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Heterotic Orientation of Maize (*Zea mays* L.) germplasm and Single Cross Hybrids Performance in the North-western Himalaya

Sawan Kumar[1]*, Gaurav Sharma[1], Uttam Chandel[2], Ravinder Kumar[1] and Satish Kumar Guleria[3]
[1]Department of Genetics and Plant Breeding,
CSK Himachal Pradesh Agricultural University, Palampur (Himachal Pradesh), India.
[2]CSKHPKV, SAREC, Kangra (Himachal Pradesh), India.
[3]CSKHPKV, HAREC, Bajaura (Himachal Pradesh), India.

(Corresponding author: Sawan Kumar)*
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ABSTRACT: Assigning germplasm into different heterotic groups is fundamental for exploitation of heterosis for hybrid development. The objective of this study was to categorize the 30 medium maturing inbred lines into different heterotic groups on the basis of combining ability, and selection of best inbred lines and hybrid combinations on the basis of agronomic traits under studied. Thirty inbred lines were crossed with two diverse testers *viz*., BAJIM 08-26 and BAJIM 08-27 to develop sixty crosses. These crosses along with parents were evaluated in randomized block design along with two commercial checks. Three hybrids *viz*., $L_{28} \times T_2$, $L_{15} \times T_2$ and $L_{23} \times T_1$ were identified as the best on the basis of per se performance, earliness and superiority over the checks. The maize germplasm was categorized in two different heterotic groups on the basis of GCA and SCA effects for grain yield. Fifteen lines were included in group A and fifteen in group B. However, eight lines which showed positive GCA effects and positive SCA effects with BAJIM 08-27 and negative SCA effects with BAJIM 08-26 were considered more productive in the heterotic group A. Similarly, eight lines were considered more productive in heterotic group B. High yielding hybrids could be developed by involving these lines directly from two different groups. These heterotic groups could serve as sources for developing populations and pools for deriving the productive lines and synthetics. Based on *per se* performance and GCA effects for grain yield, five lines *viz*., CML-292, CML-269-1, HKI-1040-7, CML-141 and TNAU/CBE-83 were identified as the best inbred lines which could be involved in breeding program for developing hybrids and composites.

Keywords: Heterotic grouping; general combining ability; Maize; specific combining ability; *Zea mays.*

INTRODUCTION

Maize is the primary staple food in many developing countries in the world. It is a versatile crop with wider genetic variability and able to grow successfully throughout the world covering tropical, subtropical and temperate agro-climatic conditions (Amiruzzaman *et al.*, 2010). In North western Himalayan region, it is the most important crop of *Kharif* season. It occupies 290.0 thousands hectare with a production of 760.0 metric tonnes and productivity is high (25.70 q/ha) as compared to the national average of 22.46 q/ha in *kharif* season (Anonymous, 2019), yet there is considerable scope for increasing the productivity further with the use of quality seeds of recommended varieties/hybrids. The main target of maize breeding programme is to increase the yield using commercial exploitation of high yielding maize hybrids. The selection of parents and breeding strategies for the successful maize hybrid production will be facilitated by heterotic groupings of parental lines. Therefore, information on heterotic groupings of maize germplasm is essential for hybrid breeding program (Kumar *et al.*, 2019, Chandel *et al.*, 2019, Eisele *et al.*, 2021). A Set of lines deriving from a common origin and displaying similar combining ability when crossed with lines from different origins is defined as a heterotic group. After development of inbred lines from known or unknown sources, breeders need to make thousands of crosses and evaluate grain yield in resulting F_1 plants in replicated field experiments. Assigning lines to heterotic groups would avoid the development and evaluation of crosses that should be discarded, allowing maximum heterosis to be exploited by crossing inbred lines belonging to different heterotic groups (Mousa *et al.*, 2021). Heterotic effects of the maize lines and their allocation into well-known heterotic groups is the secret for the success of a maize breeding programme, which would give utmost exploitation of heterosis. The classification of inbred lines into heterotic groups is therefore of very high importance in hybrid maize breeding. Melchinger and Gumber (1998) described a heterotic group "as a group of related or unrelated genotypes from the same or different populations, which display similar combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm groups".

Two major methods of heterotic group classification are mainly used in breeding programme: In the traditional method, breeders assign the germplasm into the different heterotic groups based on the estimates of the combining ability patterns obtained using information from testcross trials (Fan *et al.*, 2001; 2004). The second method utilizes molecular markers to compute genetic similarity or genetic distance to assign maize inbred lines to different heterotic groups (Barata and Carena 2006). The present investigation was aimed to characterize the maize germplasm into different heterotic groups and evaluation of single cross hybrids in the sub-temperate region of north western Himalayas.

MATERIAL AND METHODS

A. Experimental material

The experimental material comprised of 30 maize inbred lines crossed with two diverse male parents *viz.*, BAJIM-08-26 (T_1) and BAJIM-08-27 (T_2) from two different pools during *Kharif* season in experimental field at CSK Himachal Pradesh Krishi Vishva Vidyalaya, Hill Agricultural Research & Extension Center, Bajaura, Kullu, (H.P.) India (Table 1). Sixty crosses along with parents and two standard checks *viz.*, Bio-9544 and Palam Sankar Makka-2 were evaluated in randomized block design (RBD) with two replications during *Kharif*, 2016. Observations were recorded on ten randomly selected plants per treatment per replication for the traits *viz.*, plant height (cm), cob placement (cm), cob length (cm), cob girth (cm), kernel rows per cob and kernels per row and were used for statistical analysis. However, days to 50 per cent tasseling, days to 50 per cent silking, days to 75 per cent brown husk, grain yield (q/ha), 1000 grain weight (g) and biological yield (q/ha) were recorded on plot basis.

Table 1: Description of the lines, testers and checks used in the study.

Code	Genotypes	Code	Genotypes
Lines			
L_1	BAJIM-12-01	L_{19}	CML-337
L_2	BAJIM-13-01	L_{20}	CML-439
L_3	BAJIM-13-02	L_{21}	CML-465-B-B
L_4	BAJIM-15-08	L_{22}	DMRQPM-58
L_5	BAJIM-15-09	L_{23}	HKI-1040-7
L_6	BAJIM-15-10	L_{24}	HKI-1105
L_7	BAJIM-15-11	L_{25}	LQPM-15-01
L_8	BAJIM-15-12	L_{26}	MRCQPM-16
L_9	BML-6	L_{27}	MRCQPM-18
L_{10}	BML-7	L_{28}	TNAU/CBE—83
L_{11}	CML-44	L_{29}	TNAU/CBE-115
L_{12}	CML-141	L_{30}	V-334
L_{13}	CML-269	**Testers**	
L_{14}	CML-269-1	T_1	BAJIM 08-26
L_{15}	CML-292	T_2	BAJIM 08-27
L_{16}	CML-294	**Checks**	
L_{17}	CML-334	Check-1	Bio 9544
L_{18}	CML-336	Check-2	Palam Sankar Makka-2

B. Statistical Analysis

Analysis of variance for mean data recorded was carried out as per suggested by Panse and Sukhatme (1985) to determine significant differences among genotypes. Combining ability analysis for grain yield was done according to Kempthorne (1957) and SAS statistical software was used for heterotic grouping of germplasm under study.

RESULTS AND DISCUSSION

A. Analysis of variance

Analysis of variance for yield and yield contributing traits has been presented in Table 2. Significant differences among the genotypes were observed for all the characters except days to 50% pollenshed. The results of ANOVA revealed that there was significant variability among the genotypes under study.

Table 2: Analysis of variance for yield and yield contributing traits.

Sr. No.	Character Source of Variation DF	Replication 1	Treatment 93	Error 93
1.	Grain yield	742.57	2160.08^{**}	206.27
2.	1000 grain weight	2.82	1728.83^{**}	214.11
3.	Shelling percentage	126.3	437.76^{**}	55.63
4.	Kernel rows/cob	0.29	3.48^{*}	0.92
5.	Kernels/ row	0.67	99.97^{**}	4.55
6.	Cob length	0.12	19.13^{**}	1.51
7.	Cob girth	0.24	6.63^{**}	0.29
8.	Biological yield	3.96	8786.14^{**}	68.87
9.	Harvest index	0.01	0.12^{**}	0.001
10.	Days to 50% pollenshed	3.06	30.93	10.63
11.	Days to 50% silking	6.52	24.39^{**}	1.81
12.	Days to 75% brown husk	0.26	30.84^{**}	3.91
13.	Plant height	11.53	1544.82^{**}	65.33
14.	Cob placement	279.38	663.10^{**}	75.51

B. Mean performances of parents and crosses

Seven crosses were found to have a mean yield significantly higher than the best check Bio-9544 for grain yield (Table 3). The top yielder crosses were $L_{28} \times T_2$, $L_{15} \times T_2$, $L_{23} \times T_1$ and $L_{10} \times T_1$. However, none of the parents exhibited the higher mean grain yield than the best check (Table 4). The range of mean values in parents for grain yield varied from 49.09 q/ha (L_{15}) to 20.81 q/ha (L_8). For 1000 grain weight, none of the parents showed a mean value for 1000 grain weight greater than the best check Palam Sankar Makka-2 (340 g). Only one cross combination $L_{14} \times T_2$ recorded higher 1000 grain weight than the Palam Sankar Makka-2 and the lowest was recorded for $L_2 \times T_2$. Among the parents four lines *viz.*, L_3, L_{13}, L_{17} and L_{28} recorded a mean value higher than the best check Bio-9544 for shelling percentage. Twenty four crosses exhibited a mean value for shelling percentage greater than Bio-9544. The highest shelling percentage of 87.68 per cent was recorded for $L_{15} \times T_2$ and the lowest of 78.60 per cent for $L_{24} \times T_1$.

Table 3: Mean values of crosses and checks for grain yield and yield related characters.

Entry	GY	GW	SP	KRC	KPR	CL	CG	BY	HI	DP	DS	DBH	PH	CP
Crosses														
$L_1 \times T_1$	81.17	280	81.64	14.50	35.83	16.21	13.66	207.67	0.39	59.00	61.00	94.50	165.83	80.00
$L_1 \times T_2$	85.20	240	86.33	16.50	30.66	14.41	13.82	178.58	0.48	59.50	61.50	94.00	158.00	67.16
$L_2 \times T_1$	105.42	220	85.00	15.83	37.00	14.25	16.16	295.00	0.36	63.50	66.00	98.00	193.83	106.33
$L_2 \times T_2$	62.76	160	84.19	13.16	29.50	14.37	11.50	166.93	0.38	66.00	68.50	106.00	149.66	64.83
$L_3 \times T_1$	108.98	240	80.46	15.83	36.16	19.83	15.50	249.00	0.44	63.50	66.00	100.50	201.08	125.68
$L_3 \times T_2$	90.26	320	84.81	14.50	42.66	21.25	17.04	278.18	0.32	61.50	64.50	102.50	171.33	96.48
$L_4 \times T_1$	90.21	260	85.15	15.50	29.75	17.33	16.25	245.50	0.37	57.00	60.00	94.00	171.50	97.33
$L_4 \times T_2$	96.75	240	84.24	16.66	36.50	18.75	16.25	240.00	0.40	57.00	59.50	97.00	153.66	87.50
$L_5 \times T_1$	89.21	300	86.79	14.16	24.33	17.75	14.91	206.67	0.43	61.00	63.00	96.00	174.00	90.67
$L_5 \times T_2$	108.71	280	84.32	16.00	39.50	19.83	14.33	259.83	0.42	62.00	64.00	97.00	172.33	95.50
$L_6 \times T_1$	100.14	280	83.40	16.50	31.83	17.87	14.33	212.29	0.47	60.50	63.00	98.50	193.83	103.00
$L_6 \times T_2$	108.02	280	84.43	15.50	33.83	19.00	17.25	221.34	0.49	59.50	61.50	97.00	178.67	92.33
$L_7 \times T_1$	109.03	300	85.47	14.00	32.08	15.83	14.33	204.58	0.53	59.50	61.50	98.00	159.33	78.50
$L_7 \times T_2$	65.18	240	85.22	14.83	26.16	16.96	16.04	121.98	0.53	65.50	67.50	101.50	132.33	55.67
$L_8 \times T_1$	84.19	280	83.15	13.50	31.50	19.08	15.08	193.19	0.44	61.50	64.00	97.00	176.83	83.17
$L_8 \times T_2$	86.25	300	83.18	14.16	35.16	18.66	16.75	209.86	0.41	60.50	61.00	96.00	165.66	87.58
$L_9 \times T_1$	93.50	280	87.29	14.50	35.25	17.04	14.29	244.35	0.38	64.00	66.00	100.00	198.00	106.66
$L_9 \times T_2$	104.64	280	83.05	13.50	33.58	15.16	13.75	227.07	0.46	62.00	64.50	100.50	182.16	93.00
$L_{10} \times T_1$	115.88	300	87.06	13.16	36.66	17.21	13.21	303.10	0.38	64.50	66.50	102.50	210.83	113.00
$L_{10} \times T_2$	107.76	280	84.65	13.16	36.91	19.16	15.83	276.81	0.39	62.00	64.00	101.00	182.50	98.00
$L_{11} \times T_1$	101.05	300	85.12	15.66	39.16	18.25	14.33	299.62	0.34	62.00	64.50	99.00	184.16	99.00
$L_{11} \times T_2$	114.27	280	84.48	15.50	30.08	15.75	14.46	259.84	0.44	59.00	61.50	96.00	178.33	98.33
$L_{12} \times T_1$	118.41	340	84.47	14.00	32.75	20.91	15.16	258.18	0.46	64.50	67.00	98.00	217.50	110.83
$L_{12} \times T_2$	119.36	340	85.51	13.50	30.58	20.16	16.62	234.69	0.51	59.50	61.50	98.00	203.00	106.33
$L_{13} \times T_1$	93.36	320	84.95	14.83	30.08	18.83	15.62	192.94	0.48	65.50	67.50	99.50	188.17	102.66
$L_{13} \times T_2$	102.73	300	85.90	14.83	34.08	21.16	17.25	207.35	0.50	62.00	63.50	99.00	195.00	104.40
$L_{14} \times T_1$	111.02	340	84.56	13.33	33.66	18.25	14.04	244.64	0.45	62.00	64.00	98.00	202.67	104.16
$L_{14} \times T_2$	101.06	360	84.62	14.33	34.16	20.62	16.66	269.01	0.38	62.00	64.00	100.00	189.83	98.83
$L_{15} \times T_1$	69.46	240	87.36	14.00	38.91	19.46	15.16	206.82	0.34	65.00	67.50	102.00	194.00	90.66
$L_{15} \times T_2$	133.96	340	87.68	12.83	39.00	19.00	16.41	295.60	0.45	63.50	66.00	102.00	182.50	95.33
$L_{16} \times T_1$	114.79	260	83.42	14.16	43.16	20.00	16.08	271.82	0.42	65.50	67.50	102.00	206.00	115.00

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Entry	GY	GW	SP	KRC	KPR	CL	CG	BY	HI	DP	DS	DBH	PH	CP
L_{16}×T_2	108.33	260	82.92	15.16	31.91	16.33	16.08	266.39	0.41	64.50	66.50	102.00	189.83	100.83
L_{17}×T_1	91.15	300	85.42	15.83	34.83	20.41	16.50	292.94	0.31	57.00	58.50	92.50	161.50	71.66
L_{17}×T_2	98.21	300	85.46	14.50	39.25	19.66	16.16	213.84	0.46	58.00	59.00	95.00	170.16	75.50
L_{18}×T_1	90.42	320	85.24	14.00	40.66	21.33	14.71	208.84	0.43	61.00	63.00	98.50	177.33	89.50
L_{18}×T_2	82.49	240	85.74	15.00	35.83	17.25	12.83	140.27	0.59	60.00	62.50	99.50	166.00	79.33
L_{19}×T_1	82.90	300	84.51	16.58	37.00	18.21	16.21	242.28	0.34	59.00	61.00	94.00	196.83	96.66
L_{19}×T_2	110.94	320	81.15	14.83	39.66	18.33	17.40	177.89	0.62	59.50	62.00	97.50	185.00	94.00
L_{20}×T_1	84.25	280	84.29	14.66	39.08	16.96	14.37	175.23	0.48	61.50	64.00	98.00	191.50	100.16
L_{20}×T_2	84.22	240	82.36	15.66	38.50	18.15	16.11	258.42	0.33	61.00	63.00	99.00	180.00	90.16
L_{21}×T_1	93.01	240	83.73	14.83	39.25	20.16	16.58	242.57	0.38	65.50	67.50	102.50	196.50	110.50
L_{21}×T_2	104.14	280	84.00	14.66	35.16	17.00	13.91	194.95	0.53	65.50	67.50	104.00	194.16	111.83
L_{22}×T_1	89.31	260	84.08	16.66	29.41	16.41	14.50	210.49	0.42	60.00	62.00	97.00	153.50	77.50
L_{22}×T_2	84.34	320	86.97	16.16	31.16	17.00	17.29	194.88	0.43	60.50	62.50	96.00	161.50	94.33
L_{23}×T_1	122.61	320	86.12	16.33	34.66	19.25	17.08	202.68	0.57	58.00	60.50	96.00	180.16	104.16
L_{23}×T_2	102.06	280	85.85	14.16	28.33	16.75	16.50	230.27	0.44	58.50	60.00	96.00	174.67	100.33
L_{24}×T_1	104.82	280	78.60	14.16	30.08	18.50	14.00	271.86	0.39	64.00	66.00	101.50	194.83	104.83
L_{24}×T_2	102.76	230	82.85	14.00	33.91	18.16	13.91	236.60	0.43	61.00	63.00	99.00	182.16	88.16
L_{25}×T_1	86.90	240	86.05	14.66	36.83	22.16	15.33	223.62	0.39	61.00	62.50	97.00	190.00	93.33
L_{25}×T_2	76.90	240	84.83	14.66	30.16	17.25	14.46	198.02	0.39	62.50	64.00	99.00	195.83	89.33
L_{26}×T_1	106.76	260	84.43	13.83	35.41	16.16	13.04	219.82	0.49	61.50	64.50	98.50	184.33	91.50
L_{26}×T_2	102.91	260	85.32	13.50	37.75	15.75	14.06	197.52	0.52	56.50	58.50	96.50	165.83	85.00
L_{27}×T_1	79.50	320	81.88	14.00	30.16	18.62	13.71	245.65	0.32	57.50	59.50	95.50	191.50	89.00
L_{27}×T_2	86.48	260	82.40	14.00	35.00	19.25	15.25	288.20	0.30	59.00	61.00	97.00	186.33	86.66
L_{28}×T_1	106.86	240	85.29	14.16	34.66	20.87	15.33	276.85	0.39	63.50	68.50	103.50	205.83	114.00
L_{28}×T_2	138.26	280	84.99	14.33	38.50	19.25	14.00	329.78	0.42	62.50	65.00	101.50	195.83	101.65
L_{29}×T_1	89.26	320	81.58	15.50	37.33	18.54	14.50	231.32	0.39	60.50	62.50	101.00	191.83	106.50
L_{29}×T_2	98.39	300	84.06	13.66	35.08	17.00	13.79	202.95	0.49	59.00	61.50	98.50	178.33	94.00
L_{30}×T_1	82.61	300	82.69	14.33	32.83	15.71	12.83	196.18	0.42	60.00	61.50	95.00	193.00	89.83
L_{30}×T_2	89.62	260	84.31	14.33	33.83	18.41	15.75	211.48	0.43	58.50	61.00	97.00	192.50	101.33
Checks														
Check-1	114.35	260	84.98	15.50	40.50	19.09	13.59	303.28	0.45	65.5	67.5	102	195.17	109.33
Check-2	110.56	340	84.45	14.17	35.00	21.25	16.92	246.01	0.41	61	63	98.5	169.17	94.67
CV	4.32	1.97	1.41	4.40	5.37	6.66	2.97	4.34	5.54	2.15	1.99	1.58	4.14	7.25
CD(0.05)	6.45	9.91	2.34	1.25	3.21	2.15	0.84	16.48	0.06	2.65	2.55	3.08	13.71	12.28

Note. GY, grain yield; GW, 1000 grain weight; SP, shelling percentage; KRC, kernel rows per cob; KPR, kernels per row; CL, cob length; CG, cob girth; BY, biological yield; HI, harvest index; DP, days to 50 % pollenshed; DS, days to 50% silking; DBH, days to 75% brown husk; PH, plant height; CP, cob placement; PC, protein content; TC, tryptophan content.

The mean value for rows per cob among the parents ranged from 9.8 (L_{25}) to 16.6 (L_{22}) and two lines L_{19}, L_{22} exhibited a greater mean value than best check Bio-9544 (15.5). Thirteen crosses recorded a higher mean value for rows per cob than the Bio-9544. The highest value of 16.67 was observed for $L_4 \times T_2$ and the lowest of 12.8 for $L_{15} \times T_2$ cross combination. For kernels per row, none of the parents exhibited the mean value for kernels per row higher than the best check Bio-9544 (40.50). Three crosses showed the value for kernels per row to be higher than Bio-9544. The maximum number of kernels per row 43.17 was recorded for $L_{16} \times T_1$ and the lowest of 28.34 for $L_{23} \times T_2$. The crosses that showed high number kernels per row were $L_{16} \times T_1$, $L_3 \times T_2$ and $L_{18} \times T_1$. A range of 15.5 cm (L_{18}) to 9.4 cm (L_8) for cob length was observed among the parents. No parent had the average cob length more than the best check Palam Sankar Makka-2 (21.25 cm). Two crosses had a mean value for cob length higher than Palam Sankar Makka-2. The maximum cob length of 22.17 cm for the cross $L_{25} \times T_1$ and the lowest of 14.25 cm for cross $L_2 \times T_1$ was observed. Some other crosses with high mean value for this character were $L_{18} \times T_1$ (21.34 cm) and $L_3 \times T_2$ (21.26 cm). Six crosses showed the mean cob girth to be higher than the Palam Sankar Makka-2 (16.92 cm) some of these were $L_{22} \times T_2$ (17.92 cm) $L_{19} \times T_2$ (17.40 cm), $L_6 \times T_2$ (17.25 cm) and $L_{13} \times T_2$ (17.25 cm). None of the parents showed higher value than best check Palam Sankar Makk-2. Out of sixty crosses only single cross $L_{28} \times T_2$ (329.78 q/ha) was observed to have a higher mean value for biological yield than the best check Bio-9544. The parents showed a range of 179.17 q/ha (L_9) to 69.74 q/ha (L_{24}) for this trait. Seventeen crosses recorded a higher mean value than Bio-9544 for this character. Among the crosses, $L_{19} \times T_2$ recorded the highest mean value of 0.62 whereas the lowest value of 0.30 was observed for the cross $L_{27} \times T_2$ for harvest index. No single parent had mean value of harvest index higher than that of the best check Bio-9544 (0.45).

For days to 50 per cent pollen shed, five lines *viz.*, L_{17}, L_{26}, L_{28}, L_5, L_1 recorded mean value to be less than the best check Palam Sankar Makka-2 (61 days). Twenty six crosses had mean days for 50 per cent pollen shed less than the best check; some of these crosses were $L_{26} \times T_2$ (56.5 days), $L_4 \times T_1$ (57 days), $L_4 \times T_2$ (57 days), $L_{17} \times T_1$ (57 days) and $L_{27} \times T_1$ (57.5 days). Five lines *viz.*, L_{17}, L_{26}, L_5, L_{28} and L_1 showed mean days to 50 per cent silking less than the best check Palam Sankar Makka-2 (63 days). Twenty seven crosses had mean days to 50 per cent silking less than the best check Palam Sankar Makka-2. The mean days for this character ranged from 58.5 days ($L_{17} \times T_1$, $L_{26} \times T_2$) to 68.5 days ($L_2 \times T_2$, $L_{28} \times T_1$). Among parents fifteen lines exhibited mean days to 75 per cent brown husk to be less than the best check Palam Sankar Makka-2 (98.5 days). The means days of parents for this trait ranged from 88.5 days (L_{17}) to 96.5 days (L_4). Thirty crosses exhibited the less number of mean days as that of the best check Palam Sankar Makka-2. The highest number of mean days of 106 days was observed in the cross $L_2 \times T_2$ and lowest days of 92.5 days was for cross $L_{17} \times T_1$. The results obtained are in conformity with the findings of Suthamathi and Nallathambi (2015) for early maturity. All lines except L_{21} and both the testers T_1 and T_2 showed a mean plant height less than the best check Palam Sankar Makka-2 (169.17 cm). The mean plant height for parents ranged from 101.67 cm (L_{28}) to 173.67 cm (L_{21}). Twelve crosses exhibited mean plant height less than that of the best check Palam Sankar Makka-2. The least mean height among all the crosses was exhibited by the cross $L_7 \times T_2$ (132.33 cm) and the highest mean height of 217.5 cm by cross $L_{12} \times T_1$. Twenty nine lines and both the testers T_1 and T_2 showed the mean height of cob placement to be less than the best check Palam Sankar Makka-2 (94.67 cm). Twenty nine crosses exhibited the mean height for cob placement less than that of the best check Palam Sankar Makka-2. It ranged from 55.67 cm ($L_7 \times T_2$) to 125.69 cm ($L_3 \times T_1$). Similar results were reported by Aminu *et al.* (2014); Talukder *et al.* (2016) with high negative GCA as desirable for plant height and cob placement.

Table 4: Mean values of parents for grain yield and yield related characters.

Entry	GY	GW	SP	KRC	KPR	CL	CG	BY	HI	DP	DS	DBH	PH	CP
Lines														
L_1	29.07	220.00	80.49	14.00	24.83	12.75	12.75	76.77	0.38	60.50	62.50	92.50	122.50	62.83
L_2	36.19	160.00	84.61	14.75	26.41	13.50	13.30	112.94	0.32	66.00	68.50	107.00	158.83	82.33
L_3	32.63	140.00	88.35	12.66	18.16	12.33	12.08	136.76	0.23	70.50	72.50	107.00	151.33	90.17
L_4	31.63	200.00	82.05	14.00	22.58	11.21	10.25	129.83	0.24	61.50	64.00	96.50	130.00	62.33
L_5	31.95	280.00	81.46	14.50	25.00	13.75	13.25	98.67	0.33	60.00	62.00	92.50	129.50	55.00
L_6	36.69	199.50	81.25	14.83	17.75	9.75	12.58	131.67	0.28	62.00	64.50	96.00	115.33	63.16
L_7	33.20	200.00	77.38	14.33	16.33	12.95	13.87	129.03	0.25	63.00	65.50	99.50	117.66	56.33
L_8	20.81	200.50	81.67	12.00	19.33	9.41	10.58	80.94	0.26	67.50	70.00	94.50	118.50	65.66
L_9	37.19	240.00	84.24	13.66	25.50	13.65	11.71	179.17	0.2	67.50	69.50	102.50	150.00	65.50
L_{10}	39.52	140.00	84.21	12.41	28.08	13.46	12.08	157.23	0.25	69.50	72.00	107.00	158.33	81.00
L_{11}	35.72	220.00	82.29	11.16	25.00	12.26	14.40	121.17	0.3	65.00	67.00	92.50	138.33	72.50
L_{12}	36.80	220.00	79.06	14.33	21.83	13.12	12.91	161.46	0.23	66.00	68.50	103.00	161.50	80.16
L_{13}	41.67	240.00	87.50	12.83	21.16	13.08	12.83	135.33	0.31	68.00	70.00	105.00	155.67	66.50
L_{14}	44.04	260.50	82.53	12.83	20.08	13.42	12.87	139.69	0.32	66.50	68.50	102.00	148.67	71.00
L_{15}	49.08	242.50	84.47	11.33	23.16	13.08	12.33	134.68	0.37	69.00	71.00	106.00	147.83	84.83
L_{16}	34.99	251.50	83.65	13.66	27.66	12.75	11.50	127.51	0.27	69.50	71.50	105.00	167.33	87.67
L_{17}	32.33	180.00	87.97	14.33	25.00	14.25	13.25	92.27	0.35	56.00	57.50	88.50	140.66	59.16
L_{18}	31.65	180.00	83.52	13.66	24.50	15.50	11.83	89.67	0.36	64.50	67.00	94.00	145.50	58.33
L_{19}	40.47	160.00	84.31	16.25	24.91	13.21	13.75	140.36	0.29	63.00	65.00	99.00	160.00	69.00
L_{20}	25.94	160.00	78.72	13.50	23.66	13.66	12.66	137.1	0.19	63.50	66.00	94.50	141.50	73.16
L_{21}	35.76	240.00	80.33	15.08	24.08	14.08	13.33	123.99	0.29	69.50	72.50	103.50	173.66	99.83
L_{22}	41.34	200.00	84.50	16.58	18.00	11.08	12.87	92.68	0.45	62.50	64.50	94.00	114.00	62.50
L_{23}	38.07	200.00	81.70	14.33	19.66	12.00	14.12	137.18	0.28	63.50	66.50	102.00	118.33	66.33
L_{24}	29.06	200.00	71.07	13.75	24.50	14.87	13.37	69.74	0.42	66.50	68.50	96.50	133.33	61.50
L_{25}	31.61	240.00	79.87	9.83	21.00	14.79	10.50	131.57	0.24	68.00	70.00	105.00	147.00	71.00
L_{26}	29.05	240.00	81.20	12.35	19.41	9.62	10.75	111.17	0.26	57.00	61.00	94.00	121.00	61.17
L_{27}	28.16	200.00	72.90	11.65	18.91	12.75	12.25	97.43	0.29	62.00	64.50	93.50	128.33	53.66
L_{28}	24.38	160.00	85.32	14.50	14.25	10.08	12.25	80.56	0.3	60.00	62.00	91.00	101.66	45.83
L_{29}	31.00	220.00	75.13	13.33	18.66	14.04	12.75	81.22	0.38	62.00	64.50	99.50	109.83	66.83
L_{30}	24.48	140.00	82.70	14.00	20.19	10.50	8.58	84.14	0.29	65.50	67.50	96.00	147.00	67.33
Testers														
T_1	37.38	260.00	81.92	13.33	20.16	11.91	11.75	153.92	0.24	66.00	69.00	104.00	130.50	70.83
T_2	33.97	120.00	78.09	13.16	24.50	13.25	13.16	95.00	0.36	68.50	71.50	104.50	126.16	60.83

Note. GY, grain yield; GW, 1000 grain weight; SP, shelling percentage; KRC, kernel rows per cob; KPR, kernels per row; CL, cob length; CG, cob girth; BY, biological yield; HI, harvest index; DP, days to 50 % pollenshed; DS, days to 50% silking; DBH, days to 75% brown husk; PH, plant height; CP, cob placement; PC, protein content; TC, tryptophan content.

C. Heterotic grouping of germplasm

Among thirty inbred lines, eleven lines exhibited positive and significant GCA effects and twelve lines exhibited negative and significant GCA effects for grain yield, out of these L_{28} (25.14) had the highest GCA effect followed by L_{12} (21.46), L_{10} (14.10), L_{16} (14.14) and L_{23} (10.92). Line L_{28} was the best general combiner and L_{25} the poorest general combiner (Table 5). Thirteen crosses out of total of sixty crosses recorded significantly positive SCA effects. These were $L_{15} \times T_2$, $L_7 \times T_1$, $L_2 \times T_1$, $L_{28} \times T_2$, $L_{19} \times T_2$, $L_3 \times T_1$, $L_5 \times T_2$, $L_{23} \times T_1$, $L_{25} \times T_1$, $L_{14} \times T_1$, $L_{11} \times T_2$, $L_{10} \times T_1$ and $L_{18} \times T_1$. The SCA effects ranged from 31.11 ($L_{15} \times T_2$) to -31.11 ($L_{15} \times T_1$) (Table 6).

Table 5: Estimates of general combining ability (GCA) of parents for grain yield.

Parents	GCA		GCA		GCA
Lines		Lines		Lines	
L_1	-14.233**	L_{12}	21.464**	L_{23}	10.914**
L_2	-13.328**	L_{13}	0.629	L_{24}	6.369**
L_3	2.204	L_{14}	8.622**	L_{25}	-15.518**
L_4	-3.941*	L_{15}	4.289*	L_{26}	7.419**
L_5	1.542	L_{16}	14.139**	L_{27}	-14.428**
L_6	6.662**	L_{17}	-2.741	L_{28}	25.139**
L_7	-10.313**	L_{18}	-10.963**	L_{29}	-3.593*
L_8	-12.198**	L_{19}	-0.498	L_{30}	-11.306**
L_9	1.652	L_{20}	-13.183**	**Testers**	
L_{10}	14.402**	L_{21}	1.154	T_1	-1.146*
L_{11}	10.242**	L_{22}	-10.593**	T_2	1.146*

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

Table 6: Estimates of specific combining ability (SCA) effects of crosses for grain yield.

Crosses	SCA	Crosses	SCA	Crosses	SCA	Crosses	SCA
$L_1 \times T_1$	-0.866	$L_8 \times T_2$	-0.114	$L_{16} \times T_1$	4.376	$L_{23} \times T_2$	-7.421**
$L_1 \times T_2$	0.866	$L_9 \times T_1$	-4.426	$L_{16} \times T_2$	-4.376	$L_{24} \times T_1$	2.176
$L_2 \times T_1$	22.474**	$L_9 \times T_2$	4.426	$L_{17} \times T_1$	-2.384	$L_{24} \times T_2$	-2.176
$L_2 \times T_2$	-22.474**	$L_{10} \times T_1$	5.204*	$L_{17} \times T_2$	2.384	$L_{25} \times T_1$	6.149*
$L_3 \times T_1$	10.506**	$L_{10} \times T_2$	-5.204*	$L_{18} \times T_1$	5.114*	$L_{25} \times T_2$	-6.149*
$L_3 \times T_2$	-10.506**	$L_{11} \times T_1$	-5.466*	$L_{18} \times T_2$	-5.114*	$L_{26} \times T_1$	3.071
$L_4 \times T_1$	-2.124	$L_{11} \times T_2$	5.466*	$L_{19} \times T_1$	-12.871**	$L_{26} \times T_2$	-3.071
$L_4 \times T_2$	2.124	$L_{12} \times T_1$	0.671	$L_{19} \times T_2$	12.871**	$L_{27} \times T_1$	-2.341
$L_5 \times T_1$	-8.601**	$L_{12} \times T_2$	-0.671	$L_{20} \times T_1$	1.159	$L_{27} \times T_2$	2.341
$L_5 \times T_2$	8.601**	$L_{13} \times T_1$	-3.539	$L_{20} \times T_2$	-1.159	$L_{28} \times T_1$	-14.554**
$L_6 \times T_1$	-2.791	$L_{13} \times T_2$	3.539	$L_{21} \times T_1$	-4.419	$L_{28} \times T_2$	14.554**
$L_6 \times T_2$	2.791	$L_{14} \times T_1$	6.124*	$L_{21} \times T_2$	4.419	$L_{29} \times T_1$	-3.421
$L_7 \times T_1$	23.069**	$L_{14} \times T_2$	-6.124*	$L_{22} \times T_1$	3.634	$L_{29} \times T_2$	3.421
$L_7 \times T_2$	-23.069**	$L_{15} \times T_1$	-31.104**	$L_{22} \times T_2$	-3.634	$L_{30} \times T_1$	-2.359
$L_8 \times T_1$	0.114	$L_{15} \times T_2$	31.104**	$L_{23} \times T_1$	7.421**	$L_{30} \times T_2$	2.359

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

The maize inbred lines were grouped into different heterotic groups on the basis of SCA effects were analyzed for yield traits (Table 7). Germplasm lines showing positive SCA effects with T_2 and negative with T_1 were grouped into heterotic group A whereas the germplasm lines showing positive SCA effects with T_1 and negative with T_2 were assigned into group B. Fifteen lines *viz.*, L_1, L_4, L_5, L_6, L_9, L_{11}, L_{13}, L_{15}, L_{17}, L_{19}, L_{21}, L_{27}, L_{28}, L_{29} and L_{30} assigned to Group A whereas remaining fifteen lines namely; L_2, L_3, L_7, L_8, L_{10}, L_{12}, L_{14}, L_{16}, L_{18}, L_{20}, L_{22}, L_{23}, L_{24}, L_{25} and L_{26} were assigned to Group B.

Table 7: Germplasm lines assigned into heterotic groups A and B based upon the GCA and SCA effects for grain yield.

Sr. No.	Heterotic Group A	Heterotic group B
1.	L_1 (BAJIM-12-01)	L_2 (BAJIM-13-01)
2.	L_4 (BAJIM-15-08)	L_3 (BAJIM-13-02)
3.	L_5 (BAJIM-15-09)	L_7(BAJIM 15-11)
4.	L_6 (BAJIM-15-10)	L_8 (BAJIM-15-12)
5.	L_9 (BML-6)	L_{10} (BML-7)
6.	L_{11} (CML-44)	L_{12} (CML-141)
7.	L_{13} (CML-269)	L_{14} (CML-269-1)
8.	L_{15} (CML-292)	L_{16} (CML-294)
9.	L_{17} (CML-334)	L_{18} (CML-336)
10.	L_{19} (CML-337)	L_{20} (CML-439)
11.	L_{21} (CML-465-B-B)	L_{22} (DMRQPM-58)
12.	L_{27} (MRCQPM-18)	L_{23} (HKI-1040-7)
13.	L_{28} (TNAU/CBE-83)	L_{24} (HKI-1105)
14.	L_{29} (TNAU/CBE-115)	L_{25} (LQPM-15-01)
15.	L_{30} (V-334)	L_{26} (MRCQPM-16)

However, the lines with positive GCA effects for yield are of practical importance to a breeder for developing high yielding hybrids. Keeping this aspect in view, the eight lines *viz.*, L_5, L_6, L_9, L_{11}, L_{13}, L_{15}, L_{21} and L_{28} which showed a positive GCA effect and positive SCA effects with T_2 and negative SCA effects with T_1 are considered more productive in the heterotic group A whereas the eight lines *viz.*, L_3, L_{10}, L_{12}, L_{14}, L_{16}, L_{23}, L_{24} and L_{26} which showed a positive GCA effect and positive SCA effects with T_1 and negative SCA effects with T_2 are more productive in heterotic group B (Table 7). Similar results with respect to the heterotic grouping of maize germplasm have been reported by several workers. Ejigu *et al.* (2017) assigned 16 lines and two testers in two heterotic groups. Elmyhun *et al.* (2020) also grouped the maize germplasm in heterotic groups on the basis of combining ability.

CONCLUSION

Germplasm within the same group are genetically similar whereas between the two groups are diverse. High yielding hybrids could be developed by involving these lines directly from two different groups. These heterotic groups could serve as sources for developing populations and pools for deriving the productive lines and synthetics. In the present investigation thirty maize inbred lines of medium maturity were crossed with two diverse testers. The maize inbred lines were grouped into different heterotic groups on the basis of SCA effects were analyzed for yield traits. Based on *per se* performance for different traits and GCA effect for grain yield, five lines *viz.*, L_{15} (CML-292), L_{14} (CML-269-1), L_{23} (HKI-1040-7), L_{12} (CML-141) and L_{28} (TNAU/CBE-83) were identified as the best inbred lines which could be involved in breeding programme for developing hybrids and composites. Among the sixty crosses, three crosses *viz.*, $L_{28} \times T_2$ (TNAU/CBE-83 × BAJIM-08-27), $L_{15} \times T_2$ (CML-292 × BAJIM-08-27) and $L_{23} \times T_1$ (HKI-1040-07 × BAJIM-08-26) were identified as the best hybrid combinations on the basis of *per se* performance and their mean values for yield were considerably more than that of best check Bio-9544 for which the mean yield was 114.35 q/ha and were found to be early maturing. These single cross hybrids can be used in further breeding programme for commercial exploitation of maize hybrids with the advantage of high yield and early maturity.

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