HETEROSIS AND COMBINING ABILITY STUDIES IN GRAIN SORGHUM†

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Extensive genetic analysis of exotic × Indian crosses in sorghum have led to the conclusion that the answer to a major genetic improvement in yield performance of future hybrids lies in selecting and developing known exotic × Indian cross derivatives into males and females. The present investigations were undertaken to study the magnitude of heterosis, the nature of combining ability and to explore the possibilities of developing new grain sorghum hybrids using exotic male sterile lines and the true breeding derivatives of exotic × Indian crosses.

MATERIALS AND METHODS

Two separate experiments were conducted. In experiment I eight male steriles 'ms 6920 (white martin)', 'Tx 616A', 'ms 2119 (westland)', 'ms 3118 (martin)', 'msOK 24', 'ms Redlan', 'ms 611 (waxy combine kafir)', and 'msE 800 (Uganda)' were crossed with each of four pollinator parents (IS 84, GSV-1, IS 8622 and IS 3691). In experiment II five male steriles (ms 3677, ms 2219, ms 648, ms 1587 and ms Ck 60) were crossed with 21 true breeding derivatives from exotic × Indian crosses. In both these experiments, line × Tester mating design was followed. The parents and resultant hybrids along with standard checks (GSH-1 in experiment I, and CSH-1, CSH-2 and GSH-3 in experiment II) were planted in randomized block design with three replications. The observation for mature plant height, days to 50% bloom, panicle length, grain yield per panicle, hundred grain weight and number of grains per panicle were recorded on five competitive random plants in each plot in both the experiments. The experiment II was planted at three locations (Parbhani, Dharwar and Yemmiganur).

The statistical analysis is based on the average of the five competitive random plants in a plot. Heterosis was estimated over mid-parental value and over the superior parent. The combining ability was estimated following Kempthorne (1957). The estimates of combining ability variances were based on covariances of full sibs and half sibs.

RESULTS

Magnitude of heterosis: The mean magnitude of heterosis over all the F₁ hybrids for various characters is summarised in Table 1. In both the

<table>
<thead>
<tr>
<th>Character</th>
<th>Heterosis over mid-parental value</th>
<th>Heterosis over superior parent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expt. I</td>
<td>Expt. II</td>
</tr>
<tr>
<td>Days to 50% bloom</td>
<td>-3.21</td>
<td>-4.09</td>
</tr>
<tr>
<td>Panicle length</td>
<td>15.83</td>
<td>11.09</td>
</tr>
<tr>
<td>Number of grains per panicle</td>
<td>38.01</td>
<td>37.63</td>
</tr>
<tr>
<td>Hundred grain weight</td>
<td>4.51</td>
<td>17.95</td>
</tr>
<tr>
<td>Grain yield per panicle</td>
<td>48.01</td>
<td>62.64</td>
</tr>
</tbody>
</table>

*Mean heterosis over early parents.

†Part of M.Sc. & Ph.D. theses submitted to I.A.R.I., New Delhi-12.

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Table 2

Analysis of variance for combining ability

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>D.F.</th>
<th>Mean</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mature plant height</td>
<td>Days to 50% bloom</td>
<td>Panicle length</td>
<td>Grains per panicle</td>
<td>Hundred grain weight</td>
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<tr>
<td>Replications</td>
<td>2</td>
<td>104.1</td>
<td>5.46</td>
<td>4.93</td>
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<td>149413.7</td>
<td>0.124</td>
</tr>
<tr>
<td>Males</td>
<td>3</td>
<td>3169.0**</td>
<td>286.79**</td>
<td>215.9**</td>
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<td>5013767.1**</td>
<td>3.673**</td>
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<tr>
<td>Females</td>
<td>7</td>
<td>795.7**</td>
<td>44.61**</td>
<td>25.32**</td>
<td></td>
<td>334570.0**</td>
<td>0.080</td>
</tr>
<tr>
<td>Females × Males</td>
<td>21</td>
<td>322.5**</td>
<td>15.01</td>
<td>9.54**</td>
<td></td>
<td>322538.6**</td>
<td>0.075</td>
</tr>
<tr>
<td>Error</td>
<td>62</td>
<td>59.7</td>
<td>9.83</td>
<td>2.36</td>
<td></td>
<td>127718.7</td>
<td>0.042</td>
</tr>
</tbody>
</table>

Experiment II

| Replications within locations | 6    | 1059.3**| 38.4*   | 7.6**   |          | 343700.0** | 0.134** | 411.2**   |
| Locations                    | 2    | 39286.5**| 2141.5**| 1172.0**| 47572000.6** | 14.313** | 36817.7** |
| Females                      | 4    | 15519.2**| 177.5** | 282.1*  | 7025000.0** | 7.753** | 253.8     |
| Males                        | 20   | 32107.4**| 285.5** | 246.4** |          | 4636355.0** | 4.519** | 3438.9**  |
| Females × males              | 80   | 777.9** | 10.4**  | 9.3**   | 397505.0** | 0.092   | 257.1**   |
| Females × locations          | 8    | 1724.3**| 16.2**  | 47.7**  | 967062.3** | 0.288** | 893.7**   |
| Males × Locations            | 40   | 1430.0**| 21.7**  | 19.7**  | 1311285.0** | 0.492** | 1498.2**  |
| Females × Males × locations  | 160  | 99.0*  | 6.4**   | 4.2**   | 192130.6** | 0.074** | 122.0**   |
| Error                        | 624  | 75.2 | 3.3     | 2.5     |          | 71237.3 | 0.012    | 37.9      |

*Significant at 5% level; **Significant at 1% level.
experiments, the number of grains per panicle, grain yield and plant height were the most heterotic traits and the hybrids were earlier than the mid-parental value.

Combining ability: The analysis of variance for combining ability is presented in Table 2. In experiment I, the analysis revealed that the mean squares for males and females were significant for all characters under study except for hundred grain weight and grain yield per panicle in females. The mean squares for females × males were also significant for all characters except days to 50% bloom. In experiment II with the exception of variance for grain yield due to females and for hundred grain weight due to females × males all other variances were statistically significant. The variances due to interaction of males × locations and females × locations were highly significant for all characters.

The estimates of combining ability variances are depicted in Table 3. It is seen that the general combining ability (gca) predominants for all the characters except for grain yield per panicle, for which σ² sca were more than three times in both the experiments. The ratio of σ² gca/σ² sca in these two different experiments was in agreement for all the characters studied. In experiment II, the estimates due to gca × location interaction were highly significant for all characters whereas the sca × location interactions were significant for grain yield, number of grains per panicle, plant height and flowering time. For other characters interactions of specific effects with locations were non-significant. Thus results indicated that except grain yield all the characters are

| Table 3 |

*Estimates of variances for general and specific combining ability*

<table>
<thead>
<tr>
<th>Variances</th>
<th>Mature Days to 50% Bloom</th>
<th>Days to 50% Bloom</th>
<th>Panicle Length</th>
<th>Grains per Panicle</th>
<th>Hundred Grain Weight</th>
<th>Grain Yield per Panicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>gca</td>
<td>184.25**</td>
<td>1.78**</td>
<td>1.93*</td>
<td>38342.9*</td>
<td>0.049</td>
<td>4.40</td>
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<tr>
<td>sca</td>
<td>75.44**</td>
<td>0.45*</td>
<td>0.57**</td>
<td>22819.3**</td>
<td>0.002</td>
<td>15.01**</td>
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<tr>
<td>σ²gca/σ²sca</td>
<td>2.44</td>
<td>3.94</td>
<td>3.38</td>
<td>1.68</td>
<td>24.48</td>
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<tr>
<td>gca, 1</td>
<td>38.29**</td>
<td>0.32**</td>
<td>0.76**</td>
<td>24283.1**</td>
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<td>sca, 1</td>
<td>7.92*</td>
<td>1.03*</td>
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<td>σ²gca, 1/σ²sca, 1</td>
<td>4.83</td>
<td>0.31</td>
<td>1.35</td>
<td>0.60</td>
<td>0.38</td>
<td>0.98</td>
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*Significant at 5% level; **Significant at 1% level.*
### Table 4

**Mean and general combining ability effects for some promising parents**

<table>
<thead>
<tr>
<th>Characters</th>
<th>Days to bloom</th>
<th>Panicle length (cm)</th>
<th>Grains per panicle</th>
<th>Hundred grain weight (g)</th>
<th>Grain yield per panicle (g)</th>
<th>Mean G. c. a.</th>
<th>G. c. a.</th>
<th>Experiments</th>
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<td>MS Redan</td>
<td>114.5</td>
<td>7.05</td>
<td>45.0</td>
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<td>80.0</td>
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<td>MS Westland</td>
<td>101.8</td>
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<td>18.0</td>
<td>0.01</td>
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<td>180.0</td>
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<td>MS 611</td>
<td>160.8</td>
<td>14.7</td>
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<td>1.01</td>
<td>1602</td>
<td>152.0</td>
<td>4-8</td>
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<td>IAS 94</td>
<td>150.3</td>
<td>14.7</td>
<td>34.0</td>
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<td>152.0</td>
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<td>CSV-1</td>
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<tr>
<td>Promising experimental hybrids</td>
<td>Mature plant height (cm)</td>
<td>Days to 50% bloom</td>
<td>Panicle length</td>
<td>Grains per panicle</td>
<td>Hundred grain weight (gm)</td>
<td>Grain yield per panicle</td>
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<tr>
<td></td>
<td>Mean</td>
<td>Sca effect</td>
<td>Mean</td>
<td>Sca effect</td>
<td>Mean</td>
<td>Sca effect</td>
<td>Mean</td>
<td>Sca effect</td>
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<tr>
<td><strong>Experiment I</strong></td>
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<tr>
<td><strong>Tx 616A × IS 8622</strong></td>
<td>148.5</td>
<td>11.33</td>
<td>57.0</td>
<td>2.10</td>
<td>32.2</td>
<td>2.51**</td>
<td>3533</td>
<td>649</td>
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<td><strong>MS Redlan × IS 84</strong></td>
<td>164.6</td>
<td>0.47</td>
<td>65.0</td>
<td>1.60</td>
<td>34.7</td>
<td>2.25</td>
<td>2490</td>
<td>209</td>
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<tr>
<td><strong>MS 3118 (Martin) × IS 84</strong></td>
<td>154.2</td>
<td>-0.54</td>
<td>61.0</td>
<td>1.35</td>
<td>33.2</td>
<td>1.26</td>
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<td>146</td>
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<tr>
<td><strong>MS 611 (W.C. Kafir) × IS 84</strong></td>
<td>159.1</td>
<td>11.46</td>
<td>57.0</td>
<td>-2.23</td>
<td>34.7</td>
<td>0.14</td>
<td>2430</td>
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<tr>
<td><strong>MS 3118 (Martin) × CSV-1</strong></td>
<td>141.0</td>
<td>4.55</td>
<td>57.0</td>
<td>-0.27</td>
<td>31.0</td>
<td>0.34</td>
<td>2238</td>
<td>171</td>
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<td><strong>MS 2119 (Westland) × CSV-1</strong></td>
<td>144.1</td>
<td>0.11</td>
<td>60.0</td>
<td>0.23</td>
<td>33.0</td>
<td>0.93</td>
<td>2603</td>
<td>189</td>
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<tr>
<td><strong>MS E 800 × IS 8622</strong></td>
<td>147.2</td>
<td>-6.70</td>
<td>57.0</td>
<td>-2.65</td>
<td>29.7</td>
<td>1.73</td>
<td>3490</td>
<td>431</td>
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<td><strong>CSH-1 (CK60A × IS 84)</strong></td>
<td>135.9</td>
<td>—</td>
<td>61.0</td>
<td>—</td>
<td>32.7</td>
<td>—</td>
<td>2319</td>
<td>—</td>
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<tr>
<td><strong>Experiment II</strong></td>
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<tr>
<td><strong>MS 2219 × 1452</strong></td>
<td>182.7</td>
<td>2.79</td>
<td>68.0</td>
<td>-0.25</td>
<td>27.7</td>
<td>0.28</td>
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<td>363**</td>
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<tr>
<td><strong>MS 2219 × 1635</strong></td>
<td>200.0</td>
<td>-7.86**</td>
<td>66.0</td>
<td>-0.41</td>
<td>27.0</td>
<td>0.01</td>
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<td>174*</td>
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<tr>
<td><strong>MS CK 60 × 1452</strong></td>
<td>194.5</td>
<td>2.04</td>
<td>70.0</td>
<td>-0.12</td>
<td>26.3</td>
<td>0.80</td>
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<tr>
<td><strong>MS CK 60 × 1635</strong></td>
<td>224.4</td>
<td>3.95</td>
<td>69.0</td>
<td>1.08*</td>
<td>26.4</td>
<td>1.39**</td>
<td>2189</td>
<td>117</td>
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<tr>
<td><strong>MS 1587 × 1387</strong></td>
<td>236.2</td>
<td>58.85**</td>
<td>67.0</td>
<td>3.38**</td>
<td>27.1</td>
<td>-0.30</td>
<td>2523</td>
<td>433**</td>
</tr>
<tr>
<td><strong>MS 1587 × 1452</strong></td>
<td>186.1</td>
<td>-8.53**</td>
<td>69.0</td>
<td>-0.02</td>
<td>26.9</td>
<td>0.84</td>
<td>2826</td>
<td>176*</td>
</tr>
<tr>
<td><strong>MS 1587 × 1635</strong></td>
<td>215.9</td>
<td>-6.78</td>
<td>67.0</td>
<td>-0.39</td>
<td>25.5</td>
<td>-0.06</td>
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<td>71</td>
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<tr>
<td><strong>MS 5677 × 1452</strong></td>
<td>206.2</td>
<td>1.06</td>
<td>71.0</td>
<td>0.92</td>
<td>27.8</td>
<td>-0.79</td>
<td>2219</td>
<td>101</td>
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<td><strong>MS 5677 × 743</strong></td>
<td>183.9</td>
<td>9.55**</td>
<td>65.0</td>
<td>-0.64</td>
<td>35.6</td>
<td>0.75</td>
<td>2366</td>
<td>170*</td>
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<tr>
<td><strong>MS 5677 × 1098</strong></td>
<td>221.0</td>
<td>6.37*</td>
<td>63.0</td>
<td>-0.95</td>
<td>38.5</td>
<td>2.39**</td>
<td>2494</td>
<td>167*</td>
</tr>
<tr>
<td><strong>CSH-1 (CK60A × IS 84)</strong></td>
<td>144.7</td>
<td>—</td>
<td>60.0</td>
<td>—</td>
<td>29.2</td>
<td>—</td>
<td>1578</td>
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<td><strong>CSH-2 (CK60A × IS 3691)</strong></td>
<td>185.8</td>
<td>—</td>
<td>71.0</td>
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<td>26.8</td>
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<td>2287</td>
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<td><strong>CSH-3 (2219A × IS 3691)</strong></td>
<td>167.8</td>
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<td>70.0</td>
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<td>27.3</td>
<td>—</td>
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<td><strong>CSV-1 (Swarana)</strong></td>
<td>149.8</td>
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<td>68.0</td>
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<td>27.0</td>
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<td>1503</td>
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*Significant at 5% level; **Significant at 1% level.
predominantly controlled by additive effects of genes. Non-additive effects of genes are also important in the expression of all the traits including grain yield except hundred grain weight and the non-additive effects of genes are comparatively more stable over locations for mature plant height and panicle length.

**General combining ability effects:** Mean performance and the general combining ability effects of the promising parents only are given in Table 4. In experiment I amongst the females ms Redlan, ms Westland, and ms 611 and amongst the males IS 84 and CSV-1 (Swarna) appeared to be better general combiners. In experiment II it was seen that amongst the females ms 2219 tended to produce hybrids with shorter stature, earliness, longer panicle and with more number of grains but the grains tended to be smaller. Amongst the male parents the gca effects for grain yield were desirable for 743, 781, 892, 990, 1098, 1302, 1452 and 1635. The male parent 1452 tended to result in superior hybrids but the hybrids were medium tall.

**Specific combining ability effects:** Mean performance and the specific combining ability effects for some promising experimental hybrids are given in Table 5. In experiment I, the combination Tx 616A x IS 8622 was characterised by positive and significant specific effects for panicle length, number of grains and grain yield per panicle. The combinations ms Redlan x IS 84, ms 611 x IS 84 and ms 2119 x CSV-1 exhibited positive specific effects in the desired direction.

In experiment II, some of the best specific combinations were ms 2219 x 1452, ms 2219 x 1635, ms CK 60 x 1635, ms 1587 x 1452, and ms 3677 x 1452. From the point of view of grain yield, grain quality and gca of parents and sca effects, the most promising hybrid was ms 2219 x 1452. This was characterised by positive gca effects for yield of both the parents. The female parent on account of negative gca effect for plant height and days to bloom rendered the hybrids relatively shorter and earlier which is desirable. The sca effect for this combination for plant height was positive but not significant, for days to bloom the sca effect was negative which is also desirable.

It was also observed that in experiment I the experimental hybrids were not significantly higher yielders as compared to the check hybrid CSH-1. An examination of the average grain yields of the most promising hybrids of experiment II reveals that these hybrids are much superior to the released hybrids and, therefore, offer economic potentialities.

**Discussion**

Exotic germplasm today is of greater interest than in the past and studies on the magnitude of heterosis, combining ability and stability of performance involving diverse breeding materials is of crucial interest in further elevating and stabilizing the yield levels of the present day sorghum varieties and hybrid which are predominantly grown under rainfed conditions and are, therefore, subject to severe environmental fluctuations. The foregoing discussion is based on some of the studies in this direction.
Magnitude of heterosis: Studies on the manifestation of hybrid vigour in sorghum are in general agreement revealing that the yield superiority of hybrids resulted mainly from the increase in the number of seeds per panicle. The grain yield has been observed to be the most heterotic character followed by the number of grains per panicle (Kambal and Webster, 1966; Kirby and Atkins, 1968; Quinby and Liang, 1969).

The ability of the hybrids to attain a height greater than that of the parents in a shorter time suggests that they are growing at a faster rate. Earliness of hybrids results largely from the more rapid development of the meristem prior to floral initiation and to more rapid development of panicles in hybrids (Quinby and Liang, 1969).

One of the most heterotic combinations in experiment I is E 800 X IS 8622, both the parents of which are African in origin. It thus, appears that geographic diversity does not necessarily confer genetic diversity and ultimately heterosis as suggested by Moll, Salhauna and Robinson (1962).

Nature of gene action: While a majority of studies on the nature of combining ability in sorghum populations pointed out to the preponderance of general combining ability for most characters including yield (Beil and Atkins, 1967; Rao 1970b) recent studies involving diverse germplasm sources have brought out the equal importance of specific combining ability as well (Rao, 1970; Niehaus and Pickett, 1966).

Present study indicated that general combining ability predominated for all characters except for grain yield. The gca × location interaction was highly significant for all characters and the sea × location interaction was significant for grain yield, number of grains per panicle, plant height and days to 50% blooming. This is indicative that general combining ability effects of all the characters are susceptible to location interactions.

Rojas and Sprague (1952) observed that, variances for sea effects were of relatively greater importance than the variances for gca effects when the lines under test had been subjected to previous testing and selection. The lines used in the present studies were highly selected for yield. Therefore, one might expect that the sea portion of the genotypic variances should be expressed to a pronounced extent in the populations evaluated, which has actually been observed.

The male sterile 2219 seemed to be a desirable female since it showed positive gca effect for grain yield, panicle length and number of grains per panicle and negative gca effect for plant height and days to 50% bloom, but the smaller grain size is a problem. The problem of grain size can be taken care of by selection of bold seeded male parent since gene action for this character is additive. As regards the pollinator parents IS 84,1452 (IS 3687 × Aispuri) and 1635 (M 559 × BP 53) are good general combiners and need evaluation against more desirable female lines. The specific effects of crosses with CSV-1 and 1387 (R 78 × M 35-1) are also generally desirable and they could provide potential male parents against suitable females, if overall improvement is to be brought about.
Thus, a critical examination of the relative magnitude of $gca$ and $sea$ variances and their interaction with locations, the $gca$ and $sea$ effects provides valuable guidelines for conventional as well as hybrid breeding procedures. There is considerable scope for line improvement for yield components in view of the predominance of additive genetic variance for most characters except yield. This has been realised to a great extent in the development of male parents of the experiment II which are derivatives of exotic $\times$ Indian crosses. The presence of considerable non-additive gene action for grain yield suggests that once high yielding improved lines are isolated, further yield improvement could be achieved in a hybrid programme. GSH1, 2 and 3 hybrids may be considered as low $\times$ high combinations. With the availability of high yielding females one could handle high $\times$ high combinations which could result in the capitalisation of non-additive effects over the super-structure of the additive gene effects.

**SUMMARY**

Heterosis over superior parent indicated that grain yield was most heterotic character followed by the number of grains per panicle. The yield superiority of hybrids resulted mainly from the increase in number of seeds per panicle. The hybrids were earlier and taller.

The combining ability estimates revealed that general combining ability was predominant for mature plant height, days to bloom, panicle length, number of grains per panicle and hundred grain weight, but for grain yield specific combining ability was more important. The general combining ability effects were also variable over locations. While there was considerable scope for yield component improvement, yield of hybrids can only be elevated by improving the male sterile lines.

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**REFERENCES**


