSI	RDI	STI	GMP	TOL	MP	YI	DRI	YSI	SSPI	K_1	K_2	R	SDR	RS
29	ZH161529	12	4	5	5	4	4	5	4	4	5	5	5	12	4	5.57	2.77	8.34
30	VH112563	38	15	11	11	24	24	11	25	15	10	11	11	38	15	18.50	9.82	28.32
31	ZH16929	3	11	21	21	5	5	28	5	11	14	21	28	3	11	13.36	8.97	22.32
32	ZH161035	45	6	1	1	17	17	1	15	6	1	1	1	45	6	11.64	15.37	27.01
33	ZH16929	6	22	42	42	13	13	42	11	22	29	42	42	6	22	25.29	14.39	39.68
34	ZH137998	37	5	2	2	10	10	2	10	5	4	2	2	37	5	9.50	12.04	21.54
35	ZH161034	14	16	20	20	14	14	25	14	16	18	20	25	14	16	17.57	3.92	21.49
36	VH112986	19	23	28	28	22	22	29	23	23	25	28	29	19	23	24.36	3.50	27.86
37	VH112744	42	44	40	40	42	42	33	42	44	43	40	33	42	44	40.79	3.58	44.36
38	VH121082	20	24	30	30	26	26	30	28	24	28	30	30	20	24	26.43	3.61	30.04
39	ZH116105	50	43	7	7	49	49	7	49	43	20	7	7	50	43	30.79	19.86	50.64
40	VH112888	15	28	43	43	27	27	43	26	28	39	43	43	15	28	32.00	10.25	42.25
41	VH112732	43	48	46	46	47	47	44	46	48	47	46	44	43	48	45.93	1.77	47.70
42	VH121043	34	25	22	22	30	30	22	30	25	24	22	22	34	25	26.21	4.49	30.71
43	VH12254	46	42	27	27	43	43	21	43	42	40	27	21	46	42	36.43	9.45	45.88
44	ZH161529	29	8	8	8	11	11	8	13	8	9	8	8	29	8	11.86	7.43	19.29
45	ZH161035	35	9	6	6	15	15	6	17	9	8	6	6	35	9	13.00	10.04	23.04
46	CAH 153	22	19	19	19	21	21	18	22	19	17	19	18	22	19	19.64	1.65	21.29
47	CAH 1511	4	17	33	33	9	9	40	9	17	22	33	40	4	17	20.50	13.04	33.54
48	900 MG	7	2	3	3	3	3	3	3	2	2	3	3	7	2	3.29	1.64	4.92
49	P 3502	5	12	23	23	8	8	27	8	12	15	23	27	5	12	14.86	8.10	22.96
50	Hytech 5106	1	3	18	18	1	1	23	1	3	6	18	23	1	3	8.57	9.07	17.64

STI, GMP, MP, YI and K_1STI as they were significantly associated with acceptable yield performance under stress environment and high yield performance under optimal conditions. With regard to all the indices studied genotype VH123021 followed by 900MG, ZH161529, VH131167 and VH12264 were the most drought tolerant hybrids with better rank mean, lowest rank sum and minimum standard deviation of rank.

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RESEARCH PAPER

Stability of maize (*Zea mays* L.) hybrids across heat stress environments

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Abstract: Maize is grown in different seasons of a year with varying exposure to weather extremes, including high temperatures at critical growth stages which are expected to increase with climate change. Heat stress is the most important environmental constraint contributing to grain yield instability of maize. Evaluation of maize genotypes under different stresses would be useful for identifying genotypes that combine stability with high yield potential for stress-prone areas. Field experiments were conducted to assess the stability of maize hybrids under heat stress at three locations *viz.*, Agriculture College Farm, Bheemarayanagudi, Main Agricultural Research Station, Raichur and ICRISAT, Hyderabad during summer 2017. The experimental materials for the study consisted of 64 hybrids and six checks and were evaluated in alpha-lattice design with two replications at each location. The hybrids *viz.*, ZH16903 and ZH16910 exhibited stability for anthesis to silking interval across the tested environments. The hybrids *viz.*, ZH16878 (5.69 t ha^{-1}) and ZH16930 (4.58 t ha^{-1}) were identified as stable for grain yield as they recorded regression coefficient nearer to unity and high mean grain yield and they could be tested for their commercialization.

Keywords: Environments · Heat stress · Maize · Stability

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Introduction

Maize (*Zea mays* L.) is the third most important cereal food crop of the world after wheat and rice. It is a versatile crop that adapts easily to a wide range of production environments (Gerpacio and Pingali, 2007). Globally, maize is cultivated in an area of 183.24 m ha with a production of 1036.07 m t and productivity of 5.65 t ha^{-1}. India stands 6^{th} among the maize producing countries in the globe with an area, production and productivity of 9.60 m ha, 27.15 m t and 2.83 t ha^{-1}, respectively (Anon, 2018). However, the productivity of maize in India is lower than the world average. It is because, majority of the *kharif* maize area is under rainfed condition, where crop suffers from abiotic stresses like drought or heat stress or combination of both the stresses. Karnataka, one of the major maize producing states in the country, has about 0.76 m ha of maize area under rainfed condition (Anon, 2015).

Of late increased climatic variations have become a reality. It will adversely affect food security and hence there is an urgent need to develop technologies that adapt to the changing climate. Climate variations coupled with increased cultivation of maize in the warmer seasons and environments will further exacerbate the detrimental impacts of heat stress on maize productivity (Prasanna, 2011). Since 2000, India experienced as many as seven widespread severe drought years coupled with increased day/night temperatures during *kharif* (monsoon) season covering about 80% of the total maize area, apart from scattered drought/heat almost every year in one or other state of the country (Zaidi *et al.*, 2016). An assessment of the impact of current and future heat stress on maize clearly showed that heat stress affected areas will significantly increase under the future climates, particularly in the pre-monsoon (spring) and monsoon (*kharif*) seasons and there is a potential yield advantage of heat tolerant maize varieties in both the spring and *kharif* seasons, relative to the current heat-vulnerable maize varieties that are extensively grown in the region (Tesfaye *et al.*, 2017). Further, spring maize season, an important option for intensifying and diversifying cropping systems, is prone to severe heat stress during flowering/early grain filling stages (Prasanna, 2011).

Heat stress in the flowering and grain filling periods due to elevated temperatures drastically affect crop productivity. Exposure to temperatures above 30 °C leads to reduced kernel growth rate and size of the grain and ultimately yield (Commuri and Jones, 2001). Further, high temperature (>35^{o}C) during flowering stages impact pollen viability (Herrero and Johnson, 1980; Dupuis and Dumas, 1990). Developing and deploying climate resilient maize germplasm has become one of the top most priorities in the tropical / subtropical maize growing regions (Cairns *et al.*, 2012) especially, in rainfed regions and spring season. In the present study, we are reporting the stability of selected hybrids under heat stress conditions.

Material and methods

The present study involved evaluation of maize hybrids at three locations *viz*., Agriculture College Farm, Bheemarayanagudi, Main Agricultural Research Station, Raichur and ICRISAT campus Hyderabad during summer 2017. The experimental material consisted of 64 hybrids selected for heat stress resilience at CIMMYT- Asia regional programme, ICRISAT campus, Patancheru, Hyderabad and six commercial hybrids as checks (Table 1). Geographic descriptions of experimental locations are presented in Table 2. The hybrids were evaluated in alpha-lattice design with two replications at each location. In all the three locations, minimum temperatures were > 22 ^{o}C and maximum temperatures were >35 ^{o}C for majority of the cropping season (data not shown) enabling proper assessment of the hybrids for heat stress tolerance.

The experimental plots consisted of two rows of 3 m length with a spacing of 60 cm between rows and 20 cm between plants within a row and the seeds were dibbled by hand. The crop was applied with recommended dose of fertilizers (150 kg N, 75 kg P_2O_5 and 40 kg K_2O per ha). The entire dose of P_2O_5, K_2O and one 1/10th of nitrogen was applied as basal dose. The remaining nitrogen was applied as top dressing in four splits at 20, 35, 50 and 65 days after sowing. All the necessary agronomic practices like weeding, irrigation and other cultural practices were timely followed to ensure a healthy plant stand.

Table 1. The list of hybrids evaluated under heat stress for their stability

S.No.	Hybrid Code	Sl. No.	Hybrid Code
1	ZH161005	36	ZH163
2	ZH161003	37	ZH1635
3	ZH1639	38	ZH1645
4	ZH1640	39	ZH1644
5	ZH1655	40	ZH1623
6	ZH1673	41	ZH16953
7	ZH141592	42	ZH1619
8	ZH1673	43	ZH16963
9	ZH1650	44	ZH16934
10	ZH1652	45	ZH15445
11	ZH15266	46	ZH16929
12	ZH1630	47	ZH16848
13	ZH16911	48	ZH16946
14	ZH137413	49	ZH16849
15	ZH16952	50	ZH1770
16	ZH16878	51	ZH1771
17	ZH1655	52	ZH16931
18	ZH1623	53	ZH16928
19	ZH16817	54	ZH16929
20	ZH161027	55	ZH16918
21	ZH16840	56	ZH16914
22	ZH16955	57	ZH16910
23	ZH16942	58	ZH1672
24	ZH16903	59	ZH1652
25	ZH16949	60	ZH1624
26	ZH16843	61	ZH1644
27	ZH1770	62	ZH16900
28	ZH16930	63	ZH16899
29	ZH16902	64	ZH16897
30	ZH16869	65	P 1855
31	ZH16934	66	DKC9108
32	ZH16972	67	P 1844
33	ZH16974	68	D 2244
34	ZH16834	69	BIO 9544
35	ZH1617	70	P 1855

Table 2. Geographic description of experimental locations

Location	Altitude	Global position	
	(MSL)	Latitude	Longitude
Bheemarayanagudi (Karnataka)	458 m	16° 44' N	76° 47' E
Raichur (Karnataka)	389 m	16° 15' N	77° 20' E
Hyderabad (Telangana)	545 m	17° 53' N	78° 27' E

Data collection and analysis

At each location the following observations were recorded *viz*., days to 50 per cent anthesis, days to 50 per cent silking and grain yield per plot (and later converted to t ha^{-1}) were recorded on plot basis. While, plant height (cm) and cob height (cm) were recorded on randomly selected five plants in each replication and the mean of five plants was computed. Anthesis to silking interval was computed as the difference between days to 50 per cent silking and days to 50 per cent anthesis. The data was statistically analysed as per Eberhart and Russel (1966) model which interprets the variance of regression deviations as a measure of cultivar stability and the liner regression coefficient (β) as a measure of environmental index. In this model, mean (μ) and environmental index (I_j) are used as dependent and independent variables, respectively to compute the regression coefficient. As per this model, a stable genotype should have high mean ($\mu > X$), a unit regression coefficient (β_i=1) and no deviation from linearity (S^2di = 0).

Results and discussion

Pooled analysis of variance for six characters over three environments are presented in the Table 3. Mean sum of squares due to genotypes were significant for all characters except anthesis to silking interval and plant height revealing the genetic variability in the hybrids. Analysis of variance revealed significance of mean sum of squares due to environments and environments (Linear) for all the traits indicating the diversity among the chosen environments. Further, higher value of mean squares due to environment (Linear) as compared to G× E (Linear) displayed the linear response of environments accounted for the majority of total variation for most of the traits studied.

The variance due to genotype × environment interactions was found significant for days to 50 per cent anthesis and days to 50 per cent silking across the locations. Hence, the partitioning was done as per Eberhart and Russell (1966) model in order to know the magnitude of linear and non-linear components of variations, which provide information on predictable and unpredictable sources of variations, respectively contributing to genotype × environment interactions for all the characters.

Result indicated that G × E (Linear) was significant for days to 50 per cent anthesis and days to 50 per cent silking and cob height and non-significant for antheis to silking interval, plant height grain yield. But non-significant G × E (Linear) for grain yield indicated that linear sensitivity of different genotypes is not variable as reported by Pooja (2012). Variance due to environment and (genotype x environment) were highly significant for all the characters except anthesis to silking interval. Further, pooled deviation which is the unpredictable portion of G×E interaction was significant for plant height and grain yield.

Among the hybrids, ZH16918 and ZH16911 were late and early for days to 50 per cent anthesis, respectively (Table 4). Hybrids, ZH16918 and ZH1635 exhibited highest and lowest days to 50 per cent silking over three environments, respectively. Hybrids, P 1855 and ZH1635 recorded highest and lowest anthesis to silking interval across the tested environments, respectively. ZH16899 was the tallest hybrid as indicated by the plant height across locations. DKC9108 showed the lowest cob height among the hybrids evaluated over three locations. Similarly, ZH16817 followed by ZH16834 and ZH1655 recorded highest grain yield per hectare (Table 5).

Table 3. Pooled analysis of variance for stability analysis (Eberhart and Russell, 1966)

Source of variation	df	Days to 50% anthesis	Days to 50% silking	Antheis to silking interval (d)	Plant height (cm)	Cob height (cm)	Grain yield (t ha^{-1})
Rep within Env	3	70.80**	95.86**	3.19	7705.54**	4060.98**	25.71**
Genotypes	69	9.91**	9.82**	1.20	435.90	224.56**	2.12*
Env.+ (Gen* Env.)	140	16.98**	16.91**	1.38	1428.13**	395.77**	6.06**
Environments	2	979.95**	976.56**	31.56**	83007.16**	23153.15**	344.32**
Genotypes * Env.	138	3.02*	3.01**	0.95	245.82	65.96	1.16
Environments(Lin.)	1	1959.90**	1953.12**	63.12**	166014.30**	46306.30**	688.64**
Genotypes* Env.(Lin.)	69	3.96**	4.20**	0.63	184.23	83.827**	0.93
Pooled Deviation	70	2.05	1.78	1.25	303.02**	47.40	1.37**
Pooled Error	207	2.48	2.52	0.92	141.71	67.25	0.86
Total	209	14.64	14.57	1.32	1100.55	339.25	4.76

Table 4. Stability parameters of hybrids for days to 50 per cent anthesis, days to 50 per cent silking and anthesis to silking interval under heat stress over three environments

Genotypes	Days to 50% anthesis			Days to 50% silking			Anthesis to silking interval		
	Mean	bi	s²di	Mean	bi	s²di	Mean	Bi	s²di
ZH137413	61.17	1.04	-3.46	63.00	1.39	-3.59	1.87	1.75	2.09
ZH141592	60.17	1.61	-3.30	61.50	1.52	-3.60	1.35	0.67	-0.72
ZH15266	57.83	1.40	-1.02	59.83	1.18	-1.61	2.02	1.26	1.03
ZH15445	61.00	1.06	-3.33	63.00	1.52	-3.60	2.00	0.44	4.88
ZH161003	56.00	1.29	0.07	58.67	1.39	3.30	2.67	0.55	-0.05
ZH161005	58.67	0.87	8.03	60.67	0.96	6.33	2.00	0.73	-0.94
ZH161027	60.17	0.98	-1.99	63.00	1.05	-3.40	2.83	1.61	-0.63
ZH1617	59.50	1.19	-3.43	61.17	1.12	-3.85	1.67	1.06	-0.81
ZH1619	61.83	1.02	-3.28	63.00	1.30	0.14	1.17	-0.44	2.04
ZH1623	60.00	1.02	-2.36	61.50	1.15	-2.57	1.53	1.18	-0.75
ZH1623	58.50	0.93	-3.16	60.00	0.58	-3.84	1.53	0.05	2.25
ZH1624	58.33	1.05	-1.39	59.50	0.92	-2.76	1.18	0.60	-0.17
ZH163	58.33	1.05	-1.39	60.67	1.09	0.88	2.33	1.87	-0.94
ZH1630	56.33	1.40	-1.02	58.50	1.25	1.13	2.17	2.06	0.40
ZH1635	55.83	1.85	-3.32	56.33	1.46	-0.08	0.50	0.04	2.55
ZH1639	57.83	0.66	0.56	60.50	0.55	3.34	2.67	1.32	0.14
ZH1640	56.17	1.87	-3.46	57.83	2.03	-1.96	1.67	0.55	-0.05
ZH1644	56.00	1.55	1.62	58.50	1.65	-1.55	2.52	2.38	-0.25
ZH1644	56.67	1.49	-3.12	58.33	1.67	-3.66	1.70	0.54	-0.13
ZH1645	60.17	1.42	-3.11	60.83	1.10	-2.83	0.68	0.81	1.62
ZH1650	57.67	1.01	0.14	60.67	1.01	-3.74	3.00	2.68	-0.92
ZH1652	57.17	1.04	-3.46	58.33	0.85	-3.76	1.18	1.28	0.17
ZH1652	57.67	1.29	1.13	59.67	1.09	0.88	1.68	0.60	-0.17
ZH1655	59.50	0.71	-3.40	61.00	0.58	-3.84	1.50	0.26	-0.51
ZH1655	60.33	0.82	-2.18	62.17	0.76	-2.87	1.83	0.66	-0.68
ZH1672	57.67	0.33	-3.39	59.83	0.51	-3.83	1.85	-0.08	1.13
ZH1673	57.83	1.30	9.60	59.67	1.69	-2.08	1.85	-0.81	1.49
ZH1673	59.50	1.13	-2.45	61.00	0.71	-2.52	1.50	0.77	3.01
ZH16817	56.17	0.88	-0.54	58.83	0.98	-3.36	2.67	2.02	-0.45
ZH16834	57.50	0.77	-2.19	59.00	0.82	-3.28	1.52	1.17	-0.78
ZH16840	60.67	0.43	-3.41	62.17	0.44	-3.04	1.50	-0.73	-0.94
ZH16843	60.00	0.64	-2.58	62.00	0.82	-3.28	2.00	0.95	0.23
ZH16848	58.33	0.54	-3.33	60.83	0.73	-3.47	2.50	1.69	-0.01
ZH16849	58.83	0.92	-2.61	61.00	1.06	-1.95	2.17	0.55	-0.05
ZH16869	59.17	1.07	-2.95	60.83	1.21	-3.47	1.68	1.24	-0.29
ZH16878	61.00	0.45	-3.08	62.50	0.81	-3.85	1.52	-0.01	2.45

Table 4 contd...........

Genotypes	Days to 50% anthesis			Days to 50% silking			Anthesis to silking interval		
	Mean	bi	s²di	Mean	bi	s²di	Mean	Bi	s²di
ZH16897	58.17	1.23	-2.53	60.33	1.42	-3.08	2.17	1.28	-0.27
ZH16899	55.50	1.13	-2.45	57.67	1.02	-2.77	2.18	1.07	-0.83
ZH16900	58.67	0.94	-3.18	61.17	0.90	-3.32	2.50	0.73	-0.94
ZH16902	59.67	0.59	-3.04	62.33	0.52	-3.09	2.67	0.33	-0.88
ZH16903	58.50	1.09	-3.36	60.33	1.21	-3.47	1.83	0.88	-0.48
ZH16910	59.67	1.81	-1.52	61.33	1.54	-3.53	1.67	0.85	1.57
ZH16911	55.00	1.41	-3.23	56.83	1.32	-3.81	1.83	0.66	-0.68
ZH16914	59.83	0.85	-3.26	61.33	0.96	-3.35	1.53	1.18	-0.75
ZH16918	63.00	0.19	-2.47	65.00	0.32	-0.28	2.00	1.21	-0.77
ZH16928	60.17	1.04	-3.46	61.83	0.98	-3.36	1.67	0.33	-0.88
ZH16929	59.17	0.78	-3.34	61.33	0.85	-3.76	2.17	0.81	-0.87
ZH16929	59.33	1.28	-2.82	61.33	1.56	-3.15	2.02	1.39	1.66
ZH16930	62.67	0.65	-3.18	64.67	0.74	1.91	2.03	2.60	-0.93
ZH16931	61.17	1.36	-0.31	63.33	0.98	-3.36	2.18	2.27	2.44
ZH16934	59.00	1.09	-3.36	62.17	1.13	-3.44	3.17	0.81	-0.87
ZH16934	60.50	1.22	0.70	61.67	0.87	-1.93	1.17	0.37	3.59
ZH16942	61.00	0.90	-1.73	63.50	1.18	-2.89	2.50	1.43	1.71
ZH16946	60.00	0.94	0.54	61.83	0.52	-1.36	1.83	1.18	2.47
ZH16949	60.50	0.16	-2.70	63.67	0.32	-3.51	3.17	0.55	-0.05
ZH16952	59.00	0.55	12.42	61.33	0.31	5.60	2.35	1.40	-0.59
ZH16953	56.50	0.84	2.77	59.00	0.93	-3.72	2.53	3.07	-0.46
ZH16955	59.17	0.47	5.60	62.50	0.26	0.27	3.33	1.40	-0.54
ZH16963	59.33	0.54	-3.33	62.33	0.63	-3.63	3.00	0.48	-0.65
ZH16972	61.33	0.69	-1.72	62.33	0.85	-3.76	1.02	-0.22	-0.54
ZH16974	60.67	0.81	1.42	62.00	0.91	-0.78	1.35	0.41	-0.92
ZH1770	61.67	0.68	2.29	62.33	0.83	-0.88	0.70	0.04	-0.77
ZH1770	61.33	0.70	-1.95	63.17	0.66	-3.84	1.85	1.83	-0.94
ZH1771	59.67	1.78	-3.24	62.00	1.86	-3.85	2.35	2.31	-0.76
Checks									
BIO 9544	61.50	1.06	-3.33	63.67	0.75	-0.98	2.18	2.27	2.44
D 2244	57.50	1.32	-3.46	59.83	1.20	-3.85	2.33	1.40	-0.54
DKC9108	56.17	1.27	1.70	58.17	1.26	-1.10	2.03	1.91	-0.84
P 1844	59.17	0.84	-1.13	62.50	1.14	-0.48	3.33	1.36	0.56
P 1855	58.83	0.82	-2.18	60.50	0.67	1.77	1.70	2.02	0.34
P 1855	60.50	0.93	-3.16	61.17	0.44	-3.04	0.67	-0.84	5.58
Population Mean	59.048			61.01			1.96		

Table 5. Stability parameters of hybrids with respect to plant height (cm) cob height (cm) and grain yield per hectare (t ha^{-1}) under heat stress over three environments

Genotypes	Plant height (cm)			Cob height (cm)			Grain yield (t ha^{-1})		
	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
ZH137413	165.00	0.93	-159.81	89.17	1.16	-104.09	3.99	1.25	1.68
ZH141592	166.67	1.26	-207.80	87.50	1.64	-100.14	3.67	1.15	-0.80
ZH15266	159.17	0.91	113.83	84.17	0.50	238.44	4.63	1.34	-1.17
ZH15445	180.83	0.78	-198.79	95.00	0.63	-122.87	4.34	1.24	1.78
ZH161003	160.00	0.97	146.63	86.67	1.24	-121.55	3.53	1.11	2.53
ZH161005	165.83	1.28	-114.06	78.33	1.11	-123.70	2.13	0.85	-0.49
ZH161027	161.67	0.50	432.05	80.00	0.66	-71.30	5.04	1.09	-0.99
ZH1617	151.67	1.09	256.34	81.67	1.18	164.62	4.54	1.21	-0.07
ZH1619	147.50	1.37	-196.82	84.17	1.27	-104.74	3.60	1.05	-1.19
ZH1623	173.33	1.22	281.80	86.67	0.99	-20.90	5.44	0.74	-0.39
ZH1623	143.33	1.32	881.01	85.00	1.12	-116.43	5.25	0.59	4.18
ZH1624	170.83	1.21	-238.34	96.67	1.24	-121.55	5.05	0.88	-1.22
ZH163	157.50	0.73	-144.92	90.83	0.70	-120.28	3.88	1.16	-1.04
ZH1630	156.67	0.66	-249.39	74.17	0.96	-123.60	4.62	0.87	-0.62
ZH1635	146.67	0.78	-246.74	86.67	0.94	-76.38	5.57	-0.27	2.14
ZH1639	145.83	0.81	-249.73	88.33	1.11	-123.70	3.98	1.11	4.23
ZH1640	145.00	0.78	-92.50	85.00	1.04	-124.30	4.13	1.18	-1.13
ZH1644	154.17	0.77	208.88	83.33	0.65	-96.71	5.13	0.92	-1.22
ZH1644	139.17	0.93	-233.08	80.83	0.67	-107.69	4.47	0.45	-1.19
ZH1645	152.50	0.62	227.15	73.33	0.73	-58.87	2.81	0.76	-1.03
ZH1650	151.67	1.10	-241.81	84.17	0.99	-96.82	4.11	1.14	-1.21
ZH1652	142.50	1.00	-219.03	87.50	1.01	-37.86	4.65	0.95	-0.95
ZH1652	152.50	0.28	517.96	77.50	0.52	-64.69	5.39	1.09	-0.54
ZH1655	166.67	0.85	-249.44	94.17	0.50	-111.09	5.83	1.10	-1.22
ZH1655	150.00	1.24	3335.63	90.00	0.63	-122.87	4.26	1.12	-1.04
ZH1672	151.67	0.69	-209.59	81.67	0.77	34.34	4.66	0.86	-1.17
ZH1673	165.83	0.75	85.62	83.33	0.51	-92.24	5.66	0.88	-0.70
ZH1673	150.83	0.67	-63.05	78.33	0.95	-100.34	4.32	1.03	-0.15
ZH16817	153.33	1.02	1799.86	82.50	0.41	-122.79	6.01	0.77	0.63
ZH16834	158.33	0.74	-247.90	85.83	0.56	-118.46	5.78	0.56	-0.46
ZH16840	165.00	1.22	-247.65	99.17	1.05	-120.32	5.84	1.11	-1.21
ZH16843	186.67	1.16	-37.89	103.33	1.49	-81.61	4.90	1.12	-1.13
ZH16848	145.83	0.99	-236.67	75.83	0.89	-121.58	4.99	1.21	-1.06
ZH16849	151.67	1.15	-223.54	80.00	1.04	-124.30	4.90	1.72	-0.98
ZH16869	185.83	0.94	87.33	110.00	0.71	-108.03	4.82	1.13	-1.04

Table 5 contd........

Genotypes	Plant height (cm)			Cob height (cm)			Grain yield (t ha^{-1})		
	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
ZH16878	175.00	0.64	57.02	104.17	0.72	-36.89	5.69	0.95	-0.13
ZH16897	166.67	1.40	-195.36	89.17	1.57	-30.48	4.63	0.86	0.70
ZH16899	188.33	1.21	133.63	99.17	1.37	-120.02	4.83	1.19	-0.64
ZH16900	160.83	0.96	-138.07	89.17	0.45	-76.95	3.26	1.01	0.13
ZH16902	143.33	0.84	-204.05	73.33	0.89	-121.58	4.84	0.76	-0.62
ZH16903	144.17	1.07	-154.31	76.67	1.16	-5.16	3.43	1.02	-1.15
ZH16910	180.00	1.23	196.72	100.83	1.00	-58.02	3.72	1.08	4.21
ZH16911	175.00	0.89	-16.87	98.33	1.22	-91.65	4.43	0.84	0.58
ZH16914	179.17	0.88	260.39	92.50	1.37	-107.52	5.06	1.10	1.29
ZH16918	174.17	0.55	557.52	87.50	1.26	-118.56	1.98	0.49	-0.47
ZH16928	159.17	1.58	-220.63	90.00	1.77	-95.94	3.94	1.28	-0.98
ZH16929	170.00	1.34	-249.65	101.17	0.92	-3.23	4.93	1.20	-0.75
ZH16929	170.83	1.23	454.11	95.00	1.06	-36.70	5.38	1.33	4.09
ZH16930	146.67	1.17	-247.05	82.50	1.75	-108.28	4.58	1.03	0.10
ZH16931	172.50	1.40	-47.37	95.83	1.44	-113.49	4.43	1.40	0.63
ZH16934	169.17	0.97	-39.25	95.00	0.63	-122.87	3.82	1.22	-1.21
ZH16934	169.17	0.82	369.64	94.17	1.24	-121.55	4.84	1.30	-0.10
ZH16942	152.50	1.08	743.05	89.17	1.21	-64.36	4.51	1.27	-1.19
ZH16946	158.33	0.62	-249.71	80.83	0.84	66.53	4.91	1.42	1.96
ZH16949	181.67	0.91	-241.54	100.83	0.78	-100.85	3.81	0.66	1.93
ZH16952	151.67	0.91	-241.54	87.50	0.71	-108.03	4.35	0.84	-1.19
ZH16953	163.33	1.10	-186.06	90.83	1.03	-120.06	4.64	0.28	-0.99
ZH16955	155.00	0.89	-248.88	79.17	0.56	-124.15	5.34	0.47	-1.18
ZH16963	181.67	0.95	-192.62	102.50	0.85	-111.17	4.21	1.24	-0.94
ZH16972	162.50	1.66	-249.19	101.67	1.73	-124.30	5.34	1.17	4.90
ZH16974	169.17	0.92	-249.39	95.00	1.53	-121.82	4.46	1.03	-0.66
ZH1770	159.17	1.54	-224.48	97.50	1.64	-100.14	4.87	1.10	-1.20
ZH1770	168.33	1.25	-244.01	95.00	1.15	-45.31	4.93	1.18	-1.17
ZH1771	165.00	1.33	606.05	88.33	1.52	-124.10	4.61	1.23	-1.18
Checks									
BIO 9544	153.33	0.81	-249.73	86.67	1.05	-120.32	5.23	0.46	-1.15
D 2244	162.50	1.06	-188.22	76.67	0.69	-124.30	3.85	1.12	-1.22
DKC9108	145.00	0.81	-137.15	71.67	0.42	89.22	3.98	1.11	0.67
P 1844	158.33	0.85	449.18	80.00	0.60	-100.44	2.42	0.72	-0.38
P 1855	160.00	1.62	500.00	82.50	1.37	3.71	3.70	1.43	1.28
P 1855	168.33	0.81	-249.73	79.17	0.96	139.80	5.17	0.80	15.13
Population Mean	161.17			88.01			4.51		

The stability parameters indicated that hybrids *viz*., ZH1650, ZH1652, ZH163, and ZH1624 as stable for days to 50 per cent anthesis (mean values lower than the grand mean were considered as desirable for flowering traits and cob height). The hybrids *viz.*, ZH1650, ZH16889, and ZH16817 showed stability for days to 50 per cent silking across three locations (Table 4). The hybrids *viz.*, ZH16903 and ZH16910 exhibited stability for anthesis to silking interval across the tested environments. The hybrids, ZH16963 and D2244 showed stability for plant height across locations. The hybrids *viz.*, ZH 1640, ZH1673, ZH16849, ZH16953 and BIO9544 had regression coefficient equal to unity and low mean value indicating their stability in performance across three locations for cob height. The hybrids *viz.*, ZH16878 (5.69 t ha^{-1}) and ZH16930 (4.58 t ha^{-1}) were identified as stable for grain yield per hectare and these genotypes were well adapted for all the locations and high temperature regimes (Table 5). These genotypes showed high mean grain yield, were having coefficient of regression nearer to one (bi =1) and showed small deviation from regression ($S^2di=0$). Archana (2017) evaluated 24 hybrids under heat stress across three locations and identified a stable hybrid (ZL11959 × VL128) for days to 50 per cent anthesis, days to 50 per cent silking and anthesis to silking interval and two hybrids *viz*., VL062609 × VL128 (3.91 t ha^{-1}) and VL107 × VL1033 (3.74 t ha^{-1}) for grain yield across the environments. Koirala *et al*. (2017) in Nepal identified several stable hybrids *viz.*, CAH-151, CAH-153, CAH-1515, CAH-1511 and RML-95/RML-96 for heat stress.

Conclusion

From the present study it is concluded that hybrids, *viz.*, ZH16878 (5.69 t ha^{-1}) and ZH16930 (4.58 t ha^{-1}) were identified as stable for grain yield under heat stress and could be promoted them for extensive testing and commercialization. Also, these heat resilient hybrids could be utilized for development of second cycle inbreds.

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RESEARCH PAPER

Combining ability and heterosis of maize (*Zea mays* L.) doubled haploid lines derived from heat tolerant populations

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Abstract: A field experiment was conducted to assess the general combining ability of parents, specific combining ability of hybrids and to estimate heterosis of hybrids under heat stress condition. The experiment consisted of 16 hybrids developed by crossing four female and four male doubled haploid lines in NCD-II design. The hybrids were evaluated along with the commercial check, P1855 during summer 2017 at Agriculture College Farm, Bheemarayanagudi. The magnitude of GCA variance was lesser than SCA variance for tassel blast, ear height, ear girth, number of kernels per cob and shelling percentage indicating the predominance of non-additive gene action in controlling these traits. However, the magnitude of GCA variance was larger than SCA variance for days to 50% anthesis, anthesis to silking interval, plant height, ear length, 100 grain weight indicating the predominance of additive gene action than non-additive gene action in the inheritance of these traits. The magnitude of GCA variance was equal to SCA variance for days to 50% silking and grain yield per plant indicating the predominance of both additive and non-additive gene action in the inheritance of these two traits. Among females, ZL155203 was a good general combiner for days to 50% silking. Whereas, ZL155347 was a good general combiner for days to 50% anthesis, days to 50% silking, plant height, ear length, ear girth, number of kernels per cob and grain yield per plant among the male haploid maize lines. Among the hybrids, ZL155201 × ZL155320 exhibited significant negative *sca* for days to 50% silking. While, ZL155203 × ZL155347 exhibited significant positive standard heterosis for grain yield per plant under heat stress. These promising hybrids could also be used for the isolation of second cycle inbred lines, besides promoting them for deployment.

Keywords: Combining ability · Double haploid · Heat stress · Heterosis · Maize

Introduction

Maize (*Zea mays* L.) is a major cereal crop worldwide, serving as an important staple for both human consumption and animal feed. Globally, maize is cultivated on an area of 183.24 million hectares with a production of about 1036.07 million tonnes of grain and productivity of 5.65 tonnes per hectare. In India, maize is grown over an area of 9.22 million hectares with productivity of 3.12 t/ha (USDA, 2018). It is the third most important food crop after rice and wheat mainly used as staple food for human being (24%) and feed for poultry (44%) and animals (16%) and it also acts as industrial raw material (16%) for production of starch for textile, pharmaceutical, cosmetic industries, high quality corn oil, protein, alcoholic beverages, food sweeteners etc. (India Maize Summit, 2015). Karnataka is one of the major maize producing states in the country with a total area of 1.31 million hectares and production of 3.85 million tonnes with a productivity of 2948 kg ha^{-1} (Anon., 2018). The other important states which contribute for maize production are Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh and Himachal Pradesh.

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Climate change is affecting agricultural productivity. Scientists from the Intergovernmental Panel on Climate Change carrying out global warming research predicted that average global temperatures could increase between 1.4 and 5.8 °C by the year 2100. Changes resulting from global warming may include rising sea levels due to the melting of the polar ice caps, as well as an increase in occurrence and severity of storms and other severe weather events (IPCC, 2014).

At a regional scale, climate change would reduce rainfed maize yield by an average of 3.3–6.4% in 2030 and 5.2–12.2% in 2050 and irrigated yield by 3.0 –8.0% in 2030 and 5.0–14.0% in 2050, if current varieties were grown under the future climate. Under projected climate, heat-tolerant varieties could minimize yield loss (relative to current maize varieties) by up to 36 and 93% in 2030 and 33 and 86% in 2050 under rainfed and irrigated conditions, respectively (Tesfaye *et al*., 2017). Therefore, there is an urgent need to breed climate resilient maize genotypes that can perform better at specific locations and across locations to circumvent the adverse effects of high temperatures. Since 2000, India experienced as much as seven widespread severe drought years coupled with increased day/night temperatures during *kharif* (monsoon) season covering about 80% of the total maize area, apart from scattered drought/heat almost every year in one or other state of the country (Zaidi *et al*., 2016). Development of climate resilient maize has become more important because of its plasticity to produce sound yield under both optimal and stress environments. Heat-tolerant maize varieties, therefore, have the potential to shield maize farmers from severe yield loss due to heat stress and help them adapt to climate change impacts.

By identification of diverse population and going for selection for primary traits such as yield in a target environment and for secondary traits like flowering, cell membrane stability, chlorophyll content and senescence that show strong association with yield, one can achieve genetic improvement in tropical maize under heat stress. Various parameters have been used other than grain yield to enhance the rate of genetic improvement for maize populations under abiotic stresses (Betran *et al*., 2003).

The development of homozygous lines is an important part of maize breeding. Traditionally, homozygous lines are obtained by repeated selfing of heterozygous lines for six to seven generations, which is a time-consuming and expensive process. The induction and subsequent doubling of maternal haploids is an efficient alternative to generate homozygous lines in quick time frame of two to three generations (Prasanna *et al.,* 2012) and can be evaluated for their breeding value with regard to their *per se* performance and/or test-cross performance and combining abilities. Information on the combining ability of parental germplasm is greatly beneficial to the breeders in defining a breeding strategy. This can be achieved by combining lines from different heterotic groupings so as to transfer traits of interest to their progenies (Ricci *et al.,* 2007). The adoption of the doubled haploid (DH) technology in the public sector maize breeding institutions, as well as small and medium enterprise seed companies in tropical maize growing countries in South Asia, have lagged behind (Prasanna *et al*., 2010; Kebede *et al*., 2011). Hence, an attempt was made to assess the general combining ability of DH lines, specific combining ability and heterotic potential of hybrids developed by involving four DH female (ZL155094, ZL155118, ZL155201, ZL155203) and four DH male (ZL155320, ZL155347, ZL155380, ZL155551) lines received from CIMMYT (Asia), ICRISAT, Hyderabad for different heat adaptive traits and yield under heat stress.

Material and methods

Test-crosses of a set of DH lines derived from heat tolerant populations were evaluated under heat stress in previous year (2016) spring season and the lines with high combining ability for heat stress were identified. Among them, four DH lines *viz*., ZL155094, ZL155118, ZL155201, ZL155203 belonging to heterotic group B were used as female and four DH lines *viz*., ZL155320, ZL155347, ZL155380, ZL155551 belonging to heterotic group A were used as males and crossed in North Carolina Design II to generate a total of 16 hybrids. The newly generated hybrids were evaluated in randomized complete block design with two replications along with a commercial check, P 1855 during summer (Mid-March to July) 2017 at Agriculture College Farm, Bheemarayanagudi, situated at 16° 44' N latitude and 76° 47' E longitude with an altitude of 458 m above mean sea level. Each entry was grown in a single row of 4.0 m length at a spacing of 60 x 20 cm. Recommended agronomic practices were adopted to raise a healthy crop under drip irrigation till the physiological maturity. The climate data was collected from automatic weather station situated at Agricultural Research Station, Bheemarayanagudi (Karnataka), which is known for its intense dry heat during summer. Since the experiment was conducted during summer, the crop was exposed to heat stress from seedling stage to maturity. The maximum temperature during the crop growth period ranged from 34.0 to 42.7°C and the minimum temperature ranged from 18.2 to 30.5 °C. At the time of flowering, the average T_{max} was 41.09 and T_{min} was 27.72 °C coupled with very low Relative Humidity (38.9%) Thus, the hybrids were appropriately screened for heat stress. During the course of investigation, the characters *viz.*, days to 50% anthesis, days to 50% silking, anthesis to silking interval (days), tassel blast (%), leaf firing (%), plant height (cm), ear height (cm), ear length (cm), ear girth (cm), number of kernels per cob, 100 grain weight (g), shelling% and grain yield per plant (g) were recorded as per the standard procedure. Leaf firing/ tassel blast was recorded by counting the number of plants that showed leaf firing/ tassel blast symptoms out of total number of plants in a particular plot. Then, the value was expressed in percentage. The mean data of all the characters was subjected for analysis as per Kempthorne (1957) by using WINDOSTAT 9.2 software.

Results and discussion

Estimates of GCA and SCA variances for various traits under heat stress

The estimates of GCA and SCA variances and ratios (σ^2 GCA/ σ^2 SCA) for various maize traits under heat stress are presented in Table 1. The magnitude of GCA variance was lesser than SCA variance for tassel blast, ear height, ear girth, number of kernels per cob and shelling percentage indicating the predominance of non-additive gene action in controlling these traits. However, the magnitude of GCA variance was larger than SCA variance for days to 50% anthesis, anthesis to silking interval, plant height, ear length, 100 grain weight, indicating the predominance of additive gene action than non-additive gene action in the inheritance of these traits. The magnitude of GCA variance was equal to SCA variance for days to 50% silking and grain yield per plant indicating the predominance of both additive gene action and non-additive gene action in the inheritance of these traits. Similarly, the importance of both additive and non-additive gene actions in the inheritance of traits *viz.*, days to 50 percent anthesis, days to 50 percent silking, anthesis to silking interval, tassel blast, leaf firing, plant height, ear length, 100 grain weight and grain yield per plant were reported by Rupinder Kaur and Saxena (2011) and Khodarahmpour (2011) for number of kernels per cob under heat stress condition. However, involvement of only non-additive gene action in controlling tassel blast, ear height, ear girth and shelling % by Jodage *et al.* (2017) and Gazala *et al.* (2017); ear height by Hussain *et al.* (2007); days to 50% silking, ear height by Akbar *et al.* (2008) and Dinesh *et al.* (2016); ear girth by Jodage *et al.* (2017) were also reported.

Combining ability

Combining ability analysis helps in assessing the potentiality of inbred lines and also aid in identifying the nature of gene action involved in controlling various quantitative characters. This information helps the plant breeders to formulate hybrid breeding programmes.

Table 1. Estimates of GCA and SCA variances for various traits under heat stress condition

S.No.	Characters	σ^2 GCA	σ^2 SCA	σ^2 GCA/σ^2 SCA
1.	Days to 50% anthesis	3.24	1.43	2.26
2.	Days to 50% silking	5.26	3.30	1.59
3.	Anthesis to silking interval (days)	-0.27	-2.32	0.11
4.	Tassel blast (%)	1.99	76.26	0.02
5.	Leaf firing (%)	-0.61	-0.06	10.16
6.	Plant height (cm)	92.76	41.52	2.23
7.	Ear height (cm)	16.74	33.12	0.50
8.	Ear length (cm)	0.64	-0.46	1.39
9.	Ear girth (cm)	0.62	1.03	0.60
10.	No. of kernels per cob	4018.86	5287.24	0.76
11.	Shelling percentage (%)	-2.43	-4.62	0.52
12.	100 grain weight (g)	9.49	-2.68	3.54
13.	Grain yield/plant (g)	9.54	8.07	1.18

General combining ability

The general combining ability (*gca*) effects revealed that among the male parents, ZL155347 was a good general combiner as it registered significant *gca* effects for days to 50% anthesis, days to 50% silking, plant height, ear length, ear girth, number of kernels per cob and grain yield per plant. ZL155203 was a good general combiner for days to 50% silking among females as it recorded significant *gca* effects (Table 2). However, many lines among male and female exhibited general combining ability (*gca*) effects in desired direction but the effects were non-significant.

Specific combining ability

The hybrids *viz.*, ZL155094 x ZL155320, ZL155094 x ZL155380, ZL155118 x ZL155551, ZL155201 x ZL155320, ZL155201x ZL155347, ZL155201 x ZL155551 and ZL15520 x ZL155347, ZL155203 x ZL155380 exhibited desired specific combining ability (*sca*) effects for Tassel blast. Whereas, hybrids *viz.*, ZL155094 x ZL155380, ZL155094 x ZL155551, ZL155118 x ZL155347, ZL155118 x ZL155380, ZL155201 x ZL155320, ZL155201x ZL155347, ZL155201 x ZL155551, ZL15520 x ZL155347 and ZL155203 x ZL155380 exhibited desired *sca* effects for Leaf firing. Five hybrids *viz.*, ZL155094 x ZL155320, ZL155118 x ZL155380, ZL155201x ZL155347, ZL15520 x ZL155347 and ZL155203 x ZL155380 registered desired *sca* effects for plant height. Hybrids *viz.*, ZL155094 x ZL155320, ZL155118 x ZL155551, ZL155201x ZL155347, ZL15520 x ZL155347 and ZL155203 x ZL155380 for ear height (cm), hybrids ZL155201 x ZL155320 and ZL155203 x ZL155380 for ear length (cm), ZL155094 x ZL155551, ZL155118 x ZL155380, ZL155118 x ZL155551, ZL155201 x ZL155320, ZL155201x ZL155347, ZL15520 x ZL155347and ZL155203 x ZL155380 hybrids for number of kernels / cob exhibited desired *sca* effects. Hybrid, ZL155201 x ZL155320 registered desired *sca* effects for shelling (%), 100-grain weight (g) and grain yield/ plant(g). Among all the hybrids studied, ZL155201 × ZL155320 exhibited desired specific combining ability effects and could be used as good specific combiner for days to 50% silking (Table 3). Previously, Dinesh *et al.* (2016), Jodage *et al.* (2017) and Gazala *et al.* (2017) reported good general combiners and specific combiners for grain yield and its contributing traits in maize under heat stress condition.

Per cent standard heterosis for selected traits of maize hybrids under heat stress

The estimates of per cent heterosis over standard check for selected traits of maize hybrids under heat stress condition are presented in Table 4. The commercial hybrid P1855 was used as standard check to calculate standard heterosis of test hybrids. The extent of standard heterosis ranged from - 50 to 100% for anthesis to silking interval, -14.29 to 38.1% for plant height, - 59.56 to 352.74% for grain yield per plant, 0.00 to 8280% for tassel blast, 0.00 to 8280% for leaf firing, -68.55to 132.73% for number of kernels per cob and - 59.57 to 25.90 100-grain weight. The hybrid ZL155201 × ZL155347 recorded significant positive heterosis for plant height (33.33%), number of kernel per cob (132.73%) and grain yield per plant (382.74%) while, the hybrid ZL155203 × ZL155347 exhibited significant positive heterosis for grain yield per plant (364.98%). ZL155094 × ZL155320 (38.10%) also recorded significant positive heterosis for plant height (Table 4). Similarly, Jodage *et al.* (2017) and Gazala *et al.* (2017) reported hybrids exhibiting significant positive heterosis over the check for grain yield per plant and plant height under heat stress. The standard heterosis for tassel blast, leaf firing and 100-grain weight ranged from -50 to 33.28%, 0 to 8280% and -59.57 to 25.9%, respectively and none of the test hybrids exhibited significant standard heterosis for anthesis to silking interval, tassel blast, leaf firing and 100-grain weight.

Conclusion

In the present investigation the magnitude of GCA variance was less than SCA variance for tassel blast, ear height, ear girth, number of kernels per cob and shelling percentage indicating the predominance of non-additive gene action in controlling these traits. Whereas, days to 50% anthesis, anthesis to silking interval, plant height, ear length, 100 grain weight recorded larger GCA variance than SCA variance indicating the role additive gene action. Characters, days to 50% silking and grain yield per plant registered equal magnitude of GCA and SCA variance indicating the predominance of both additive gene action and non-additive gene action. Lines ZL155203 and ZL155347 were identified as was good general combiners. While, ZL155201 × ZL155320 was identified as good specific combiner for days to 50% silking. The promising DH lines identified could be used to develop heterotic hybrids with other proven

Table 2. General combining ability effects of parents for various traits under heat stress condition

S. No.	Parents	Days to 50% anthesis	Days to 50% silking	ASI (days)	Tassel blast (%)	Leaf firing (%)	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of kernels/ cob	Shelling (%)	100-grain weight (g)	Grain yield/ plant (g)
Females (Lines)														
1	ZL155094	0.53	0.25	-0.28	5.76	0.87	10.00	4.68	0.12	0.34	4.48	3.76	2.31	0.95
2	ZL155118	-0.09	0.50	0.59	4.80	-0.98	-9.37	-7.81	-0.30	-0.73	-59.20	-5.16	1.85	-2.84
3	ZL155201	0.65	0.37	-0.28	-1.12	1.09	8.12	4.06	0.07	-0.06	23.85	0.19	-4.48**	1.07
4	ZL155203	-1.09	-1.12*	-0.03	-9.44	-0.98	-8.75	-0.93	0.11	0.45	30.85	1.21	0.31	0.81
Males (Testers)														
5	ZL155320	2.53*	2.12***	-0.40	-3.03	-0.36	3.75	0.31	-0.70	-0.71	-64.12	-4.64	3.02	-2.43
6	ZL155347	-3.71**	-4.25**	-0.53	1.19	0.25	14.37*	9.06	1.85**	1.79**	117.82**	9.13	2.49	6.37**
7	ZL155380	-0.21	-0.75	-0.53	3.78	1.09	-10.62	-7.18	0.19	-0.32	27.022	1.46	-5.01**	-0.42
8	ZL155551	1.40	2.87***	1.46	-1.94	-0.98	-7.50	-2.18	-1.33*	-0.74	-80.73*	-5.94	-0.50	-3.51*
	CD at 5% female	1.88	1.08	1.95	11.12	2.73	11.13	10.24	1.23	1.05	68.37	12.29	3.11	3.10
	CD at 1% female	2.61	1.49	2.69	15.38	3.78	15.39	14.16	1.70	1.46	94.52	16.99	2.57	4.29
	S.E m±	0.88	0.50	0.91	5.22	1.28	5.22	4.80	0.57	0.49	32.07	5.76	0.87	1.45
	CD at 5% male	1.88	1.08	1.95	11.12	2.73	11.13	10.24	1.23	1.05	68.37	12.29	3.11	3.10
	CD at 1% male	2.61	1.49	2.69	15.38	3.78	15.39	14.16	1.70	1.46	94.52	16.99	2.57	4.29
	S.E m±	0.88	0.50	0.91	5.22	1.28	5.22	4.80	0.57	0.49	32.07	5.76	0.87	1.45

*, ** significant at 5% and 1% level of probability, respectively.

Table 3. Specific combining ability effects of experimental hybrids produced using doubled haploid lines for various traits under heat stress condition

S. No.	Hybrids	Days to 50% anthesis	Days to 50% silking	ASI (days)	Tassel blast (%)	Leaf firing (%)	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of kernels/ cob	Shelling (%)	100-grain weight (g)	Grain yield/ plant (g)
Experimental hybrids														
1	ZL155094 x ZL155320	3.59	3.12**	-0.46	-7.22	0.96	17.50	20.31	-0.21	0.63	-1.87	-3.27	2.39	1.69
2	ZL155094 x ZL155347	-1.65	-1.50	0.15	9.54	2.84	-8.12	-5.93	-0.26	-0.60	-12.71	-5.17	-3.16	-2.75
3	ZL155094 x ZL155380	-1.15	-0.50	0.65	-19.05	-2.94	-3.12	-9.68	0.07	0.41	-15.01	-1.60	-0.60	-0.51
4	ZL155094 x ZL155551	-0.78	-1.12	-0.34	16.73	-0.87	-6.25	-4.68	0.39	-0.43	29.59	10.05	1.38	1.57
5	ZL155118 x ZL155320	-1.28	-1.62	-0.34	9.47	0.36	-0.62	-4.68	-0.77	-0.04	-12.08	-4.21	-1.68	-0.23
6	ZL155118 x ZL155347	1.46	1.25	-0.21	1.17	-0.25	-6.25	-8.43	-0.01	-1.59	-112.00	-2.91	0.15	-4.93
7	ZL155118 x ZL155380	-0.53	-0.25	0.28	1.65	-1.09	6.25	7.81	0.35	0.45	66.27	-0.47	1.95	3.88
8	ZL155118 x ZL155551	0.34	0.62	0.28	-12.30	0.98	0.62	5.31	0.43	1.19	57.82	7.60	-0.42	1.27
9	ZL155201 x ZL155320	-2.03	-2.50*	-0.46	-5.28	-1.70	-3.12	-4.06	1.49	1.24	110.05	17.83	1.26	3.32
10	ZL155201x ZL155347	-0.78	-1.12	-0.34	-9.51	-2.32	3.75	9.68	0.27	1.63	98.51	6.67	2.36	4.07
11	ZL155201 x ZL155380	3.21	2.37*	-0.84	21.17	5.12	-13.75	-6.56	-1.54	-1.59	-136.10	-5.06	-0.41	-4.69
12	ZL155201 x ZL155551	-0.40	1.25	1.65	-6.37	-1.09	13.12	0.93	-0.21	-1.28	-72.48	-19.44	-3.21	-2.70
13	ZL155203 x ZL155320	-0.28	1.00	1.28	3.03	0.36	-13.75	-11.56	-0.50	-1.83	-96.10	-10.36	-1.97	-4.78
14	ZL15520 x ZL155347	0.96	1.37	0.40	-1.19	-0.25	10.62	4.68	0.005	0.56	26.21	1.41	0.65	3.61
15	ZL155203 x ZL155380	-1.53	-1.62	-0.09	-3.78	-1.09	10.62	8.43	1.11	0.73	84.81	7.15	-0.93	1.32
16	ZL155203 x ZL155551	0.84	-0.75	-1.59	1.94	0.98	-7.50	-1.56	-0.60	0.53	-14.93	1.78	2.26	-0.14
	CD at 5%	3.77	2.16	3.90	22.25	5.47	22.27	20.48	2.46	2.11	136.74	24.58	6.23	6.21
	CD at 1%	5.22	2.98	5.39	30.76	7.57	30.78	28.32	3.40	2.92	189.04	33.98	5.15	8.58
	S.E m±	1.77	1.01	1.83	10.44	2.56	10.44	9.61	1.15	0.99	64.15	11.53	1.74	2.91

*, ** significant at 5% and 1% level of probability, respectively.

Table 4. Per cent heterosis over standard check for selected traits under heat stress condition

S. No.	Hybrids	ASI (days)		Plant height (cm)		Tassel blast (%)		Leaf firing (%)		No. of kernels per cob		100 grain weight (g)		Grain yield per plant (g)	
		Mean	Per cent standard hetrosis	Mean	Per cent standard hetrosis	Mean	Per cent standard hetrosis	Mean	Per cent standard hetrosis	Mean	Per cent standard hetrosis	Mean	Per cent standard hetrosis	Mean	Per cent standard hetrosis
1	ZL155094 x ZL155320	2.00	-33.33	145.00	38.10*	5.05	4950.00	2.55	2450.00	125.60	-31.59	25.98	25.90	8.25	103.58
2	ZL155094 x ZL155347	2.50	-16.67	130.00	23.81	26.05	25950.00	5.05	4950.00	296.70	61.60	19.89	-3.61	12.63	211.34
3	ZL155094 x ZL155380	3.00	0.00	110.00	4.76	0.05	-50.00	0.10	0.00	203.60	10.89	14.95	-27.59	8.07	99.01
4	ZL155094 x ZL155551	4.00	33.33	110.00	4.76	30.10	30005.00	0.10	0.00	140.45	-23.50	21.44	3.88	7.05	73.98
5	ZL155118 x ZL155320	3.00	0.00	107.50	2.38	20.78	20685.00	0.10	0.00	51.70	-71.84	21.46	3.97	2.54	-37.48
6	ZL155118 x ZL155347	3.00	0.00	112.50	7.14	16.72	16615.00	0.10	0.00	133.70	-27.18	22.76	10.27	6.65	64.00
7	ZL155118 x ZL155380	3.50	16.67	100.00	-4.76	19.78	19680.00	0.10	0.00	221.20	20.48	17.05	-17.42	8.67	113.81
8	ZL155118 x ZL155551	5.50	83.33	97.50	-7.14	0.10	0.00	0.10	0.00	105.00	- 42.81	19.18	-7.05	2.96	-27.00
9	ZL155201 x ZL155320	2.00	-33.33	122.50	16.67	0.10	0.00	0.10	0.00	256.90	39.92	18.07	-12.45	10.01	146.98
10	ZL155201x ZL155347	2.00	-33.33	140.00	33.33*	0.10	0.00	0.10	0.00	427.30	132.73*	18.63	-9.74	19.57	382.74**
11	ZL155201 x ZL155380	1.50	-50.00	97.50	-7.14	33.38	33280.00*	8.38	8280.00*	101.90	-44.50	8.35	-59.57**	4.01	-1.23
12	ZL155201 x ZL155551	6.00	100.00	127.50	21.43	0.10	0.00	0.10	0.00	57.75	-68.55	10.05	-51.31*	2.90	-28.48
13	ZL155203 x ZL155320	4.00	33.33	95.00	-9.52	0.10	0.00	0.10	0.00	57.75	-68.55	19.61	-4.97	1.64	-59.56
14	ZL15520 x ZL155347	3.00	0.00	130.00	23.81	0.10	0.00	0.10	0.00	362.00	97.17	21.72	5.23	18.86	364.98**
15	ZL155203 x ZL155380	2.50	-16.67	105.00	0.00	0.10	0.00	0.10	0.00	329.80	79.63	12.61	-38.91	9.77	140.81
16	ZL155203 x ZL155551	3.00	0.00	90.00	-14.29	0.10	0.00	0.10	0.00	122.30	-33.39	20.32	-1.55	5.20	28.36
17	P 1855 (check)	3.00		105.00		0.10		0.10		183.60		20.63		4.05	
	CD at 5%	2.59		14.77		14.76		3.63		90.72		4.13		4.12	
	CD at 1%	5.52		31.49		31.47		7.74		193.37		8.81		8.78	
	S.E m±	7.63		43.54		43.51		10.70		267.34		12.19		12.14	

*, ** significant at 5% and 1% level of probability, respectively.

inbred lines of on-going breeding programme. Double Haploid parents with high *gca* could also be used in producing pedigree crosses and their segregating populations could be advanced to generate new breeding material/ potential inbred lines possessing combination of different alleles.

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SHORT COMMUNICATION

Heterotic effects of maize hybrids of different maturity groups for grain yield

Preeti Sharma* · M. C. Kamboj · Narender Singh · Mehar Chand

Abstract: To identify superior cross combinations in maize breeding programmes, the utility of half diallel crosses of maize was exploited by computing heterosis. The experiment was conducted to study newly developed maize hybrids of different maturity for heterotic effects over their respective best performing standard checks. The experiment was conducted using randomized block design with three replications during growing seasons of *kharif* 2016 to *kharif* 2017 at CCSHAU, Regional Research Station, Karnal, Haryana. Results revealed considerable amount of heterosis in cross combinations. A total of fourteen hybrids of different maturity groups were having more than 10 percent superiority over their respective checks and these includes one white maize hybrid**,** one late maturing yellow maize hybrid, eight medium maturing yellow maize hybrids and four early maturing normal yellow maize hybrids against respective checks HM 5, HM 11, HM 8 and HM 6. The most promising cross combinations selected separately on the basis of heterotic effect over their respective best checks may be exploited commercially after multi location testing.

Keywords: Economic heterosis · Hybrids · Maize · Standard heterosis

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Globally, maize is referred as 'Queen of the Cereals' due to its high yield potential compared to other cereal crops. It plays a significant role in human, livestock nutrition and is a source of large number of industrial products worldwide. It is one of the major fodder crops in north-west India during summer season. Maize has gained tremendous importance due to rising demand from diversified sectors like food, feed and ethanol production (Singh *et al*., 2017). The demand of maize is increasing every year due to growth in poultry industry and expansion of maize based industries. The single cross maize hybrids have become popular all over the world due to their high yield potential and excellent uniformity. As in terms of area and production, it ranks next to the wheat and rice while in yield; it surpasses all the cereal crops. As per fourth advance estimate in India area under maize was 9.50 million ha with total production of 26.30 million tonnes with productivity 2630 kg/ha (Anonymous, 2017). It was evident that major breakthrough in yield of maize came with the release of hybrids with high yield potential (Sharma *et al*., 2016). Enhancement of maize production and productivity can be achieved by identifying elite parent materials which can be used to develop high yielding varieties and by forming broad based source population serving the breeding program (Sharma *et al*., 2017). The dramatic increase in production and yield levels of maize during the last four decades is mostly due to genetic improvement of hybrids and better production technology. Currently, one of the acclaimed alternatives for increasing maize yield is accomplished through utilization of heterosis in hybrid cultivars. As maize is a highly cross pollinated crop and the scope for the exploitation of hybrid vigour will depend on the direction and magnitude of heterosis. The magnitude of heterosis provides information on extent of genetic diversity of parents in developing superior F_1s. This phenomenon of heterosis attracted the consideration of plant breeders due to its prominent effect on economic characters especially grain yield and also maturity, quality traits. Keeping the view, the experimental hybrids were developed and tested with the objectives to determine extent of heterosis in respect of grain yield and maturity and to identify best experimental hybrids.

Among different maturity groups of inbred lines, two white normal maize inbred lines *viz*., HKI 1344 and HKI 1348-6-2 used as females were crossed with three white maize normal inbred lines *viz*., HKI 1354-2, HKI 1378 and HKI 1354-7 to develop three cross combinations (experimental hybrids). For developing normal yellow late maturing maize hybrids, six inbred lines used as female parent viz., HKI 1015-6, HKI 1040-7, HKI 1128, HKI 1015-6, HKI 659-3 and HKI 193-2 were crossed with four pollen producing parental inbred lines viz., HKI 288-2, HKI 193-2, HKI 76-33and HKI L287 to develop six cross combinations. Ten cross combinations were developed by using nine normal yellow medium maturing inbred lines *viz.*, HKI 193-2, HKI 193-1, HKI 327 T, HKI-1040-7, HKI 164-7-6, HKI 1128, HKI 5072-2BT, HKI 1011and HKI 295 crossed with six normal yellow medium maturing inbred lines viz., HKI 488, HKI L-287, HKI 193-2, HKI 1128, HKI 323 and HKI 1040-4. Among normal yellow early maturing maize cross combinations, six inbred lines viz., HKI 1011, HKI 295, HKI 1332, HKI 1011, HKI 139 and HKI 1040-7 were crossed with four inbred lines viz., HKI 1105, HKI L-287, HKI 1011 and HKI 1040-4 to develop six cross

Table 1. List of inbred lines to develop cross combinations

S.No.	Inbred lines used as female	Inbred lines used as males	No. of crosses developed
Normal white maize			
1.	**HKI 1344**	**HKI 1354-2**	**HKI 1344** × **HKI 1354-2**
2.	HKI 1348-6-2	HKI 1378	HKI 1348-6-2 × HKI 1378
3.	HKI 1354-7	**HKI 1344** × HKI 1354-7	
Normal yellow late maturing maize			
4.	**HKI 1015-6**	**HKI 288-2**	**HKI 1015-6 x HKI 288-2**
5.	HKI 1040-7	HKI 193-2	HKI 1040-7 x HKI 193-2
6.	HKI 1128	HKI 76-33	HKI 1128 x HKI 76-33
7.	HKI 1015-6	HKI L287	HKI 1015-6 x HKI 288-2
8.	HKI 659-3		HKI 659-3 x HKI 193-2
9.	HKI 193-2		HKI 193-2 x HKI L287
Normal yellow medium maturing maize			
10.	HKI 193-2	HKI 488	HKI 193-2 x HKI 488
11.	**HKI 193-1**	**HKI L-287**	**HKI 193-1 x HKI L-287**
12.	HKI 327 T	HKI 193-2	HKI 327 T x HKI 193-2
13.	**HKI-1040-7**	**HKI 1128**	**HKI 327T x HKI L-287**
14.	HKI 164-7-6	HKI 323	**HKI-1040-7 x HKI 1128**
15.	HKI 1128	HKI 1040-4	HKI 164-7-6 x HKI 488
16.	HKI 5072-2BT		HKI 5072-2BT x HKI L-287
17.	HKI 1011		HKI 1011 x HKI 1128
18.	HKI 295		HKI 295 x HKI 323
19.			HKI 193-1 x HKI 1040-4
Normal yellow early maturing maize			
20.	**HKI 1011**	**HKI 1105**	**HKI 1011 x HKI 1105**
21.	**HKI 295**	**HKI L-287**	**HKI 295 x HKI L-287**
22.	HKI 1332	HKI 1011	HKI 1332 x HKI 1011
23.	HKI 1011	HKI 1040-4	HKI 139 x HKI 1011
24.	HKI 139		HKI 1040-7 x HKI L-287
25.	HKI 1040-7		HKI 295 x HKI 1040-4
Quality protein maize			
26.	HKI 164 D-3-3	HKI 193-2	HKI 164 D-3-3 x HKI 193-2

combinations. One quality protein maize hybrid was developed by crossing HKI 164 D-3-3 used as female parent with HKI 193-2 used as male parent. All these twenty six cross combinations or experimental hybrids were developed by using half diallel mating design during growing seasons of *rabi* 2015-16 and *rabi* 2016-17. These hybrids were evaluated in large scale trials along with their parents with three replications in the experimental area of CCSHAU, RRS, Uchani, Karnal during *kharif* 2016 and *kharif* 2017. The entries were sown in a two row plot of 4 m with inter and intra-row spacing of 75 cm and 20 cm, respectively. All the recommended agronomic practices were adopted to raise a good crop. The Analysis of Variance was carried out to know the precise genetic worth of crosses. The magnitude of heterosis for grain yield was estimated over respective standard checks hybrid *viz*., HM 5 hybrid of normal white maize, HM 11 hybrid of normal yellow late maturing maize, HM 8 normal yellow medium maturing maize, HM 6 normal yellow early maturing maize and HQPM 1 quality protein maize by using formula:

$$\frac{\bar{F}_1 - \overline{CC}}{\overline{CC}} \text{ X } 100$$

Where, CC = mean performance of commercial cultivar

F_1 = mean performance of a cross

Table 2. Performance of maize hybrids tested in large scale trials during *kharif* 2016

S.No.	Name of entry	Grain yield (q/ha)	Maturity (days)	Standard heterosis (%) increase over check
	Normal white maize			
1	**HKI 1344 × HKI 1354-2**	**78.9**	**92**	**12.4**
2	HKI 1348-6-2 × HKI 1378	73.6	91	4.8
3	HKI 1344 × HKI 1354-7	71.6	92	2.0
	HM 5 (check)	70.2	91	-
	Normal yellow late maturing maize			
4	**HKI 1015-6 × HKI 288-2**	**73.6**	**92**	**14.8**
5	HKI 1040-7 × HKI 193-2	63.1	90	-1.6
6	HKI 1128 × HKI 76-33	65.4	89	2.0
	HM 11 (check) late	64.1		-
	Normal yellow medium maturing maize			
7	HKI 193-2 × HKI 488	58.8	85	-2.2
8	**HKI 193-1 × HKI L-287**	**78.1**	**85**	**30.0**
9	HKI 327 T × HKI 193-2	62.1	87	3.3
10	**HKI 327T × HKI L-287**	**72.4**	83	**20.5**
11	**HKI-1040-7 × HKI 1128**	**69.4**	85	**15.5**
12	HKI 164-7-6 × HKI 488	61.9	83	3.0
	HM 8 (check) medium	60.1	84	-
	Normal yellow early maturing maize			
13	**HKI 1011 × HKI 1105**	**64.6**	78	17.2
14	**HKI 295 × HKI L-287**	**65.3**	79	18.5
15	HKI 1332 × HKI 1011	57.4	80	4.2
	HM 6 (check) early	55.1	78	-
	Quality protein maize			
16	HKI 164 D-3-3 × HKI 193-2	59.1	85	-6.5
	HQPM 1(check)	63.2	90	-
	CD (5%)	5.3	3.1	
	CV %	8.9	6.7	

Twenty six hybrids (cross combinations) of different maturity groups were evaluated for standard heterosis for grain yield and days to maturity. The pertinent results based on *Per se* performance of hybrids and check varieties and percentage of heterosis measured as increase or decrease over best checks over their respective checks have been presented in Table 1 and 2. Critical difference and Coefficient of variation implies that these experimental hybrids have differences for all the characters under study. For grain yield per plot, which is most important aspect of breeding results revealed considerable amount of heterosis for fourteen experimental hybrids and were selected based on more than 10% standard heterosis in grain yield over the checks over two years of testing. As per the recommendations of All India Coordinated Research Project (AICRP) on Maize and Central Variety Release Committee, the new hybrid can only be considered for identification if its grain yield is 10 per cent higher than the existing variety or check variety. Therefore, the hybrids which have given more than 10% grain yield warrant their further testing under different agro climatic conditions to confirm the results for exploitation of heterosis. These performing hybrids includes one white maize hybrid HKI 1344 × HKI 1354-2, one late maturing yellow maize hybrid HKI 1015-6 × HKI 288-2, eight medium maturing yellow maize hybrids *viz.*, HKI 193-1 × HKI L-287, HKI 327T × HKI L-287, HKI 295 × HKI L-287, HKI 1128 × L287, HKI 5072-2BT × HKI L-287, HKI 1011 × HKI 1128, HKI 285 × HKI 323 and HKI 193-1 × HKI 1040-4 four early maturing normal yellow maize hybrids *viz.*, HKI 1011 × HKI 1105, KI 295 × HKI L-287, HKI 139 × HKI 1011 and HKI 1040-7 × HKI L-287 against respective checks HM 5 (70.2 q/ha), HM 11 (64.1 q/ha), HM 8 (64.5 q/ha) and HM 6 (59.3 q/ha). The results coincide with the earlier findings of Shrestha

Table 3. Performance of maize hybrids tested in large scale trials during *kharif* 2017

S.No.	Name of entry	Grain yield (q/ha)	Maturity (days)	Standard heterosis (%) increase over check
	Normal white maize			
1	HKI 1344 × HKI 1354-2	82.9	92	18.25
2	HKI 1348-6-2 × HKI 1378	70.6	91	0.71
	HM 5 (check)	70.1	92	-
	Normal yellow late maturing maize			
3	HKI 1015-6 × HKI 288-2	66.2	92	3.27
4	HKI 659-3 × HKI 193-2	66.3	95	3.43
5	HKI 193-2 × HKI L287	65.4	89	2.02
	HM 11 (check) late	64.1	90	-
	Normal yellow medium maturing maize			
6	HKI 193-1 × HKI L-287	78.1	85	21.08
7	HKI 327T × HKI L-287	75.6	83	17.20
8	HKI 1128 × HKI L-287	74.2	84	15.03
9	HKI 5072-2BT × HKI L-287	77.9	83	20.77
10	HKI 1011 × HKI 1128	75.3	83	16.74
11	HKI 295 × HKI 323	73.8	82	14.41
12	HKI 193-1 × HKI 1040-4	74.7	83	15.81
	HM 8 (check) medium	64.5	84	-
	Normal yellow early maturing maize			
13	HKI 1011 × HKI 1105	67.6	78	13.99
14	HKI 295 × HKI L-287	74.5	79	25.63
15	HKI 139 × HKI 1011	65.3	79	10.11
16	HKI 1040-7 × HKI L-287	68.4	81	15.34
17	HKI 295 × HKI 1040-4	61.8	80	4.21
	HM 6 (check) early	59.3	78	-
	CD (5%)	4.7	3.1	-
	CV %	7.6	5.4	-

et al. (2018); Kumari *et al*. (2018); Sharma *et al*. (2017); Shazia *et al*. (2017); Sharma *et al*. (2016); Sorsa *et al*. (2014); Rajesh *et al*. (2014); Netravati *et al*. (2013) where standard heterosis was observed for this trait. The parents of highly heterotic crosses explained the existence of genes with some degree of dominance controlling the character. The expression of heterosis also depends on the divergence between genotypes, as differences in allele frequencies are required at loci involved in the expression of desirable characteristics. Whereas, low heterotic effect is likely due to low genetic complementarily of loci with non-additive effects, possibly because these crosses displayed some degree of parental relationship. The most promising combinations selected separately on the basis of heterotic effect over their respective best checks revealed scope of improvement through hybridization and improvement may be exploited commercially after multi location testing.

Information on heterosis is pre requisites for developing a good, economically viable hybrid. The present study revealed that a number of crosses produced high heterosis for grain yield per plot. The mean heterosis over the years of best performing hybrids *viz*., HKI 193-1x HKI L 287, HKI 327T x HKI L287, HKI 5072-2BT x HKI L-287 and HKI 295 x HKI L-287 over two years of testing also had high *per se* performance and heterosis for grain yield on plot basis and thus improvement of grain yield is possible All the four best performing hybrids had pollen producing parent (male parent) common that means inbred line HKI L-287 is good general combiner and may be used to develop new hybrids. Hence, the most promising combinations selected separately on the basis of heterotic effect over best checks therefore, also suggested that as such these results will be useful for choosing populations to be used in developing new improved maize populations.

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AUTHOR INDEX

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