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# COMBINING ABILITY OF BEAN GENOTYPES ESTIMATED BY LINE × TESTER ANALYSIS UNDER HIGHLY-CALCAREOUS SOILS

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## ABSTRACT

Line × Tester analysis involving six lines (local populations viz., PV1, PV2, PV3, PV4, PV5 and PV6) and three testers (cultivars viz., Şehirali 90, Akman 98 and Yunus 90) of dry bean (*Phaseolus vulgaris* L.) was conducted to determine combining ability of seed yield and its related traits under highly calcareous soils. Significant differences of linextester interaction was observed for all characters under the study indicating the prevalence of non-additive variance. Similarly, less than one value of $\sigma^2_{gca}$ / $\sigma^2_{sca}$ ratio for all traits indicated predominance of non-additive gene effects. Significant general and specific combining ability (GCA and SCA) effects were also noted in all the traits. Among the parents, PV5 (Line) and Akman 98 (Tester) were found to be good general combiners for seed yield and yield components. The most promising specific combinations for yield and other traits were PV3 ×Akman 98, PV2xYunus 90, PV6xŞehirali 90 and PV5xYunus 90. These crosses had significant estimates of SCA effects suggesting predominance of non-additive gene action for these traits under highly-calcareous soils. The average heterosis was 53.61 % for seed yield. This study has shown that in order to improve seed yield and yield components in dry bean under highly calcareous soils, the selection of parents should be based on *per se* performance as well as combining ability.

**Key words**: Bean, seed yield, general and specific combining ability.

## INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a legume of worldwide significance and a staple food of the rural poor in developing countries (Mutlu *et al.,* 2005). Dry bean is an important pulse, primarily cultivated in the Central Anatolia, Turkey (Ceyhan, 2004). The closed basin - Central Anatolia Region soils are relatively rich by means of lime. The amount of lime in the soil is quite important for plants. The pH increases by the increase in lime amount. The caution $Ca^{++}$ is high in soils that are rich in lime and more than pH 8.5. As increasing as $Ca^{++}$ caution in the soil, receivable phosphorus and iron create insoluble compounds combining with calcium. Necrosis, which is also called as "lime chlorosis", appears in the plants due to iron deficiency growing under a high amount of lime soils. Plant nutrition is difficult in high amount of lime in soils and, it causes decrease in yield and quality. Variable yield of the bean under highly-calcareous soils has led to the development of bean improvement programs that depend on selection of lines based on desirable genetic attributes including high-seed yield. The nature and magnitude of gene effect involved in expression of quantitative traits are important for successful development of crop varieties and cultivars through proper choice of parents for hybridization (Griffings, 1956; Falconer, 1989; Kwaye *et al*., 2008).

Breeding programs of many crops use linextester analysis because they offer breeders genetic information on quantitative traits (Ceyhan, 2003). Information of genetic systems controlling the characters is essential for the breeder when deciding on the selection method and breeding procedure to follow. From linextester analysis, plant breeders are able to gather information on heterosis, general combining ability (GCA) and specific combining ability (SCA) of parents in crosses (Ceyhan, 2003, Ceyhan *et al.*, 2008). Linextester mating systems have provided genetic understanding for a chosen set of parents (Ceyhan, 2003; Ceyhan *et al.*, 2008) and have been used to study various traits in many crops (Ahuja and Dhayal, 2007, Venkatraman *et al.*, 2007; Kwaye *et al.*, 2008; Kadanapuradadoddi *et al*., 2011).

Generally seed yield is a quantitative trait which is governed by polygenes in bean (Arunga *et al.*, 2010). Selection on the basis of seed yield alone is usually not effective, whereas selection along with yield components could be more efficient and reliable (Kwaye *et al.*, 2008). Consequently, information on the association between seed yield and its components and among the yield characters themselves can improve the efficiency of selection in plant breeding programs (Muhammad *et al.*, 1994; Shimelis, 2006; Kwaye *et al.*, 2008). The objectives of this study are to determine combining ability of yield and yield components (plant height, pods per plant, seeds per pod, seeds per plant, 100 seed weight) among cross-combinations of nine selected bean parents under highly calcareous soils.

## MATERIALS AND METHODS

Six lines selected from local populations (PV1, PV2, PV3, PV4, PV5 and PV5) and three tester cultivars Şehirali 90, Akman 98 and Yunus 90 of dry bean (Table 1), all originating from Turkey, were crossed in linextester crosses to produce the 18 $F_1$ hybrids (6 × 3) in 2009 growing season. The parental genotypes were chosen on the basis of their overall lime to highly calcareous resistance as assessed and superior seed yield performance under highly-calcareous soils trial conducted by Harmankaya *et al.* (2008), Ceyhan *et al.* (2009), Ülker and Ceyhan (2008) and Varankaya and Ceyhan (2012) at Central Anatolian, Turkey.

Konya is located at 32$^o$31 N\` latitude and 37$^o$52\` E longitude with an altitude of 1020 m above the mean sea level. According to the meteorological data, the average temperature was 20.9 $^o$C for 5 months in Konya city during the vegetation period. The total precipitation and relative humidity were 77.0 mm, 43.5 % respectively, which were less than the 27-year average (83.8 mm and 46.7%) of the Konya.

The characteristics of soil follow as clay-loam structure, a normal level of organic matter (2.25%) in 0-30 cm depth and low level in 30-60 cm depth. Lime content was high (37.6%, 34.4%, respectively), alkali reaction (pH = 8.05 – 8.00), no salinity problem was seen in the soil. The available phosphorus (17.9 kg ha$^{-1}$ – 13.4 kg ha$^{-1}$) and zinc (0.32 ppm – 0.34 ppm) levels were low. Low presence of these elements in the soil stems substantially from the high rate of lime. According to the soil analysis, the level of iron (14.74 ppm – 8.74 ppm), copper (1.70 ppm – 1.74 ppm) and manganese (7.50 ppm – 5.76 ppm) were sufficient.

The experiment was a randomized complete block design with three replications in the experimental field of the Faculty of Agriculture, Konya, Turkey. The parents and crosses were directly sown at 5 cm depth by 50 x 20 cm planting density on May, 15, 2009. Each of the rows two meters long and contained a total of 10 seeds. Di-ammonium phosphate (18-46 %) fertilizer was given with a dose of 15 kg da$^{-1}$ on each of sowing times spring irrigation was made to plots for providing of germination and stem elongation. Later, drip irrigation was made for five times depending on the plant's need. Weeds were eliminated by hand or hoeing and the harvest was made by hand from 28$^{th}$ of August to 8$^{th}$ of September in 2009 depending on maturation.

Observations were recorded on the middle five competitive plants for plant height, pods per plant, seeds per pod, seeds per plant, seed yield and 100 seed weight at the $F_1$ generation. Analysis of variance was done according to Steel *et al.* (1997) Line x Tester method (Kempthorne, 1957;) was used for genetic analysis of each characteristic.

## RESULTS AND DISCUSSION

The Line x Tester analyses were performed on all the traits for which crossed genotypes had shown significant differences (Table 2). Most of the hybrids had higher values than their parents for all the characters (Table 3). The mean values of the parents ranged from 12.78 to 20.20 g for seed yield, from 38.33 to 62.67 cm for plant height, from 11.43 to 16.83 number for pods per plant, from 3.10 to 4.45 number for seeds per pod, from 38.88 to 61.85 number for seeds per plant, from 24.75 to 43.11 g for 100- seed weight among the parents and varied from 19.19 to 38.57 g for seed yield, from 53.00 to 83.67 cm for plant height, from 17.10 to 26.03 number for pods per plant, from 3.20 to 5.23 number for seeds per pod, from 61.65 to 110.59 number for seeds per plant, from 25.44 to 38.44 g for 100- seed weight among in the $F_1$ generations. Significant differences of testers were established for seeds per plant, seed yield and 100-seed weight, and significant differences of lines were determined for seed yield and 100-seed weight. The linextester interaction showed significant differences for all traits under the study indicating the prevalence of non-additive variance. Despite non-significant effects of line and testers for plant height, pods per plant, and seeds per pod, their line x tester interactions were found significant. This might be due to the high moment of non-additive actions, substantially complementary epistasis effects.

The estimates of variance components for seed yield and its components (Table 4) indicated a lower $\sigma^2_{gca}$ than the $\sigma^2_{sca}$ for all traits. Additionally, the results also revealed that $\sigma^2_D$ was lower than $\sigma^2_H$ suggesting predominance of non-additive gene action in all the characters in the bean under highly-calcareous soils. Rodrigues *et al.* (1998) indicated that number of the pod was influenced by the genes effecting non-additively, and in contrast Barelli *et al.* (2000) revealed that both additive and non-additive gene effects were significant for controlling the number of pod. Non-additive gene action for seed yield was reported by Barelli *et al.* (2000), while Zimmermann *et al.* (1985), Singh and Urrea (1994), Oliveira-Junior *et al.* (1997) and Rodrigues *et al.* (1998) reported that additive gene affects were determined for seed yield, Barelli *et al.* (2000) also reported that additive and non-additive gene effects have equal effects in the heredity of seed per plant in bean. These results suggested that heterosis breeding was suitable for all the characters including seed yield and its component under highly-calcareous soils. Furthermore, importance of non-additive gene action has also been observed in self-pollinated crops. In pea, (Ceyhan 2003; Ceyhan *et al*., 2008) predominance of non-additive gene effects was observed for plant height, pods per plant, seeds per pod, seeds per plant, seed yield and 100 seed weight. Consequently, effects of the non-additive gene was found as economically valuable. So that, the mentioned genotypes can be used in selection works for highly-calcareous soils. The results are in conformity with previous reports by Barelli *et al.* (2000), Ceyhan (2003), Ceyhan *et al.* (2008) and Ceyhan and Kahraman (2013).

Estimates of GCA of the nine genotypes for six characters showed that PV3, PV5 and Akman 98 were the best combiners for seed yield (Table 5). Apart from seed yield, PV5 was also found to be a good general combiner for other yield traits. PV4, PV5 and Akman 98 were good general combiners for plant height, PV1, PV5, Akman 98 and Yunus 90 for pods per plant, PV5, PV6 and Akman 98 for seeds per pod, PV1, PV5 and Akman 98 for seeds per plant, PV3, PV4, PV5, Şehirali 90 and Yunus 90 for 100 seed weight (Table 5).

In this study, genotypes PV5 and Akman 98 were found to be good general combiners for seed yield and its components. These genotypes could be utilized in hybridization programs, while other genotypes were not good general combiners for seed yield and its components in the bean crosses under highly-calcareous soils.

The estimates of SCA of 18 crosses for the six characters are presented in Table 6. Five crosses, PV3xAkman 98, PV2xYunus 90, PV1xŞehirali 90, PV6xŞehirali 90 and PV5xYunus 90 exhibited highly significant SCA effects for seed yield. Good specific combiners for plant height were PV3xŞehirali 90, PV5xAkman 98, PV4xYunus 90, PV2xYunus 90, PV4xAkman 98, PV1xYunus 90 and PV5xŞehirali 90. Crosses PV1xŞehirali 90, PV2xYunus 90, PV3xYunus 90 and PV6xAkman 98 were good combiners for pods per plant. The best specific combiners for seeds per pod were PV6xŞehirali 90, PV3xAkman 98, PV1xAkman 98 and PV2xŞehirali 90. Crosses PV3xAkman 98, PV6xŞehirali 90, PV5xYunus 90, PV2xYunus 90 and PV1xAkman 98 exhibited highly significant positive SCA effects for seeds per plant. For 100 seed weight, highly significant positive SCA effects were showed by the crosses PV5xŞehirali 90, PV1xYunus 90, PV2xYunus 90, PV3xAkman 98, PV6xAkman 98 and PV4xŞehirali 90.

**Table 1. Some characteristics of parents and lines**

| Genotypes | General Characteristics |
|---|---|
| **PV1** | Dwarf dry bean line. The plant length is 50-60 cm. Pods are straight flat, light green color, spineless. The seeds are in dermason type and white colored. |
| **PV2** | Growing is vertical, plant height is 50 cm, leach, flower color is white, pod shape is straight and light convoluted towards terminal, dermason type and the seeds are white colored. |
| **PV3** | The plant is semi-wrapping, pod color is light green and the top side is pink colored mosaic, white seeds are in the shape of circular-oval and big on the maturing period. The seeds are white colored. |
| **PV4** | Growing is vertical, plant height is 55-60 cm, spineless, flower color is white, pod shape is straight and light convoluted towards terminal, horoz type and white color seeds. |
| **PV5** | Early maturing plants are semi-wrapping, the color of pods are light green and the top side is pink colored mosaic, white seeds are in the shape of circular-oval and big on the maturing period. |
| **PV6** | Growing is vertical, plant height is 50 cm, spineless, flower color is white, pod shape is straight and light convoluted towards terminal, the color of the seeds are white. |
| **Şehirali-90** | Growing is vertical, plant height is 55-60 cm, spineless, flower color is white, pod shape is straight and light convoluted towards terminal, horoz type and white color seeds. This cultivar is tolerant to fungi. |
| **Akman 98** | The plant is semi-wrapping, plant height is 60-70 cm, leech, flower color is white, pod shape is straight and light convoluted towards terminal, the seeds are in dermason type and the seeds are white. Protein rate in the seed is 23-26, and tolerant to virus and bacterial diseases. |
| **Yunus-90** | Growing type is dwarf-vertical and plant height is 60-65 cm, spineless, flower color is white, pod shape is straight and light convoluted towards terminal, number of seed per pod is 4-5, the type of seed is horoz, the color of the seed is white. |

The most promising specific combiners for seed yield and other characters were PV2xYunus 90, PV3xAkman 98, PV5xYunus 90 and PV6xŞehirali 90 (Table 6). These hybrids involved high/low or average/low combinations indicating additive x dominance type of gene interactions for expression of traits. The superiority of these crosses may be required for complementary and duplicate gene actions (Rodrigues *et al.*, 1998; Baralli *et al.*, 1999; Ceyhan, 2003; Ceyhan *et al.*, 2008 and Ceyhan and Kahraman, 2013). High ranges of SCA, also emphasis association of non additive effects in control of the all characters. Therefore, these hybrids are expected to produce desirable segregates and can be exploited successfully in bean improvement programs under highly-calcareous soils.

This study propound found the importance of non-additive gene effects in governing yield and its components in bean under highly-calcareous soils.

Amongst the parental lines, PV5 and Akman 98 were the best general combiners for seed yield along with other traits and thus could be used in bean hybridization programs under highly-calcareous soils. The most promising specific combiners for seed yield and other traits were PV2xYunus 90, PV3xAkman 98, PV5xYunus 90 and PV6xŞehirali 90 for further utilization in hybrid development in bean under highly-calcareous soils. Plant height, pods per plant, seeds per pod, seeds per plant, seed yield and 100 seed weight were identified as the best selection criteria in bean breeding under highly-calcareous soils.

**Table 2. Analysis of variance (line × tester) for seed yield and its components in bean**

| Source of variation | DF | Plant Height | Pods per Plant | Seeds per Pod | Seeds per Plant | Seed Yield | 100-Seed Weight |
|---|---|---|---|---|---|---|---|
| **Replication** | 2 | 7.864 | 15.560 | 0.170 | 63.706 | 7.739 | 0.985 |
| **Treatments** | 26 | 459.970$^{**}$ | 56.343$^{**}$ | 0.890$^{**}$ | 1254.423$^{**}$ | 133.719$^{**}$ | 52.646$^{**}$ |
| **Parents** | 8 | 203.593$^{**}$ | 10.901$^{**}$ | 0.511$^{**}$ | 141.351$^{**}$ | 12.412$^{**}$ | 86.990$^{**}$ |
| **Par vs Hyb** | 1 | 382.777$^{**}$ | 25.445$^{**}$ | 1.047$^{**}$ | 721.067$^{**}$ | 95.008$^{**}$ | 39.048$^{**}$ |
| **Hybrids** | 17 | 3823.265$^{**}$ | 945.159$^{**}$ | 1.241$^{**}$ | 19226.062$^{**}$ | 1762.261$^{**}$ | 9.050$^{**}$ |
| **Line** | 5 | 488.019 | 28.047 | 1.056 | 756.173 | 189.596$^{**}$ | 122.110$^{**}$ |
| **Tester** | 2 | 39.463 | 54.808 | 1.558 | 2174.205$^{*}$ | 141.143$^{*}$ | 11.107$^{*}$ |
| **Line vs Tester** | 10 | 398.819$^{**}$ | 18.271$^{**}$ | 0.941$^{**}$ | 412.886$^{**}$ | 38.488$^{**}$ | 3.106$^{**}$ |
| **Error** | 52 | 10.236 | 1.948 | 0.146 | 38.381 | 2.457 | 0.159 |

$^{*}$ : *p < 0.05*; $^{**}$ : *p < 0.01*

**Table 3. Means of the investigated characteristics in the parents and $F_1$ hybrids of beans**

| Genotypes | Plant height (cm) | Pods per plant (number) | Seeds per pod (number) | Seeds per plant (number) | Seed yield (g per plant) | 100-seed weight (g) |
|---|---|---|---|---|---|---|
| **Parents** | | | | | | |
| **PV1** | 52.00 $^{ghi}$ | 12.73 kl | 4.45 abc | 56.79 $^{ijk}$ | 19.20 $^{h-k}$ | 35.08 $^{de}$ |
| **PV2** | 51.00 $^{hi}$ | 12.07 l | 3.94 c-f | 47.86 $^{kl}$ | 12.78 $^{l}$ | 24.75 $^{n}$ |
| **PV3** | 38.33 $^{k}$ | 13.30 jkl | 3.69 c-g | 49.14 $^{jkl}$ | 17.25 $^{k}$ | 36.26 $^{c}$ |
| **PV4** | 47.00 $^{ij}$ | 13.60 jkl | 4.11 b-e | 55.78 $^{ijk}$ | 17.27 $^{k}$ | 32.04 $^{gh}$ |
| **PV5** | 41.67 $^{jk}$ | 11.43 l | 3.41 efg | 38.88 $^{l}$ | 16.85 $^{k}$ | 43.11 $^{a}$ |
| **PV6** | 43.67 $^{jk}$ | 16.23 hij | 3.82 c-g | 61.85 $^{hij}$ | 17.33 $^{k}$ | 26.59 $^{m}$ |
| **Şehirali 90** | 59.33 $^{c-f}$ | 15.30 ijk | 3.36 efg | 51.12 $^{jkl}$ | 17.69 $^{jk}$ | 35.04 $^{de}$ |
| **Akman 98** | 62.67 $^{c}$ | 15.37 ijk | 3.84 c-g | 58.75 $^{ijk}$ | 20.20 $^{h-k}$ | 32.47 $^{gh}$ |
| **Yunus 90** | 56.00 $^{c-h}$ | 16.83 hi | 3.10 g | 51.39 $^{jkl}$ | 16.78 $^{k}$ | 32.35 $^{gh}$ |
| **$F_1$ crosses** | | | | | | |
| **PV1xŞehirali 90** | 55.00 $^{e-h}$ | 25.30 $^{ab}$ | 3.47 $^{d-g}$ | 87.68 $^{cde}$ | 24.30 $^{efg}$ | 27.11 $^{lm}$ |
| **PV1xAkman 98** | 53.00 $^{f-i}$ | 22.80 $^{b-e}$ | 4.86 $^{ab}$ | 110.59 $^{a}$ | 24.73 $^{ef}$ | 25.44 $^{n}$ |
| **PV1xYunus 90** | 59.00 $^{c-f}$ | 22.20 $^{cde}$ | 3.56 $^{d-g}$ | 79.01 $^{efg}$ | 23.65 $^{fg}$ | 28.51 $^{jk}$ |
| **PV2xŞehirali 90** | 62.33 $^{cd}$ | 17.23 $^{ghi}$ | 3.85 $^{c-g}$ | 66.24 $^{ghi}$ | 19.19 $^{ijk}$ | 29.37 $^{j}$ |
| **PV2xAkman 98** | 61.33 $^{cde}$ | 22.70 $^{b-e}$ | 3.48 $^{d-g}$ | 78.99 $^{efg}$ | 23.64 $^{fg}$ | 27.85 $^{kl}$ |
| **PV2xYunus 90** | 74.00 $^{b}$ | 26.03 $^{a}$ | 3.33 $^{efg}$ | 86.57 $^{c-f}$ | 27.35 $^{de}$ | 30.71 $^{i}$ |
| **PV3xŞehirali 90** | 78.67 $^{ab}$ | 18.87 $^{fgh}$ | 3.20 $^{fg}$ | 60.63 $^{h-k}$ | 21.14 $^{ghi}$ | 35.88 $^{cd}$ |
| **PV3xAkman 98** | 55.00 $^{e-h}$ | 22.73 $^{b-e}$ | 4.86 $^{ab}$ | 110.03 $^{a}$ | 37.32 $^{a}$ | 35.49 $^{cde}$ |
| **PV3xYunus 90** | 54.67 $^{e-h}$ | 24.47 $^{abc}$ | 3.47 $^{d-g}$ | 84.13 $^{def}$ | 28.36 $^{d}$ | 35.18 $^{de}$ |
| **PV4xŞehirali 90** | 55.67 $^{d-h}$ | 17.17 $^{hi}$ | 3.58 $^{d-g}$ | 61.65 $^{hij}$ | 21.04 $^{g-j}$ | 34.71 $^{e}$ |
| **PV4xAkman 98** | 83.00 $^{a}$ | 21.00 $^{def}$ | 4.26 $^{bcd}$ | 89.06 $^{cde}$ | 27.39 $^{de}$ | 32.08 $^{gh}$ |
| **PV4xYunus 90** | 83.00 $^{a}$ | 18.10 $^{f-i}$ | 3.75 $^{c-g}$ | 67.70 $^{ghi}$ | 22.62 $^{fgh}$ | 33.56 $^{f}$ |
| **PV5xŞehirali 90** | 74.67 $^{b}$ | 20.33 $^{efg}$ | 4.25 $^{bcd}$ | 86.45 $^{c-f}$ | 32.22 $^{bc}$ | 38.44 $^{b}$ |
| **PV5xAkman 98** | 83.67 $^{a}$ | 22.30 $^{b-e}$ | 4.44 $^{abc}$ | 98.88 $^{abc}$ | 35.29 $^{ab}$ | 35.78 $^{cd}$ |
| **PV5xYunus 90** | 58.33 $^{c-g}$ | 24.00$^{a-d}$ | 4.49 $^{abc}$ | 107.17 $^{ab}$ | 38.57 $^{a}$ | 35.88 $^{cd}$ |
| **PV6xŞehirali 90** | 55.67 $^{d-h}$ | 17.10 $^{hi}$ | 5.23 $^{a}$ | 88.91 $^{cde}$ | 27.22 $^{de}$ | 31.66 $^{h}$ |
| **PV6xAkman 98** | 62.67 $^{c}$ | 23.33 $^{a-e}$ | 4.10 $^{b-e}$ | 94.16 $^{bcd}$ | 30.10 $^{cd}$ | 32.13 $^{gh}$ |
| **PV6xYunus 90** | 56.00 $^{c-h}$ | 18.50 $^{fgh}$ | 3.98 $^{c-f}$ | 73.56 $^{fgh}$ | 24.65 $^{ef}$ | 32.81 $^{fg}$ |

[a] Figures in the same column followed by a common letter are not significantly different using LSD at 5% probability level

**Table 4. Estimates of genetic components of the investigated characteristics in parents and $F_1$ hybrids of beans**

| Characteristics | $\sigma^2_{gca}$ | $\sigma^2_{sca}$ | $\sigma^2_{gca} / \sigma^2_{sca}$ | $\sigma^2_D$ | $\sigma^2_H$ |
|---|---|---|---|---|---|
| **Plant height** | 0.259 | 99.251 | 0.003 | 0.519 | 129.528 |
| **Pods per plant** | 0.215 | 10.372 | 0.021 | 0.430 | 5.441 |
| **Seeds per pod** | 0.003 | 0.343 | 0.009 | 0.006 | 0.265 |
| **Seeds per plant** | 9.240 | 349.440 | 0.026 | 18.480 | 124.835 |
| **Seed yield** | 1.695 | 38.512 | 0.044 | 3.389 | 12.010 |
| **100 seed weight** | 1.078 | 14.016 | 0.078 | 2.155 | 0.982 |

**Table 5. General Combining Ability (GCA) of the investigated characteristics in parents of beans**

| Parents | Plant height | Pods per plant | Seeds per pod | Seeds per plant | Seed yield | 100-seed weight |
|---|---|---|---|---|---|---|
| **Lines** | | | | | | |
| **PV1** | -9.09** | 2.09** | -0.05 | 7.35** | -2.93** | -5.35** |
| **PV2** | 1.13 | 0.65 | -0.46** | -7.811** | -3.76** | -3.06** |
| **PV3** | -1.98* | 0.68 | -0.16 | -0.15 | 1.79** | 3.15** |
| **PV4** | 9.13** | -2.59** | -0.14 | -12.27** | -3.47** | 1.08** |
| **PV5** | 7.46** | 0.87* | 0.38** | 12.42** | 8.21** | 4.33** |
| **PV6** | -6.65** | -1.70** | 0.43** | 0.47 | 0.17 | -0.17 |
| **SE** | **1.06** | **0.47** | **0.13** | **2.07** | **0.27** | **0.13** |
| **Testers** | | | | | | |
| **Şehirali 90** | -1.09 | -2.01** | -0.08 | -9.82** | -2.97** | 0.50** |
| **Akman 98** | 1.69* | 1.14** | 0.33** | 11.87** | 2.59** | -0.91** |
| **Yunus 90** | -0.59 | 0.87** | -0.25** | -2.06 | 0.38 | 0.41** |
| **SE** | **0.75** | **0.33** | **0.09** | **1.46** | **0.14** | **0.10** |

** : $p < 0.05$; ** : $p < 0.01$*

**Table 6. Specific Combining Ability (SCA) of the investigated characteristics in $F_1$ hybrids of beans**

| $F_1$ Hybrids | Plant height | Pods per plant | Seeds per pod | Seeds per plant | Seed yield | 100-seed weight |
|---|---|---|---|---|---|---|
| **PV1xŞehirali 90** | 0.43 | 3.88** | -0.42* | 5.07 | 3.05** | -0.40* |
| **PV1xAkman 98** | -4.35* | -1.77* | 0.57** | 6.29* | -2.09* | -0.68** |
| **PV1xYunus 90** | 3.93* | -2.11** | -0.16 | -11.36** | -0.96 | 1.08** |
| **PV2xŞehirali 90** | -2.46 | -2.75** | 0.37* | -1.21 | -1.23 | -0.44* |
| **PV2xAkman 98** | -6.24** | -0.42 | -0.40* | -10.15** | -2.35** | -0.55* |
| **PV2xYunus 90** | 8.70** | 3.17** | 0.02 | 11.36** | 3.58** | 0.99** |
| **PV3xŞehirali 90** | 16.98** | -1.15 | -0.56** | -14.48** | -4.83** | -0.13 |
| **PV3xAkman 98** | -9.46** | -0.42 | 0.69** | 13.22** | 5.79** | 0.88** |
| **PV3xYunus 90** | -7.52** | 1.57* | -0.13 | 1.26 | -0.96 | -0.74** |
| **PV4xŞehirali 90** | -17.13** | 0.42 | -0.20 | -1.34 | 0.32 | 0.77** |
| **PV4xAkman 98** | 7.43** | 1.11 | 0.07 | 4.38 | 1.12 | -0.47* |
| **PV4xYunus 90** | 9.70** | -1.53* | 0.13 | -3.05 | -1.44 | -0.30 |
| **PV5xŞehirali 90** | 3.54* | 0.13 | -0.07 | -1.23 | -0.17 | 1.25** |
| **PV5xAkman 98** | 9.76** | -1.05 | -0.28 | -10.49** | -2.66** | -0.02 |
| **PV5xYunus 90** | -13.30** | 0.92 | 0.34 | 11.73** | 2.83** | -1.23** |
| **PV6xŞehirali 90** | -1.35 | -0.54 | 0.87** | 13.19** | 2.86** | -1.04** |
| **PV6xAkman 98** | 2.87 | 2.55** | -0.66** | -3.26 | 0.19 | 0.84** |
| **PV6xYunus 90** | -1.52 | -2.02** | -0.21 | -9.93** | -3.05** | 0.20 |
| **SE** | **1.85** | **0.81** | **0.22** | **3.58** | **0.91** | **0.23** |

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

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