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Determination of Some Agronomic Traits of Fresh Bean Parents and Hybrids and Their Heritability with Diallel Analysis Method

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ABSTRACT

In this study, three commercial fresh bean cultivars (SF08/03, Ribera and Java) and two pole-type fresh bean lines (Mor Toparlak and Beyaz Toparlak) were hybridized (20 hybrid combinations) in accordance with full-diallel analysis method in 2016. F_1 generations and parents were grown in fully-automated plant breeding greenhouse of Selcuk University in 2017. Measurements, counts, weightings and analyses were formed to determine plant height, pod length, number of pods per plant, number of seed per pod, number of seed per plant, seed yield, hundred-seed weight, protein ratio and protein yields of the parents and hybrids. For investigated traits, diallel analysis method was employed to determine general combining ability (GCA) and specific combining ability (SCA), heterosis and heterobeltiosis values, broad and narrow sense heritability and correlations among the investigated traits of the parents and hybrids. For seed yield, non-additive gene effects and narrow sense heritability values were low. Heterosis and heterobeltiosis values for seed yield of F_1 generation were positive. As to conclude, proper parents and hybrids to be used in further bean breading programs were identified and their agronomic traits and heredities were determined.

1. Introduction

Among the vegetables, beans (*Phaseolus vulgaris* L.) with quire rich nutritional values and great consumptions throughout the world, are significant plants of *Leguminosae* family. They have a significant place in human nutrition (Nadeem et al. 2004). Beans are consumed as fresh, dried and canned foods. Fresh bean is produced almost in all regions of Turkey. It is quite rich in vitamins A, B1, B2 and D. It also neutralize body acids and create base excess in the body. Digestibility of the beans is 84.1%. It was even reported that *phasol* and *phaseolin* in bean pods had similar characteristics with insulin used in diabetes and therefore used to reduce blood sugar levels. Fresh beans supply raw material to vegetable processing industry (Madakbas 2017).

World fresh bean production was 213 651 119 tons from 15 million hectares in 2019. Indonesia with annual production of 881 613 tons corresponding to 41% of world production is the leading fresh bean producer of the world. Indonesia is followed by Turkey (30%) and India (29%) in fresh bean production of the world. On the other hand, with regard to fresh been cultivated lands, India with 1.7 million hectares has the first place and it is followed by Thailand and Indonesia (FAO 2020).

Genotypes with significantly positive general and specific combining ability (GCA and SCA) were reported for plant height, number of pods per plant, number of seed per pod, number of seed per plant and seed yield per plant of fresh bean hybrids (Zimmermann et al. 1985; Singh and Urrea 1994; Oliveira et al. 1997; Rodrigues et al. 1998; Barelli et al. 2000; Bozoglu and Sozen 2007; Ceyhan et al. 2014a;b). The genotypes with a high GCA variance can be used as a basic breeding source in such breeding programs (Oliveira et al., 1997; Oliveira et al., 1997).

It was reported that non-additive genes were effective on plant height, seed yield and hundred-seed weights of beans (Ceyhan et al. 2014b), additive genes were effective on seed yield and harvest index (Zimmermann et al. 1985; Singh and Urrea 1994; Oliveira et al. 1997; Rodrigues et al. 1998; Barelli et al. 2000), a single gene allele was effective on number of ovaries in broad beans (Al-Mukhtar and Coyne 1981), non-additive genes were effective on heredity of pod characteristics and plant height (Rodrigues et al. 1998; Ceyhan et al. 2014b), non-additive genes were also effective on heredity of protein ratio and yield (Ceyhan et al. 2014a).

Previous breeding studies of beans have mostly focused on selection breeding. Therefore, it is now evi-

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dent to focus on hybridizations to improve genetic variations. Such variation to be created through hybridizations and can be used to develop and breed bean varieties and ultimately improve unit area yields and quality, to develop cultivars resistant to pests and diseases and to create gene sources. Plant genetics and environmental factors are the most significant conditions influencing yield and quality of plants. If the genetic structure of the plant is not available for high yield and quality, it will be impossible to improve the yield and quality regardless of quite available environmental conditions. To develop new varieties through breeding works, either high-yield and quality genotypes adaptable to available environmental conditions should be selected or the insufficient aspects of available genotypes should be improved. In present study, hybridizations were performed among 5 fresh bean genotypes with superior agronomic and technological characteristics. The objectives of the present study were set as to investigate genetic structure of F_1 hybrids, to identify proper parents and combinations, to determine heritability, heterosis and heterobeltiosis of investigated traits and finally to identify the hybrids with superior agronomic and technological characteristics and available for machine-agriculture.

2. Materials and Methods

In present study, 3 fresh bean cultivars (Ribera (Romano-type, medium-power plant structure, medium-green fruits, high-yield, able to preserve pod color and freshness for longer periods. Available for fresh consumption, industrial process and machine-harvest), SF08/03 (strong root system, medium earliness. ground-type, cylindrical fruits, elliptic and white seeds) and Java (dwarf-type, early cultivar, smooth pod shape, bright green pod color, stringless pods, recommended to be sown in spring and autumn, available for fresh consumption and canning, suitable for manual and machine-harvest), with already known and superior characteristics and 2 pole-type fresh bean lines (Mor Toparlak (climbing –type, cylindrical pods, light green stringless pods, oval, large and light brown seeds) and Beyaz Toparlak (climbing –type, cylindrical pods, light green stringless pods, oval, large and white seeds) developed by Prof. Dr. CEYHAN through hybridizations and with different characteristics were used as the plant material.

Experiments were conducted in fully-automated breeding greenhouse of Field Crops Department at Selcuk University Agricultural Faculty in 2016. Experiments were initiated with the sowing of 5 fresh bean genotypes at 4 different sowing dates starting from 20th of March. In this way, concurrent flowering of fresh bean genotypes was achieved. For convenient hybridizations, parents were sown over 2m long rows with 1 m row spacing and 20 cm on-row plant spacing. Hybridizations were performed in accordance with Ceyhan et al. (2014b). At least 23 seeds were obtained from each one of 20 hybrid combinations.

Hybridizations were conducted with 9 full-diallel (reciprocal) parents in accordance with 5x5 equation and 20 hybrid combinations were obtained. Of the hybrid seeds, 15 and parents were also grown under greenhouse conditions. Greenhouse experiments were conducted in “Randomized Blocks Design” with three replications over 1 m long plots. Experiments were set up at “Fully Automated Plant Breeding Greenhouse of Selcuk University” on 15 April 2017. Harvest was performed in August. To meet the nutritional needs of the hybrids and parents, a uniform 15 kg DAP (Diammonium Phosphate) was applied to all plots. Manual and machine weed control was practiced and 5 irrigations were performed through drip irrigation. Throughout out plant growth period in fully-automated breeding greenhouse, day temperature was set at 25 ºC, night temperature was set at 18 ºC, relative humidity was set at 50-55% and wind speed was set at 5 km/h.

Measurements and counts on investigated parameters were performed on parents and hybrids of 5 plants of each plot. Plant height, pod length, number of pods per plant, number of seed per pod, number of seed per plant, seed yield, hundred-seed weight, protein ratio and protein yield were investigated in this study (Ceyhan et al. 2014a;b).

The measurements and observations made on F_1 plants were initially subjected to variance analysis in accordance with “Randomized Blocks Design”. Diallel analysis was performed for traits between with there are 1% and at least 5% significant variance. This analysis and calculations were conducted with TARPOPGEN software.

The method specified by (Griffing 1956) was taken into consideration and Model-I and Metot-1 were employed in diallel hybrids. This method covers parents and hybrids including reciprocals. Broad sense heritability of investigated traits was determined with variance components method. Narrow sense heritability was expressed as the ratio of additive genetic variance to phenotypic variance (Falconer 1980). Percent heterosis values were calculated in accordance with the principles specified in Fonseca and Patterson (Fonseca and Patterson 1968).

3. Results and Discussion

Mean squares of initial variance analysis and combining ability variance analysis for investigated traits are provided in full diallel hybrid set in Table 1.

In full diallel variance analysis for investigated traits, mean squares of hybrids were found to be significant for all traits. Genotypes had significant variation at 1% level for all traits (Table 1). Combining ability variance analysis in full-diallel hybrid set revealed significant differences in GCA values for all traits except for number of seeds per pod. On the other hand, significant differences were observed in SCA values for all traits. With regard to variations in reciprocal effect, differences in all traits were found to be significant (Table 1).

Table 1
Mean squares of initial variance analysis and combining ability variance analysis for investigated traits in full-diallel hybrid set

Source of Variation	SD	Plant Height	Pod Length	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
Blocks	2	205.013	2.736	3.040	0.120	18.840
Genotypes	24	6152.802**	8.884**	53.667**	1.919**	1302.056**
Error	48	487.861	2.456	9.373	0.676	159.604
GCA	4	8168.603**	4.681**	26.394**	0.192	444.839**
SCA	10	1084.378**	3.600**	21.326**	0.930**	571.920**
Reciprocal Effect	10	570.422**	1.635	11.050**	0.528*	291.789**
Error	48	162.620	0.819	3.124	0.225	53.2013
Source of Variation	SD	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield	
Blocks	2	52.239	10.720	0.234	4.184	
Genotypes	24	306.678**	463.333**	19.017**	17.453**	
Error	48	37.905	17.803	0.228	2.446	
GCA	4	155.144**	225.322**	27.983**	2.5392*	
SCA	10	104.539**	179.6933**	2.483**	8.226**	
Reciprocal Effect	10	78.746**	100.844**	1.537**	4.720**	
Error	48	12.635	5.934	0.076	0.815	

* : significant at 5% level , ** : significant at 1% level

3.1. Plant heights:

Among the morphological characteristics, plant height plays a significant role in yield levels, therefore it is considered as an important yield factor (Ceyhan 2004; Sozen et al., 2014). Recent breeding studies on fresh beans focused on development of dwarf cultivars available for machine harvest. Plant heights of F_1 generation varied between 32.67 cm (SF 08/03 x Ribera) and 166.33 cm (Mor Toparlak x SF 08/03) (Table 2). Previous researchers also reported similar findings for plant heights of fresh bean cultivars (Ceyhan et al. 2014b; Ceyhan 2004; Genchev 1995; Ulker and Ceyhan 2008).

With regard to plant height, σ^2GCA was lower than σ^2SCA and $(H/D)^{1/2}$ ratio was greater than 1 (Table 2). Such findings revealed that non-additive gene effects and dominant gene effects were effective on heredity of this trait. Ceyhan et al. (2014b) also reported the effects of non-additive genes and dominant gene effects on heritability of plant height of fresh beans.

With regard to parent GCA for plant height, while Mor Toparlak and Beyaz Toparlak had significant positive ($p < 0.01$) GCA, SF 08/03 ($p<0.05$), Ribera ($p<0.01$) and Java ($p<0.01$) had significant negative GCA (Table 3). Therefore, Mor Toparlak and Beyaz Toparlak cultivars with significant positive GCA were identified as the parents to be used in hybridization studies to increase plant heights. On the other hand, SF 08/03, Ribera and Java cultivars with significant negative GCA could reliably be used in breeding for short or medium-height cultivars.

Considering the SCA of the hybrids in F_1 generation, it was observed that “Ribera x Java”, “SF 08/03 x Mor Toparlak”, “SF 08/03 x Beyaz Toparlak” ($p<0.05$) hybrids had significant positive SCA and these combinations were identified as the genotypes with a breeding potential for long plant heights (Table 3). With regard to reciprocal effects of hybrids in F_1 generation, it was observed that “Mor Toparlak x SF 08/03” and “Beyaz Toparlak x Ribera” ($p<0.05$) hybrids had significant positive reciprocal effects. Such findings revealed that cytoplasm or cytoplasm x nucleus interactions created significant variations in this trait.

Very plant heights are not ideal because of lodging problem. Therefore, medium-height cultivars are preferred in bean culture. In this sense, the parents with significant negative GCA values could be used to shorten plant heights and the parents with significant positive GCA values could be used to increase plant heights. On the other hand, the hybrids with significant positive SCA values could be used for greater plant heights and the ones with significant negative SCA values could be used for shorter or medium plant heights. Previous researchers working on plant height also reported significant GCA and SCA values for various parents and hybrids (Rodrigues et al. 1998; Barelli et al. 2000; Ceyhan et al. 2014b; Arunga et al. 2010).

Mean heterosis value in F_1 generation was 33.56%. Except for 5 hybrids, the rest had positive heterosis values. Present heterosis values varied between -32.16% (Mor Toparlak x Beyaz Toparlak) and 137.99% (Java x Ribera) (Table 4). Rodrigues et al. (1998), Barelli et al. (2000), Ceyhan et al. (2014b) and Arunga et al. (2010) also investigated heterosis values for plant height and reported either greater or lower heterosis values for this trait.

Broad sense and narrow sense heritability values for plant height in F_1 generation was identified as 0.93 and 0.47 respectively (Table 2). High broad sense heritability for plant height and medium narrow sense heritability values indicated that this trait had high environmental variation and genotype variation was also effective. Non-additive gene effects were also significant in F_1 generation. These findings also indicated that selection for plant height could be performed at later generations.

Table 2
Mean values for investigated traits in full-diallel hybrid set

Parents	Plant Height	Pod Length	Number of Pods per Palnt	Number of Seeds per Pod	Number of Seeds per Plant
SF 08/03	40.00	15.43	10.67	4.00	42.33
Ribera	29.00	15.70	10.67	4.33	42.67
Java	30.67	16.17	10.33	3.33	33.00
Mor Toparlak (MT)	167.67	10.83	16.67	4.67	77.00
Beyaz Toparlak (BT)	136.00	13.17	16.33	4.67	76.00
F_1 Hybrids					
SF 08/03 X Ribera	32.67	13.00	14.67	4.67	67.33
SF 08/03 X Java	41.33	13.33	14.33	7.00	100.00
SF 08/03 X MT	123.67	12.87	27.00	4.33	116.67
SF 08/03 X BT	149.33	13.53	16.33	3.67	58.00
Ribera X SF 08/03	60.67	11.77	19.00	4.67	86.00
Ribera X Java	48.00	11.67	17.33	5.67	97.67
Ribera X MT	104.00	10.23	26.67	3.67	97.00
Ribera X BT	59.67	9.50	16.67	4.33	71.67
Java X SF 08/03	59.33	11.67	15.00	5.33	80.00
Java X Ribera	71.00	11.30	11.67	3.33	39.67
Java X MT	118.00	11.43	15.33	5.00	76.67
Java X BT	115.33	13.17	16.67	3.67	59.33
MT X SF 08/03	166.33	10.67	23.33	4.00	93.33
MT X Ribera	115.00	11.00	14.67	4.67	69.00
MT X Java	121.67	11.17	16.33	5.33	86.67
MT X BT	103.00	11.67	14.33	4.67	65.33
BT X SF 08/03	152.67	13.27	16.33	4.33	69.67
BT X Ribera	137.67	13.20	17.00	4.67	79.33
BT X Java	83.00	10.17	13.33	4.00	53.33
BT X MT	129.00	11.67	14.33	4.00	57.33
GCA	533.73	0.26	1.55	0.00	26.11
SCA	921.76	2.78	18.20	0.71	518.72
Reciprocal	135.93	0.27	2.64	0.10	79.53
σ^2GKK/ σ^2ÖKK	0.58	0.09	0.09	0.01	0.05
$H/D^{1/2}$	2125.16	3.57	23.95	0.80	650.47
H^2	0.93	0.80	0.88	0.78	0.93
h^2	0.47	0.12	0.11	0.01	0.07

GCA: General Combining Ability; SCA: Specific Combining Ability; $H/D^{1/2}$: Mean Degree of Dominance; H^2: Broad Sense Heritability; h^2: Narrow Sense

*3.2. Pod lengths***:**

In breeding of high-yield bean cultivars, selection of plants with longer pod lengths is a significant issue. With increasing pod lengths, number of seeds per pod and pod yield will increase, thus the yield will ultimately also increase (Ulker and Ceyhan 2008). Parent pod lengths varied between 10.83 cm (Mor Toparlak) and 16.17 cm (Java), F_1 generation pod lengths varied between 9.50 cm (Ribera x Beyaz Toparlak) and 13.53 cm (SF 08/03 x Beyaz Toparlak) (Table 2). Similar findings were also reported by previous researchers (Zimmermann et al. 1985; Ceyhan et al. 2014b; Genchev 1995; Ulker and Ceyhan 2008).

Greater σ^2SCA than σ^2GCA for pod length indicated that non-additive gene effect was effective in heredity of this trait (Table 3). Similar findings were also reported by Ceyhan et al. (2014b). Significant non-additive gene effect indicated that selections for this trait could be initiated at later generations.

With regard to GCA for pod length, it was observed that SF 08/03 cultivar had a significant positive value ($p<0.05$) and Mor Toparlak cultivar had a significant negative value ($p<0.05$) (Table 3). Therefore, SF 08/03 cultivar with a significant positive GCA was identified as a proper parent to be used in breeding studies to increase pod lengths.

Considering the SCA of F_1 generation, it was observed that “Ribera x Java” hybrid had a significant negative SCA ($p<0.05$) and the rest did not have significant SCA values (Table 3). With regard to reciprocal effects of hybrids in F_1 generation, while “Beyaz Toparlak x Ribera” ($p<0.05$) had significant positive effects, “Beyaz Toparlak x SF 08/03” and “Beyaz Toparlak x Java” ($p<0.05$) had significant negative reciprocal effects (Table 3). Ceyhan et al. (2014b) and Arunga et al. (2010) also reported significant GCA and SCA values for pod length.

Table 3
Genetic components for investigated traits in full-diallel hybrid set

Parents	Plant Height	Pod Length	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
SF 08/03	-9.187*	0.794*	0.533	0.120	3.767
Ribera	-27.120**	0.004	-0.300	-0.047	-2.500
Java	-23.887**	0.321	-2.133*	0.120	-5.867*
Mor Toparlak (MT)	35.813**	-1.066*	2.333*	0.020	9.800*
Beyaz Toparlak (BT)	24.380**	-0.053	-0.433	-0.213	-5.200*
F_1 Hybrids					
SF 08/03 X Ribera	-12.813	-0.717	0.400	0.113	3.600
SF 08/03 X Java	-12.380	-0.917	0.067	1.447**	20.300*
SF 08/03 X MT	22.587*	-0.264	6.100**	-0.453	19.633*
SF 08/03 X BT	40.020*	0.356	0.033	-0.387	-6.533
Ribera X SF 08/03	14.000	-0.617	2.167	0.000	9.333
Ribera X Java	14.720*	-1.144*	0.733	-0.053	5.233
Ribera X MT	5.020	-0.624	2.433*	-0.287	3.900
Ribera X BT	5.620	-0.904	1.367	0.280	11.400*
Java X SF 08/03	9.000	-0.833	0.333	-0.833*	-10.000
Java X Ribera	11.500	-0.183	-2.833*	-1.167*	-29.000**
Java X MT	12.120	-0.257	-0.567	0.547*	5.933
Java X BT	2.887	-0.904	1.367	-0.553*	-4.400
MT X SF 08/03	21.333*	-1.100	-1.833	-0.167	-11.667*
MT X Ribera	5.500	0.383	-6.000*	0.500	-14.000*
MT X Java	1.833	-0.133	0.500	0.167	5.000
MT X BT	-39.980*	0.483	-3.767*	0.047	-15.067
BT X SF 08/03	1.667	-0.133*	0.000	0.333	5.833
BT X Ribera	39.000*	1.850*	0.167	0.167	3.833
BT X Java	-16.167	-1.500*	-1.667	0.167	-3.000
BT X MT	13.000	0.000	0.000	-0.333	-4.000
G_i	13.010	0.065	0.250	0.018	4.256
S_{ij}	55.291	0.278	1.062	0.077	18.088
R_{ij}	81.310	0.409	1.562	0.113	26.601

G_i : GCA, S_{ij}: SCA; R_{ij}: Reciprocal effect, ** : significant at 1% level; * : significant at 5% level

Heterosis values for pod length varied between -34.18% (Ribera x Beyaz Toparlak) and -2.03% (SF 08/03 x Mor Toparlak). Only four hybrids, the rest had significant heterosis values for this trait (Table 4).

Broad sense and narrow sense heritability values for pod length in F_1 generation was respectively identified as 0.80 and 0.12 (Table 2). Low narrow sense heritability in F_1 generation indicated that environment had greater effects than the genetics for this trait. Since number of seeds per pod and thus the yield increase with increasing pod lengths and because of significant non-additive gene effect and weak hybrid power in present generation, a selection for pod length (together with seed yield) could be initiated at later generations.

3.3. Number of pods per plant:

Besides environmental conditions, high seed yield in beans also largely depend on yield components. Number of pods per plant is among the most significant yield components effecting yields (Ulker and Ceyhan, 2008). Number of pods per plant in parents varied between 10.33 pods/plant (Java) and 16.67 pods/plant (Mor Toparlak), number of pods per plant in F_1 generation varied between 11.67 pods/plant (Java x Ribera) and 26.67 pods/plant (Ribera x Mor Toparlak) (Table 2). Similar findings were also reported by Ceyhan et al. (2014b), Ülker and Ceyhan (2008), Varankaya and Ceyhan (2012) and Sozen and Bozoglu (2016).

Table 4
Heterosis (%) values for investigated traits in full-diallel hybrid set

F_1 Hybrids	Plant Height	Pod Length	Number of Pods	Number of Seeds per Pod	Number of Seeds per Plant
SF 08/03 X Ribera	-5.31	-16.49**	37.50**	12.00**	58.43*
SF 08/03 X Java	16.98	-15.61**	36.51**	90.91**	165.49**
SF 08/03 X MT	19.10	-2.03	97.56**	0.00	95.53**
SF 08/03 X BT	69.70	-5.36**	20.99**	-15.38**	-1.97
Ribera X SF 08/03	75.85	-24.41**	78.13**	12.00**	102.35**
Ribera X Java	60.89	-26.78**	65.08**	47.83**	158.15**
Ribera X MT	5.76	-22.86**	95.12**	-18.52**	62.12*
Ribera X BT	-27.68	-34.18**	23.46**	-3.70*	20.79
Java X SF 08/03	67.92	-26.16**	42.86**	45.45**	112.39**
Java X Ribera	137.99	-29.08**	11.11*	-13.04**	4.85
Java X MT	18.99	-15.31**	13.58**	25.00**	39.39
Java X BT	38.40	-10.23**	25.00**	-8.33**	8.87
MT X SF 08/03	60.19	-18.78**	70.73**	-7.69**	56.42*
MT X Ribera	16.95	-17.09**	7.32	3.70*	15.32
MT X Java	22.69	-17.28**	20.99**	33.33**	57.58*
MT X BT	-32.16	-2.78	-13.13**	0.00	-14.60
BT X SF 08/03	73.48	-7.23**	20.99**	0.00	17.75
BT X Ribera	66.87	-8.55**	25.93**	3.70*	33.71
BT X Java	-0.40	-30.68**	0.00	0.00	-2.14
BT X MT	-15.04	-2.78	-13.13**	-14.29**	-25.05
Mean	33.56	-16.68	33.33	9.65	48.27

** : significant at 1% level; * : significant at 5% level

Lower GCA variance than SCA variance for this trait indicated that non-additive gene effect was effective in heredity of this trait (Table 3). It was also reported in previous studies that number of ovaries in pod in beans was under the additive effect of a single gene allele (Al-Mukhtar and Coyne 1981), number of pods was under the effect of non-additive genes (Rodrigues et al. 1998; Ceyhan et al. 2014b) and additive genes (Barelli et al. 2000; Da Silva et al. 2004).

With regard to GCA values of the parents, it was observed that while Mor Toparlak ($p<0.05$) cultivar had significant positive effect, Java cultivar had significant negative effect ($p<0.05$) (Table 3). Therefore, Mor Toparlak cultivar with a significant positive GCA value can be recommended as a parent in further breeding studies to increase number of pods. There is a positive correlation between number of pods per plant and seed yield (Ceyhan 2004; Ulker and Ceyhan, 2008).

Considering the SCA of the hybrids in F_1 generation, it was observed that while “SF 08/03 x Mor Toparlak” ($p<0.01$) and “Ribera x Mor Toparlak” ($p<0.05$) combinations had significant positive SCA effect, “Mor Toparlak x Beyaz Toparlak” ($p<0.05$) combination had significant negative SCA effect. The others did not have significant SCA effects (Table 3).

Seed yield is the most significant yield component in edible legumes. Number of pods per plant contribute significantly in seed yield. Seed yields automatically increases with increasing number of pods per plant (Ceyhan et al. 2014b; Ceyhan 2004; Ulker and Ceyhan 2008; Varankaya and Ceyhan 2012). Therefore, Mor Toparlak cultivar with significant positive GCA for number of pods per plant could be recommended as a proper parent in breeding studies to be carried for high number of pods per plant. Similarly, “SF 08/03 x Mor Toparlak” ($p<0.01$) and “Ribera x Mor Toparlak” ($p<0.05$) hybrids with significant positive SCA could be used as proper combinations to improve number of pods per plant. Similar significant GCA and SCA values for number of pods per plant of the parents and hybrids were also reported by previous researchers (Rodrigues et al. 1998; Barelli et al. 2000; Ceyhan et al. 2014b; Al-Mukhtar and Coyne 1981; Arunga et al. 2010).

Heterosis values in F_1 generation varied between -13.13% (Mor Toparlak x Beyaz Toparlak x Beyaz and Toparlak x Mor Toparlak) and 97.56% (SF 08/03 x Mor Toparlak) with a mean value of 33.33%. Except for two hybrids, all the others had significant heterosis values (Table 4).

Seed yield in beans is a quantitative characteristic depending on several factors. Yield-designating factors on the other hand largely depend on genotypic and environmental conditions. Desired yield levels could be achieved only with the culture of cultivars under optimum conditions. Number of seeds per pod is also greatly influenced by environmental conditions. Large range of heterosis and heterobeltiosis values of the hybrids indicated that this treat greatly influenced by environmental conditions. High heterosis value of this generation indicated that these hybrid generations could be used as a significant source for greater number of pods per plant. Barelli et al. (2000), Ceyhan et al. (2014b) and Arunga et al. (2010) also investigated heterosis and heterobeltiosis values for number of pods per plant and reported both significant positive and negative heterosis and heterobeltiosis values.

Broad and narrow sense heritability in F_1 generation was respectively identified as 0.88 and 0.11 (Table 2). High broad sense heritability and low or medium narrow sense heritability in F_1 generation indicated that number of pods per plant was greatly influenced by environmental factors. Because of significant non-additive gene effects in present generation, selections should be initiated after 3-4 generations.

3.4. Number of seeds per pod.

Number of seeds per pod is a significant yield component in developing high-yield cultivars (Ceyhan 2004). There is a positive relationship between seed yield and number of seeds per pod. Seed yields can be increased through increasing number of seeds per pod. Number of seeds per pod of parents varied between 3.33 seeds/pod (Java) and 4.67 seeds/pod (Mor Toparlak and Beyaz Toparlak) and number of seeds per pod in F_1 generation varied between 3.33 seed/pod (Java x Ribera) and 7.00 seeds/pod (SF 08/03 x Java) (Table 2). Present findings comply with the results of Ceyhan et al. (2014b), Ülker and Ceyhan (2008) and Varankaya and Ceyhan (2012).

Quite greater SCA variance than GCA variance for number of seeds per pod indicated that non-additive gene effect was effective in heredity of this trait (Table 3). Al-Mukhtar and Coyne (1981) indicated that number of ovaries per pod in beans was under the effect of non-additive effect of single gene allele. Ceyhan et al. (2014b) also indicated non-additive gene effects for number of seeds per pod.

With regard to GCA, while Java, SF 08/03 and Mor Toparlak cultivars had positive effects, Beyaz Toparlak and Ribera cultivars had negative values (Table 3). Therefore, Java, SF 08/03 and Mor Toparlak cultivars with positive GCA values were identified as the parents to be used in breeding studies to increase number of seeds per pod in beans (Ceyhan 2004; Ulker and Ceyhan 2008).

Considering the SCA effects of hybrids in F_1 generation, it was observed that while “SF 08/03 x Java” ($p<0.01$) and “Java x Mor Toparlak” ($p<0.05$) combinations had significant positive effects, “Java x Beyaz Toparlak” ($p<0.05$) combination had significant negative SCA effect. Except for these hybrids, the rest did not have significant SCA effect (Table 3).

Since “SF 08/03 x Java” ($p<0.01$) and “Java x Mor Toparlak” ($p<0.05$) hybrids had highly significant positive SCA effects, they were considered as proper combinations to be used in increasing number of seeds per pod. Significant GCA and SCA effects were also reported in previous studies for number of seeds per pod (Rodrigues et al. 1998; Barelli et al. 2000; Ceyhan et al. 2014b; Al-Mukhtar and Coyne 1981; Arunga et al. 2010; Ceyhan and Şimşek 2021).

Heterosis values in F_1 generations varied between -18.52% (Ribera x Mor Toparlak) and 90.91% (SF 08/03 x Java) with a mean value of 9.65%. Except for four hybrids, the rest had significant heterosis values for this trait (Table 4). Ceyhan et al. (2014b) investigated heterosis and heterobeltiosis values for number of seeds per pod and reported both positive and negative heterosis and heterobeltiosis values.

Broad and narrow sense heritability values for number of seeds per pod in F_1 generation was respectively identified as 0.78 and 0.01 (Table 2). High broad sense heritability and low narrow sense heritability in F_1 generation indicated that number of kernels per pod was greatly influenced by environmental factors. Because of significant non-additive gene effects in present generation, selections should be initiated after 3-4 generations.

3.5. Number of seeds per plant.

Several researchers indicated significant effects of number of seeds per plant on seed yield (Ceyhan et al., 2014b; Ulker and Ceyhan, 2008; Varankaya and Ceyhan, 2012). Number of seeds per plant of the parents varied between 33.00 seed/plant (Java) and 77.00 seeds/plant (Mor Toparlak) and number of seeds per plant in F_1 generation varied between 39.67 seeds/plant (Java x Ribera) and 116.67 seeds/plant (SF 08/03 x Mor Toparlak) (Table 2). Similar findings were also reported by Ceyhan et al. (2014b), Ülker and Ceyhan (2008), Varankaya and Ceyhan (2012), Sozen and Karadavut (2017) and Tamüksek and Ceyhan (2020).

For number of seeds per plant, GCA variance was smaller than SCA variance. Such a case indicated that non-additive gene effect was effective on heredity of this trait (Table 3). Barelli et al. (2000) indicated that additive and non-additive genes had equal effects on heredity of number of seeds per pod in beans. Ceyhan et al. (2014b), Tamüksek and Ceyhan (2020) and Ceyhan and Şimşek (2021) indicated significant effects of non-additive genes on heredity of number of seeds per pod in beans.

With regard to GCA of the parents, while Mor Toparlak ($p<0.05$) cultivar had significant positive effects, Java and Beyaz Toparlak cultivars had significant negative values ($p<0.05$) (Table 3). Therefore, Mor Toparlak ($p<0.05$) with a highly significant positive GCA was identified as the parent to be used in increasing number of kernels per plant in beans.

Considering the SCA of the hybrids in F_1 generation, it was observed that “SF 08/03 x Java”, “SF 08/03 x Mor Toparlak” and “Ribera x Beyaz Toparlak” combinations had significantly positive ($p<0.05$) SCA effects. Except for these hybrids, the others did not have significant SCA effects (Table 3). Since “SF 08/03 x Java”, “SF 08/03 x Mor Toparlak” and “Ribera x Beyaz Toparlak” hybrids in F_1 generation had highly significant positive SCA effects, they were identified as proper combinations to increase number of seeds per plant.

Heterosis values in F_1 generation varied between -25.05% (Beyaz Toparlak x Mor Toparlak) and 165.49% (SF 08/03 x Java). With regard to this trait, only nine hybrids had significant heterosis values (Table 4).

Broad and narrow sense heritability of number of seeds per plant in F_1 generation was respectively identified as 0.93 and 0.07 (Table 2). High broad sense heritability and low narrow sense heritability in F_1 generation indicated that number of seeds per plant was also greatly influenced by environmental factors. Because of significant non-additive gene effects in present generation, it is better to initiate selections after 3-4 generations.

3.6. Seed yield:

It is quite difficult to identify high-yield genotypes of self-pollinating plants like beans in early generations. Although single seed yields are used to determine the seed yields of the genotype in breeding programs, great impacts of environmental conditions on this trait make precise assessments difficult. Mean seed yields of the parents varied between 19.34 g/plant (Java) and 45.09 g/plant (Beyaz Toparlak) and mean seed yields in F_1 generation varied between 20.72 g/plant (Java x Ribera) and 56.92 g/plant (Beyaz Toparlak x Ribera) (Table 5). Present findings comply with the results of Ceyhan et al. (2014b), Ülker and Ceyhan (2008), Varankaya and Ceyhan (2012) and Sozen et al. (2018).

Greater SCA variance than GCA variance for seed yield indicated that non-additive gene effect was effective on heredity of this trait. Similarly, a $(H/D)^{1/2}$ ratio of greater than 1 indicated superior dominance and supported that finding (Table 5). Present findings revealed that heredity of seed yield of beans was not a simple characteristic. Some previous researchers indicated that additive genes were effective in heredity of seed yield in beans (Zimmermann et al., 1985; Singh and Urrea, 1994; Oliveira et al., 1997; Rodrigues et al., 1998) and some others indicated that non-additive genes were effective (Barelli et al. 2000 and Ceyhan et al. 2014b; Tamüksek and Ceyhan 2020; Ceyhan and Şimşek 2021).

If the heredity of seed yield is dominated by additive gene effect, then selections can be initiated at early generations and superior genotypes can be identified at greater success. However, dominancy was effective in heredity of seed yield in beans instead of additive genes and such a case then reduces the rate of success in selections for this trait at early generations. In such cases, success is largely depending on type of effective epistasis. Selections for seed yield should be performed at later generations and transfer of superior genotypes to further generations should be provided.

With regard to GCA values in F_1 generation, it was observed that Mor Toparlak and Beyaz Toparlak cultivars had significant positive values ($p<0.05$) and SF 08/03, Ribera and Java cultivars had significant negative values ($p<0.05$) (Table 6). Therefore, Mor Toparlak and Beyaz Toparlak cultivars with significant positive GCA value were identified as promising parents to be used in further hybridizations for seed yield.

Considering the SCA values of hybrids in F_1 generation, it was observed that "SF 08/03 x Mor Toparlak", "Java x Mor Toparlak" and "Ribera x Beyaz Toparlak" ($p<0.05$) had significant positive SCA effect. These hybrid combinations with quite high significant SCA values could be considered as genotypes with a breeding potential for seed yields in further generations (Table 6). Previous researchers also investigated GCA and SCA effects on seed yield of beans and reported significant GCA and SCA values for parents and hybrids (Zimmermann et al. 1985; Singh and Urrea 1994; Oliveira et al. 1997; Rodrigues et al. 1998; Barelli et al., 2000; Arunga et al., 2010, Ceyhan et al. 2014b; Tamüksek and Ceyhan 2020).

Heterosis values for seed yield varied between -27.11% (Beyaz Toparlak x Mor Toparlak) and 105.99% (Ribera x Java) with a mean value of 31.82% (Table 7). Except for two hybrids, the rest exhibited significant positive heterosis. These hybrids were then identified as proper hybrids for further generations (Ceyhan et al. 2014b; Tamüksek and Ceyhan 2020).

Broad and narrow sense heritability for seed yield in F_1 generation was respectively identified as 0.90 and 0.13 (Table 5). High broad sense heritability and low narrow sense heritability for seed yield indicated that this trait was greatly influenced by environmental factors. Again low narrow sense heritability and non-additive gene effects on heredity of this trait reduce the rate of success in selections for seed yield in early generations. Rate of success can be improved through selecting the genotypes with quite high heredity for seed yield instead of selecting high-yield genotypes in early generations.

3.7. Hundred seed weight.

As it was in all plants, hundred seed weight is a significant yield component with direct impacts on yields. Hundred seed weights of the parents varied between 55.67 g (Ribera and Mor Toparlak) and 62.67 g (Beyaz Toparlak) and hundred seed weight of hybrids in F_1 generation varied between 29.33 g (Java x SF 08/03 and SF 08/03 x Java) and 77.33 g (Beyaz Toparlak x Java) (Table 5). Similar findings were also reported by previous researchers (Ceyhan et al. 2014b; Ceyhan 2004; Ulker and Ceyhan 2008; Arunga et al. 2010; Tamüksek and Ceyhan 2020; Ceyhan and Şimşek 2021).

Greater GCA variance than SCA variance indicated that non-additive gene effect was effective on heredity of hundred seed weight (Table 5). Ceyhan et al. (2014b) also indicated non-additive gene effects on heredity of hundred seed weight in beans.

Table 5
Mean values for investigated traits in full-diallel hybrid set

Parents	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
SF 08/03	23.46	57.33	25.71	6.01
Ribera	22.73	55.67	23.57	5.36
Java	19.34	59.33	26.80	5.24
Mor Toparlak (MT)	39.56	55.67	20.01	7.93
Beyaz Toparlak (BT)	45.09	62.67	21.99	9.92
F_1 Hybrids				
SF 08/03 X Ribera	34.40	53.33	28.90	9.95
SF 08/03 X Java	31.19	29.33	28.13	8.76
SF 08/03 X MT	54.94	58.67	26.06	14.31
SF 08/03 X BT	39.47	68.33	28.11	11.07
Ribera X SF 08/03	28.31	36.33	28.42	8.05
Ribera X Java	43.33	49.33	25.91	11.21
Ribera X MT	43.00	47.33	23.72	10.20
Ribera X BT	27.93	37.67	25.49	7.12
Java X SF 08/03	26.87	29.33	28.33	7.62
Java X Ribera	20.72	45.67	28.60	5.92
Java X MT	45.75	58.00	24.66	11.31
Java X BT	38.75	67.33	23.57	9.14
MT X SF 08/03	44.22	54.67	23.74	10.50
MT X Ribera	40.09	55.67	24.04	9.64
MT X Java	45.23	60.00	24.23	10.96
MT X BT	35.08	54.00	21.28	7.46
BT X SF 08/03	42.63	66.33	24.16	10.27
BT X Ribera	56.92	76.67	24.15	13.74
BT X Java	42.80	77.33	23.85	10.21
BT X MT	30.85	54.00	20.95	6.46
GCA	9.50	14.63	1.86	0.11
SCA	91.90	173.76	2.41	7.41
Reciprocal	22.04	31.64	0.49	1.30
σ^2GKK/ σ^2ÖKK	0.10	0.08	0.77	0.02
$H/D^{1/2}$	132.94	234.65	6.62	8.94
H^2	0.90	0.97	0.99	0.90
h^2	0.13	0.12	0.56	0.02

GCA: General Combining Ability; SCA: Specific Combining Ability; $H/D^{1/2}$: Mean Degree of Dominance; H^2: Broad Sense Heritability; h^2: Narrow Sense

Considering the GCA of the parents for hundred seed weight, it was observed that while Beyaz Toparlak cultivar had a significant positive value ($p<0.01$), SF 08/03 and Ribera cultivars had a significant negative ($p<0.01$) value (Table 6). Beyaz Toparlak with significant positive GCA value was considered as a proper parent to be used in further breeding studies to increase hundred seed weight of the beans.

With regard to SCA of hybrids in F_1 generation, it was observed that “SF 08/03 x Mor Toparlak”, “Java x Mor Toparlak”, “SF 08/03 x Beyaz Toparlak”, “Java x Beyaz Toparlak” hybrids with significant positive SCA value could be used as promising genotypes in further breeding studies to be carried out to increase hundred seed weights. On the other hand, “SF 08/03 x Ribera”, “SF 08/03 x Java” and “Mor Toparlak x Beyaz Toparlak” hybrids had significant negative SCA values (Table 6). Barelli et al. (2000), Ceyhan et al. (2014b), Tamüksek and Ceyhan (2020) and Ceyhan and Şimşek (2021) also reported genotypes with significant positive GCA and SCA values.

Heterosis values in F_1 generation varied between -49.71% (SF 08/03 x Java and Java x SF 08/03) and 29.58% (Beyaz Toparlak x Ribera). Except for six hybrids, all the rest had significant heterosis values (Table 7). Negative mean heterosis value of F_1 generations indicated that non-additive gene effects were effective on this trait. Such a case was probably resulted from the above mention reason or reverse dominance effect.

Broad and narrow sense heritability for hundred seed weight in F_1 generation was respectively identified as 0.97 and 0.12 (Table 5). Lower narrow sense heritability value indicated that hundred seed weights were greatly influenced by environmental factors. Considering the significant effects of non-additive genes on heredity of hundred seed weight, it was recommended that selections should be initiated in later generations.

Table 6
Genetic components for investigated traits in full-diallel hybrid set

Parents	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
SF 08/03	-2.012*	-3.700**	1.751**	0.121
Ribera	-2.891*	-3.467**	0.662**	-0.479
Java	-3.575*	-1.300	1.113**	-0.573*
Mor Toparlak (MT)	4.923*	0.567	-2.105**	0.535*
Beyaz Toparlak (BT)	3.555*	7.900**	-1.421**	0.396
F_1 Hybrids				
SF 08/03 X Ribera	-0.646	-2.800*	1.269**	0.222
SF 08/03 X Java	-2.292	-20.467**	0.391*	-0.494
SF 08/03 X MT	9.764*	5.000*	0.279	2.616**
SF 08/03 X BT	2.600	8.333**	0.827**	1.019
Ribera X SF 08/03	-3.043	-8.500**	-0.242	-0.951
Ribera X Java	1.582	-2.533	0.504*	0.486
Ribera X MT	2.607	-0.400	0.349*	0.731
Ribera X BT	4.855*	-2.067	0.605*	1.377*
Java X SF 08/03	-2.160	0.000	0.098	-0.573
Java X Ribera	-11.305*	-1.833	1.342**	-2.645*
Java X MT	7.239*	4.933*	0.459*	2.037*
Java X BT	3.886	10.933**	-0.956**	0.717
MT X SF 08/03	-5.360*	-2.000	-1.158**	-1.906*
MT X Ribera	-1.455	4.167**	0.158	-0.280
MT X Java	-0.258	1.000	-0.213	-0.172
MT X BT	-12.418**	-9.267**	-0.334*	-3.106**
BT X SF 08/03	1.582	-1.000	-1.977**	-0.398
BT X Ribera	14.492**	19.500**	-0.672*	3.308**
BT X Java	2.025	5.000*	0.138	0.534
BT X MT	-2.115	0.000	-0.163	-0.499
G_i	1.011	0.475	0.006	0.065
S_{ij}	4.296	2.018	0.026	0.277
R_{ij}	6.317	2.967	0.038	0.408

G_i : GCA, S_{ij}: SCA; R_{ij}: Reciprocal effect, ** : significant at 1% level; * : significant at 5% level

3.8. Protein content:

Protein content of parents varied between 20.01% (Mor Toparlak) and 26.80% (Java) and protein ratios of the hybrids varied between 20.95% (Beyaz Toparlak x Mor Toparlak) and 28.90% (SF 08/03 x Ribera) (Table 5). Present findings comply with the results of Ceyhan et al. (2014a), Varankaya and Ceyhan (2012), Ceyhan (2006).

Lower GCA variance than the SCA variance indicated that non-additive gene effect and superior dominancy were effective on heredity of protein ratio (Table 5). Ceyhan et al. (2014a) in a study indicated that non-additive gene effect was effective on heredity of protein ratios in beans.

With regard to GCA of the parents for protein ratio, it was observed that while SF 08/03, Ribera and Java cultivars had a significant positive (p<0.01) value, Mor Toparlak and Beyaz Toparlak cultivars had a significant negative (p<0.01) value (Table 6). Therefore, SF 08/03, Ribera and Java cultivars with significant positive GCA values can be recommended for further breeding programs to be carried out to increase protein ratios.

Considering the SCA effects of the hybrids in F_1 generation, it was observed that all hybrids, except for one, had significant SCA effects. Therefore, “SF 08/03 x Ribera” (p<0.01), “SF 08/03 x Java” (p<0.05), “SF 08/03 x Beyaz Toparlak” (p<0.01), “Ribera x Java” (p<0.05), “Ribera x Mor Toparlak” (p<0.05), “Ribera x Beyaz Toparlak” (p<0.05) and “Java x Mor Toparlak” (p<0.05) hybrids with significant positive GCA effects were found to be promising genotypes to be used in further breeding programs for protein ratios (Table 6). In a previous study, Ceyhan et al. (2014a) also reported genotypes with significant positive GCA and SCA values for protein ratio.

Heterosis values for protein ratio in F_1 generation varied between -3.38% (Java x Beyaz Toparlak) and 17.85% (SF 08/03 x Beyaz Toparlak). While all hybrids had significant heterosis values for protein ratio, heterobeltiosis values of two hybrids were insignificant (Table 7).

Broad and narrow sense heritability in F_1 generation was respectively identified as 0.99 and 0.56 (Table 5). Medium narrow sense heritability indicated that besides environment, genetic variance was also effective on heredity of protein ratio. Significant non-additive gene effect on protein ratio indicated that selections should be initiated at late generations.

Table 7
Heterosis (%) values for investigated traits in full-diallel hybrid set

F_1 Hybrids	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
SF 08/03 X Ribera	48.97**	-5.60	17.27**	74.93**
SF 08/03 X Java	45.74**	-49.71**	7.14**	55.66**
SF 08/03 X MT	74.37**	3.83	13.98**	105.33**
SF 08/03 X BT	15.15	13.89**	17.85**	38.92**
Ribera X SF 08/03	22.61*	-35.69**	15.31**	41.49**
Ribera X Java	105.99**	-14.20**	2.88**	111.53**
Ribera X MT	38.07**	-14.97**	8.86**	53.56**
Ribera X BT	-17.63*	-36.34**	11.89**	-6.81*
Java X SF 08/03	25.55**	-49.71**	7.89**	35.31**
Java X Ribera	-1.51	-20.58**	13.53**	11.75*
Java X MT	55.35**	0.87	5.33**	71.71**
Java X BT	20.27*	10.38**	-3.38**	20.58**
MT X SF 08/03	40.34**	-3.24	3.85**	50.64**
MT X Ribera	28.73*	0.00	10.31**	45.13**
MT X Java	53.59**	4.35	3.51**	66.47**
MT X BT	-17.12*	-8.73**	1.32**	-16.42**
BT X SF 08/03	24.38*	10.56**	1.27**	28.93**
BT X Ribera	67.85**	29.58**	6.00**	79.79**
BT X Java	32.84**	26.78**	-2.25**	34.65**
BT X MT	-27.11*	-8.73**	-0.24*	-27.59**
Mean	31.82	-7.36	7.12	43.78

** : significant at 1% level; * : significant at 5% level

3.9. Protein yield.

Protein yields of the parents varied between 5.24 g plant^{-1} (Java) and 9.92 g /plant^{-1} (Beyaz Toparlak) and protein yields of the hybrids varied between 5.92 g /plant^{-1} (Java x Ribera) and 14.31 g plant^{-1} (SF 08/03 x Mor Toparlak) (Table 5). Present findings comply with the results of Varankaya and Ceyhan (2012).

With regard to protein yield, σ^2GCA was lower than σ^2SCA and $(H/D)^{1/2}$ ratio was greater than 1 (Table 5). Such findings revealed that non-additive gene effects and dominant gene effects were effective on heredity of protein yield.

Considering the GCA of the parents, while Mor Toparlak cultivar had a significant positive ($p<0.05$) value, Java cultivar had a significant negative ($p<0.05$) value (Table 6). Therefore, Mor Toparlak cultivar with significant positive GCA can be used as a parent in further breeding studies to increase protein yields.

With regard to SCA of the hybrids in F_1 generation, “SF 08/03 x Mor Toparlak” ($p<0.01$), “Ribera x Beyaz Toparlak” ($p<0.05$) ve “Java x Mor Toparlak” ($p<0.05$) hybrids with significant positive SCA effects were identified as prominent genotypes to be used in further breeding programs to improve protein yield of the beans. On the other hand, “Mor Toparlak x Beyaz Toparlak” hybrid had significant negative SCA effect (Table 6).

Heterosis values in F_1 generation for protein yield varied between -27.59% (Beyaz Toparlak x Mor Toparlak) and 111.53% (Ribera x Java) with a mean value of 43.78%. All of the hybrids had significant heterosis values for protein yield (Table 7).

Broad and narrow sense heritability for protein yield in F_1 generation was respectively identified as 0.90 and 0.02 (Table 5). Lower narrow sense heritability indicated that environmental factors significantly influenced heredity of protein yield. Significant effects of non-additive genes on heredity of protein yield indicated that selections for this trait should be performed at late generations.

4. Conclusions

It was concluded based on current findings that the present population had a sufficient variation for investigated agronomic traits. Non-additive genes and dominant genes were more effective on investigated traits. Further selections in this population should be considered together with seed yield and better be performed especially at late generations.

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6. References

Al-Mukhtar FA, Coyne DP (1981). Inheritance and association of flower ovule, seed, pod and maturity characters in dry edible beans (*Phaseolus vulgaris* L.). *Journal of the American Society for Horticultural Science* 106(6): 713-719.

Arunga EE, Van Rheenen HA, Owuoche JO (2010). Diallel analysis of snap bean (*Phaseolus Vulgaris* L.), varieties for important traits. *African Journal of Agricultural Research* 5(15): 1951-1957.

Barelli MAA, Goncalves Vidigal MC, Amaral Junior ATD, Vidigal Filho PS, Scapim CA, Sagrilo E (2000). Diallel analysis for grain yield and yield components in *Phaseolus vulgaris* L.. *Acta Scientiarum* 22(4), 883-887.

Bozoglu H, Sozen O (2007). Some agronomic properties of the local population of common bean (*Phaseolus Vulgaris* L.) of Artvin province. *Turkish Journal of Agriculture and Forestry* 31(5): 327-334.

Ceyhan E (2004). Effects of sowing dates on some yield components and yield of dry bean (*Phaseolus Vulgaris* L.) cultivars. *Turkish Journal of Field Crops* 9(2): 87-95.

Ceyhan E (2006). Varitaions in grain properties of dry bean (*Phaseolus vulgaris* L.). *International Journal of Agricultural Research* 1(2): 116-121.

Ceyhan E, Harmankaya M, Kahraman A (2014a). Combining ability and heterosis for concentration of mineral elements and protein in common bean (*Phaseolus vulgaris* L.), *Turkish Journal of Agriculture* and Forestry 38(5): 581-590.

Ceyhan E, Kahraman A, Avcı MA, Dalgıç H (2014b). Combining ability of bean genotypes estimated by line x tester analysis under highly-calcareous soils. *The Journal of Animal and Plant Sciences* 24(29): 579-584.

Ceyhan E, Şimşek D (2021). Fasulyede tarımsal özelliklerin kalıtımlarının çoklu dizi analiz metoduyla belirlenmesi. *Türk Tarım ve Doğa Bilimleri Dergisi*, 8(1): 215-225.

Da Silva MP, Do Amaral Junior AT, Rodrigues R, Pereira MG, Viana AP (2004). Genetic control on morphoagronomic traits in snap bean. *Brazilian Archives of Biology and Technology* 47(6): 855-862.

Falconer DS (1980). Introduction to Quantitative Genetics. London. *Oliver and Boyd Ltd.*, 365.

FAO (2020). World Food and Agriculture - Statistical Yearbook 2020. Rome.

Fonseca S, Patterson FL (1968). Hybrid vigor in a seven parent diallel cross in common winter wheat. *Crop Science* 8: 85-88.

Genchev D (1995). Assessment of tolerance to stress factors in breeding material of kidney beans (*Phaseolus vulgaris* L.). *Bulgarian Journal of Agricultural Science* 1(4): 415-422.

Griffing B (1956). Concept of general and specific combining ability relation to diallel crossing systems. *Australian Journal of Biological Sciences* 9: 463-493.

Madakbaş SY (2017). Taze Fasulye Tarımı, http://www.arastirma.tarim.gov.tr: [15.08.2017].

Nadeem MA, Gündoğdu M, Ercişli S, Karaköy T, Saracoğlu O, Habyarimana E, Lin X, Hatipoğlu R, Nawaz MA, Sameeullah M, Ahmad F, Jung BM, Chung G, Baloch FS (2020). Uncovering Phenotypic Diversity and DArTseq Marker Loci Associated with Antioxidant Activity in Common Bean. *Genes*11(1):36.

Oliveira Junior A, Miranda GV, Cruz CD (1997). Evaluation of the combining ability of dry bean cultivars based on unbalanced circulating and partial diallel crossing systems. *Revista Ceres* 44(252): 215-229.

Rodrigues R, Leal NR, Pereira MG (1998). Diallel analysis of six agronomic traits in *Phaseolus vulgaris* L. *Bragantia* 57(2): 241-250.

Singh SP, Urrea CA (1994). Selection for seed yield and other traits among early generations of intra- and interracial populations of the common bean, Brasileira de Genetica, 17(3): 299-303.

Sozen O, Ozcelik H, Bozoglu H (2014). A research on some agronomic properties of colored bean (*Phaseolus vulgaris* L.) populations of Kelkit valley in Turkey. *Journal of Selcuk University Natural and Applied Science* 3(4): 61-74.

Sozen O, Bozoglu H (2016). The determination of some agronomic properties of lines selected among domestic dry bean populations collected from Kelkit valley and Artvin province. *American Journal of Experimental Agriculture* 12(5): 1-11.

Sozen O, Karadavut U (2017). Determination of yield and yield components of some dry bean (*Phaseolus vulgaris* L.) genotypes grown in Central Anatolia ecological conditions. *Scholars Bulletin* 3(11): 603-609.

Sozen O, Karadavut U, Akcura M (2018). A study on the determination of the performance some yield components in dry bean genotypes (*Phaseolus vulgaris* L.) in different environments. *Fresenius Environmental Bulletin* 27(12): 8677-8686.

Tamüksek Ş, Ceyhan E (2020). Determination of characteristics of dry bean lines hybridized by line x tester method and the effect of heredity. *Türk Tarım ve Doğa Bilimleri Dergisi*, 7 (1): 157-164.

Ulker M, Ceyhan E (2008). Orta Anadolu ekolojik şartlarında yetiştirilen fasulye (*Phaseolus vulgaris* L.) genotiplerinin bazı tarımsal özelliklerinin belirlenmesi. *Selçuk Üniversitesi Ziraat Fakültesi Dergisi* 22(46): 77-89.

Varankaya S, Ceyhan E (2012). Yozgat ekolojik şartlarında yetiştirilen fasulye (*Phaseolus vulgaris* L.) genotiplerinin bazı tarımsal özelliklerinin belirlenmesi. *Selçuk Tarım ve Gıda Bilimleri Dergisi* 26(1): 27-33.

Zimmerman MJO, Rosielle AA, Foster KW, Waines JG (1985). Gene action for grain yield and harvest index of common bean grown as sole crop and in intercrop with maize. *Field Crops Research* 12: 319-329.