African Journal of Biotechnology Vol. 7 (16), pp. 2810-2817, 18 August, 2008
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB08.399
ISSN 1684–5315 © 2008 Academic Journals

*Full Length Research Paper*

# Line X tester analysis in pea (*Pisum sativum* L.): Identification of superior parents for seed yield and its components

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Accepted 1 July, 2008

**This research was carried out to investigation the genetic structure of the 24 $F_1$ pea hybrids established from eight exotic female lines and three local winter hardiness male testers, to determine parents showing general combining ability (GCA) and determine crosses showing specific combining ability (SCA.), and to evaluate the heterosis. Broad genetic variability was observed among the genotypes. Estimates of variance due to GCA and SCA and their ratio revealed predominantly non-additive gene effects for all studied traits. While PS9830S329 (female) and H (male) were the best general combiners among the parents, PS9830S329 x $B_{12}$ was the best cross for seed yield. Hybrids generally showed greater yield potential than their parental genotypes. Heterosis was observed in some hybrids for each trait studied.**

**Key words:** *Pisum sativum*, line x tester, seed yield, yield components.

## INTRODUCTION

The seeds of the pea contain high protein as 20 – 30% and have sufficient carbohydrates. Considering this fact, the pea is rich as calcium, iron and especially phosphorus and in addition to this, it contains different kinds of vitamins and that is why it is considered as a good protein source (Akcin, 1988). From this point of view, the pea, which is considerably used especially in the tinned and frozen food industry, is very important to supply the necessary proteins for human nutrition.

The line x tester analysis method is used to breed both self and cross-pollinated plants and to estimates favorable parents and crosses, and their general and specific combining abilities (Kempthorne, 1957). Combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits (Basbag et al., 2007). GCA and SCA which identify the hybrids with high yield are the most important criteria in breeding programs (Ceyhan, 2003). High GCA and SCA for seed yield and yield related components of pea are reported by Lejeune-Henaut et al. (1992), Mishra et al. (1993), Sarawat et al. (1994), Sharma et al. (1996) and (Ceyhan, 2003). Agronomic characters of pea show significant differences in heterosis (Lejeune-Henaut et al., 1992; Mishra et al., 1993; Sarawat et al., 1994; Sharma et al., 1996; Ceyhan 2003).

The objectives of this study was to evaluate the association of yield and yield related traits with resistance to terminal winter hardiness in pea, to measure the phenotypic variability of these traits, to obtain the general and specific combining ability, and to estimate heritability and heterosis and assess their potential use in breeding for winter resistance in pea as a good source of plant protein.

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## MATERIALS AND METHODS

One commercial cultivar and ten lines were chosen for this experiment (Table 1). Genotypes were chosen for their diverse adaptation, as well as their winter hardiness to the Central Anatolian Turkey. They were crossed in 8 x 3 line x tester crosses to produce 24 possible $F_1$ hybrids.

Parent and their $F_1$ hybrids (line x tester set) were grown at the experimental field of the Faculty of Agriculture, Selcuk University, Konya, Turkey during 2003 – 2004 crop season. The soil was clay loam, with pH 8.03 and phosphorous, potassium, iron, zinc, organic matter and $CaCO_3$ contents of 55.9, 17.9 kg $ha^{-1}$, 14.74, 0.32 ppm

**Table 1.** Pea parentages used in the research.

| Name of genotypes | Distinctive features |
|---|---|
| $B_6$ (local line) | Winter, smooth, a late-season line and uniform maturity, pink- flowered, normal leaves, high yielding |
| $B_{12}$ (local line) | Winter, smooth, a mid-season line and uniform maturity, pink- flowered, normal leaves, normal yielding, pod shattering |
| H (local line) | Winter, smooth, a mid-season line and uniform maturity, pink- flowered, normal leaves, low yielding, pod shattering |
| PS9830S431 | Clear-seeded, yellow cotyledon winter pea, normal leaves, white-flowered |
| PS9830S329 | Clear-seeded, yellow cotyledon winter pea, semi-leafless, white-flowered |
| PS9430706 | Clear-seeded, yellow cotyledon winter pea, semi-leafless, white-flowered |
| PS9830F035 | Clear-seeded, yellow cotyledon winter pea, semi-leafless, white-flowered |
| PS9830F009 | Clear-seeded, yellow cotyledon winter pea, semi-leafless, white-flowered |
| PS9830S307 | Clear-seeded, yellow cotyledon winter pea, semi-leafless, white-flowered |
| PS9830F010 | Clear-seeded, yellow cotyledon winter pea, semi-leafless, white-flowered |
| Granger | Austrian type winter pea, yellow cotyledon, semi-leafless, purple-flowered, long vine |

and 37.6, 2.25%, respectively. 10 year annual precipitation is 289.7 mm per year, annual mean temperature is 9.2°C and average relative humidity is 60.4% (Figure 1a, c, d). Total annual precipitation was 314.9 mm, which was more than 10 year averag (289.7 mm) of the site (Figure 1c). During the experimental period, average temperature was 9.8°C and lowest temperature was -16.0°C (Figure 1a, b).

The experiment was a randomized complete block design with three replications. Sowings were made on 18 October 2003. Each plot consisted of 24 $F_1$ or parent plants on three 1.5 m apart and 50 cm rows. Plant spacing was 10 cm. Weeds were removed manually, when necessary. In the 2003 - 2004 growing season, no-irrigation was required due to the rainy season (Figure 1c). All plots were treated with 18 - 46 DAP (diammoniumphosphate) fertilizer to provide 27 kg $ha^{-1}$ N and 69 kg $ha^{-1}$ $P_2O_5$. After seeding, grass weeds were controlled by hand hoeing. Plants and harvested on 5 July 2004.

In the research, seed yield (g), pod yield (g), plant height (cm), number of pods per plant, number of seeds per pod and hundred seed weight were observed as the yielding criteria with the related methods.

The breeding value of the plant material was evaluated by analyzing the data on heterosis or combining ability for all the traits in the $F_1$. The studied data were analyzed with the program TARPOPGEN PC Program (Ozcan and Acikgoz, 1999).

## RESULTS AND DISCUSSION

### Growth habit and winter hardiness

At a given sub-zero temperature ranged 0 -16.0°C the freezing injury was observed in the field. The $F_1$ generations and the parents were not killed at -16.0°C on January in 2004. But, at or below -10°C, low damage first appears on the edge of the leaflets, later on the whole leaflets. The young tissues are more resistant. The males were more resistant compared to female and $F_1$ generations. The air temperatures gradually dropped as the winter plants started to redevelop cold resistance. This air minimum temperatures ranged from 0 to -25.0°C (Figure 1b) while short periods temperatures were -13.0°C with little effect on cold hardiness of pea hybrids, long period of -13.0°C cause little severe damage. Our hybrids and parents survived exposure to air temperatures of -16.0°C without snow cover in field. Ceyhan (2003) emphasized that among the pea hybrids, a temperature of -16.5°C caused no damage to leaves (100% survival). Resistance in the cultivars of *Pisum sativum* ranged 7 to 100%; it was highest in three local pea lines. Air temperatures of -23°C and below are considered lethal to over wintering pea, while air temperatures of -6 to -14°C are not injurious to fully hardened pea (Eteve 1985). The findings of this study agree with above mentioned previous reports.

### Seed yield and its components

Lines x tester analyses were performed on all the traits for which crossed genotypes gave significant differences. Results of these analyses are summarized in Table 2. Significant differences among lines were found for only seed yield, pods per plant and pod yield. On the contrary, testers showed non-significant differences for all traits. Finally, the line x tester interaction gave significant differences for all traits.

There were significant differences among crossed genotypes for all traits, except seeds per pod (Table 2); crosses having the tester H, yielded almost 26 g/plant. In addition, these crosses produced the most pods per plant, seeds per pod and pod yield, in contrast to crosses involving $B_6$ which showed the lowest values for same traits (Table 3). Similar to the parental lines, the top yielding crosses were those derived from PS9830S329, averaging 19 g/plant more seed yielded than the lowest (PS9830F010). This group of crosses also had the highest plant height, pods per plant, seeds per pod and pod yield (Table 3).

There were significant differences among parents for all traits. Hybrid performance was generally better than

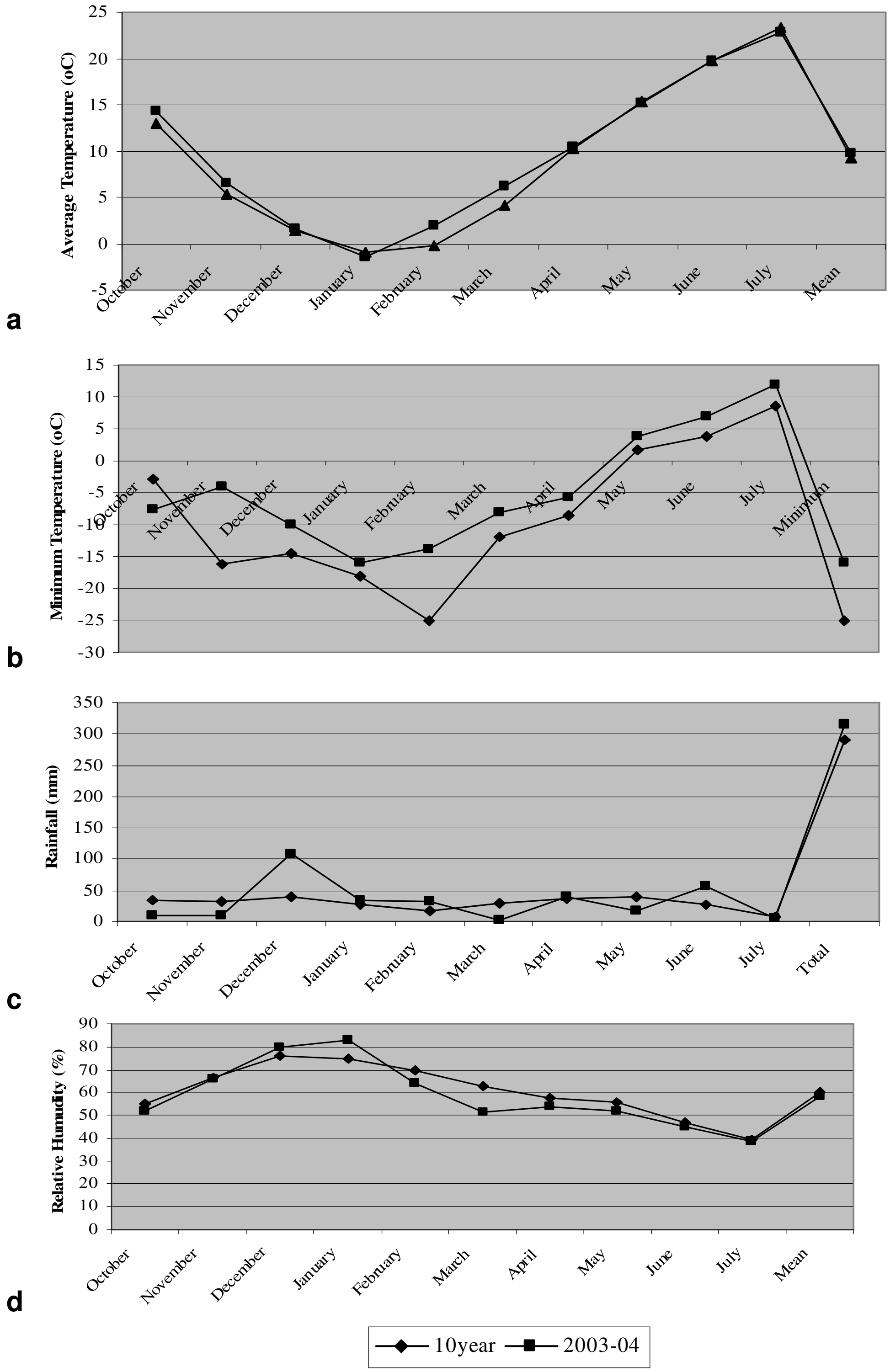


**Figure 1.** Monthly mean air temperature (a), minimum air temperature (b), total rainfall (c) and relative air humidity (d) during the 2003 – 2004 growing seasons and 10 year average.

parental performance for all characters except hundred seed weight (Table 2). Hybrid performances including seed yield, plant height, pods per plant, seeds per pod was also found better than parental performance in the other experiments conducted by Lejeune-Henaut et al. (1992), Sarawat et al. (1994), Kumar et al. (1996),

**Table 2.** Analysis of variance and estimates of variance components for seed yield and its components for parents and their $F_1$ progeny.

| Source of Variation | Df | Seed yield (g) | Plant height (cm) | Pods per plant (number) | Seeds per pod (number) | Pod yield (g) | Hundred seed weight (g) |
|---|---|---|---|---|---|---|---|
| Replications | 2 | 0.935 | 56.581 | 11.010 | 0.086 | 0.263 | 0.733* |
| Treatments | 34 | 213.992** | 226.83** | 231.925** | 1.117** | 426.209** | 12.387** |
| Parents | 10 | 93.667** | 210.618** | 121.424** | 0.533 | 180.564** | 12.769* |
| Parents vs crosses | 1 | 2195.880** | 234.394* | 1722.016** | 9.642** | 5347.777** | 11.204* |
| Crosses | 23 | 180.138** | 233.550** | 215.183** | 0.999** | 319.030** | 12.272** |
| Lines | 7 | 384.943* | 331.760 | 485.887** | 1.284 | 736.530** | 13.494 |
| Testers | 2 | 40.510 | 512.514 | 13.625 | 2.181 | 64.244 | 1.622 |
| Lines x testers | 14 | 97.683** | 144.593** | 108.625** | 0.688** | 146.678** | 186.178** |
| Error | 68 | 7.677 | 45.503 | 9.686 | 0.272 | 7.990 | 0.165 |
| **Estimates of genetic components** | | | | | | | |
| GCA | | 3.797 | 4.096 | 4.907 | 0.014 | 7.936 | 0.047 |
| SCA | | 30.002 | 33.030 | 32.980 | 0.139 | 46.229 | 4.378 |
| GCA/SCA | | 0.127 | 0.124 | 0.149 | 0.101 | 0.172 | -------- |
| $h^2$ | | 0.05 | 0.05 | 0.06 | 0.04 | 0.06 | 0.01 |
| $H^2$ | | 0.49 | 0.45 | 0.49 | 0.42 | 0.49 | 0.50 |

*: $p < 0.05$, ** : $p < 0.01$.

**Table 3.** Mean seed yield and its components in pea.

| Lines | Seed Yield (g) | Plant Height (cm) | Pods per Plant (number) | Seeds per Pod (number) | Pod yield (g) | Hundred Seed Weight (g) |
|---|---|---|---|---|---|---|
| PS9830S431 | 7.8 | 53.0 | 13.3 | 4.3 | 9.6 | 11.3 |
| PS9830S329 | 16.8 | 61.7 | 27.3 | 4.0 | 21.8 | 13.3 |
| PS9430706 | 8.5 | 50.0 | 18.3 | 4.0 | 10.5 | 12.1 |
| PS9830F035 | 20.8 | 65.0 | 19.0 | 5.0 | 24.0 | 16.9 |
| PS9830F009 | 14.6 | 61.7 | 20.7 | 5.0 | 22.3 | 12.9 |
| PS9830S307 | 14.3 | 53.3 | 20.7 | 5.0 | 18.1 | 14.4 |
| PS9830F010 | 12.2 | 48.3 | 17.7 | 5.0 | 15.1 | 13.8 |
| Granger | 22.1 | 60.0 | 30.0 | 5.0 | 31.2 | 14.6 |
| **Testers** | | | | | | |
| $B_6$ | 24.1 | 75.0 | 34.3 | 4.3 | 31.9 | 15.6 |
| $B_{12}$ | 12.5 | 64.0 | 18.7 | 4.7 | 18.4 | 10.8 |
| H | 9.14 | 48.3 | 16.3 | 5.0 | 10.8 | 10.3 |
| **Hybrids** | | | | | | |
| PS9830S431 x $B_6$ | 28.3 | 53.3 | 41.7 | 6.0 | 37.3 | 11.3 |
| PS9830S431 x $B_{12}$ | 27.7 | 70.0 | 34.3 | 6.3 | 36.6 | 12.3 |
| PS9830S431 x H | 33.6 | 56.7 | 35.3 | 6.0 | 49.4 | 14.7 |
| PS9830S329 x $B_6$ | 28.8 | 81.7 | 31.7 | 5.3 | 48.5 | 14.6 |
| PS9830S329 x $B_{12}$ | 42.3 | 78.3 | 51.7 | 6.0 | 58.9 | 12.3 |
| PS9830S329 x H | 33.9 | 66.0 | 41.3 | 5.3 | 49.2 | 15.2 |
| PS9430706 x $B_6$ | 21.0 | 56.7 | 25.3 | 4.7 | 36.2 | 16.0 |
| PS9430706 x $B_{12}$ | 10.6 | 64.7 | 17.0 | 5.0 | 15.2 | 12.2 |
| PS9430706 x H | 20.9 | 50.0 | 25.3 | 5.3 | 33.3 | 13.3 |
| PS9830F035 x $B_6$ | 31.3 | 58.3 | 38.7 | 5.0 | 36.5 | 15.7 |
| PS9830F035 x $B_{12}$ | 16.2 | 55.0 | 22.3 | 4.0 | 24.4 | 15.0 |
| PS9830F035 x H | 34.4 | 69.0 | 34.3 | 6.0 | 40.1 | 15.9 |
| PS9830F009 x $B_6$ | 22.5 | 62.3 | 21.0 | 5.3 | 30.2 | 13.5 |
| PS9830F009 x $B_{12}$ | 14.9 | 75.0 | 21.7 | 5.0 | 21.9 | 13.4 |

**Table 3** Contd.

| | | | | | | |
|---|---|---|---|---|---|---|
| PS9830F009 x H | 24.7 | 50.0 | 25.3 | 5.7 | 31.1 | 12.9 |
| PS9830S307 x $B_6$ | 18.5 | 41.7 | 26.0 | 3.0 | 24.1 | 9.5 |
| PS9830S307 x $B_{12}$ | 32.3 | 65.0 | 37.7 | 5.0 | 44.7 | 15.1 |
| PS9830S307 x H | 23.8 | 61.7 | 29.7 | 6.0 | 33.0 | 14.4 |
| PS9830F010 x $B_6$ | 16.5 | 50.7 | 20.7 | 5.3 | 22.4 | 13.3 |
| PS9830F010 x $B_{12}$ | 16.8 | 61.7 | 26.7 | 4.7 | 27.4 | 12.2 |
| PS9830F010 x H | 14.7 | 53.3 | 22.7 | 6.0 | 22.0 | 11.1 |
| Granger x $B_6$ | 20.5 | 65.0 | 30.0 | 5.0 | 29.7 | 11.6 |
| Granger x $B_{12}$ | 26.1 | 61.7 | 24.7 | 5.0 | 36.3 | 20.5 |
| Granger x H | 21.5 | 51.7 | 27.0 | 5.0 | 33.5 | 14.7 |

Sharma et al. (1999) and Ceyhan (2003).

Table 2 also reveals the fact that the ratio of variance of GCA and SCA was much less than unity for all characters which indicate the predominant role of non-additive gene action in the inheritance of all the traits in pea. Narrow sense heritability ranged from 0.06 for pods per plant and pod yield, to 0.01 for hundred seed weight. Broad sense heritability changed from 0.50 from hundred seed weight, to 0.42 for seeds per pod.

The ratio of $\sigma^2$ GCA to $\sigma^2$ SCA was less than one for the six characters (Table 2) indicating the importance of non-additive gene action for these characters. Sharma et al. (1999) reported the importance of non-additive gene actions for pod yield, pods per plant. They also reported the importance of additive gene action for plant height. Ceyhan (2003) demonstrated that seed yield, plant height, pods per plant, seeds per plant, pod yield and hundred seed weight are controlled by non-additive gene. An important influence of non-additive gene action on seed yield in pea has been frequently reported in the literature (Singh and Singh, 1990; Kumar et al., 1996).

Low heritability (narrow sense) was obtained for all traits (Table 2). Low heritability in case of all traits suggest non fixable component of variation governing these traits and, therefore, $F_1$ populations should be exploited to utilize these components of variation. Thus, these traits can be improved by making selections among the recombinants obtained through segregating populations. The results are in conformity with earlier reports by Sharma et al. (1999) and Ceyhan (2003).

## General combining ability (GCA) and specific combining ability (SCA)

The GCA and SCA genetic effects are shown in Table 4. Significant positive and negative GCA genetic effects were observed for all traits. Lines PS9830S329, PS9830S431, PS9830S307, PS9830F035 and H had a positive and significant GCA effects for seed yield and pod yield. Two parental genotypes, PS9830S329 and PS9830S307, were characterized by significantly high GCA effects for plant height. PS9830S329, PS9830S431 and PS9830S307 genotypes, a positive, significant GCA effect was noted for pods per plant. For seeds per pod, only two genotypes (PS9830S431 and H) were found to have a positive and significant GCA effect. Among the studied genotypes, only three lines PS9830F035, PS9830S307 and Granger had a positive and significant GCA effect for hundred seed weight.

Both GCA and SCA have previously been shown in pea to be major contributing factors for pods per plant (Venkateswarlu and Singh, 1983), and seeds per pod (Cervato et al., 1997), and these two factors together with seed yield, pod yield, plant height and hundred seed weight (Ceyhan, 2003).

At least two of the eleven genotypes exhibited significant GCA effects for each trait with most genotypes exhibiting significant GCA effects for the four traits. This reinforces the fact that sufficient variation existed among the genotypes. Among the parents the highest positive effect for seed yield was exhibited by PS9830S329 and H, hence they should be considered as the best female and male combiners. In this study, two of the seven lines showed significant, positive GCA effects for at least one of the seven parameters. The presence of positive GCA effects indicates that continued progress should be possible though breeding for yield and yield components in pea with these results. Similar conclusions were obtained by Sarawat et al. (1994), Kumar et al. (1996), Sharma et al. (1999) and Ceyhan (2003).

Six crosses had large SCA effects for seed yield: PS9830S329 x $B_{12}$, PS9430706 x $B_6$, PS9430706 x H, PS9830F035 x $B_6$, PS9830F035 x H, PS9830S307 x $B_{12}$ and Granger x $B_{12}$. The largest SCA for plant height was obtained in 9830F035 x H; for pods per plant, PS9830S431 x $B_1$, PS9830S329 x $B_{12}$, PS9830F035 x $B_6$, and PS9830F010 x $B_{12}$; for seeds per pod, in PS9830S329 x $B_{12}$ and PS9830F035 x H; pod yield, in PS9830S431 x H, PS9830S329 x $B_{12}$, PS9430706 x $B_6$, PS9430706 x H, PS9830F035 x H, PS9830S307 x $B_{12}$, PS9830F010 x $B_{12}$ and Granger x $B_{12}$; for hundred seed weight, in PS9830S431 x H, PS9830S329 x $B_6$, PS9830S329 x H, PS9430706 x $B_6$, PS9830F009 x $B_6$, PS9830F010 x $B_6$ and Granger x $B_{12}$.

Specific combining ability is a suitable index to deter-

**Table 4.** General (GCA) and specific (SCA) combining ability related to seed yield and its components in pea.

| Lines | Seed yield | Plant height | Pods per plant | Seeds per pod | Pod yield | Hundred seed weight |
|---|---|---|---|---|---|---|
| PS9830S431 | 5.215** | -1.431 | 6.903** | 0.792** | 6.317** | -1.188** |
| PS9830S329 | 10.320** | 13.903** | 11.347** | 0.236 | 17.436** | 0.057 |
| PS9430706 | -7.141** | -4.319 | -7.653** | -0.319 | -6.595** | -0.132 |
| PS9830F035 | 2.633** | -0.653 | 1.569 | -0.319 | -1.127 | 1.568** |
| PS9830F009 | -3.946** | 1.014 | -7.542** | 0.014 | -7.096** | -0.710** |
| PS9830S307 | 3.587** | -0.319 | 5.236** | -0.097 | 3.584** | 0.557** |
| PS9830F010 | -8.683** | -6.208** | -6.875** | 0.014 | -10.875** | -1.776** |
| Granger | -1.985* | -1.986 | -2.986** | -0.319 | -1.644 | 1.624** |
| SE | 0.924 | 2.249 | 1.037 | 0.174 | 0.942 | 0.135 |
| **Tester** | | | | | | |
| $B_6$ | 0.029 | -0.847 | 0.792 | -0.153 | -0.017 | -0.206* |
| $B_{12}$ | -1.313* | 4.986** | -0.708 | -0.194 | -1.628** | 0.149 |
| H | 1.284* | -4.139** | -0.083 | 0.347** | 1.644** | 0.057 |
| SE | 0.566 | 1.377 | 0.635 | 0.106 | 0.577 | 0.083 |
| **Hybrids** | | | | | | |
| PS9830S431 x $B_6$ | -1.562 | -5.819 | 3.764* | 0.042 | -3.778* | -1.250** |
| PS9830S431 x $B_{12}$ | -0.880 | 5.014 | -2.069 | 0.417 | -2.893 | -0.638** |
| PS9830S431 x H | 2.442 | 0.806 | -1.694 | -0.458 | 6.671** | 1.888** |
| PS9830S329 x $B_6$ | -6.258** | 7.181 | -10.681** | -0.069 | -3.680* | 0.772** |
| PS9830S329 x $B_{12}$ | 8.591** | -1.986 | 10.819** | 0.639* | 8.334** | -1.915** |
| PS9830S329 x H | -2.333 | -5.194 | -0.139 | -0.569 | -4.654** | 1.143** |
| PS9430706 x $B_6$ | 3.450* | 0.403 | 1.986 | -0.181 | 8.015** | 2.361** |
| PS9430706 x $B_{12}$ | -5.568** | 2.569 | -4.847** | 0.194 | -11.418** | -1.760** |
| PS9430706 x H | 2.118 | -2.972 | 2.861 | -0.014 | 3.403* | -0.601* |
| PS9830F035 x $B_6$ | 3.933* | -1.597 | 6.097** | 0.153 | 2.820 | 0.328 |
| PS9830F035 x $B_{12}$ | -9.734** | -10.764** | -8.736** | -0.806** | -7.609** | -0.660** |
| PS9830F035 x H | 5.801** | 12.361** | 2.639 | 0.653* | 4.789** | 0.332 |
| PS9830F009 x $B_6$ | 1.789 | 0.736 | -2.458 | 0.153 | 2.492 | 0.472* |
| PS9830F009 x $B_{12}$ | -4.529** | 7.569 | -0.292 | -0.139 | -4.217* | -0.015 |
| PS9830F009 x H | 2.740 | -8.306* | 2.750 | -0.014 | 1.724 | -0.457 |
| PS9830S307 x $B_6$ | 0.425 | -3.597 | 2.764 | -0.403 | -0.894 | -0.194 |
| PS9830S307 x $B_{12}$ | 5.321** | -1.097 | 2.931 | -0.028 | 7.947** | 0.418 |
| PS9830S307 x H | -5.747** | 4.694 | -5.694** | 0.431 | -7.052** | -0.224 |
| PS9830F010 x $B_6$ | 0.445 | -3.708 | -3.458 | 0.153 | -1.542 | 1.306** |
| PS9830F010 x $B_{12}$ | 2.095 | 1.458 | 4.042* | -0.472 | 5.072** | -0.149 |
| PS9830F010 x H | -2.540 | 2.250 | -0.583 | 0.319 | -3.530* | -1.157** |
| Granger x $B_6$ | -2.222 | 6.403 | 1.986 | 0.153 | -3.433* | -3.794** |
| Granger x $B_{12}$ | 4.703** | -2.764 | -1.847 | 0.194 | 4.784** | 4.718** |
| Granger x H | -2.481 | -3.639 | -0.139 | -0.347 | -1.351 | -0.924** |
| SE | 1.600 | 3.895 | 1.797 | 0.301 | 1.632 | 0.235 |

SE: Standard Error, * : $p < 0.05$, ** : $p < 0.01$.

mine the usefulness of a cross. In this study some crosses showed significant positive SCA effects for seed yield and its components and other significant negative SCA effects, indicating non-additive gene action. Therefore, it is suggested that in pea emphasis should be given to specific crosses followed by selection in progenies rather than pursuing GCA by mass selection. This study showed that SCA effects were important for seed yield

**Table 5.** Heterosis (%) values over mid-parent (HMP) of seed yield and its component in pea hybrids.

| Hybrids | Seed yield | Plant height | Pods per plant | Seeds per pod | Pod yield | Hundred seed weight |
|---|---|---|---|---|---|---|
| PS9830S431 x $B_6$ | 77.4** | -16.7 | 75.2* | 39.5 | 79.7** | -15.9 |
| PS9830S431 x $B_{12}$ | 172.9** | 19.6 | 114.3** | 40.0 | 161.4** | 11.3 |
| PS9830S431 x H | 296.6** | 11.9 | 138.5** | 29.0 | 384.3** | 36.1* |
| PS9830S329 x $B_6$ | 40.8 | 19.5 | 2.9 | 27.7 | 80.6** | 1.0 |
| PS9830S329 x $B_{12}$ | 188.7** | 24.5 | 124.7** | 37.9 | 193.0** | 2.0 |
| PS9830S329 x H | 161.3** | 20.0 | 89.4** | 18.4 | 201.8** | 28.8* |
| PS9430706 x $B_6$ | 28.8 | -9.2 | -3.8 | 13.2 | 70.7** | 15.5 |
| PS9430706 x $B_{12}$ | 0.9 | 13.5 | -8.1 | 14.9 | 5.1 | 6.5 |
| PS9430706 x H | 136.9** | 1.72 | 46.2 | 17.7 | 212.6** | 18.8 |
| PS9830F035 x $B_6$ | 39.4 | -16.7 | 45.2 | 7.5 | 30.5 | -3.3 |
| PS9830F035 x $B_{12}$ | -2.7 | -14.7 | 18.3 | -17.5 | 15.0 | 8.3 |
| PS9830F035 x H | 129.7** | 21.8 | 94.3** | 20.0 | 130.4** | 16.9 |
| PS9830F009 x $B_6$ | 16.2 | -8.8 | -23.6 | 13.9 | 11.4 | -5.2 |
| PS9830F009 x $B_{12}$ | 9.9 | 19.3 | 10.1 | 3.0 | 7.6 | 13.0 |
| PS9830F009 x H | 108.0** | -9.0 | 36.7 | 14.0 | 87.9** | 11.2 |
| PS9830S307 x $B_6$ | -3.6 | -34.9 | -5.4 | -35.4 | -3.6 | -36.6* |
| PS9830S307 x $B_{12}$ | 141.0** | 10.8 | 91.3** | 3.0 | 144.9** | 19.8 |
| PS9830S307 x H | 103.0** | 21.4 | 60.5 | 20.0 | 128.3** | 16.6 |
| PS9830F010 x $B_6$ | -14.0 | -20.9 | -24.7 | 13.9 | -10.4 | -11.3 |
| PS9830F010 x $B_{12}$ | 25.3 | 5.2 | 35.5 | -3.0 | 50.1* | -3.1 |
| PS9830F010 x H | 25.4 | 4.9 | 22.7 | 20.0 | 52.2* | -10.1 |
| Granger x $B_6$ | 12.9 | 5.4 | 15.3 | 7.5 | 26.3 | -21.0 |
| Granger x $B_{12}$ | 111.3** | 9.8 | 35.7 | 3.0 | 116.7** | 66.6** |
| Granger x H | 101.4** | 7.0 | 58.8 | 0.0 | 158.6** | 22.0 |
| Mean | 79.5 | 3.6 | 43.8 | 12.9 | 97.3 | 7.8 |

$p < 0.05$. ** : $p < 0.01$.

and its components. Specific combining ability has previously been shown in pea to be the major contributing factor for seed yield and yield components (Singh and Singh 1987; Sarawat et al., 1994; Kumar et al., 1996; Sharma et al., 1999; Ceyhan 2003).

## Heterosis

Table 4 contains the computed heterosis in percentages for traits studied. In general, heterosis for seed yield was large and positive. The cross PS9830S431 x H exhibited very large heterosis for seed yield, and one crosses had heterosis of more than 200%. Similarly, PS9830S329 x $B_{12}$ produced the second largest effects for seed yield, as many as 10 crosses exhibited heterosis larger than 100%, especially crosses involving H and $B_{12}$ as male parents. Heterosis for plant height and seeds per pod were low and unimportant. Heterosis for pods per plant was very large and positive. The maximum value was for PS9830S431 x H (138.5%); and three crosses produced heterosis larger than 100%. Pod yield showed extremely large heterosis. It is mostly positive, but the few negative ranged from -3.6 to 384.3% in PS9830S307 x $B_6$ and PS9830S431 x H crosses. Heterosis for hundred seed weight was mostly positive and large. Six crosses showed heterosis larger than 20%. Finally, Granger x $B_{12}$ and PS9830F010 x H exhibited the largest positive and negative heterosis for hundred seed weight, respectively.

The analysis of mean performance of parents and their $F_1$ hybrids showed that for pod yield, 22 $F_1$ hybrids exceeded the mid parent value, 21 $F_1$ hybrids achieved this performance for seed yield, and 16 $F_1$ hybrids exceeded the mid parent value for plant height and 100 seeds weight (Table 5). Average heterosis expressed as a percentage of mid-parent values confirm this result. Thus, for all of the traits studied, $F_1$ progeny on average exceeded the mid-parent performance (Table 5). Thus, $F_1$ hybrids had more seed yield, more plant height, more pods per plant, more seeds per pod, a greater pod yield and more 100 seeds weight than the average of their parents.

Heterosis was found to be significant for seed yield and its components. The values reported in this study are in agreement with the values of heterosis obtained by Lejeune- Henaut et al. (1992), Mishra et al. (1993), Sarawat et al. (1994) and Ceyhan (2003) which is attributable to non-additive gene effects rather than over dominant ones.

In conclusion, from the results of the breeding program, we were able to improve some characters in pea cultivars. The hybrids were characterized by higher seed yield and yield components compared to the parents. In addition, new germplasm for useful morphological and agronomic traits was identified.

## ACKNOWLEDGEMENTS

Prof. Dr. Kevin E. MCPHEE is recognized for his valuable suggestions and critical review of the manuscript. The financial support from the Selcuk University Scientific Research Projects (BAP) is gratefully acknowledged.

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