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# HETEROSIS AND COMBINING ABILITY IN CORN (*ZEA MAYS* L.)

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*Key words:* Heterosis, Gene action, GCA, SCA, Corn

**Abstract**

A full diallel cross comprising seven inbred lines was studied for ten characters to determine the nature of gene action in parents and hybrid population. The analysis of variance revealed significant differences for general combining ability (gca) and specific combining ability (sca) indicated the presence of additive as well as non additive gene effects for controlling the traits. However, relative magnitude of these variances indicated that additive gene effects were more prominent for all the characters studied except grain yield/plant. Parent $P_1$ was the best general combiner for grain yield and $P_7$ for both earliness and dwarf plant type. The crosses showing significant sca effects for yield involved high × high, high × low and low × low gca parents and could be exploited for hybrid vigour. The range of heterobeltiosis expressed by different crosses was from 8.23 to 25.78 per cent and -0.22 to -8.31 per cent, respectively, for grain yield and days to silking. The better performing four crosses ($P_1 \times P_7$, $P_6 \times P_7$, $P_1 \times P_4$ and $P_4 \times P_5$) can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.

## Introduction

Corn (*Zea mays* L.) plays a significant role in human and livestock nutrition world-wide. In Bangladesh it is an important cereal crop and ranks third position in terms of acreage. Due to the high yield potentiality, versatile uses, almost year round growth ability and higher per acre yield than the other cereals, area and production of maize is increasing day by day in our country. Hybrid maize cultivation is also becoming popular among the farmers. Its production has increased significantly in the country because of high demand of the fast growing poultry feed industry.

Exploitation of hybrid vigor and selection of parents based on combining ability has been used as an important breeding approach in crop improvement. Developing of high yielding $F_1$s along with other favourable traits are receiving considerable attention. For developing desirable hybrids, information about combining ability of the parents and the resulting crosses is essential. The present study involving a 7 × 7 diallel analysis aimed to determine the better general combining parents and specific combining parents for cross combinations in maize for evolving productive hybrid(s) locally.

## Materials and Methods

Seven inbred lines of corn *viz.* $P_1$ (BIL 29), $P_2$ (BIL 43), $P_3$ (BIL 47), $P_4$ (CML 480), $P_5$ (CML 481), $P_6$ (CML 486) and $P_7$ (CML 487) collected from International Maize and Wheat Improvement Centre (CIMMYT), Mexico were crossed in all possible combinations in the *rabi* season of 2003-2004 at Bangladesh Agricultural Research Institute (BARI), Gazipur. During *rabi* season 2004-05, the 42 $F_1$s and along with their seven parents were grown following Randomized Complete Block Design with three replications in the same farm. Each plot comprised of a single 5.0 m long row. The unit plot size was 5 × 0.75 m. Spacing adopted was 75 × 20 cm between rows and hills, respectively. One healthy seedling per hill was kept after proper thinning. Fertilizers were applied at the rate of 250, 120, 120, 40 and 5 kg/ha of N, $P_2O_5$, $K_2O$, S and Zn, respectively.

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Standard agronomic practices were followed (Quayyum 1993) and plant protection measures were taken when required. Data on days to 50% tasseling (DT) and silking (DS) were recorded on whole plot basis. Ten randomly selected plants were used for recording observations on YP = Yield (t/ha.); PH = Plant height (cm), EH = Ear height (cm); GR = No. of grain per row; NR = No. of seed row per cob; CL= Cob length (cm); CD = Cob diameter (cm) and TSW = Thousand seed weight (g). General and specific combining ability variances were estimated according to Griffings (1956) Method II Model I.

## Results and Discussion

Analysis of variances for combining ability (Table 1) revealed that both gca and sca variances were highly significant for all the characters studied indicating importance of additive as well as non-additive type of gene action in controlling the traits. However, variances due to gca were much higher in magnitude than sca for all the characters, except number of seeds row per cob. The ratio of the components revealed that the magnitudes of sca components were much higher than that of gca in all crosses except number of seeds row per cob. This indicated predominance of additive gene action for all the characters except number of seeds per cob in a row. Ivy and Hawlader (2000) in their study also found higher gca variances in plant height, ear height and days to maturity. Debnath *et al*. (1988), Sanghi *et al*. (1983) Roy *et al.* (1998) and Das and Islam (1994) also reported predominance of non-additive gene action for grain yield in the same crop.

**Table 1. Analysis of variance for combining ability of different characters in maize in a 7 × 7 diallel cross.**

| Source of variation | df | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| | | YP | DT | DS | PH | EH |
| Rep. | 2 | 0.05 | 0.88 | 0.24 | 0.79 | 0.52 |
| Crosses | 48 | 13.65** | 43.32** | 36.70** | 1093.76** | 733.74** |
| gca | 6 | 28.25** | 138.61** | 107.26** | 2321.01** | 2024.67** |
| sca | 21 | 19.99** | 47.80** | 46.64** | 1194.36** | 816.16** |
| Reciprocal cross | 21 | 3.15** | 11.60** | 6.60** | 642.51** | 282.48** |
| Error | 96 | 0.11 | 0.36 | 0.43 | 0.28 | 0.12 |
| gca/sca | | 1.41 | 2.90 | 2.30 | 1.94 | 2.48 |

(Contd.)

| Source of variation | df | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| | | GR | NR | CL | CD | TSW |
| Rep. | 2 | 0.02 | 0.14 | 0.25 | 0.09 | 0.13 |
| Crosses | 48 | 43.18** | 1.90** | 11.07** | 6.98** | 2.52** |
| gca | 6 | 90.25** | 1.77** | 29.63** | 19.12** | 6.77** |
| sca | 21 | 65.39** | 2.62** | 13.88** | 8.97** | 2.71** |
| Reciprocal cross | 21 | 7.53** | 1.21** | 2.96** | 1.52** | 1.12** |
| Error | 96 | 0.20 | 0.22 | 0.11 | 0.10 | 0.06 |
| gca/sca | | 1.38 | 0.68 | 2.13 | 2.13 | 2.50 |

**P = 0.01, GCA = General Combining Ability, SCA = Specific Combining Ability, YP = Yield (t/ha.); DT = Days to tasseling; DS = Days to silking; PH = Plant height (cm), EH = Ear height (cm); GR = No. of grain per row; NR = No. of seed row per cob; CL = Cob length (cm); CD = Cob diameter (cm) and TSW = Thousand seed weight (g).

*General combining ability (gca) effects:* The gca effects and *per se* performance of the parents revealed that none of the parents were found to be a good general combiner for all the characters studied (Table 2). A wide range of variability of gca effects was observed among the parents. For grain yield, parents $P_1$, and $P_4$, showed significant positive gca effect and simultaneously possessed high mean value indicating that the *per se* performance of the parents could prove as an useful index for combining ability. Roy *et al.* (1998) and Hussain *et al.* (2003) also observed similar phenomenon. So, these four parents could be used extensively in hybrid breeding program with a view to increasing the yield level.

**Table 2. Estimates of general combining ability effects (gca) and mean performance of the parents for different characters in maize.**

| Parents | YP | | DT | | DS | | PH | | EH | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | gca | Mean | gca | Mean | gca | Mean | gca | Mean | gca |
| $P_1$ | 9.2 | 1.4** | 86.26 | 1.51** | 90.90 | 1.31** | 206.7 | 14.67** | 100.5 | 10.11** |
| $P_2$ | 8.0 | 0.1 | 83.48 | –1.28** | 88.36 | –1.23** | 192.3 | 0.25* | 86.5 | –3.91** |
| $P_3$ | 6.9 | –1.0** | 81.33 | –3.42** | 86.81 | –2.78** | 188.6 | –3.41** | 83.6 | –6.76** |
| $P_4$ | 8.5 | 0.7** | 86.52 | 1.77** | 91.43 | 1.84** | 190.7 | –1.29** | 99.8 | 9.37** |
| $P_5$ | 7.2 | –0.6** | 85.57 | 0.82** | 89.88 | 0.29** | 187.3 | –4.74** | 88.5 | –1.93** |
| $P_6$ | 7.5 | –0.3** | 85.38 | 0.63** | 90.48 | 0.88** | 195.0 | 3.00** | 89.3 | –1.14** |
| $P_7$ | 7.5 | –0.3** | 84.74 | –0.02 | 89.29 | – 0.31* | 183.5 | –8.47** | 84.6 | –5.75** |
| SE (gi) | | 0.05 | | 0.09 | | 0.09 | | 0.08 | | 0.05 |
| LSD(5%) | | 0.12 | | 0.222 | | 0.222 | | 0.20 | | 0.12 |
| LSD(1%) | | 0.19 | | 0.334 | | 0.334 | | 0.30 | | 0.19 |

(Contd.)

| Parents | GR | | NR | | CL | | CD | | TSW | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | gca | Mean | gca | Mean | gca | Mean | gca | Mean | gca |
| $P_1$ | 36.68 | 1.42** | 13.90 | –0.14 | 18.27 | 0.89** | 15.14 | 0.16** | 332.4 | 17.34** |
| $P_2$ | 37.14 | 1.88** | 14.00 | –0.04 | 18.36 | 0.98** | 15.87 | 0.89** | 327.7 | 12.60** |
| $P_3$ | 34.24 | –1.02** | 14.28 | 0.24** | 16.59 | –0.79** | 14.25 | –0.72** | 308.3 | –6.83** |
| $P_4$ | 34.43 | –0.83** | 13.70 | –0.33** | 16.50 | –0.88** | 14.41 | –0.56** | 297.7 | –17.35** |
| $P_5$ | 36.04 | 0.78** | 14.11 | 0.07 | 17.59 | 0.21** | 15.73 | 0.76** | 315.0 | –0.09** |
| $P_6$ | 35.25 | –0.01 | 14.28 | 0.24** | 17.87 | 0.49** | 15.13 | 0.16** | 320.7 | 5.63** |
| $P_7$ | 33.02 | –2.24** | 14.01 | –0.03 | 16.49 | –0.89** | 14.28 | –0.69** | 303.8 | –11.30** |
| SE (gi) | | 0.06 | | 0.07 | | 0.05 | | 0.04 | | 0.01 |

| | | | | | |
|---|---|---|---|---|---|
| LSD(5%) | 0.15 | 0.17 | 0.12 | 0.10 | 0.02 |
| LSD(1%) | 0.22 | 0.26 | 0.19 | 0.15 | 0.04 |

Parents $P_2$ and $P_3$ showed significant negative gca both for days to tasseling and days to silking and use of $P_3$ might be useful in developing early hybrid varieties. In case of plant height parents $P_3$, $P_4$, $P_5$ and $P_7$ showed significant negative heterosis and $P_7$ might be useful for developing dwarf hybrid. Parent $P_1$ showed significant positive gca for yield/plant, days to tasseling, days to silking, plant height, ear height, no. of grain per cob, cob length, cob diameter and 1000 seed weight. So, $P_1$ may be good combiner both for high yield and other traits. The estimate of gca effect showed that parents $P_1$ and $P_4$, respectively were the best combiner for grain yield and earliness. Debnath and Sarker (1989), Das and Islam (1994) and Hussain *et al.* (2003) also found inbred line(s) as good general combiner for short plant type in their study.

Parents $P_2$, $P_3$, $P_5$, $P_6$ and $P_6$ showed significant negative gca for ear height. Ahamed and Khatun (2004) found similar results in three parents and Roy *et al.* (1998) also observed similar results in two parents.

*Specific combining ability effects (sca):* The sca and reciprocal effects are shown in Table 3. For grain yield generally the crosses showing significant positive sca effects also possessed high mean performance and significant negative sca effects possessed low mean performance. This reflects that high *per se* value of the crosses indicated their potentiality. Thirteen crosses exhibited significant positive sca effects for grain yield. These crosses involved high × high, high × low and low × low general combining parents. Although the cross $P_6 \times P_7$ involved low × low general combiners, exhibited the highest significant positive sca effect. The cross $P_1 \times P_4$ involved the two best general combiners showed the medium sca effects. The cross $P_1 \times P_7$ involved high × low general combiner, exhibited second highest significant sca effect possessed highest mean value. Except in one cross ($P_4 \times P_6$), all high × low general combiners showed significant positive sca effects. Ivy and Hawlader (2000) also reported that good general combining parents do not always show high sca effects in their hybrid combinations. On the contrary, Paul and Duara (1991) reported that the parents with high gca always produce hybrids with high estimates of sca.

**Table 3. Estimates of specific combining ability effects (sca) and mean performance of the parents for different characters in maize.**

| Parents | YP | | DT | | DS | | PH | | EH | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | sca | Mean | sca | Mean | sca | Mean | sca | Mean | sca |
| $P_1 \times P_2$ | 10.26 | 0.89** | 86.17 | 1.18** | 88.83 | –0.84** | 204.4 | –2.60** | 93.9 | –2.70** |
| $P_1 \times P_3$ | 8.64 | 0.35** | 81.17 | –1.67** | 88.50 | 0.38 | 198.0 | –5.34** | 103.9 | 10.12** |
| $P_1 \times P_4$ | 10.86 | 0.90** | 90.00 | 1.97** | 94.67 | 1.93** | 225.6 | 20.14** | 117.7 | 7.85** |
| $P_1 \times P_5$ | 7.67 | –0.94** | 89.67 | 2.59** | 93.33 | 2.14** | 213.6 | 11.62** | 106.5 | 7.88** |
| $P_1 \times P_6$ | 8.89 | –0.05 | 90.17 | 3.28** | 95.17 | 3.38** | 223.9 | 14.22** | 112.9 | 13.56** |
| $P_1 \times P_7$ | 10.93 | 2.01** | 86.00 | –0.24 | 89.83 | –0.77** | 201.3 | 3.01** | 94.4 | –0.36* |
| $P_2 \times P_3$ | 7.14 | 0.14 | 83.00 | 2.95** | 88.17 | 2.59** | 189.3 | 0.38 | 85.6 | 5.91** |
| $P_2 \times P_4$ | 8.66 | –0.01 | 85.33 | 0.09 | 88.67 | –1.53** | 195.2 | 4.15** | 88.4 | –7.42** |
| $P_2 \times P_5$ | 7.72 | 0.39** | 81.83 | –2.46** | 88.00 | –0.65* | 176.6 | –10.9** | 79.7 | –4.90** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_2 \times P_6$ | 7.07 | –0.57** | 79.83 | –4.27** | 85.00 | –4.24** | 185.9 | –9.39** | 82.5 | –2.85** |
| $P_2 \times P_7$ | 7.45 | –0.18 | 83.50 | 0.04 | 89.83 | 1.78** | 198.5 | 14.64** | 90.1 | 9.33** |
| $P_3 \times P_4$ | 8.95 | 1.37** | 80.83 | –2.27** | 86.67 | –1.98** | 185.0 | –2.35** | 96.3 | 3.29** |
| $P_3 \times P_5$ | 6.84 | 0.60** | 80.17 | –1.98** | 86.17 | –0.93** | 189.2 | 5.26** | 79.9 | –1.80** |
| $P_3 \times P_6$ | 7.14 | 0.57** | 81.67 | –0.29 | 86.67 | –1.03** | 188.2 | –3.44** | 84.8 | 2.34** |
| $P_3 \times P_7$ | 5.74 | –0.81** | 79.83 | –1.48** | 83.83 | –2.67** | 178.9 | –1.28** | 81.0 | 3.08** |
| $P_4 \times P_5$ | 9.70 | 1.79** | 86.00 | –1.34** | 90.17 | –1.55** | 163.0 | –22.9** | 107.9 | 10.07** |
| $P_4 \times P_6$ | 9.50 | 1.26** | 87.67 | 0.52* | 91.67 | –0.65** | 198.9 | 5.11** | 102.3 | 3.67** |
| $P_4 \times P_7$ | 7.49 | –0.72** | 85.50 | –1.01** | 90.50 | –0.62* | 181.7 | –0.59* | 100.4 | 6.35** |
| $P_5 \times P_6$ | 7.61 | 0.72** | 84.33 | –1.86** | 89.17 | –1.60** | 163.7 | 16.86** | 60.2 | 11.09** |
| $P_5 \times P_7$ | 8.64 | 1.77** | 84.33 | –1.22** | 87.33 | –2.24** | 207.2 | 19.15** | 98.4 | 3.99** |
| $P_6 \times P_7$ | 9.43 | 2.24** | 83.67 | –1.70** | 88.67 | –1.50** | 198.0 | –4.98** | 86.7 | –8.91** |
| SE (ij) | | 0.12 | | 0.21 | | 0.23 | | 0.26 | | 0.12 |
| LSD (5%) | | 0.25 | | 0.44 | | 0.48 | | 0.54 | | 0.25 |
| LSD (1%) | | 0.34 | | 0.59 | | 0.65 | | 0.74 | | 0.34 |

(Contd.)

| Parents | GR | | RC | | CL | | CD | | TSW | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | sca | Mean | sca | Mean | sca | Mean | sca | Mean | sca |
| $P_1 \times P_2$ | 38.70 | 0.14 | 13.80 | –0.05 | 19.60 | 0.35 | 15.17 | –0.86** | 338.3 | –6.70** |
| $P_1 \times P_3$ | 36.60 | 0.94** | 14.43 | 0.30 | 17.13 | –0.35 | 14.33 | –0.09 | 320.8 | –4.77** |
| $P_1 \times P_4$ | 39.65 | 3.80** | 13.47 | –0.09 | 18.57 | 1.17 | 15.23 | 0.66** | 332.2 | 17.09** |
| $P_1 \times P_5$ | 36.67 | –0.79** | 13.50 | –0.47* | 18.42 | –0.07 | 15.62 | –0.28* | 344.8 | 12.49** |
| $P_1 \times P_6$ | 38.63 | 1.96** | 13.90 | –0.23 | 18.87 | 0.10 | 15.90 | 0.61** | 351.7 | 13.61** |
| $P_1 \times P_7$ | 36.20 | 1.76** | 13.97 | 0.10 | 17.53 | 0.15 | 15.18 | 0.74** | 325.8 | 4.71** |
| $P_2 \times P_3$ | 34.80 | –1.32** | 13.57 | -0.67** | 17.28 | –0.28 | 15.17 | 0.02 | 317.5 | –3.36** |
| $P_2 \times P_4$ | 35.97 | –0.34* | 14.47 | 0.81** | 17.30 | –0.18 | 16.00 | 0.69** | 311.7 | 1.33** |
| $P_2 \times P_5$ | 34.67 | –3.25** | 14.13 | 0.06 | 17.82 | –0.75 | 16.23 | –0.39** | 328.3 | 0.73** |
| $P_2 \times P_6$ | 38.60 | 1.47** | 14.13 | -0.10 | 18.47 | –0.38 | 16.10 | 0.08 | 331.8 | -1.48** |
| $P_2 \times P_7$ | 37.82 | 2.92** | 13.87 | -0.10 | 18.78 | 1.32 | 16.07 | 0.89** | 347.8 | 31.45** |
| $P_3 \times P_4$ | 36.98 | 3.57** | 14.47 | 0.53** | 17.27 | 1.56 | 14.75 | 1.06** | 295.0 | 4.09** |
| $P_3 \times P_5$ | 35.07 | 0.05 | 14.40 | 0.05 | 16.67 | –0.13 | 15.00 | –0.01 | 301.3 | -6.84** |
| $P_3 \times P_6$ | 35.38 | 1.15** | 14.57 | 0.05 | 17.60 | 0.52 | 14.03 | –0.38** | 328.3 | 14.45** |
| $P_3 \times P_7$ | 34.10 | 2.10** | 15.03 | 0.78** | 15.97 | 0.27 | 13.23 | –0.33** | 332.8 | 35.87** |
| $P_4 \times P_5$ | 38.03 | 2.82** | 13.67 | –0.11 | 18.17 | 1.45 | 16.10 | 0.93** | 275.0 | –22.65** |
| $P_4 \times P_6$ | 34.13 | –0.29 | 14.60 | 0.66** | 17.67 | 0.67 | 15.47 | 0.90** | 320.0 | 16.64** |
| $P_4 \times P_7$ | 30.83 | –1.36** | 13.13 | –0.55** | 16.57 | 0.96 | 14.00 | 0.28* | 265.0 | –21.44** |
| $P_5 \times P_6$ | 36.83 | 0.80 | 14.33 | –0.02 | 18.20 | 0.12 | 15.60 | –0.29* | 309.0 | –11.63** |
| $P_5 \times P_7$ | 35.40 | 1.60** | 13.57 | –0.52** | 17.33 | 0.64 | 16.17 | 1.13** | 320.8 | 17.14** |
| $P_6 \times P_7$ | 34.78 | 1.77** | 15.60 | 1.35** | 18.63 | 1.66 | 15.73 | 1.29** | 309.2 | –0.24** |
| SE (ij) | | 0.16 | | 0.17 | | 0.12 | | 0.11 | | 0.03 |
| LSD(5%) | | 0.33 | | 0.35 | | 0.25 | | 0.23 | | 0.06 |

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| LSD(1%) | 0.45 | 0.48 | 0.34 | 0.31 | 0.08 |
|---|---|---|---|---|---|

*P = 0.05, **P = 0.01, YP = Yield (t/ha.); DT = Days to tasseling; DS = Days to silking; PH = Plant height (cm) EH = Ear height (cm); GR = No. of grain per row; NR = No. of seed row per cob; CL = Cob length (cm); CD = Cob diameter (cm) and TSW = Thousand seed weight (g)

Roy *et al.* (1998) also found significant positive sca effects in high × low general combiners. Three crosses $P_2 \times P_6$, $P_3 \times P_7$ and $P_4 \times P_7$ showed significant negative sca effects for grain yield involved low × low, low × low and high × low general combiners. Roy *et al.*(1998) and Ivy and Hawlader (2000) also found the similar results.

**Table 4. Reciprocal effects.**

| Parents | YP | | DT | | DS | | PH | | EH | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | sca | Mean | sca | Mean | sca | Mean | sca | Mean | sca |
| $P_2 \times P_1$ | 9.10 | 0.86 | 87.33 | –1.50 | 90.00 | –1.17 | 192.5 | 11.70 | 86.27 | 8.50 |
| $P_3 \times P_1$ | 5.69 | 0.07 | 82.33 | –1.17 | 88.67 | 0.50 | 191.9 | 9.23 | 96.53 | 6.67 |
| $P_4 \times P_1$ | 9.09 | –0.19 | 90.33 | -0.33 | 94.67 | 0.00 | 224.3 | 0.17 | 123.80 | –6.07 |
| $P_5 \times P_1$ | 7.29 | –0.23 | 89.33 | –0.33 | 94.33 | –1.00 | 209.5 | 3.53 | 100.13 | 6.82 |
| $P_6 \times P_1$ | 9.94 | –0.83 | 89.67 | –0.17 | 95.00 | –0.17 | 226.9 | –1.20 | 109.67 | 2.80 |
| $P_7 \times P_1$ | 10.00 | 0.59 | 86.67 | 0.67 | 91.00 | –1.17 | 202.7 | –1.07 | 95.00 | –0.93 |
| $P_3 \times P_2$ | 6.08 | 0.56 | 85.00 | –2.33 | 89.67 | –1.83 | 196.1 | -6.73 | 96.40 | –10.83 |
| $P_4 \times P_2$ | 6.25 | 0.01 | 84.33 | 1.00 | 87.33 | 1.33 | 196.7 | -0.98 | 91.67 | –3.23 |
| $P_5 \times P_2$ | 7.21 | 0.49 | 83.33 | –1.50 | 88.33 | –0.33 | 183.1 | -6.10 | 80.60 | –1.02 |
| $P_6 \times P_2$ | 8.29 | 0.44 | 80.33 | –0.17 | 86.00 | –1.00 | 175.3 | 10.57 | 78.87 | 3.03 |
| $P_7 \times P_2$ | 6.45 | 0.93 | 84.00 | 0.50 | 89.67 | 0.17 | 199.7 | -1.87 | 105.33 | –15.27 |
| $P_4 \times P_3$ | 7.80 | 1.42 | 81.33 | –0.50 | 90.00 | –1.33 | 181.7 | 3.00 | 98.50 | –2.37 |
| $P_5 \times P_3$ | 5.10 | 1.57 | 81.00 | –0.83 | 88.33 | –2.17 | 178.8 | 10.17 | 65.87 | 12.70 |
| $P_6 \times P_3$ | 6.60 | 0.87 | 82.00 | –0.67 | 85.33 | –0.33 | 187.9 | 0.07 | 76.93 | 7.50 |
| $P_7 \times P_3$ | 6.39 | 0.01 | 81.00 | –1.17 | 85.67 | –1.17 | 168.7 | 12.17 | 74.60 | 4.43 |
| $P_5XP_4$ | 9.25 | 0.07 | 86.00 | 1.00 | 89.67 | 0.17 | 123.5 | 37.30 | 110.67 | –2.43 |
| $P_6 \times P_4$ | 8.77 | 0.94 | 85.67 | 2.67 | 91.33 | 0.33 | 197.2 | 0.53 | 110.47 | –8.17 |
| $P_7 \times P_4$ | 7.62 | 0.01 | 85.00 | 0.50 | 90.67 | 0.50 | 180.9 | 1.30 | 95.73 | 4.63 |
| $P_6 \times P_5$ | 7.10 | 1.18 | 81.33 | 3.00 | 87.33 | 1.83 | 196.5 | 10.50 | 93.67 | 5.15 |
| $P_7 \times P_5$ | 9.00 | –0.03 | 82.00 | 2.33 | 87.67 | 0.33 | 195.3 | 2.33 | 86.07 | 0.37 |
| $P_7 \times P_6$ | 9.12 | 0.13 | 84.67 | –1.33 | 90.33 | –1.00 | 188.7 | –6.6 | 81.00 | –6.73 |
| SE | | 0.13 | | 0.24 | | 0.27 | | 0.22 | | 0.14 |
| LSD(5%) | | 0.27 | | 0.50 | | 0.56 | | 0.46 | | 0.29 |
| LSD(1%) | | 0.37 | | 0.68 | | 0.76 | | 0.62 | | 0.40 |

(Contd.)

| Parents | GR | | RC | | CL | | CD | | TSW | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | sca | Mean | sca | Mean | sca | Mean | sca | Mean | sca |
| $P_2 \times P_1$ | 38.13 | –0.97 | 14.27 | –0.60 | 17.6 | 0.00 | 15.73 | –0.43 | 320 | 0.022 |
| $P_3 \times P_1$ | 35.93 | 1.87 | 14.27 | 0.17 | 15.9 | 1.13 | 14.47 | –0.20 | 310 | –0.001 |
| $P_4 \times P_1$ | 35.73 | 2.75 | 12.93 | 0.53 | 16.2 | 0.83 | 14.20 | –0.03 | 340 | –0.005 |
| $P_5 \times P_1$ | 35.80 | 0.87 | 14.00 | 0.10 | 18.3 | 0.15 | 15.87 | –0.32 | 330 | 0.014 |
| $P_6 \times P_1$ | 39.70 | –0.30 | 13.00 | 0.77 | 18.4 | 0.53 | 15.90 | 0.10 | 320 | 0.007 |
| $P_7 \times P_1$ | 34.5 | 0.60 | 13.2 | 0.10 | 17.00 | 0.53 | 15.00 | 0.18 | 310 | 0.001 |
| $P_3 \times P_2$ | 33.93 | 0.60 | 14.20 | –0.83 | 17.5 | –0.22 | 15.00 | 0.10 | 320 | –0.004 |
| $P_4 \times P_2$ | 31.25 | –0.97 | 12.5 | 0.07 | 15.25 | 0.30 | 13.00 | 0.00 | 310 | –0.003 |
| $P_5 \times P_2$ | 35.50 | 1.87 | 14.00 | 0.13 | 18.0 | 0.12 | 16.50 | –0.10 | 350 | –0.002 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_6 \times P_2$ | 37.00 | 2.75 | 14.27 | –0.13 | 18.3 | 0.80 | 16.00 | –0.50 | 350 | –0.022 |
| $P_7 \times P_2$ | 39.20 | 0.87 | 14.80 | 0.13 | 19.6 | -0.58 | 15.40 | 0.93 | 340 | –0.002 |
| $P_4 \times P_3$ | 35.80 | –0.30 | 15.60 | –0.67 | 16.6 | 0.97 | 14.60 | 0.48 | 300 | 0.000 |
| $P_5 \times P_3$ | 31.87 | 0.60 | 14.00 | 0.93 | 15.1 | 1.33 | 13.73 | 1.13 | 270 | 0.017 |
| $P_6 \times P_3$ | 35.47 | 0.60 | 14.53 | 0.03 | 17.1 | 0.20 | 13.93 | 1.30 | 310 | 0.018 |
| $P_7 \times P_3$ | 28.15 | –0.97 | 15.27 | –0.83 | 13.9 | 0.50 | 13.00 | –0.03 | 310 | –0.013 |
| $P_5XP_4$ | 34.2 | 1.87 | 15.01 | 0.33 | 14.00 | 0.17 | 12.00 | 0.10 | 310 | 0.000 |
| $P_6 \times P_4$ | 336.00 | 2.75 | 152.00 | –0.20 | 17.0 | 1.03 | 15.80 | 0.13 | 300 | 0.025 |
| $P_7 \times P_4$ | 31.00 | 0.87 | 13.20 | –0.07 | 16.8 | 0.00 | 14.00 | 0.00 | 270 | 0.000 |
| $P_6 \times P_5$ | 38.53 | –0.30 | 15.20 | –0.20 | 19.1 | –1.47 | 15.13 | 0.13 | 290 | 0.034 |
| $P_7 \times P_5$ | 35.87 | 0.60 | 13.33 | 0.10 | 17.7 | 0.10 | 16.33 | –0.17 | 330 | 0.006 |
| $P_7 \times P_6$ | 33.10 | 0.60 | 12.00 | 0.00 | 14.00 | 0.63 | 14.00 | 0.73 | 0.31 | 0.009 |
| SE | | 0.18 | | 0.19 | | 0.13 | | 0.13 | | 0.003 |
| LSD(5%) | | 0.37 | | 0.40 | | 0.27 | | 0.27 | | 0.01 |
| LSD(1%) | | 0.51 | | 0.54 | | 0.37 | | 0.37 | | 0.01 |

*P = 0.05, **P = 0.01, YP = Yield (t/ha.); DT = Days to tasseling; DS = Days to silking; PH = Plant height (cm) EH = Ear height (cm); GR = No. of grain per row; NR = No. of seed row per cob; CL = Cob length (cm); CD = Cob diameter (cm) and TSW = Thousand seed weight (g)

For days to tasseling 11 crosses exhibited significant negative sca effects, indicating early pollen shading. These crosses mostly involved high × average, high × low, average × low and low × low general combining parents. For days to silking 14 crosses showed significant negative sca effects indicating early maturity.

For plant height, nine crosses exhibited significant negative sca effects indicating dwarfness of the hybrid. These crosses involved mainly high × high , high × low and low × low general combining parents. Ear height followed the same trend. For this character eight crosses showed significant positive sca effects. None of the crosses in plant height and ear height showed significant negative sca effects although many crosses involved low general combining parents.

*Heterosis:* For grain yield/plant heterosis over better parent was found in the range of 8.23 to 25.78 per cent (Table 29). Ten crosses showed significant positive heterobeltiosis. Appreciable percentage of heterosis for grain yield in maize was also reported by Lonnquist and Gardner (1961), Akhtar and Singh (1981) and Gerrish (1981). In another study, Debnath (1987) and Roy *et al.*(1998), respectively, observed 13.95 to 245.10 per cent and -16.42 to 71.82 per cent heterobeltiosis.

Significant negative heterobeltiosis ranged from –0.6 to –7.73% and –0.22 to 8.31% was observed for days to tasseling and days to silking, respectively. Sixteen crosses showed significant negative heterobeltiosis for days to tasseling and days to silking and at the same time significant positive heterobeltiosis for yield. Fourteen crosses showed significant negative heterobeltiosis both in days to tasseling and days to silking coupled with significant positive heterobeltiosis for yield. Roy *et al.*(1998) also observed the same trend for some crosses in their study. Heterobeltiosis for different crosses ranged from –16.05 to 9.14 percent and –31.59 to 17.11 per cent, respectively, for plant and ear height. Thirteen crosses gave significant negative heterobeltiosis both in plant height and ear height. Except cross $P_2 \times P_5$, rest of the crosses showed significant positive heterobeltiosis both in plant and ear height.

**Table 5. Heterobeltiosis (%) of the crosses for different characters in maize.**

| Cross | YP | DT | DS | PH | EH |
|---|---|---|---|---|---|
| $P_1 \times P_2$ | 11.50** | –0.10 | –2.28** | –1.11 | –6.57* |
| $P_1 \times P_3$ | –6.12 | –5.90** | –2.64** | –4.21** | 3.38 |
| $P_1 \times P_4$ | 17.99** | 4.34** | 4.15** | 9.14** | 17.11** |
| $P_1 \times P_5$ | –16.65** | 3.64** | 2.08* | 3.34** | 5.97* |
| $P_1 \times P_6$ | –3.39 | 4.53** | 4.70** | 8.32** | 12.34** |
| $P_1 \times P_7$ | 18.77** | –0.30 | –1.18 | –2.61** | –6.07* |
| $P_2 \times P_3$ | –10.81** | –0.57 | –0.22 | –1.56** | –1.04 |
| $P_2 \times P_4$ | 8.23* | 2.22* | 0.35 | 1.51** | –11.42** |
| $P_2 \times P_5$ | –9.24* | –5.42** | –3.75** | –7.39** | –9.94** |
| $P_2 \times P_6$ | –11.58** | –4.37** | –6.06** | –4.67** | –7.61** |
| $P_2 \times P_7$ | –6.90 | –1.46 | 0.60 | 3.22* | 4.16 |
| $P_3 \times P_4$ | 5.27 | –6.58** | –5.21** | –2.99** | –3.51 |
| $P_3 \times P_5$ | –19.53** | –7.34** | –5.75** | –0.79 | –19.94** |
| $P_3 \times P_6$ | –16.04** | –5.61** | –5.21** | –3.49** | –15.03** |
| $P_3 \times P_7$ | –32.53** | –7.73** | –8.31** | –6.19** | –18.84** |
| $P_4 \times P_5$ | 14.10** | –0.60 | –1.38 | –14.53** | 8.12** |
| $P_4 \times P_6$ | 11.71** | 1.33 | 0.26 | 2.00** | 2.51 |
| $P_4 \times P_7$ | –11.88** | –1.18 | –1.02 | –4.72** | 0.60 |
| $P_5 \times P_6$ | 1.49 | –1.45 | –1.45 | –16.05** | –32.59** |
| $P_5 \times P_7$ | 15.16** | –1.23 | –3.48** | 6.26** | 10.19** |
| $P_6 \times P_7$ | 25.78** | –2.00* | –2.00* | 1.54** | –2.91 |
| SE | 3.34 | 0.82 | 0.72 | 1.40 | 2.62 |
| LSD(5%) | 6.95 | 1.71 | 1.50 | 2.91 | 5.45 |
| LSD (5%) | 9.45 | 2.32 | 2.04 | 3.96 | 7.41 |

(Contd.)

| Cross | GR | RC | CL | CD | TSW |
|---|---|---|---|---|---|
| $P_1 \times P_2$ | 4.20** | –1.43 | 6.75** | –4.41** | 1.77 |
| $P_1 \times P_3$ | –1.45 | 1.05 | –6.24** | –5.35** | –3.49* |
| $P_1 \times P_4$ | 8.10** | –3.09** | 1.64 | 0.59 | –0.06 |
| $P_1 \times P_5$ | –0.03 | –4.32** | 0.82 | –0.70 | 3.73** |
| $P_1 \times P_6$ | 5.32** | –2.66** | 3.28** | 5.02** | 5.81** |
| $P_1 \times P_7$ | –1.31 | –0.29 | –4.05** | 0.26 | –1.99 |
| $P_2 \times P_3$ | –6.30** | –4.97** | –5.88** | –4.41** | –3.11** |
| $P_2 \times P_4$ | –3.15* | 3.36** | –5.77** | 0.82 | –4.88** |
| $P_2 \times P_5$ | –6.65** | 0.14 | 8.00** | 2.27** | 0.18 |
| $P_2 \times P_6$ | 3.93* | –1.05 | 0.60 | 1.45 | 1.25 |
| $P_2 \times P_7$ | 1.83 | –1.00 | 2.29** | 1.26 | 6.13** |
| $P_3 \times P_4$ | 7.41** | 1.33 | 4.10** | 2.36** | –4.31** |
| $P_3 \times P_5$ | 1.86 | 0.84 | –5.23** | –4.64** | –4.35** |
| $P_3 \times P_6$ | 2.76* | 2.03** | –1.51 | –7.27** | 2.37 |
| $P_3 \times P_7$ | -0.96 | 5.25** | –3.74** | –8.19** | 9.55** |
| $P_4 \times P_5$ | 5.52** | –3.12** | 3.30** | 2.35 | –12.70** |
| $P_4 \times P_6$ | –5.30** | 2.24** | –1.12 | 2.25 | –0.22 |
| $P_4 \times P_7$ | –14.46** | –6.28** | 0.42 | –2.85* | –12.77** |
| $P_5 \times P_6$ | 2.19 | 0.35 | 3.47** | –0.83 | –3.65** |
| $P_5 \times P_7$ | –1.78 | –3.83** | –1.48 | 2.80* | 1.84 |

(Contd.)

(Contd.)

| | | | | | |
|---|---|---|---|---|---|
| $P_6 \times P_7$ | –1.33 | 9.24** | 4.25** | 3.97** | –3.59** |
| SE | 1.17 | 0.79 | 0.92 | 0.82 | 1.20 |
| LSD (5%) | 2.43 | 1.64 | 1.91 | 1.71 | 2.50 |
| LSD (5%) | 3.31 | 2.24 | 2.60 | 2.32 | 3.40 |

*P = 0.05, **P = 0.01, YP = Yield (t/ha.); DT = Days to tasseling; DS = Days to silking; PH= Plant height (cm) EH = Ear height (cm); GR = No. of grain per row; NR = No. of seed row per cob; CL = Cob length (cm); CD = Cob diameter (cm) and TSW = Thousand seed weight (g)

Parents with good positive gca for yield ($P_1$ and $P_4$), negative gca for days to silking and days to maturity ($P_2$ and $P_5$), dwarf plant height and ear height ($P_7$) may be extensively used in hybridization program as a donor. The better performing four crosses ($P_1 \times P_7$, $P_6 \times P_7$, $P_1 \times P_4$, and $P_4 \times P_5$) can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor. These crosses also need to be evaluated through multiplications.

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