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GENETICS AND PLANT BREEDING

Combining ability and heterosis in maize (*Zea mays* L.) for grain yield and yield components

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Abstract

An investigation was carried out to assess the combibing ability and heterosis for nine characters viz., days to 50% tasseling, days to 50% silking, days to maturity, plant height, cob length, kernel rows per cob, 100-seed weight, protein content and grain yield per plant in 29 genotypes (twenty one hybrids, their seven parents along with a check). Combining ability studies revealed that, the line DHK-12-2091 found to be good combiner for the traits, grain yield per plant, kernel rows per cob, 100-seed weight and protein content while another line DHK-12-2003 also found to be good combiner for 100-seed weight, protein content, days to 50% tasseling and days to 50% silking. Therefore these lines can be utilized in improvement of the respective traits in any breeding programme where hybridization is involved. Among all the crosses, based on average heterosis, heterobeltiosis, standard heterosis, *sca* effects and *per se* performance, the cross DHK-12-2141 × DHK-12-2047 was identified as a promising hybrid for majority of characters studied. However it has not recorded significant standard heterosis for grain yield per plant.

Highlights

- In the present investigation Combining ability analysis for seven Maize inbred lines and Heterosis for nine characters viz., days to 50% tasseling, days to 50% silking, days to maturity, plant height, cob length, kernel rows per cob, 100-seed weight, protein content and grain yield per plant was carried out.
- Combining ability studies revealed that, the line DHK-12-2091 found to be good combiner for the traits, grain yield per plant, kernel rows per cob, 100-seed weight and protein content
- Another line DHK-12-2003 also found to be good combiner for 100-seed weight, protein content, days to 50% tasseling and days to 50% silking.
- The cross DHK-12-2141 × DHK-12-2047 was identified as a promising hybrid for majority of characters studied.

Keywords: Combining ability, heterosis, yield, maize

Maize (*Zea mays* L.) is a diploid (2n =20) cross pollinated crop. It is the second most important cereal crop in the world's economy. It ranks first in both productivity and production among the cereals and is having worldwide significance due to its demand as food, feed and industrial utilization. It is a good source of carbohydrate, starch, fat, protein, oil in addition to some of the important minerals and vitamins. Maize is known as "Queen of cereals" because of its high production potential and wider adaptability. It is an allogamous crop endowed with the mechanism of protandry and monoecy which lent itself feasible for the exploitation of hybrid vigour. Yield in maize crop has increased substantially over the years as the breeders are successful in harnessing the heterosis or hybrid vigour than in other crop species. This indicates the importance of maize in the ever-increasing demand for food and warrants the continuous development of new high yielding hybrids.

The commercial production of hybrids however, depends upon two factors viz., behaviour of a line itself and the behaviour of line in hybrid combination. The behaviour of a line in hybrid combination is assessed through the estimation of general combining ability (*gca*) and specific combining ability (*sca*) effects. Diallel analysis which involves the crossing of all lines in all possible combinations is an efficient method for the study of combining ability and also the gene action of the characers under study. This approach has practical utility in identifying the superior lines along with their heterotic effects which in turn can be utilized for genetic improvement of yield.

The phenomenon of heterosis provides a criterion for selection of superior crosses involved in the breeding programme. Different types of heterosis viz., relative heterosis, heterobeltiosis and standard heterosis explains the superiority of F_1 over mid parent, better parent and standard check, respectively. The magnitude of heterosis provides a basis for genetic diversity and acts as a guide in choosing desirable lines and cross combinations.

Materials and Methods

Seven inbred lines (DHK-12-2034, DHK-12-2141, DHK-12-2102, DHK-12-2047, DHK-12-2095, DHK-12-2091 and DHK-12-2003) were mated in Diallel fashion without reciprocals during *kharif* 2013 to produce twenty one F_1s. All these twenty one F_1s, seven parents along with a check, 30-V-92 were evaluated during *rabi* 2013 at Agricultural College Farm, Bapatla in a Randomized Block Design with three replications. The experimental material were raised in three rows of 3m length with the spacing of 60 × 30 cm. Observations were recorded on ten randomly chosen plants for nine quantitative characters viz., days to 50% tasseling, days to 50% silking, days to maturity, plant height, cob length, kernel rows per cob, 100-seed weight, protein content and grain yield per plant.

The entire genetic variability observed for each trait was partitioned into its components i.e. general and specific combining ability (Sprague and Tatum, 1942). General combining ability (*gca*) is used to designate the average performance of a line in hybrid combinations while specific combining ability (*sca*) define those cases in which certain combinations do relatively better or worse than expected on the basis of the average performance of the lines involved. The general combining ability (*gca*) effects were due to the additive type of gene action whereas, specific combining ability (*sca*) effects are due to the genes which are non-additive i.e. either dominant or epistatic in nature (Sprague and Tatum, 1942). The relative importance of general and specific combining ability can be assessed by estimating the components of variance and expressed in the ratio $2\sigma^2\ gca\ /\ 2\sigma^2\ gca + \sigma^2\ sca$ (Baker, 1978). The closer the ratio to unity, greater is the magnitude of additive gene action and *vice versa*. Further the gene action can be confirmed by the estimates of narrow sense heritability. Higher values of narrow sense heritability indicate the presence of additive gene action.The data were subjected to statistical analysis and estimates of combining ability effects were worked out as per Griffing (1956).

The heterotic effects were measured as deviation of F1 mean from mid parent (relative heterosis), better parent (heterobeltiosis) and the standard check (standard heterosis) mean. The test of significance of heterosis over mid parent, better parent and standard check was done by 't' test as suggested by Snedecor and Cochran (1967).

Results and Discussion

Analysis of variance for combining ability for different characters under study is presented in Table 2. The results revealed the existence of variability among different cross combinations for all of the nine characters studied in the present investigation.

Among the seven lines tested for their combining abilities pertaining to different characters under study, line DHK-12-2091 recorded significant *gca* effects in desirable direction for four different characters viz., kernel rows per cob, 100-seed weight, protein content and grain yield per plant and DHK-12-2003 also recorded significant *gca* effects in desirable direction for four characters viz., days to 50% tasseling, days to 50% silking, 100-seed weight and protein content followed by DHK-12-2102 for days to 50% tasseling, days to 50% silking and days to maturity and DHK-12-2095 for kernel rows per cob, 100-seed weight and grain yield per plant and DHK-12-2034 for cob length and protein content and DHK-12-2141 for plant height and cob

Table 1: Mean performance of lines, their F_1s and check in maize (*Zea mays* L.)

Sl. No.	Lines, F_1s and Check	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Cob length (cm)	Kernel rows per cob	100-seed weight (g)	Protein content (%)	Grain yield per plant (g)
1	DHK-12-2034	57.33	60.33	87.67	150.63	12.26	12.53	7.16	7.85	36.36
2	DHK-12-2141	57.67	61.67	87.33	140.36	11.10	13.20	4.46	8.21	10.86
3	DHK-12-2102	52.00	54.33	82.67	119.90	13.60	13.26	12.10	7.62	27.50
4	DHK-12-2047	57.67	60.00	87.33	144.70	15.06	13.67	7.03	8.41	12.83
5	DHK-12-2095	55.33	57.33	86.67	150.36	13.80	15.93	16.16	7.84	75.03
6	DHK-12-2091	54.00	57.00	87.00	153.16	15.80	15.53	14.80	7.61	100.46
7	DHK-12-2003	48.33	57.00	86.00	160.06	13.90	14.60	15.96	8.87	61.36
8	DHK-12-2034 × DHK-12-2141	55.00	57.00	86.33	261.60	21.00	15.33	13.03	8.15	75.30
9	DHK-12-2034 × DHK-12-2102	47.33	52.67	83.67	196.06	20.63	14.86	15.26	7.46	100.03
10	DHK-12-2034 × DHK-12-2047	51.67	56.33	86.33	245.60	19.86	15.40	10.43	7.85	83.50
11	DHK-12-2034 × DHK-12-2095	51.00	55.00	85.33	219.76	19.13	17.13	15.40	7.35	105.46
12	DHK-12-2034 × DHK-12-2091	48.33	51.33	85.00	215.03	19.20	15.53	12.33	8.22	85.20
13	DHK-12-2034 × DHK-12-2003	50.33	54.67	84.67	214.76	21.60	14.06	22.43	7.65	110.10
14	DHK-12-2141 × DHK-12-2102	50.67	53.67	84.33	237.83	21.36	14.20	17.43	7.42	130.43
15	DHK-12-2141 × DHK-12-2047	54.67	58.67	87.67	260.30	21.67	17.00	18.30	7.89	145.36
16	DHK-12-2141 × DHK-12-2095	57.00	60.67	88.00	234.26	18.80	15.26	20.03	7.53	145.73
17	DHK-12-2141 × DHK-12-2091	53.33	56.00	85.33	250.67	20.53	16.26	25.30	8.47	125.60
18	DHK-12-2141 × DHK-12-2003	54.33	57.00	87.00	284.33	20.66	15.46	21.43	8.11	137.20
19	DHK-12-2102 × DHK-12-2047	51.67	55.33	82.67	219.93	19.40	15.06	17.23	8.60	105.73
20	DHK-12-2102 × DHK-12-2095	48.33	51.00	82.33	193.03	16.23	14.73	14.13	8.15	110.40
21	DHK-12-2102 × DHK-12-2091	49.33	52.33	83.33	153.13	17.36	14.20	15.43	8.02	110.76
22	DHK-12-2102 × DHK-12-2003	48.00	51.67	81.67	200.53	15.23	12.67	16.00	8.52	87.20
23	DHK-12-2047 × DHK-12-2095	54.67	57.00	86.67	190.56	17.96	16.33	16.36	7.85	110.80
24	DHK-12-2047 × DHK-12-2091	56.00	59.00	87.67	180.83	18.26	15.60	15.06	8.38	85.33
25	DHK-12-2047 × DHK-12-2003	50.00	55.00	85.33	262.60	19.73	15.67	20.33	7.36	115.80
26	DHK-12-2095 × DHK-12-2091	53.00	56.33	87.33	187.46	15.96	16.00	15.00	8.38	100.46
27	DHK-12-2095 × DHK-12-2003	49.00	54.00	84.00	235.06	18.60	15.13	19.43	7.77	120.20
28	DHK-12-2091 × DHK-12-2003	48.33	57.33	84.33	165.60	14.67	14.06	23.16	8.46	92.40
29	30 V 92 (Check)	55.33	58.33	88.00	254.23	21.30	15.60	25.46	8.40	133.20
	Mean	52.40	56.14	85.57	202.84	17.75	14.98	16.09	8.02	94.51
	CV	1.65	1.64	2.01	11.75	7.27	5.43	4.81	1.04	18.14
	SEd	0.71	0.75	1.41	19.46	1.05	0.66	0.63	0.07	13.99
	CD at 5%	1.42	1.50	2.82	38.98	2.11	1.33	1.26	0.14	28.03

length and DHK-12-2047 for cob length and kernel rows per cob (Table 3).

Further the tested lines were given ranking based on the respective combining abilities of all the characters studied. While doing so DHK-12-2091 and DHK-12-2003 ranked first followed by DHK-12-2095 (Table 6). Therefore these lines can be utilized in improvement of the respective traits in any breeding programme wherever hybridization is involved. Due to their good combining ability these lines can be utilized straightaway as parents for production of good hybrids by crossing with other divergent lines and can also be employed in the development of synthetic varieties.

Among the 21 cross combinations, the cross DHK-12-2141 × DHK-12-2091 recorded significant *sca* effect in the desirable direction for all the nine characters under study (Table 4). The *gca* effects of

Table 2: Analysis of variance for combining ability for yield and yield contributing characters in maize (*Zea mays* L.)

Source of variation	d.f.	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height	Cob length	Kernel rows per cob	100-seed weight	Protein content	Grain yield per plant
Replications	2	0.369	0.940	0.869	1294.168	2.827	0.083	0.039	0.018	417.986
Treatments	27	32.799**	24.446**	10.456**	5992.267**	27.735**	4.281**	70.101**	0.520**	3939.662**
Parents	6	36.603**	19.190**	8.937*	501.641	7.567**	4.906**	70.028**	0.641**	3407.135**
Hybrids	20	25.752**	20.600**	10.319**	3641.690**	13.052**	3.295**	43.232**	0.505**	1233.186**
Parents vs. Hybrids	1	150.893**	132.893**	22.321**	5947.560**	442.418**	20.230**	607.913**	0.096**	61264.340**
Error	54	0.764	0.866	3.054	552.959	1.706	0.659	0.552	0.006	297.362
Total	83	11.175	8.539	5.409	2340.214	10.200	1.823	23.164	0.174	1485.113

* Significant at 5% level; ** Significant at 1% level

inbreds and *sca* effects of their hybrid combinations indicated that the crosses with high *sca* effects were resulted due to all possible parental gca combinations i.e. high × high, high × low, low × high and low × low. Therefore, one can afford to include some low general combiners also along with good combiners in breeding programmes where hybridization is involved.

The estimates of variance due to both *sca* and *gca* are signicant in case of days to 50% tasseling, days to 50% silking and kernel rows per cob indicating the role of both additive and non-additive gene action in the inheritance of these characters (Table 5). Similar results were also reported by Desai and Singh (2001) and Amiruzzaman (2011) for days to 50% tasseling and Geetha and Jayaraman (2000) and Rajitha (2013) for days to 50% silking and kernel rows per cob. These results are further confirmed by the moderate values of narrow sense heritability. Further the characters plant height, cob length, 100-seed weight, protein content and grain yield per plant also recorded significant *gca* and *sca* variances indicating the role of both additive and non-additive gene actions in governing the inheritance of these traits which is also confirmed by the ratio of *gca* variance to total genetic variance which is intermediate (Table 5). These results were in accordance with the findings of Gautam (2003) and Katna *et al.* (2005) for plant height and cob length and Pavan *et al.* (2011), Kumar *et al*. (2012) and Ahmed (2013) for 100-seed weight and Rajitha (2013) for protein content and Afshar and Bahram (2012) for grain yield per plant. As both additive and non-additive gene actions are involved in the inheritance of all the above eight characters, they can be improved by employing breeding methods which exploits both additive and non-additive genetic components.

The component of variance due to *gca* was high and significant while the component of *sca* variance was low and non-significant for the character days to maturity and the ratio of *gca* component of variance to total genetic variance was closer to unity and also recorded high narrow sense heritability (Table 5). These results indicate the predominance of additive gene action in the inheritance of this character. Similar results were reported by Alam *et al.* (2008) and Singh and Singh (2011). As the additive gene action is predominant, breeding methods involving simple selection like mass selection, ear-to-row method, etc. are to be followed in improving this trait.

Mean square due to genotypes was significant for all the traits, indicating that experimental material had sufficient genetic variability for all the traits studied. Mean squares due to parents Vs hybrids were also significant for all the traits. This revealed the presence of substantial amount of heterosis in various cross combinations.

Relative heterosis, Heterobeltiosis and Standard heterosis (with 30-V-92 as check) were estimated and results were presented in Table 6. Eighteen crosses showed significant relative heterosis, twenty crosses for heterobeltiosis and sixteen crosses for standard heterosis estimates in desirable for days to 50% tasseling (Table 7). The cross DHK-12-2034 ×

Table 3: Estimates of general combining ability (*gca*) effects of lines for different characters in maize (*Zea mays* L.)

Parents	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height	Cob length	Kernel rows per cob	100-seed weight	Protein content	Grain yield per plant
DHK-12-2034	-0.005	-0.090	0.307	5.119	0.554*	-0.249	-2.538**	-0.180**	-12.517**
DHK-12-2141	2.439**	1.984**	1.048**	22.412**	0.584*	0.033	-0.179	-0.001	4.042
DHK-12-2102	-2.116**	-2.571**	-2.286**	-18.633**	-0.394	-0.819**	-0.708**	-0.066**	-5.047
DHK-12-2047	1.735**	1.429**	0.788*	4.578	0.672**	0.307*	-1.586**	0.082**	-8.088*
DHK-12-2095	0.587**	0.021	0.344	-5.237	-0.742**	0.759**	0.736**	-0.143**	10.905**
DHK-12-2091	-0.228	-0.238	0.344	-16.562**	-0.376	0.344*	1.092**	0.129**	6.190*
DHK-12-2003	-2.413**	-0.534**	-0.545	8.323	-0.298	-0.375*	3.184**	0.179**	4.516
S.E	0.156	0.166	0.311	4.190	0.233	0.145	0.132	0.014	3.072
C.D at 5 %	0.312	0.332	0.624	8.400	0.466	0.290	0.265	0.028	6.160

* Significant at 5% level; ** Significant at 1% level

DHK-12-2102 recorded highest significant values for all the three types of heterosis in desired direction. Further this cross also recorded significant *sca* effect (Table 4) in desirable direction. The lines DHK-12-2034 and DHK-12-2102 involved in the above heterotic cross had better *per se* performance for this trait (Table 1). Similar findings were reported by Reddy *et al.* (2011) and Rajitha (2013).

Seventeen crosses showed significant relative heterosis and heterobeltiosis and fifteen crosses for standard heterosis in desirable direction for days to 50% silking (Table 7). The cross DHK-12-2034 × DHK-12-2091 recorded negative significant heterosis over mid, better parent and standard check. Further this cross also recorded highest significant *sca* effect in desirable direction (Table 4). Inspite of relatively low *per se* performances of the lines involved in the above cross they resulted in heterotic hybrid indicating their good general combining ability. Similar findings were reported by Rajitha (2013).

Only one cross for relative heterosis, six crosses for heterobeltiosis and ten crosses for standard heterosis showed significance in desirable direction for days to maturity (Table 7). The cross DHK-12-2102 × DHK-12-2003 recorded highest significant heterosis over mid, better parent and check. This cross also recorded significant *sca* effect (Table 4) in desirable direction. Further the lines involved in the above heterotic cross were also good in their *per se* performance. These results were in accordance with the findings of Reddy *et al.* (2011).

For plant height, eighteen, seventeen and ten crosses showed significant and positive heterotic effects over mid parent, better parent and standard check respectively. The cross DHK-12-2141 × DHK-12-2003 recorded highest positive significant heterosis over mid parent and better parent. The *sca* effect of this cross is also high and significant in the positive direction (Table 4). The parental lines involved in the above heterotic cross were poor in their per se performance. This higher magnitude of heterosis inspite of their low performance may be due to their good general combining ability. Similar findings were reported by Alam *et al.* (2008) and Raghu *et al.* (2011).

Eighteen and seventeen crosses showed significant and positive heterotic effects over mid and better parents respectively for cob length. None of the crosses showed significant standard heterosis in desired direction (Table 7). The cross DHK-12-2034 × DHK-12-2141 recorded highest positive significant heterosis over mid and better parent. Further this cross also recorded significant *sca* effect in desirable direction (Table 4). The lines DHK-12-2034 and DHK-12-2141 involved in the above heterotic cross had poor *per se* performance (Table 1) but resulted in heterotic cross indicating their good general combining ability. Similar findings were reported by Rajitha (2013).

For kernel rows per cob, eleven, five and two crosses showed significant and positive heterotic effects over mid parent, better parent and standard check respectively. The cross DHK-12-2141 × DHK-12-2047 recorded positive significant heterosis over mid parent, better parent and standard check. This cross

Table 4: Estimates of specific combining ability (*sca*) effects of F_1s for different characters in maize (*Zea mays* L.)

Sl. No.	Crosses	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height	Cob length	Kernel rows per cob	100-seed weight	Protein content	Grain yield per plant
1	DHK-12-2034 × DHK-12-2141	0.269	-0.954**	-0.509	33.066**	2.240**	0.594**	-0.009	0.328**	-9.348*
2	DHK-12-2034 × DHK-12-2102	-2.843**	-0.731**	0.157	8.577	2.851**	0.980**	2.754**	-0.291**	24.474**
3	DHK-12-2034 × DHK-12-2047	-2.361**	-1.065**	-0.250	34.899**	1.018**	0.387*	-1.202**	-0.055**	10.981**
4	DHK-12-2034 × DHK-12-2095	-1.880**	-0.991**	-0.806	18.881**	1.699**	1.669**	1.443**	-0.331**	13.956**
5	DHK-12-2034 × DHK-12-2091	-3.731**	-4.398**	-1.139**	25.473**	1.399**	0.483*	-1.980**	0.275**	-1.596
6	DHK-12-2034 × DHK-12-2003	0.454	-0.769**	-0.586	0.321	3.721**	-0.265	6.028**	-0.352**	24.978**
7	DHK-12-2141 × DHK-12-2102	-1.954**	-1.806**	0.083	33.051**	3.555**	0.031	2.561**	-0.513**	38.315**
8	DHK-12-2141 × DHK-12-2047	-1.806**	-0.806**	0.343	32.306**	2.788**	1.706**	4.306**	-0.193**	56.289**
9	DHK-12-2141 × DHK-12-2095	1.676**	2.602**	1.120**	16.088**	1.336**	-0.480*	3.717**	-0.323**	37.663**
10	DHK-12-2141 × DHK-12-2091	-1.176**	-1.806**	-1.546**	43.814**	2.703**	0.935**	8.628**	0.340**	22.244**
11	DHK-12-2141 × DHK-12-2003	2.009**	-0.509*	1.009*	52.595**	2.758**	0.854**	2.669**	-0.064**	35.519**
12	DHK-12-2102 × DHK-12-2047	-0.250	0.417	-1.324**	32.984**	1.499**	0.624**	3.769**	0.581**	25.744**
13	DHK-12-2102 × DHK-12-2095	-2.435**	-2.509**	-1.213**	15.899**	-0.253	-0.161	-1.654**	0.359**	11.419**
14	DHK-12-2102 × DHK-12-2091	-0.620**	-0.917**	-0.213	-12.675*	0.514	-0.280	-0.709**	-0.042*	16.500**
15	DHK-12-2102 × DHK-12-2003	0.231	-1.287**	-0.991*	9.840	-1.697**	-1.094**	-2.235**	0.407**	-5.393
16	DHK-12-2047 × DHK-12-2095	0.046	-0.509*	0.046	-9.779	0.414	0.313	1.457**	-0.092**	14.859**
17	DHK-12-2047 × DHK-12-2091	2.194**	1.750**	1.046*	-8.186	0.347	-0.006	-0.198	0.174**	-5.893
18	DHK-12-2047 × DHK-12-2003	-1.620**	-1.954**	-0.398	48.695**	1.736**	0.780**	2.976**	-0.903**	26.248**
19	DHK-12-2095 × DHK-12-2091	0.343	0.491*	1.157**	8.262	-0.538	-0.057	-2.587**	0.391**	-9.752*
20	DHK-12-2095 × DHK-12-2003	-1.472*	-1.546**	-1.287**	30.977**	2.018**	-0.206	-0.246	-0.263**	11.656**
21	DHK-12-2091 × DHK-12-2003	-1.324**	2.046**	-0.954*	-27.264**	-2.282**	-0.857**	3.131**	0.156**	-11.430**
	S.E	0.453	0.482	0.906	12.185	0.677	0.420	-0.385	0.041	8.936
	C.D at 5 %	0.908	0.967	1.816	24.430	1.357	0.843	0.772	0.083	17.915

* Significant at 5% level; ** Significant at 1% level

Table 5: Estimates of genetic components of variance for different characters in maize (*Zea mays* L.)

	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height	Cob length	Kernel rows per cob	100-seed weight	Protein content	Grain yield per plant
σ_g^2	29.487**	19.411**	11.357**	1901.448**	3.054**	2.493**	32.046**	0.168**	662.297**
σ_s^2	5.632**	4.931**	1.236	2024.844**	11.014**	1.122**	20.887**	0.175**	1499.199**
$2\sigma_g^2:2\sigma_g^2+\sigma_s^2$	0.913	0.873	0.948	0.652	0.357	0.816	0.754	0.657	0.469
Heritability (narrow sense)	53.60	46.30	65.00	15.90	4.80	31.00	25.30	17.40	7.70

* Significant at 5% level; ** Significant at 1% level

also recorded highest significant *sca* effect in the desirable direction (Table 4). The *per se* performance of the lines involved in the above heterotic cross were also on par with the mean (Table 1). these results were in accordance with Rajitha (2013) for relative heterosis and heterobeltiosis.

Nineteen and thirteen crosses showed significant relative heterosis and heterobeltiosis in desirable direction for 100-seed weight. None of the crosses showed significant standard heterosis in positive direction. The cross DHK-12-2141 × DHK-12-2047 recorded highest positive heterosis over mid

Table 6: Good general combiners among parental lines for yield and yield components in maize (*Zea mays* L.)

Sl. No.	Characters	Lines						
		DHK-12-2034	DHK-12-2141	DHK-12-2102	DHK-12-2047	DHK-12-2095	DHK-12-2091	DHK-12-2003
1	Days to 50% tasseling	0	-1	+1	-1	-1	0	+1
2	Days to 50% silking	0	-1	+1	-1	0	0	+1
3	Days to maturity	0	-1	+1	-1	0	0	0
4	Plant height	0	+1	-1	0	0	-1	0
5	Cob length	+1	+1	0	+1	-1	0	0
6	Kernel rows per cob	0	0	-1	+1	+1	+1	-1
7	100-seed weight	-1	0	-1	-1	+1	+1	+1
8	Protein content	-1	0	-1	+1	-1	+1	+1
9	Grain yield per plant	-1	0	0	-1	+1	+1	0
	Overall Score	-2	-1	-1	-2	0	3	3
	Rank	4	3	3	4	2	1	1

+ indicates significant *gca* in desirable direction; - indicates significant *gca* in undesirable direction

Table 7: Relative heterosis, heterobeltiosis and standard hetrosis for yield and yield contributing characters in maize (*Zea mays* L.)

Crosses	Days to 50% tasseling			Days to 50% silking			Days to maturity		
	Relative heterosis	Hetero beltiosis	Standard heterosis[a]	Relative heterosis	Hetero beltiosis	Standard heterosis[a]	Relative heterosis	Hetero Beltiosis	Standard heterosis[a]
DHK-12-2034 × DHK-12-2141	-4.35**	-4.62**	-0.60	-6.56**	-7.57**	-2.29**	-1.33	-1.52	-1.89
DHK-12-2034 × DHK-12-2102	-13.41**	-17.44**	-14.46**	-8.14**	-12.7**	-9.71**	-1.76	-4.56**	-4.92**
DHK-12-2034 × DHK-12-2047	-10.14**	-10.40**	-6.63**	-6.37**	-6.63**	-3.43*	-1.33	-1.52	-1.89
DHK-12-2034 × DHK-12-2095	-9.47**	-11.05**	-7.83**	-6.52**	-8.84**	-5.71**	-2.10	-2.66	-3.03
DHK-12-2034 × DHK-12-2091	-13.17**	-15.70**	-12.65**	-12.50**	-14.92**	-12.00**	-2.67	-3.04	-3.41*
DHK-12-2034 × DHK-12-2003	-4.73**	-12.21**	-9.04**	-6.82**	-9.39**	-6.29**	-2.50	-3.42*	-3.79*
DHK-12-2141 × DHK-12-2102	-7.60**	-12.14**	-8.43**	-7.47**	-12.97**	-8.00**	-0.78	-3.44*	-4.17*
DHK-12-2141 × DHK-12-2047	-5.20**	-5.20**	-1.20	-3.56**	-4.86**	0.57	0.38	0.38	-0.38
DHK-12-2141 × DHK-12-2095	0.88	-1.16	-3.01*	1.96	-1.62	4.00**	1.15	0.76	0.00
DHK-12-2141 × DHK-12-2091	-4.48**	-7.51**	-3.61**	-5.62**	-9.19**	-4.00**	-2.10	-2.29	-3.03
DHK-12-2141 × DHK-12-2003	2.52*	-5.78**	-1.81	-3.93**	-7.57**	-2.29	0.38	-0.38	-1.14
DHK-12-2102 × DHK-12-2047	-5.78**	-10.40**	-6.63**	-3.21**	-7.78**	-5.14**	-2.75	-5.34**	-6.06**
DHK-12-2102 × DHK-12-2095	-9.94**	-12.65**	-12.65**	-8.66**	-11.05**	-12.57**	-2.76	-5.00**	-6.44**
DHK-12-2102 × DHK-12-2091	-6.92**	-8.64**	-10.84**	-5.99**	-8.19**	-10.29**	-1.77	-4.21*	-5.30**
DHK-12-2102 × DHK-12-2003	-4.32**	-7.69**	-13.25**	-7.19**	-9.36**	-11.43**	-3.16*	-5.04**	-7.20**
DHK-12-2047 × DHK-12-2095	-3.24**	-5.20**	-1.20	-2.84*	-5.00**	-2.29	-0.38	-0.76	-1.52
DHK-12-2047 × DHK-12-2091	0.30	-2.89*	1.20	0.85	-1.67	1.14	0.57	0.38	-0.38
DHK-12-2047 × DHK-12-2003	-5.66**	-13.29**	-9.64**	-5.98**	-8.33**	-5.71**	-1.54	-2.29	-3.03
DHK-12-2095 × DHK-12-2091	-3.05**	-4.22**	-4.22**	-1.46	-1.74	-3.43*	0.58	0.38	-0.76
DHK-12-2095 × DHK-12-2003	-5.47**	-11.45**	-11.45**	-5.81**	-5.81**	-7.43**	-2.70	-3.08	-4.55**
DHK-12-2091 × DHK-12-2003	-5.54**	-10.49**	-12.65**	0.58	0.58	-1.71	-2.50	-3.07	-4.17*
Range	-13.41 to 2.52	-17.44 to -1.16	-14.46 to 1.20	-12.50 to 1.96	-14.92 to 0.58	-12.57 to 4.00	-3.16 to 1.15	-5.34 to 0.76	-7.20 to 0.00
Average	5.65	-9.05	-7.17	-5.01	-7.36	-5.14	-1.38	-2.37	-3.19

Crosses	Plant height			Cob length			Kernel rows per cob		
	Relative heterosis	Hetero beltiosis	Standard heterosis[a]	Relative heterosis	Hetero beltiosis	Standard heterosis[a]	Relative heterosis	Hetero beltiosis	Standard heterosis[a]
DHK-12-2034 × DHK-12-2141	79.79**	73.67**	2.90	79.74**	71.20**	-1.41	19.17**	16.16**	-1.71
DHK-12-2034 × DHK-12-2102	44.95**	30.16*	-22.88**	59.54**	51.72**	-3.13	15.25**	12.06*	-4.70
DHK-12-2034 × DHK-12-2047	66.32**	63.04**	-3.40	45.37**	31.86**	-6.73	17.56**	12.68*	-1.28
DHK-12-2034 × DHK-12-2095	46.02**	45.90**	-13.56	46.80**	38.65**	-10.17*	20.37**	7.53	9.83*
DHK-12-2034 × DHK-12-2091	41.56**	40.39**	-15.42*	36.82**	21.52**	-9.86	10.69*	0.00	-0.43
DHK-12-2034 × DHK-12-2003	38.25**	34.17**	-15.52*	65.10**	55.40**	1.41	3.69	-3.65	-9.83*
DHK-12-2141 × DHK-12-2102	82.76**	69.44**	-6.45	73.01**	57.11**	0.31	7.30	7.04	-8.97*
DHK-12-2141 × DHK-12-2047	82.62**	79.89**	2.39	65.61**	43.81**	1.72	26.55**	24.39**	8.97*
DHK-12-2141 × DHK-12-2095	61.16**	55.80**	-7.85	51.00**	36.23**	-11.74*	4.81	-4.18	-2.14
DHK-12-2141 × DHK-12-2091	70.79**	63.66**	-1.40	52.66**	29.96**	-3.60	13.23**	4.72	4.27
DHK-12-2141 × DHK-12-2003	89.28**	77.63**	11.84	65.33**	48.68**	-2.97	11.27**	5.94	-0.85
DHK-12-2102 × DHK-12-2047	66.24**	51.99**	-13.49	35.35**	28.76**	-8.92	11.88**	10.24*	-3.42
DHK-12-2102 × DHK-12-2095	42.85**	28.38*	-24.07**	18.49**	17.63*	-23.79**	0.91	-7.53	-5.56
DHK-12-2102 × DHK-12-2091	12.16	-0.02	-39.77**	18.14**	9.92	-18.47**	-1.39	-8.58*	-8.97*
DHK-12-2102 × DHK-12-2003	43.26**	25.28*	-21.12**	10.79	9.59	-28.48**	-9.09*	-13.24**	-18.80**
DHK-12-2047 × DHK-12-2095	29.17*	26.73*	-25.04**	24.48**	19.25**	-15.65**	10.36**	2.51	4.70
DHK-12-2047 × DHK-12-2091	21.42	18.06	-28.87**	18.36**	15.61*	-14.24**	6.85	0.43	0.00
DHK-12-2047 × DHK-12-2003	72.33**	64.06**	3.29	36.25**	30.97**	-7.36	10.85**	7.31	0.43
DHK-12-2095 × DHK-12-2091	23.52*	22.39	-26.26**	7.88	1.05	-25.04**	1.69	0.42	2.56
DHK-12-2095 × DHK-12-2003	51.44**	46.86**	-7.54	34.30**	33.81**	-12.68*	-0.87	-5.02	-2.99
DHK-12-2091 × DHK-12-2003	5.67	3.39	-34.90**	-1.23	-7.17	-31.14**	-6.64	-9.44*	-9.83*
Range	5.67 to 89.28	-0.02 to 79.89	-39.77 to 11.84	-1.23 to 79.74	-7.17 to 71.2	-31.14 to 1.72	-9.09 to 26.55	-13.24 to 24.39	-18.8 to 9.83
Average	51.03	43.85	-13.67	40.18	30.74	-11.04	8.31	2.85	2.32

Crosses	100-Seed weight			Protein content			Grain yield per plant		
	Relative heterosis	Hetero beltiosis	Standard heterosis[a]	Relative heterosis	Hetero beltiosis	Standard heterosis[a]	Relative heterosis	Hetero beltiosis	Standard heterosis[a]
DHK-12-2034 × DHK-12-2141	124.07**	81.86**	-48.82**	1.43*	-0.77	-2.98**	218.84**	107.06**	-43.47**
DHK-12-2034 × DHK-12-2102	58.48**	26.17**	-40.05**	-3.51**	-4.96**	-11.11**	213.26**	175.07**	-24.90*
DHK-12-2034 × DHK-12-2047	46.95**	45.58**	-59.03**	-3.48**	-6.66**	-6.55**	239.43**	129.61**	-37.31**
DHK-12-2034 × DHK-12-2095	32.00**	-4.74	-39.53**	-6.39**	-6.45**	-12.50**	89.35**	40.56*	-20.82
DHK-12-2034 × DHK-12-2091	12.29*	-16.67**	-51.57**	6.36**	4.71**	-2.06*	24.53	-15.20	-36.04**
DHK-12-2034 × DHK-12-2003	93.95**	40.50**	-11.91**	-8.53**	-13.75**	-8.93**	125.31**	79.41**	-17.34
DHK-12-2141 × DHK-12-2102	110.46**	44.08**	-31.54**	-6.23**	-9.62**	-11.63**	579.93**	374.30**	-2.08
DHK-12-2141 × DHK-12-2047	218.26**	160.19**	-28.14**	-5.07**	-6.18**	-6.07**	1126.72**	1032.73**	9.13
DHK-12-2141 × DHK-12-2095	94.18**	23.92**	-21.34**	-6.14**	-8.24**	-10.28**	239.31**	94.22**	9.41
DHK-12-2141 × DHK-12-2091	162.63**	70.95**	-0.65	7.03**	3.13**	0.83	125.63**	25.02	-5.71
DHK-12-2141 × DHK-12-2003	109.79**	34.24**	-15.84**	-4.98**	-8.49**	-3.37**	279.88**	123.57**	3.00
DHK-12-2102 × DHK-12-2047	80.14**	42.42**	-32.33**	7.30**	2.26**	2.38**	424.30**	284.48**	-20.62
DHK-12-2102 × DHK-12-2095	0.00	-12.58**	-44.50**	5.43**	3.91**	-2.94**	115.34**	47.13*	-17.12
DHK-12-2102 × DHK-12-2091	14.75**	4.28	-39.40**	5.34**	5.29**	-4.48**	73.12**	10.25	-16.84

(Contt...)

DHK-12-2102 × DHK-12-2003	14.01**	0.21	-37.17**	3.38**	-3.91**	1.47	96.25**	42.10	-34.53**
DHK-12-2047 × DHK-12-2095	41.09**	1.24	-35.73**	-3.42**	-6.66**	-6.55**	152.20**	47.67*	-16.82
DHK-12-2047 × DHK-12-2091	38.02**	1.80	-40.84**	4.68**	-0.28	-0.16	50.63*	-15.06	-35.94**
DHK-12-2047 × DHK-12-2003	76.81**	27.35**	-20.16**	-14.81**	-17.02**	-12.38**	212.13**	88.70**	-13.06
DHK-12-2095 × DHK-12-2091	-3.12	-7.22	-41.10**	8.41**	6.80**	-0.24	14.49	0.00	-24.57*
DHK-12-2095 × DHK-12-2003	20.95**	20.21**	-23.69**	-6.96**	-12.33**	-7.42**	76.25**	60.20**	-9.76
DHK-12-2091 × DHK-12-2003	50.60**	45.09**	-9.03**	2.73**	-4.55**	0.79	14.19	-8.03	-30.63**
Range	-3.12 to 218.26	-16.67 to 160.19	-59.03 to -0.65	-14.81 to 8.41	-17.02 to 6.80	-12.50 to 2.38	14.19 to 1126.72	-15.20 to 1032.73	-43.47 to 9.41
Average	66.49	29.95	-32.01	-0.83	-3.99	-4.96	213.86	129.70	-18.38

* Significant at 5% level; ** Significant at 1% level; a – standard check considered was 30-V-92

Table 8: The best heterotic combinations identified for yield and yield components based on overall performance

S. No.	Characters	Cross combinations	Per se performance	Sca effect	Relative heterosis	Hetero beltiosis	Standard heterosis
1	Days to 50% tasseling	DHK-12-2034 × DHK-12-2091	48.33	-3.73**	-13.17**	-15.70**	-12.65**
		DHK-12-2034 × DHK-12-2102	47.33	-2.84**	-13.41**	-17.44**	-14.46**
2	Days to 50% silking	DHK-12-2034 × DHK-12-2091	51.33	-4.40**	-12.50**	-14.92**	-12.00**
		DHK-12-2102 × DHK-12-2095	51.00	-2.51**	-8.66**	-11.05**	-12.57**
3	Days to maturity	DHK-12-2102 × DHK-12-2095	82.33	-1.21**	-2.76	-5.00**	-6.44**
		DHK-12-2102 × DHK-12-2003	81.67	-0.99**	-3.16*	-5.04**	-7.20**
4	Plant height (cm)	DHK-12-2141 × DHK-12-2003	284.33	52.59**	89.28**	77.63**	11.84
		DHK-12-2141 × DHK-12-2047	260.30	32.31**	82.62**	79.89**	2.39
5	Cob length (cm)	DHK-12-2141 × DHK-12-2102	21.36	3.55**	73.01**	57.11**	0.31
		DHK-12-2034 × DHK-12-2141	21.00	2.24**	79.74**	71.20**	-1.41
6	Kernel rows per cob	DHK-12-2034 × DHK-12-2095	17.13	1.67**	20.37**	7.53	9.83*
		DHK-12-2141 × DHK-12-2047	17.00	1.71**	26.55**	24.39**	8.97*
7	100-seed weight (g)	DHK-12-2141 × DHK-12-2047	18.30	4.31**	218.6**	160.19**	-28.14**
		DHK-12-2034 × DHK-12-2141	13.03	-0.01	124.07**	81.86**	-48.82**
8	Protein content (%)	DHK-12-2102 × DHK-12-2047	8.60	0.58**	7.30**	2.26**	2.38**
		DHK-12-2095 × DHK-12-2091	8.38	0.39**	8.41**	6.80**	-0.24
9	Grain yield per plant (g)	DHK-12-2141 × DHK-12-2047	145.36	56.29**	1126.72**	1032.73**	9.13
		DHK-12-2141 × DHK-12-2102	130.43	38.31**	579.73**	374.30**	-2.08

parent and better parent. Further this cross also recorded significant *sca* effect in positive direction (Table 4). The lines DHK-12-2141 and DHK-12-2047 involved in the above heterotic cross had poor *per se* performance (Table 1) but resulted in heterotic cross indicating their good general combining ability. Similar findings were reported by Rajitha (2013).

Ten crosses for relative heterosis, six crosses for heterobeltiosis and single cross for standard heterosis showed significant and positive effects for protein content. The cross DHK-12-2102 × DHK-12-2047 recorded significant heterosis over mid parent, better parent and standard check. The *sca* effect of this cross is also significant in the desirable direction (Table 4). Further the lines DHK-12-2102 and DHK-12-2047 involved in the above heterotic cross also had good *per se* performance (Table 1). These results were in accordance with the findings of Shete *et al.* (2011) and Avinashe *et al.* (2012).

For grain yield per plant, eighteen crosses for relative heterosis and thirteen crosses for heterobeltiosis showed significant and positive effects. None of the crosses showed significant standard heterosis in positive direction (Table 7). The cross DHK-12-2141 × DHK-12-2047 recorded highest significant positive heterosis over mid parent and better parent. This cross also recorded highest significant *sca* effect in desirable direction (Table 4). However the lines DHK-12-2141 and DHK-12-2047 involved in the above mentioned heterotic cross had poor *per se* performance (Table 1). Similar results over mid and parent parent were reported by Raghu *et al.* (2012) and Rajitha (2013).

The cross combination DHK-12-2141 × DHK-12-2047 recorded significant magnitudes of all three types of heterosis in desirable direction for kernel rows per cob while the same cross registered significant relative heterosis and heterobeltiosis for plant height, cob length, 100-seed weight and grain yield per plant. It also recorded significant *sca* effects and better *per se* performance for all the 4 characters mentioned above. Thus among all the crosses, based on relative heterosis, heterobeltiosis, standard heterosis, *sca* effects and *per se* performance, the cross DHK-12-2141 × DHK-12-2047 was identified as a promising hybrid for majority of characters studied (Table 8). However it has not recorded significant standard heterosis for grain yield per plant.

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