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Genetic Analysis of Grain Yield and its Components in Green Bean for Soils with High Lime Content

Şemsi Tamüksek[1]
https://orcid.org/0000-0002-7215-3044

Ercan Ceyhan[1*]
https://orcid.org/0000-0002-9154-9984

[1]Selcuk University, Faculty of Agriculture, Department of Field Crops, Konya, Turkey.

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*Correspondence: eceyhan@selcuk.edu.tr; Tel.: +90-553-4702430 (E.C.)

HIGHLIGHTS

- Green beans are an important part of a healthy diet thanks to their rich nutritional content and high fiber, vitamin, and mineral content.
- High lime levels increase the soil pH for plants, making nutrient uptake difficult and adversely affecting plant growth.
- Green bean breeding is important for the development of bean varieties with higher yield, disease resistance and quality.

Abstract: Green beans are a legume used in human diets throughout the world. One of the most important factors limiting the yield of bean crops in the world is high lime. Two registered varieties (Beyzade and Lida) resistant to high lime and three commercial varieties (Ribera, Albeni, and Garrafol) which are superior in terms of some agricultural characteristics were used as materials. In this study, 20 F_1 hybrid combinations were obtained from green bean varieties Beyzade, Lida, Riberia, Albeni, and Garrafol using full diallel crosses. The effects of GCA and SCA on the traits examined in the study were found to be important and the most suitable parent and cross combinations for green bean breeding were identified. The study found that additive genes can effectively inherit grain yield and plant height, while non-additive genes can effectively inherit other traits studied. Garrafol had the highest GCA for grain yield. The “Lida x Garrafol” cross exhibited high SCA effects for seed yield per plant. These results indicate that sufficient levels of genetic variation exist in the study population for the agricultural traits observed in this study.

Keywords: diallel analysis; green bean; GCA; SCA.

INTRODUCTION

The most important function of legumes in the diet is as a source of protein. Pulses are not only rich in protein but also in vitamins and minerals and are an important food source in the human diet due to their high fiber content. They also have very important advantages in terms of soil sustainability. In underdeveloped and developing countries, legumes are more likely to be consumed as a source of protein in the diet [1,2]. In 2020, 15.796 million hectares of land around the world produced 23.276 million tons of green beans. China ranks first with 18 million tons, while Turkey ranks fourth with approximately 547.000 tons [3]. Therefore, every country strives to achieve self-sufficiency in important nutritional products [1].

In order to achieve the success of high-yield breeding programs in beans resistant to high lime, it is necessary to determine the appropriate starting materials that can be used in these programs. For this purpose, different studies have been carried out to determine gene effects for different traits in bean plants and to identify genotypes that can be used as source material in breeding studies. When the studies carried out for this purpose are taken into consideration, the studies related to yield [4-8], high lime tolerance, and quality [5,9-11] are noteworthy.

Previous studies determined the effect of additive genes on the inheritance of plant height, number of pods per plant [4], the effect of non-additive genes on plant height, number of pods and seeds per plant, grain yield, protein ratio and protein yield per plant [5-9,11,12], and the effects of additive genes on the inheritance of 100 seed weight trait [4].

The genetic structure of plants and environmental conditions are important factors that influence the yield and quality of plants obtained through breeding programs. To develop new varieties through breeding research, it is necessary to find high-yield and high-quality genotypes suitable for environmental conditions or to exploit the shortcomings of existing varieties. Therefore, the cultivation of green beans is very important for the sustainability of calcareous soils. To this point, the aim of the study was to develop a legume breeding program based on line selection for genetic characteristics required for variable legume yield on high calcareous soils. For this purpose, five green bean genotypes with very superior agricultural and technical characteristics were crossed. The purpose of this study was to study the genetic structure of parents and F_1 hybrids, identify suitable parents and genotypes, and determine the heritability and heterosis values of the studied traits.

MATERIAL AND METHODS

Two registered varieties (Beyzade and Lida) resistant to high lime and three commercial varieties (Ribera, Albeni, and Garrafol) which are superior in terms of some agricultural characteristics were used as materials in the study. These varieties are adapted to the conditions of Central Anatolia, show advantages in various yield components and quality characteristics, and have different morphological characteristics. As part of the study, green bean seeds were grown at 4 different sowing times in a plant breeding greenhouse in 2019 using the Diallel analysis method. This ensures that the green bean genotypes are used for the cross flower at the same time. The hybridization process was carried out in the same way as in previous studies [5-8]. During the research process, 20 hybrid combinations were obtained through diallel hybridization based on the 5×5 equation.

The parents and F_1 hybrids were planted on May 27, 2020, in the experimental field of the Faculty of Agriculture, Selcuk University. The experiment was conducted on 1 m long blocks and repeated three times according to a “Randomized Complete Block Design”. To meet the nutrient requirements of the parents and F1 hybrids, 15 kg of urea was evenly applied to the experimental area. To ensure germination and emergence of seedlings, water them 5 times using sprinkler irrigation after planting. Weed control is done mechanically or manually.

The results show that the experimental field has a clay soil structure, the organic matter content of the 0-30 cm soil layer is at a medium level, 2.25%, and the soil depth of the 30-60 cm is 1.23%, which is at a low level. The experimental field has a high lime content (37.6% - 34.4%) and an alkaline structure (pH=8.05 - 8.00), so there is no salinity problem. The amounts of available phosphorus (0.179 kg ha^{-1} – 0.134 kg ha^{-1}) and zinc (0.32 ppm - 0.34 ppm) in the experimental plots were quite low. Taking into account the results of the analysis at the test site, the levels of iron (14.74 ppm - 8.74 ppm), copper (1.70 ppm - 1.74 ppm) and manganese (7.50 ppm - 5.76 ppm) are sufficient.

The study was conducted in Konya Province and recorded 20 years of weather data. The average temperature when the parent and F_1 plants were growing in 2020 was 19.3°C. The study found that the total rainfall in the 2020 growing season was 109.6 mm, and the total rainfall in the 2020 growing season was 104.0 mm. The study found that the average relative humidity during the 20-year growing period was 48.0%, and the average relative humidity during the 2020 growing period was 45.8%. It can be seen from these values that the 20-year precipitation in the growing season is relatively close to what F_1 plants were growing in 2020.

Data were recorded on agronomic traits such as plant height, number of pods per plant, number of seeds per pod, number of seeds per plant, grain yield per plant, hundred seed weight, protein ration, and protein yield per plant. In this research, the study characteristics of parental and F_1 hybrids from each plot were measured, weighed, and analyzed [5,10]. In the study, measurements performed in F_1 hybrids were initially calculated using an analysis of variance according to a “Randomized Complete Block Design”. Traits with significant variance values between hybrids at 1% and 5% were calculated using the diallel analysis method [13]. Through research, analysis, and calculation, the AGD-R package solution was determined [14].

RESULTS AND DISCUSSION

All traits in Table 1 showed significant differences between genotypes. A high degree of variability in various traits among bean genotypes has been reported in previous studies [4-12,15,16]. Genetic variance is an important genetic parameter for selecting the best parents with the trait of interest from a population. The analysis of combining ability (Table 2) shows that the mean square values produced by GCA are significant for all features, indicating the existence of additive gene actions for all traits. Considering the mean square based on SCA values, only the number of seeds per pod and the protein ratio were significant, reflecting the presence of non-additive gene actions for all studied traits. A combined analysis of these findings suggests that both yield and related traits are determined by a combination of additive and nonadditive genes. Estimates of the highly significant GCA and SCA variance for this trait indicate the importance of additive and non-additive genes in trait expression [4,8-12].

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

Source of Variation	DF	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
Blocks	2	91,245	396,343	5,495	7841,471
Genotypes	24	149,054**	571,226**	2,897**	6652,122**
Error	48	33,789	183,922	0,873	2679,993
GCA	4	147,606**	229,300*	2,386**	3954,351**
SCA	10	17,482	66,888	0,704*	537,820
Reciprocal Effect	10	42,719**	298,373**	0,659*	3202,137**
Error	48	11,263	61,307	0,291	893,331
GCA		27,27	33,60	0,42	612,20
SCA		18,66	16,74	1,24	-1066,53
Reciprocal		31,46	237,07	0,37	2308,81
υ^2GCA / υ^2SCA		1,46	2,01	0,34	----
H/D$^{1/2}$		104,65	321,01	2,45	----
Source of Variation	**DF**	**Grain Yield per Plant**	**Hundred Seed Weight**	**Protein Ration**	**Protein Yield per Plant**
Blocks	2	32,682	1371,359	0,450	106,017
Genotypes	24	185,872**	1831,604**	4,225**	137,015**
Error	48	63,935	732,020	0,243	54,499
GCA	4	192,927**	1117,814**	2,933**	87,279**
SCA	10	32,428	161,656	1,265**	12,180
Reciprocal Effect	10	39,099	856,502**	0,941**	62,521**
Error	48	21,312	244,007	0,081	18,166
GCA		34,32	174,76	0,57	13,82
SCA		33,35	-247,05	3,55	-17,96
Reciprocal		17,79	612,50	0,86	44,35
υ^2GCA / υ^2SCA		1,03	----	0,16	----
H/D$^{1/2}$		119,78	----	5,55	----

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

In this study, the fact that υ^2GCA / υ^2SCA for plant height, pod number per plant, and grain yield per plant were greater than 1 and $H/D^{1/2}$, indicating additive genetic effects in beans (Table 1). On the other hand, non-additive gene effects and dominant gene effects were also found to be effective in the inheritance of the number of seeds per pod, number of seeds per plant, 100-seed weight, protein ratio, and protein yield per plant in green beans. The additive gene effects were identified for plant height [4], pods per plant [4], and grain yield per plant [4,15] in beans. Non-additive gene effects have been reported for plant height [5-7,16], pods per plant [5-7,16], number of seeds per pod [5-7,16], grain yield in the plant [5-9], hundred-seed weight [5-9], protein ratio [9,10], and protein yield in bean [7,10].

The mean values of grain yield and composition of each genotype and F_1 hybrid are listed in Table 2. The parental values ranged from 28.02 cm (Ribera) to 42.51 cm (Garrafol) for plant height, varied between 17.20 number (Ribera) and 31.55 number (Albeni) for the number of pods per plant, found between 4.57 number (Ribera) and 5.30 number (Garrafol) for number of grains per pod, ranged between 62.73 number (Ribera) and 122.29 number (Garrafol) for number of grains per plant, differed between 30.32 g/plant (Lida) and 53.21 g/plant (Garrafol) for grain yield, ranged between 21.78 g (Ribera) and 66.35 g (Garrafol) for between hundred-grain weight, found to be between 24.82% (Albeni) and 29.08% (Riberia) for protein ratio and ranged from 6.35 g/plant (Ribera) to 18.75 g/plant (Garrafol) for protein yield (Table 2). Large variations resulted in statistically different groups with respect to plant height (Ribera x Lida, 19.67 cm; Beyzade x Garrafol, 56.00 cm), number of pods per plant (Beyzade x Lida, 12.50 number; Beyzade x Garrafol, 77.50 number), number of grains per pod (Ribera x Garrafol, 2.89 number; Albeni x Beyzade, 6.67 number), number of grains per plant (Ribera x Albeni, 32.83 number; Lida x Beyzade, 217.00 number), grain yield (Albeni x Beyzade, 31.18 g/plant; Garrafol x Beyzade, 55.94 g/plant), hundred-grain weight (Ribera x Albeni, 14.07 g; Lida x Beyzade, 104.10 g), protein ratio (Riberia x Lida, 26.56%; Lida x Ribera, 29.08%), protein yield (Ribera x Albeni, 3.91 g/plant; Lida x Beyzade, 28.31 g/plant) for F_1 hybrids (Table 2). Similar results to our results have been reported by many researchers who have previously carried out studies on these subjects [1,2,4-12,17-19].

Estimates of the parental GCA effects on various traits are shown in Table 3. The GCA effects of the traits analyzed varied significantly between parents. Significant positive (positive/negative) GCA effects were found between parents for all traits analyzed. In each of the traits analyzed, the GCA effect of at least one parent was found to be significant. The presence of these significant GCA values indicates that there are potential parents for increasing yield and related traits in bean breeding studies. Apart from grain yield, Garrafol was found to be a good general combiner for other yield components including plant height, number of pods per plant, number of seeds per plant, hundred-seed weight, protein ratio, and protein yield per plant. Beyazade was a high-general combiner for the number of pods per plant and number of seeds per plant, Lida for the number of seeds per pod and protein ratio, and Ribera for protein ratio in green beans. The presence of positive GCA effects suggests that further progress through the breeding of green bean grain yield, its composition, and protein ratio characteristics should be positive Garrafol with high GCA effects in desirable directions for yield and associated traits suggests that genotypes may combine well with other genotypes to produce superior progeny. This strain can be used as green bean breeding material in terms of grain yield and composition. These findings support earlier studies in which the individual parental line was identified as a strong general combiner for grain yield and related traits [4,6-9,11].

The SCA estimates of grain yield and its components for 20 F_1 crosses are shown in Table 3. The SCA effect is due to a nonadditive genetic component, demonstrating the role of nonadditive genetic action in trait expression. The SCA effect is reflected as a reliable indicator for identifying promising hybrids. The "Lida x Garrafol" hybrid showed a higher SCA effect on grain yield. Cross with high SCA for plant height included "Beyzade x Garrafol". The "Beyzade x Garrafol" and "Albeni x Ribera" cross combination was a good combiner for pods per plant. A good specific combiner for seeds per pod was the "Lida x Albeni" "Albeni x Beyzade" and "Garrafol x Ribera" crosses. Crosses "Lida x Albeni", "Beyzade x Ribera", "Beyzade x Garrafol", "Albeni x Garrafol", "Garrafol x Lida", "Garrafol x Beyzade", "Garrafol x Ribera", and Beyzade x Lida", showed high SCA for protein ratio. "Albeni x Garrafol" cross was a high SCA effect for protein yield per plant.

The SCA effect estimates indicate that no single cross is uniformly promising for all traits. These crosses can be used in breeding programs to improve the traits being studied. It is worth noting that virtually all of the best crosses for each trait also had an ideal average performance. Based on mean performance, positive heterosis, and high positive SCA effect, the best crosses for grain yield per plant were "Lida x Garrafol", "Albeni x Ribera", "Garrafol x Beyzade, and "Garrafol x Albeni". Therefore, this cross can be used to obtain desired recombinants from a specific population and used to improve hybrid vigor and achieve high-yielding genotypes. Many studies have also reported similar results from identification crosses based on the SCA effects on bean yield and its components [4,6-9,11].

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

Parents/ F_1 Hybrids	Plant Height (cm)		Pods per Plant (number)		Seeds per Pod (number)		Seeds per Plant (number)	
Lida	33,01	bcd	23,59	bcd	4,69	a-g	84,65	bc
Beyzade	34,44	bcd	26,48	bcd	4,77	a-g	116,17	abc
Ribera	28,02	cde	17,20	cd	4,57	b-g	62,73	bc
Albeni	38,31	bcd	31,55	bcd	5,21	a-f	111,57	abc
Garrafol	42,51	b	30,76	bcd	5,30	a-f	122,39	abc
Lida x Beyzade	33,50	bcd	46,00	bc	6,45	abc	217,00	a
Lida x Ribera	30,00	b-e	30,67	bcd	4,67	a-g	115,33	abca
Lida x Albeni	37,00	bcd	29,00	bcd	6,50	ab	118,00	abc
Lida x Garrafol	42,50	b	52,50	ab	5,00	a-f	170,50	ab
Beyzade x Lida	29,00	cde	12,50	d	5,20	a-f	42,00	c
Beyzade x Ribera	31,00	b-e	22,00	cd	4,67	a-g	82,00	bc
Beyzade x Albeni	39,33	bc	39,33	bcd	4,00	d-g	119,33	abc
Beyzade x Garrafol	56,00	a	77,50	a	4,50	b-g	215,50	a
Ribera x Lida	19,67	e	16,00	d	4,33	d-g	57,17	bc
Ribera x Beyzade	26,00	de	21,67	cd	3,83	d-g	59,00	bc
Ribera x Albeni	30,17	b-e	15,00	d	3,67	efg	32,83	c
Ribera x Garrafol	27,44	cde	20,61	cd	2,89	g	53,89	c
Albeni x Lida	39,00	bc	34,75	bcd	6,50	ab	105,50	abc
Albeni x Beyzade	32,67	bcd	27,00	bcd	6,67	a	94,00	bc
Albeni x Ribera	31,67	b-e	28,00	bcd	3,42	fg	73,00	bc
Albeni x Garrafol	36,94	bcd	25,05	bcd	5,67	a-e	99,78	bc
Garrafol x Lida	38,28	bcd	21,67	cd	5,83	a-d	83,94	bc
Garrafol x Beyzade	31,05	b-e	20,22	cd	4,78	a-g	76,00	bc
Garrafol x Ribera	30,66	b-e	20,00	cd	4,44	c-g	53,33	c
Garrafol x Albeni	38,00	bcd	31,67	bcd	5,00	a-f	111,67	abc
Parents/ F_1 Hybrids	**Grain Yield per Plant (g)**		**Hundred Seed Weight (g)**		**Protein Ration (%)**		**Protein Yield per Plant (g)**	
Lida	30,32	g	29,60	c	28,52	a-d	8,46	d
Beyzade	37,63	c-g	42,60	bc	25,38	j	10,80	d
Ribera	35,20	efg	21,78	c	29,08	abc	6,35	d
Albeni	39,61	a-g	47,10	abc	24,82	j	11,68	cd
Garrafol	53,21	a-d	66,35	abc	28,29	c-f	18,75	a-d
Lida x Beyzade	40,23	a-g	104,10	a	27,20	ghi	28,31	a
Lida x Ribera	33,22	efg	40,65	bc	29,58	a	12,05	bcd
Lida x Albeni	35,35	efg	35,35	c	28,57	a-d	10,10	d
Lida x Garrafol	55,55	ab	102,78	a	27,44	e-ı	28,05	ab
Beyzade x Lida	44,60	a-g	21,52	c	27,79	d-h	5,98	d
Beyzade x Ribera	41,32	a-g	36,41	c	28,25	c-g	10,42	d
Beyzade x Albeni	42,57	a-g	57,30	abc	26,61	i	15,31	a-d
Beyzade x Garrafol	46,60	a-g	97,53	ab	27,43	e-ı	27,01	abc
Ribera x Lida	35,83	d-g	25,97	c	26,56	ı	6,84	d
Ribera x Beyzade	38,30	b-g	23,07	c	28,50	b-e	6,53	d
Ribera x Albeni	31,62	fg	14,07	c	27,78	d-h	3,91	d
Ribera x Garrafol	41,88	a-g	32,21	c	27,02	hi	8,58	d
Albeni x Lida	42,50	a-g	60,76	abc	28,13	c-g	17,06	a-d
Albeni x Beyzade	31,18	g	34,08	c	26,69	i	9,12	d
Albeni x Ribera	44,12	a-g	35,42	c	27,32	f-i	9,63	d
Albeni x Garrafol	33,27	efg	34,86	c	28,48	b-e	9,89	d
Garrafol x Lida	54,54	abc	43,49	bc	29,54	ab	12,85	a-d
Garrafol x Beyzade	55,94	a	31,78	c	29,05	abc	9,15	d
Garrafol x Ribera	49,11	a-f	34,27	c	28,34	c-f	9,71	d
Garrafol x Albeni	49,67	a-e	55,74	abc	28,85	a-d	18,75	a-d

The same letter for each tested trait isn't significantly different by LSD

Table 3. Estimates of GCA and SCA for investigated traits in full-diallel cross.

Parents	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant	Grain Yield per Plant	Hundred Seed Weight	Protein Ration	Protein Yield per Plant
Lida	-0,75	0,19	0,48*	8,78	-1,48	4,23	0,37**	1,31
Beyzade	0,49	3,08	0,06	14,62	-0,13	3,94	-0,58**	0,83
Ribera	-5,98**	-7,99*	-0,79**	-33,88*	-3,15	-16,58*	0,34*	-4,46*
Albeni	1,89	0,46	0,28	-1,36	-2,78	-2,97	-0,60**	-1,05
Garrafol	4,34*	4,24	-0,03	11,84	7,56**	11,38*	0,46**	3,37*
F_1 Hybrids								
Lida x Beyzade	-2,74	-2,87	0,37	7,00	2,30	9,47	-0,11	2,49
Lida x Ribera	-2,68	2,30	-0,09	12,26	-2,56	0,51	-0,45*	0,09
Lida x Albeni	2,61	2,39	0,83*	5,24	1,46	1,64	0,76**	0,82
Lida x Garrafol	2,54	3,81	0,06	7,50	7,23*	12,37	-0,16	3,25
Beyzade x Lida	-2,25	-16,7**	-0,62*	-87,50**	2,18	-41,28**	0,29*	-11,16**
Beyzade x Ribera	-0,26	-2,0	0,08	-9,32	1,36	-2,76	0,80**	-0,39
Beyzade x Albeni	-0,63	0,78	0,08	-5,68	-1,93	-0,43	0,02	-0,07
Beyzade x Garrafol	4,44*	12,69*	-0,29	20,18	2,10	4,17	0,54**	1,36
Ribera x Lida	-5,16**	-7,33*	-0,16	-29,08*	1,30	-7,33	-1,51**	-2,60
Ribera x Beyzade	-2,50	-0,16	-0,41	-11,50	-1,51	-6,67	0,12	-1,94
Ribera x Albeni	0,76	0,20	-0,84*	-10,91	2,07	-0,84	0,00	-0,20
Ribera x Garrafol	-3,55	-4,77	-0,40	-23,43	-0,65	-6,70	-0,93**	-2,27
Albeni x Lida	1,00	2,87	0,00	-6,25	3,57	12,70	-0,22	3,48*
Albeni x Beyzade	-3,33*	-6,16*	1,33**	-12,66	-5,69*	-11,61	0,03	-3,09
Albeni x Ribera	0,75	6,50*	-0,12	20,08	6,25**	10,67	-0,22*	2,86
Albeni x Garrafol	-3,01	-5,17	0,18	-3,85	-5,04	-8,26	0,99**	-1,83
Garrafol x Lida	-2,11	-15,41**	0,41	-43,27**	-0,50	-29,64**	1,05**	-7,60**
Garrafol x Beyzade	-12,47**	-28,64**	0,13	-69,75**	4,67*	-32,87*	0,80**	-8,93*
Garrafol x Ribera	1,61	-0,30	0,77**	-0,27	3,61	1,02	0,65**	0,56
Garrafol x Albeni	0,52	3,30	-0,33	5,94	8,20**	10,43	0,18	3,09
Gi	0,90	4,90	0,02	71,46	1,70	19,52	0,01	1,45
Sij	3,82	20,84	0,09	303,73	7,24	82,96	0,03	6,17
Rij	5,63	30,65	0,14	446,66	10,65	122,00	0,04	9,08

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

Table 4. Estimates of GCA and SCA for investigated traits in full-diallel cross.

F_1 Hybrids	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant	Grain Yield per Plant	Hundred Seed Weight	Protein Ration	Protein Yield per Plant
Lida x Beyzade	-0,67	83,74**	36,36**	116,12	18,40	188,33	0,91*	194,10
Lida x Ribera	-1,68	50,34**	0,79	56,51	1,40	58,22	2,70**	62,79
Lida x Albeni	3,76	5,17**	31,31	20,28	1,09	-7,84	7,14**	0,30
Lida x Garrafol	12,56	93,17**	0,03	64,71	33,00	114,23	-3,41**	106,19
Beyzade x Lida	-14,01	-50,07**	9,94**	-58,17	31,27	-40,39	3,10**	-37,85
Beyzade x Ribera	-0,74	0,73*	0,00	-8,33	13,47	13,12	3,74**	21,62
Beyzade x Albeni	8,13	35,56**	-19,79	4,80	10,23	27,76	6,03**	36,20
Beyzade x Garrafol	45,55	170,79**	-10,63**	80,67	2,59	79,02	2,24*	82,87
Ribera x Lida	-35,55	-21,56**	-6,41*	-22,42	9,39	1,10	-7,78**	-7,60
Ribera x Beyzade	-16,75	-0,79*	-17,86**	-34,04	5,17	-28,33	4,65**	-23,80
Ribera x Albeni	-9,03	-38,47**	-24,97**	-62,33	-15,47	-59,16	3,08**	-56,62
Ribera x Garrafol	-22,17	-14,07**	-41,51**	-41,78	-5,27	-26,90	-5,79**	-31,66
Albeni x Lida	9,37	26,03**	31,31**	7,53	21,55	58,41	5,47**	69,43
Albeni x Beyzade	-10,19	-6,94**	33,69**	-17,45	-19,26	-24,03	6,34**	-18,86
Albeni x Ribera	-4,51	14,86**	-30,08**	-16,24	17,97	2,86	1,39	6,88
Albeni x Garrafol	-8,57	-19,59**	7,83*	-14,70	-28,31	-38,54	7,28**	-34,99
Garrafol x Lida	1,37	-20,28**	16,71**	-18,91	30,59	-9,34	3,99**	-5,56
Garrafol x Beyzade	-19,29	-29,35**	-5,13*	-36,28	23,16	-41,66	8,25**	-38,08
Garrafol x Ribera	-13,04	-16,62**	-9,96**	-42,38	11,09	-22,23	-1,20	-22,63
Garrafol x Albeni	-5,96	1,63**	-4,85*	-4,54	7,03	-1,75	8,67**	5,68
Mean	-4,07	13,21	-0,16	-1,35	8,45	12,14	2,84	15,42

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

The performance of the parents involved in the cross itself may not be a reliable indicator of genetic potential, whereas the heterotic response of the cross is more reliable. The degree of heterosis provides information about the level of genetic diversity between the hybrid parents and helps in selecting parents to obtain superior F_1 plants to exploit heterosis. Exploiting crop heterosis is one of the biggest breakthroughs in plant breeding. Overall, the degree of heterosis for the different traits in this study varied across intersections in both extent and direction.

In our study, average heterosis values were found to be positive for the number of pods and, grain yield per plant, 100-seed weight, protein ratio, and protein yield per plant, and negative for other traits. However, it was found that there were significant differences between the hybrids according to both the magnitude of the calculation results and the negative and positive directions. A perusal of Table 4 shows that the scale of heterosis for plant height was −35.55% (Ribera x Lida) to 45.55% (Beyzade x Garrafol). The Beyzade x Garrafol cross exhibited the highest significant heterosis for the number of pods per plant (170.79%), while the Ribera x Albeni cross had the lowest significant heterosis for the number of pods per plant (−38.47%). The heterosis ranged from −41.51% (Ribera x Garrafol) to 36.36% (Lida x Beyzade) for the number of seeds per pod. In the case of the number of seeds per plant, the heterosis scale varied from −62.33% (Ribera x Beyzade) to 116.12% (Lida x Beyzade). The Lida x Garrafol cross exhibited the highest heterosis for grain yield per plant (33.00%), while the Albeni x Garrafol cross had the lowest value (−28.31%). For 100-seed weight, the scale of heterosis varied from −59.16% (Ribera x Beyzade) to 188.33% (Lida x Beyzade). In the case of protein ratio, heterosis ranged from -7.78% (Ribera x Lida) to 8.67% (Garrafol x Albeni). For protein yield per plant, heterosis varied from −56.62% (Ribera x Albeni) to 194.10% (Lida x Beyzade).

Heterosis can be used to develop and identify the most heterotic and useful cross combinations to enable commercial cultivation of hybrids. The Lida x Garrafol cross showed high positive heterotic effects on grain yield per plant as well as 100-seed weight, protein yield per plant, number of pods per plant, number of seeds per plant, and plant height, and high negative heterotic effects on protein ratio. The Garrafol x Lida cross showed a positive heterotic effect for protein ratio, number of seeds per pod, and plant height. Another Garrafol x Beyzade cross, in addition to grain yield per plant, also showed a positive heterotic effect for protein ratio, and a high negative heterotic effect for 100-seed weight, protein yield per plant, plant height, number of pods per plant, number of seeds per plant, and number of seeds per pod (Table 4). These combinations have the potential to be incorporated into crop improvement programs to generate transgressive segregants in future generations. It was found in different studies that grain yield and yield traits in beans had positive or heterosis [5-8,12]. The reason for this is that it is highly influenced by the genetic material used as in our study.

CONCLUSION

According to the objectives of this study, it is possible to evaluate the results obtained under four different topics. These are the gene effects that play a role in the change of the examined traits and the materials that can be improved by selection, the heterosis status of the examined traits, and the relationships between the traits. When the gene effects calculated for the traits analyzed were taken into consideration, it was determined that additive gene effects and epistatic interactions were effective for plant height, number of pods per plant, and grain yield, and non-additive gene effects played a role in the inheritance of other traits. It was observed that grain yield could be improved by selection and the highest improvement could be obtained from the “Lida x Garrafol” cross. For protein ratio, it was found that positive genetic improvement was possible in “Lida x Albeni”, “Beyzade x Ribera”, “Beyzade x Garrafol”, “Albeni x Garrafol”, “Garrafol x Lida”, “Garrafol x Beyzade”, “Garrafol x Ribera”, and “Beyzade x Lida” populations. Heterosis analyses showed that the mean heterosis values were positive for all traits except plant height, number of seeds in pods, and number of seeds per plant. The magnitude of heterosis values varied according to the hybrids. According to the results of heterosis analysis, high positive heterosis was calculated for grain yield especially in “Lida x Garrafol” and “Garrafol x Lida” hybrids. The prominent materials in the study can be included in the breeding programs to be carried out for high grain yield in soils with lime content.

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