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Research Article

Genetic Variability Studies in F_2 Generations of Determinate High Yield Fresh Bean Lines for Seed Yield and Yield Components

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ABSTRACT

Fresh bean is the most important pulse crop which are sold fresh, canned, and frozen. The genetic variability and association studies help in selection which would increase the yield potential of fresh bean. The experiment was conducted using randomized block design in 2021 at Konya with 25 genotypes (5 parents and 20 F_2 Population). General and special combination abilities, heterosis and heterobeltiosis values, broad and narrow sense heritability, as well as the relationships between the investigated traits, were determined in the parent and F_2 hybrids suitable for the diallel analysis method. It was found that there is an additive gene effect in the inheritance of the seed yield trait, and non-additive gene effect in the inheritance of the protein ratio trait. It was determined that the heritability in the narrow sense was low for the seed yield and protein ratio traits. It was also determined that non-additive gene effects were effective in the inheritance of seed yield and protein ratio traits. In F_2 generation, the mean heterosis value determined in terms of seed yield was positive and the mean heterobeltiosis value was negative. As a result of this research, a sufficient level of genetic variation was determined in the population, considering the agronomic characteristics examined. Determination of suitable parents and hybrids for green bean breeding in terms of sustainability of calcareous soils, agronomic characteristics and inheritance of these parents and hybrids were determined.

1. Introduction

Sustainable agriculture is formed due to the combination of an agricultural structure in which agricultural inputs and technologies are used, both by ensuring the protection of natural resources in the long term and by not harming the environment. Sustainable agriculture is a system that protects natural resources such as water and soil and includes many other agricultural practices (integrated pharma management, etc.) (Turhan, 2005). As the calcareous rate in the soil increases, it combines with phosphorus, iron and calcium, which can be taken in the soil to form insoluble compounds. Necrosis, also called “lime chlorosis”, occurs due to iron deficiency in plants growing under a high amount of calcareous soil. Due to the high amount of lime in the soil, it is difficult to feed the plant, causing a decrease in yield and quality (Griffing, 1956; Falconer, 1989; Kwaye et al., 2008; Ceyhan et al., 2014).

Bean (*Phaseolus vulgaris* L.), an important cultural plant of the Leguminosae family, which is widely consumed worldwide, has an important place in terms of both high nutritional value and human nutrition. The bean plant has an important place in human nutrition with its very different usage areas as a fresh vegetable or canned form, and dry seed and seed canning (Bozoğlu, 1995). In the world, 23,276 million tons of green beans were produced in 15,796 million hectares of land in 2020. While China is in the first place with 18 million tons, Turkey is in the fourth place with approximately 547 thousand tons (FAO, 2022).

In their research, Arunga et al. (2010), determined the effects of the additive gene in the inheritance of plant height, pod number, and pod length traits, and Ceyhan et al. (2014b), Kepildek and Ceyhan (2021), determined the effects of non-additive genes in the inheritance of plant height, pod number, and pod length traits in their studies. Iqbal et al. (2010) determined the additive gene effect on the inheritance of pod length and hundred-seed weight traits, while they determined the non-additive

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gene effect on the inheritance of pod number, seed number per pod, seed yield, and protein ratio traits.

The genetic structure of the plant and environmental conditions are important factors affecting the yield and quality of the plants obtained by breeding programs. To develop new varieties with breeding studies, it is necessary to find productive and high-quality genotypes suitable for environmental conditions or to develop the insufficient aspects of existing varieties. For this reason, green bean breeding is very important for the sustainability of calcareous soils. At this point, the aim of the study has led to the development of bean breeding programs depending on the selection of lines based on the desired genetic characteristics of the variable yield of beans under high calcareous soils. For this purpose, crosses were made between 5 green bean genotypes with very superior agricultural and technological properties. The research was carried out to investigate the genetic structure of the parent and the F_2 hybrid, to determine the appropriate parents and genotypes, heritability, heterosis, and heterobeltiosis values of the examined traits. At the same time, it was also aimed to determine the yield and quality of green bean parents and genotypes in terms of the sustainability of calcareous soils.

2. Materials and Methods

In the research, two registered cultivars (Beyzade and Lida) developed by Prof. Dr. Ercan CEYHAN and 3 commercial cultivars (Ribera, Albeni, and Garrafol) were used. These cultivars are suitable for Central Anatolian conditions, show superiority in terms of various yield components and quality characteristics, and have morphologically different characteristics. In the research, green bean seeds were planted in the Plant Breeding Greenhouse in 2019 using the diallel analysis method at four different sowing times. Thus, simultaneous flowering of green bean genotypes used in hybridization was ensured. The hybridization process was carried out according to Ceyhan (2004). In the research by diallel hybridization, 20 hybrid combinations were obtained as a result of 5 x 5 equation.

In the research, parents and F_1 hybrids were carried out in 2020 in the Experimention Field of the Selcuk University's Faculty of Agriculture. On 29.04.2021 Parents and F_2 hybrids were planted in the Experimention Field of the Selcuk University's Faculty of Agriculture. The experiments were set up on blocks of 2 m length with 3 replications according to the "Random Blocks Trial Design". To meet the nutritional needs of the parent and F_2 hybrids, 15 kg of urea was given to the trial area uniformly. To ensure germination and emergence, after planting, the plots were irrigated five times with the sprinkler irrigation method. Weed control was done mechanically or manually.

It was determined that the organic matter content of the trial field, which had a clayey soil structure, was at a moderate level of 2.25% at a soil depth of 0-30 cm, and at a low level of 1.23% at a soil depth of 30-60 cm (Table1). The trial field, which has a high level of lime content (37.6%, 34.4%), has an alkaline structure (pH = 8.05 - 8.00), and there is no problem in terms of salinity (Table1). The amount of usable phosphorus (1.79 kg/da - 1.34 kg/da) and zinc (0.32 ppm - 0.34 ppm) in the trial field is quite low (Table1). Considering the analysis results of the trial field, it is sufficient in terms of iron (14.74 ppm - 8.74 ppm), copper (1.70 ppm - 1.74 ppm), and manganese (7.50 ppm - 5.76 ppm)

In the province of Konya which corresponds to the area of research', the average temperature was determined as 19.4 ^{0}C by the 21-year meteorological data, and 19.8 ^{0}C in 2021 when the parent and F_2 plants were grown. In the research, the total precipitation during the 21-year growing period was determined as 109.1 mm, and the total precipitation during the cultivation period in 2021 was determined as 134.3 mm. In the research, the average relative humidity was determined as 47.8% in the 21-year growing period and the average relative humidity in the growing period in 2021 was 44.4%.

In the study, measurements, weighing and analyzes were made in terms of the examined characteristics in the parent and F_2 hybrids obtained from each plot In the research, the applications made in terms of plant height, pod length, pod width, number of pods per plant, number of seeds per pod, number of seeds per plant, seed yield per plant, hundred-seed weight, protein ratio, and protein yield were performed according to the method proposed by Ceyhan et al. (2014a) and Ceyhan et al. (2014b).

In the research, the measurements made in the F_2 hybrids were first calculated analysis of variance according to the "Random Blocks Trial Design". Calculations were made using the Diallel Analysis Method for traits with significant variance values of 1% and 5% between hybrids. In the research, analysis and calculations were determined in TARPOPGEN PC Program (Özcan and Açıkgöz, 1999).

3. Results and Discussion

In terms of the characteristics examined in the study, mean squares of preliminary variance analysis and combining ability variance analysis in full diallel hybrid set are given in Table 1.

In the study, as a result of full diallel variance analysis, it was determined that the mean squares of the crosses were statistically significant in terms of the examined characteristics. In the F_2 generation, when the genotypes were examined, there was significant variation at the level of 5% in pod width and number of seeds per pod, while there was significant variation at the level of 1% when all other characteristics are considered (Table 1).

In the F_2 generation, when the combining ability variances were examined in the full diallel hybrid group, significant changes were noted in the GCA values for all the examined traits except for the plant height trait. When the SCA values were examined, there were significant differences in all the investigated properties except the pod width and the number of seeds per pod.

When the reciprocal effect values were examined, it was found to be statistically significant in terms of all the investigated properties except pod width, seed yield per plant, hundred-seed weight, and protein yield per plant (Table 1).

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

Source of Variation	SD	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
Blocks	2	255,110	97,469	1,433	3788,182
Genotypes	24	72,110**	71,807**	0,959*	883,355**
Error	48	11,497	21,052	0,457	273,713
GCA	4	78,525	56,708**	0,533*	644,030**
SCA	10	17,715**	15,245*	0,108	222,624*
Reciprocal Effect	10	8,563*	19,518**	0,446**	226,448*
Error	48	3,832	7,017	0,152	91,238
Source of Variation	SD	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
Blocks	2	34,781	639,091	0,321	50,140
Genotypes	24	105,782**	128,655**	3,475**	10,417**
Error	48	32,181	36,143	0,456	2,866
GCA	4	91,272**	134,467**	1,836**	9,803**
SCA	10	27,892*	28,832*	1,374**	2,577*
Reciprocal Effect	10	20,225	20,305	0,672**	1,836
Error	48	10,727	12,048	0,152	0,956

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

3.1. Plant height

In terms of plant height, it was determined that the parental values varied between 27.44 cm (Ribera) and 40.22 cm (Albeni), and in the F_2 generation, it varied between 28.77 cm (Ribera x Lida) and 50.00 cm (Beyzade x Garrafol) (Table 2). Researchers working on this subject have found similar results (Genchev, 1995; Ülker and Ceyhan, 2008a; Varankaya and Ceyhan, 2012; Kepildek and Ceyhan, 2021).

If the $\upsilon^2GCA/\upsilon^2SCA$ ratio of plant height was less than 1 in the F_2 generation, it showed that the non-additive gene effect was effective in the inheritance of this trait. Likewise, if the ratio of $(H/D)^{1/2}$ was more significant than 1, it was found that this feature had superior dominance (Table 2).They found that the non-additive gene effect and the dominant gene effect were effective in the inheritance of plant height of the bean plant (Rodrigues et al., 1998; Ceyhan et al., 2014b; Kepildek and Ceyhan, 2021).

When the parental GCA was examined for plant height, the Garrafol cultivar showed significant and positive effects at the level of 1%, while Lida (5%) and Riberia (1%) cultivars showed significant and negative effects (Table 3). Garrafol variety, whose parental GCA value was positive and significant, can be preferred as parents in breeding studies to increase plant height. Lida and Ribera varieties, which were negative and important, can be preferred in breeding studies to obtain short or medium-sized varieties suitable for machine harvesting. Kepildek and Ceyhan (2021) found significant GCA values in terms of plant height in their study.

Considering the SCA values of the hybrids, in the F_2 generation, the "Beyzade x Garrafol" cross was found to be significant and positive at the level of 5%, and the "Beyzade x Garrafol" cross was significant and positive at the level of 1%, while the "Albeni x Garrafol" cross was significant and negative at the level of 5% (Table 3). These combinations were genotypes with breeding potential for plant height. While hybrid combinations with positive and significant SCA values were preferred to increase plant height, hybrid combinations with negative and significant SCA values can be preferred in breeding studies to obtain short or medium-sized plants suitable for machine harvesting. In a study, significant, positive, and negative SCA values in terms of plant height (Kepildek and Ceyhan, 2021) were determined.

In terms of plant height in the F_2 generation, the average heterosis value was 7.74% and the heterobeltiosis value was -2.49%. In terms of plant height in the F_2 generation, heterosis values ranged between -9.60% (Lida x Albeni) and 45.19% (Beyzade x Garrafol), while heterobeltiosis values ranged between -21.00% (Albeni x Ribera) and 25.57% (Beyzade x Garrafol) (Table 4 and 5) . Investigating the heterosis and heterobeltiosis values in terms of plant height, Arunga et al. (2010), Ceyhan et al. (2014b), Kepildek and Ceyhan (2021) stated that they found high or low rates of heterosis and heterobeltiosis.

For plant height, heritability in the broad and narrow sense detected in the F_2 generation were 0.78 and 0.31 respectively (Table 2). In terms of plant height, the high heritability in the broad sense and the lower heritability in the narrow sense indicate that the effect of environmental variance on this trait was high. These results revealed that selection in terms of plant height could be made from the next generation.

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

Parents	Plant Height		Number of Pods per Plant		Number of Seeds per Pod		Number of Seeds per Plant	
Lida	33,77	c-h	16,22	cde	6,11	ab	66,00	cde
Beyzade	29,05	gh	16,66	cde	5,33	a-e	61,44	cde
Ribera	27,44	h	12,99	e	4,33	g	40,44	e
Albeni	40,22	bc	24,89	abc	5,78	a-e	80,22	a-d
Garrafol	39,82	bcd	13,55	de	5,77	a-e	44,89	cde
F_2 H Populations								
Lida x Beyzade	32,66	d-h	24,11	abc	5,44	a-f	68,66	b-e
Lida x Ribera	32,00	e-h	16,55	cde	5,78	a-e	65,33	cde
Lida x Albeni	33,44	c-h	16,33	cde	4,61	fg	56,05	cde
Lida x Garrafol	39,03	b-f	22,08	b-e	4,92	d-g	63,19	cde
Beyzade x Lida	33,22	c-h	18,78	b-e	5,75	a-g	60,33	cde
Beyzade x Ribera	34,22	c-h	16,89	cde	5,00	c-g	51,88	cde
Beyzade x Albeni	42,11	b	23,33	a-d	6,00	a-d	81,11	abc
Beyzade x Garrafol	50,00	a	33,22	a	5,11	b-g	115,78	a
Ribera x Lida	28,77	gh	13,11	e	4,55	fg	44,78	de
Ribera x Beyzade	36,11	b-g	15,66	cde	5,44	a-f	56,66	cde
Ribera x Albeni	33,33	c-h	14,88	cde	5,11	b-g	51,22	cde
Ribera x Garrafol	37,66	b-f	17,89	b-e	4,89	efg	55,00	cde
Albeni x Lida	34,66	c-h	21,83	b-e	6,33	a	66,67	cde
Albeni x Beyzade	40,11	bc	24,66	abc	5,55	a-f	78,11	bcd
Albeni x Ribera	31,77	fgh	17,44	b-e	5,55	a-f	50,11	cde
Albeni x Garrafol	37,44	b-f	22,33	b-e	6,11	ab	67,89	b-e
Garrafol x Lida	39,77	bcd	16,89	cde	6,00	a-d	67,88	b-e
Garrafol x Beyzade	37,97	b-f	17,11	b-e	6,05	abc	66,55	cde
Garrafol x Ribera	37,11	b-f	19,22	b-e	6,22	a	67,89	b-e
Garrafol x Albeni	39,33	b-e	27,00	ab	6,00	a-d	103,66	ab
GCA	14,94		9,94		0,08		110,56	
SCA	41,65		24,68		-0,13		394,16	
Reciprocal	4,73		12,50		0,29		135,21	
υ^2GCA / υ^2SCA	0,36		0,40		---		0,28	
$H/D^{1/2}$	76,26		57,06		----		750,49	
H^2	0,78		0,70		0,39		0,64	
h^2	0,31		0,24		0,19		0,19	

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. Number of Pods

In terms of the number of pods, it was determined that the parent values varied between 13.55 numbers/plant (Garrafol) and 24.89 numbers/plant (Albeni), and the F_2 generation values varied between 13.11numbers/plant (Ribera x Lida) and 33.20 numbers/plant (Beyzade x Garrafol) (Table 2). Some researchers also reached similar results (Ceyhan, 2004; Ülker and Ceyhan, 2008a; Varankaya and Ceyhan, 2012; Ceyhan et al., 2014b; Kepildek and Ceyhan, 2021; Mutari et al., 2022).

In terms of the number of pods, it was determined that the non-additive gene effect was effective if the υ^2GCA / υ^2SCA ratio was less than 1, and the superior dominance was effective if the $(H/D)^{1/2}$ ratio was more than 1 (Table 2). In some studies, the number of pods was found to be augmented by non-additive genes (Iqbal et al., 2010; Ceyhan et al., 2014b; Kepildek and Ceyhan, 2021; Mutari et al., 2022) and additive genes (Barelli et al., 2000; Arunga et al., 2010) reported that it was effective.

When the parental GCA was examined, the Albeni cultivar, which had a significant and positive GCA value of 5%, can be preferred as a parent that can be used in breeding studies to increase the number of pods. When the SCA values of the hybrids were examined, the "Beyzade x Garrafol" combination had a significant and positive SCA effect at the level of 5% in the F_2 generation. Since the "Beyzade x Garrafol" combination had a significant and positive SCA value at the 5% level, it had been determined as the appropriate hybrid combination in breeding studies to increase the number of pods (Table 3). Arunga et al. (2010), Iqbal et al. (2010), Ceyhan et al. (2014b), Kepildek and Ceyhan (2021), Mutari et al. (2022), examined the GCA and SCA values of the parents and hybrids in terms of pod number traits, obtained similar results.

In the F_2 generation, the mean heterosis value was 20.09% and the heterobeltiosis value was 6.30%. Heterosis values were found to vary between -21.42% (Ribera x Albeni) and 119.88% (Beyzade x Garrafol), and

heterobeltiosis values between -40.20% (Ribera x Albeni) and 99.36% (Beyzade x Garrafol) (Table 4 and 5). The large differences between the heterosis and heterobeltiosis values of hybrid combinations revealed that the pod number feature was affected by environmental conditions. Investigating the heterosis and heterobeltiosis values in terms of the number of pods, Ceyhan et al. (2014b), Kepildek and Ceyhan (2021) determined both negative and positive heterosis and heterobeltiosis values.

Heritability in the broad and narrow sense was 0.70 and 0.24 respectively in the F_2 generation (Table 2). High heritability in the broad sense and low heritability in the narrow sense revealed that the number of pods was under the influence of environmental conditions. Therefore it would be more appropriate to start the selection process in the next generations.

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

Parents	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
Lida	-1,930*	-1,134	0,009	-2,781
Beyzade	0,409	1,364	0,033	4,928
Ribera	-3,455**	-3,582**	-0,390*	-12,895**
Albeni	1,222	2,413*	0,172	6,256
Garrafol	3,753**	0,939	0,175	4,492
F_2 Populations				
Lida x Beyzade	-1,578	1,867	-0,164	-2,920
Lida x Ribera	-0,271	0,202	0,035	5,460
Lida x Albeni	-1,281	-1,544	-0,220	-7,386
Lida x Garrafol	1,536	0,334	-0,234	-1,442
Beyzade x Lida	0,278	-2,665*	-0,057	-4,167
Beyzade x Ribera	2,170	-0,851	0,068	-3,029
Beyzade x Albeni	3,434*	0,875	0,061	3,157
Beyzade x Garrafol	3,780**	3,518*	-0,137	16,474*
Ribera x Lida	-1,612*	-1,720	-0,613**	-10,277*
Ribera x Beyzade	0,945	-0,612	0,223	2,390
Ribera x Albeni	-1,257	-2,014	0,037	-7,967
Ribera x Garrafol	1,046	1,850	0,259	4,576
Albeni x Lida	0,608	2,750*	0,860**	5,306
Albeni x Beyzade	-1,000	0,667	-0,222	-1,500
Albeni x Ribera	-0,778	1,278	0,222	-0,557
Albeni x Garrafol	-2,631*	1,967	0,198	9,758
Garrafol x Lida	0,373	-2,597*	0,542**	2,345
Garrafol x Beyzade	-6,013**	-8,055**	0,473*	-24,613**
Garrafol x Ribera	-0,278	0,665	0,667**	6,445
Garrafol x Albeni	0,945	2,333*	-0,057	17,888**
Gi	0,307	0,561	0,012	7,299
Sij	1,303	2,386	0,052	31,021
Rij	1,916	3,509	0,076	45,619

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

3.3.Number of seeds per pod

In terms of the number of seeds per pod, it was determined that the parent values varied between 4.33 numbers/pod (Ribera) and 6.11 numbers/pod (Lida), and the F_2 generation values varied between 4.55 numbers/pod (Ribera x Lida) and 6.33 numbers/pod (Albeni x Lida) (Table 2). Ülker and Ceyhan (2008a), Iqbal et al. (2010), Varankaya and Ceyhan (2012), Ceyhan et al. (2014b), Kepildek and Ceyhan (2021), and Mutari et al. (2022) showed similar results to these research findings.

In terms of the number of seeds per pod, it had been determined that the non-additive gene effect was effective in the case of the υ^2GCA/υ^2SCA ratio of less than 1, and the superior dominance was effective in the case of $(H/D)^{1/2}$ ratio more than 1 in the F_2 generation (Table 2). Ceyhan et al. (2014b), Kepildek and Ceyhan (2021), and Mutari et al. (2022) showed similar results with this research findings.

When GCA was examined regarding the number of seeds in the pod, Albebi genotypes were found to have significant and positive values in the F_2 generation. (Table 3). As a result, Albeni genotype, which was positively important in increasing the number of seeds per pod, was determined as suitable parents for breeding studies for this purpose.

Looking at the SCA effects of crosses in the F_2 generation, "Beyzade x Garrafol", "Albeni x Lida" and "Garrafol x Albeni" hybrid had a positive significant SCA effect (Table 3). They can be considered suitable combinations thatcan be used to increase the number of seeds in the pod, as they had the effect of SCA. In many

studies, the effects of GCA and SCA for the number of seeds per pod were determined (Arunga ve ark. 2010; Iqbal ve ark. 2010; Ceyhan ve ark. 2014b; Kepildek ve Ceyhan 2021; Mutari ve ark. 2020).

When the F_2 generation was examined, the mean heterosis value was determined as -0.54% and the mean heterobeltiosis value was determined as -6.78%. Heterosis values were determined between -22.43% (Lida x Albeni) and 23.13% (Garrafol x Ribera), heterobeltiosis were determined between -25.33% (Ribera x Lida) and 7.74% (Garrafol x Ribera) (Table 4 and 5). Determined the heterosis and heterobeltiosis values in terms of the number of pods in beans, Ceyhan et al. (2014b), and Kepildek and Ceyhan (2021) found both negative and positive heterosis and heterobeltiosis values.

The heritability in the broad and narrow sense determined in terms of the number of seeds in the pod was 0.39 and 0.19, respectively (Table 2). It had been revealed that the heritability in the broad sense was high and the heritability was low in the narrow sense, the number of seeds per pod was affected by the environmental factor.

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

F_2 Populations	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
Lida x Beyzade	3,98	46,63	-8,18**	7,76
Lida x Ribera	4,54	13,32	10,66**	22,76
Lida x Albeni	-9,60	-20,54	-22,43**	-23,33
Lida x Garrafol	6,07	48,34	-17,25**	13,98
Beyzade x Lida	5,75	14,21	-10,09**	-5,32
Beyzade x Ribera	21,14	13,88	-0,83	1,85
Beyzade x Albeni	21,57	12,30	4,08**	14,51
Beyzade x Garrafol	45,19*	119,88	-11,34**	117,77
Ribera x Lida	-6,00	-10,24	-12,84**	-15,86
Ribera x Beyzade	27,83	5,63	8,04**	11,23
Ribera x Albeni	-1,48	-21,42	1,06	-15,10
Ribera x Garrafol	11,99	34,76	-3,27*	28,91
Albeni x Lida	-6,32	6,22	6,51**	-8,81
Albeni x Beyzade	15,79	18,72	-3,62*	10,28
Albeni x Ribera	-6,08	-7,92	9,83**	-16,95
Albeni x Garrafol	-6,44	16,18	5,80**	8,53
Garrafol x Lida	8,09	13,45	0,98	22,44
Garrafol x Beyzade	10,27	13,25	5,09**	25,18
Garrafol x Ribera	10,34	44,78	23,13**	59,12
Garrafol x Albeni	-1,72	40,46	3,84*	65,72
Mean	7,74	20,09	-0,54	16,23

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

3.4. Number of Seeds per Plant

In terms of the number of seeds per plant, were found to vary the parent values between 40.44 numbers/plant (Ribera) and 80.22 numbers/plant (Albeni), and the F_2 generation values were between 44.78 numbers/plant (Ribera x Lida) and 115.78 numbers/plant (Beyzade x Garrafol) (Table 2). Our study results agree with some of the results of Ülker and Ceyhan (2008a), Ceyhan et al. (2014b), Kepildek ve Ceyhan, (2021).

In terms of the number of seeds in the plant, it had been determined that the non-additive gene effect was effective in the case of the υ^2GCA / υ^2SCA ratio of less than 1, and the superior dominance was effective in the case of $(H/D)^{1/2}$ ratio more than 1 in the F_2 generation (Table 2). However, Barelli et al. (2000) reported that additive and non-additive genes had equal effects on the inheritance of the seed number in pods in beans, while Ceyhan et al. (2014b), Kepildek and Ceyhan (2021), on the other hand, reported that the effect of non-additive genes was important in the inheritance of seed number in pods in beans.

Considering the SCA values of the hybrids, the "Beyzade x Garrafol" hybrid with a significant and positive SCA value of 5% in the F_2 generation was determined as the appropriate hybrid combination in breeding studies aimed at increasing the number of seeds in the plant (Table 3). In the study by Kepildek and Ceyhan (2021), GCA and SCA values were significant.

It was determined in terms of the number of seeds in the plant, the average heterosis value was 16.23% and the average heterobeltiosis value was -0.02%. Heterosis values varied between -23.33% (Lida x Allure) and 117.77% (Beyzade x Garrafol), while heterobeltiosis values ranged between -37.54% (Albeni x Ribera) and 88.40% (Beyzade x Garrafol) (Table 4 and 5).

Heritability in the broad and narrow sense was 0.64 and 0.19, respectively (Table 2). High heritability in the broad sense and low heritability in the narrow sense explains that environmental conditions had an effect on the heritability of the number of seeds per pod. Any selection process to be made in terms of the number of seeds in the plant should be done in later generations.

Table 5
Heterobeltiosis (%) values for investigated traits in full-diallel hybrid set

F_2 Populations	Plant Height	Number of Pods per Plant	Number of Seeds per Pod	Number of Seeds per Plant
Lida x Beyzade	-3,29	44,67*	-10,91	4,04
Lida x Ribera	-5,26	2,06	-5,46	-1,01
Lida x Albeni	-16,85**	-34,38*	-24,55**	-30,13*
Lida x Garrafol	-1,98	36,16*	-19,53*	-4,25
Beyzade x Lida	-1,64	12,68	-12,77	-8,59
Beyzade x Ribera	17,78**	1,34	-13,05	-15,56
Beyzade x Albeni	4,69	-6,26	3,81	1,11
Beyzade x Garrafol	25,57**	99,36**	-11,55	88,43**
Ribera x Lida	-14,80*	-19,16	-25,53**	-32,15*
Ribera x Beyzade	24,29**	-6,00	-5,28	-7,78
Ribera x Albeni	-17,13**	-40,20**	-11,60	-36,15*
Ribera x Garrafol	-5,41	31,97*	-15,36	22,52
Albeni x Lida	-13,82*	-12,28	3,60	-16,90
Albeni x Beyzade	-0,28	-0,90	-3,87	-2,63
Albeni x Ribera	-21,00	-29,92	-3,92	-37,54*
Albeni x Garrafol	-6,91	-10,27	5,77	-15,37
Garrafol x Lida	-0,11	4,13	-1,80	2,86
Garrafol x Beyzade	-4,64	2,68	4,85	8,31
Garrafol x Ribera	-6,81	41,79*	7,74	51,24*
Garrafol x Albeni	-2,21	8,48	3,81	29,22*
Mean	-2,49	6,30	-6,78	-0,02

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

3.5. Seed yield

In terms of seed yield per plant, the parent values differed between 29.68 g/plant (Lida) and 51.61 g/plant (Garrafol), and the values of the F_2 generation differed between 27.48 g/plant (Lida x Ribera) and 51.03 g/plant (Garrafol x Lida) (Table 6). Ülker and Ceyhan (2008a), Varankaya and Ceyhan (2012), Ceyhan et al. (2014b), and Kepildek and Ceyhan (2021), reported similar results with the present study.

In terms of seed yield in the plant, it was determined that the non-additive gene effect was effective when the υ^2GCA/υ^2SCA ratio was less than 1. In addition, if the ratio $(H/D)^{1/2}$ was more than 1, it showed that there was superior dominance (Table 6). Our study revealed that there was no simple inheritance of the seed yield of a plant in the bean. Some researchers (Zimmermann et al., 1985; Singh and Urrea, 1994; Oliveira Junior et al., 1997) who researched this subject stated that additive genes were effective in the inheritance of grain yield in beans, while others (Barelli et al., 2000; Iqbal et al., 2010; Ceyhan et al., 2014b; Kepildek and Ceyhan, 2021) reported that non-additive genes were effective. In the study of Chung and Stevenson (1973), it was found that the dominant gene effect was more than the additive gene effect in the inheritance of seed yield in the plant.

When the GCA values were examined, it was determined that the Garrafol variety had an important and positive effect at the level of 1% and the Albeni variety had an important and positive effect at the level of 5%. Garrafol and Albeni varieties, which had positive and important GCA values, emerge as parents that can be recommended to be used in breeding studies in terms of seed yield in the plant. When the SCA values of the hybrids were examined, the "Lida x Garrafol" hybrid, which showed a significant and positive SCA value at the level of 5%, can be used as a breeding material in terms of seed yield (Table 7). Many studies had been carried out in terms of GCA and SCA values in beans, and as a result of these studies, it had been determined that there were a parent and hybrid combinations with significant GCA and SCA values in different numbers in terms of seed yield (Arunga et al., 2010; Iqbal et al., 2010; Ceyhan et al., 2014b; Kepildek and Ceyhan, 2021).

The mean heterosis value was determined as 0.32% and the mean heterobeltiosis value was determined as -10.06%. Heterosis values varied between -22.08% (Lida x Riberia) and 25.54% (Garrafol x Lida), while heterobeltiosis values ranged between -32.72% (Lida x Ribera) and 11.64% (Beyzade x Ribera) (Table 8 and 9).

Heritability in the broad sense was 0.74, and heritability in the narrow sense was 0.26 (Table 6). In terms of seed yield feature, the fact that the heritability in the broad sense was higher and the heritability degree in the narrow sense was less indicates that it was due to the effect of the environmental factor. For this reason, it was necessary not to carry out the selection processes in terms of seed yield in the early period. To have a high success rate, it was necessary to perform the selection process for the next generations.

Table 6
Mean values for investigated traits in full-diallel hybrid set

Parents	Seed Yield		Hundred Seed Weight		Protein Ration		Protein Yield	
Lida	29,68	ef	20,13	d-g	28,12	abc	5,68	ef
Beyzade	37,67	b-f	24,00	c-g	25,00	ef	6,05	def
Ribera	40,85	a-e	16,86	g	27,85	a-d	4,68	f
Albeni	37,15	b-f	30,17	a-f	24,31	f	7,37	b-f
Garrafol	51,61	a	23,31	c-g	26,77	cd	6,24	def
F_2 Populations								
Lida x Beyzade	41,60	a-e	26,57	b-g	27,01	bcd	7,20	b-f
Lida x Ribera	27,48	f	18,59	efg	29,12	a	5,44	ef
Lida x Albeni	37,20	b-f	20,14	d-g	28,09	abc	5,63	ef
Lida x Garrafol	42,50	a-d	27,43	b-g	26,85	bcd	7,37	b-f
Beyzade x Lida	41,61	a-e	25,39	b-g	27,22	bcd	6,95	b-f
Beyzade x Ribera	45,60	abc	22,99	c-g	27,69	a-d	6,34	def
Beyzade x Albeni	33,70	c-f	28,10	b-g	27,01	bcd	7,59	b-f
Beyzade x Garrafol	36,82	b-f	42,62	a	27,85	a-d	11,87	a
Ribera x Lida	37,06	b-f	17,14	fg	26,89	bcd	4,61	f
Ribera x Beyzade	40,57	a-e	23,31	c-g	27,88	abc	6,49	def
Ribera x Albeni	35,20	c-f	18,51	efg	27,03	bcd	4,99	ef
Ribera x Garrafol	40,14	a-e	22,63	c-g	26,39	de	5,98	def
Albeni x Lida	33,02	def	22,63	c-g	27,73	a-d	6,27	def
Albeni x Beyzade	35,84	c-f	28,49	b-g	26,69	cd	7,61	b-f
Albeni x Ribera	40,02	a-e	20,56	d-g	27,66	a-d	5,70	ef
Albeni x Garrafol	35,27	c-f	24,68	c-g	28,02	abc	6,90	c-f
Garrafol x Lida	51,03	a	34,96	abc	29,11	a	10,20	abc
Garrafol x Beyzade	49,14	ab	33,21	a-d	28,28	ab	9,41	a-d
Garrafol x Ribera	43,79	a-d	30,79	a-e	27,95	abc	8,62	a-e
Garrafol x Albeni	37,37	b-f	38,10	ab	27,94	abc	10,65	ab
GCA	16,11		24,48		0,34		1,77	
SCA	51,50		50,35		3,67		4,86	
Reciprocal	9,50		8,26		0,52		0,88	
υ^2GCA / υ^2SCA	0,31		0,49		0,09		0,36	
$H/D^{1/2}$	93,21		107,58		4,86		9,28	
H^2	0,74		0,64		0,92		0,66	
h^2	0,26		0,29		0,13		0,25	

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

3.6. Hundred-seed weight

It was determined that the parent values in terms of hundred-seed weight ranged between 16.86 g (Ribera) and 30.17 g (Albeni), and the F_2 generation values ranged between 17.14 g (Ribera x Lida) and 42.62 g (Beyzade x Garrafol) (Table 6). Researchers, who conducted similar studies, found close results (Iqbal et al., 2010; Ceyhan et al., 2014b; Senbetay et al., 2015; Kepildek and Ceyhan, 2021; Mutari et al., 2022).

In the F_2 generation, the non-additive gene effect of having υ^2GCA / υ^2SCA ratios less than 1 is effective in the inheritance of the hundred-seed weight trait, while the $(H/D)^{1/2}$ ratio being more than 1 revealed that superior dominance was effective (Table 6). Chung and Stevenson (1973), and Iqbal et al. (2010) stated that there was an additive gene effect in the inheritance of hundred-seed weight in beans, while Ceyhan et al. (2014b), and Kepildek and Ceyhan (2021) determined that non-additive genes were effective in the inheritance of hundred-seed weight in beans.

When the GCA was examined, the Garrafol variety, which had an important and positive value at the level of 5%, can be preferred as the appropriate parent in breeding studies to increase the hundred-seed weight. When the SCA values of the hybrids were examined, it was determined that the "Beyzade x Garrafol" cross in the F_2 generation was the genotype that could be preferred in breeding studies to increase the hundred-seed weight, since it had an important and positive value at the 5% level (Table 7). Iqbal et al. (2010), Ceyhan et al. (2014b), Senbetay et al. (2015), Kepildek and Ceyhan (2021), Mutari et al. (2022) determined the genotypes with significant and positive GCA and SCA values for hundred-seed weight in their studies.

The mean heterosis value was determined as 15.46% and the mean heterobeltiosis value was determined as 3.33%. Heterosis values varied between -21.28% (Riberia x Albeni) and 80.20% (Beyzade x Garrafol), while heterobeltiosis values ranged between -38.64% (Riberia x Albeni) and 77.60% (Beyzade x Garrafol) (Table 8 and 9).

Table 7
Genetic components for investigated traits in full-diallel hybrid set

Parents	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
Lida	-2,191	-2,342*	0,449*	-0,532
Beyzade	0,746	2,216*	-0,415*	0,524
Ribera	-0,120	-4,829**	0,252	-1,280**
Albeni	-3,085*	0,504	-0,501*	-0,026
Garrafol	4,650**	4,452*	0,215	1,314**
F_2 Populations				
Lida x Beyzade	3,772	0,456	-0,296	0,049
Lida x Ribera	-4,695*	-0,619	-0,074	-0,198
Lida x Albeni	1,108	-2,429	0,584	-0,529
Lida x Garrafol	5,026*	3,433	-0,060	0,965
Beyzade x Lida	0,007	-0,592	0,103	-0,125
Beyzade x Ribera	3,184	0,109	0,567	0,139
Beyzade x Albeni	-2,168	-0,077	0,386	0,069
Beyzade x Garrafol	-1,693	5,595*	0,888	1,771*
Ribera x Lida	4,790**	-0,725	-1,116	-0,413
Ribera x Beyzade	-2,513	0,158	0,095	0,074
Ribera x Albeni	1,541	-1,791	0,215	-0,385
Ribera x Garrafol	-1,840	1,435	-0,675	0,235
Albeni x Lida	-2,094	1,245	-0,183	0,318
Albeni x Beyzade	1,067	0,192	-0,159	0,005
Albeni x Ribera	2,410	1,023	0,316	0,353
Albeni x Garrafol	-4,524*	0,785	0,886	0,453
Garrafol x Lida	4,265*	3,762	1,129	1,415**
Garrafol x Beyzade	6,157**	-4,708**	0,214	-1,229*
Garrafol x Ribera	1,827	4,080	0,783	1,321**
Garrafol x Albeni	1,048	6,710**	-0,042	1,872**
Gi	0,858	0,964	0,012	0,076
Sij	3,647	4,096	0,052	0,325
Rij	5,364	6,024	0,076	0,478

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

Heritability in the broad sense was 0.74, and heritability in the narrow sense was 0.26 (Table 6). In the narrow sense, it was seen that the contribution of the environment was high in the inheritance of a hundred-seed weight trait. For this reason, it may be more appropriate to start the selection process in terms of hundred-seed weight in later generations.

3.7. Protein content

In terms of protein ratio, the parental values were found to be between 24.31% (Albeni) and 28.12% (Lida), while the values of the F_2 generation ranged between 26.39% (Riberia x Garrafol) and 29.12% (Lida x Ribera) (Table 6). Ceyhan (2006), Ülker and Ceyhan (2008b), Iqbal et al. (2010), Varankaya and Ceyhan (2012), Ceyhan et al. (2014a), and Kepildek and Ceyhan (2021) had similar results with results of this research.

For the protein ratio, which was at the top of the quality factors, υ^2GCA / υ^2SCA ratios less than 1 and $(H/D)^{1/2}$ ratio of more than 1 revealed the non-additive gene effect and superior dominance (Table 6). Iqbal et al. (2010), Ceyhan et al. (2014a), and Kepildek and Ceyhan (2021) determined in their studies that non-additive genes were effective in the inheritance of protein ratio in beans.

When the parental GCA was examined, the Lida variety, which had an important and positive value at the 5% level, had been determined to be preferred in breeding studies to increase the protein ratio (Table 7). Iqbal et al. (2010), Ceyhan et al. (2014a), and Kepildek and Ceyhan (2021) reported that there were genotypes with significant and positive GCA and SCA values in terms of protein ratio.

The mean heterosis value was 4.69% and the mean heterobeltiosis value was 0.70%. Heterosis values varied between -3.92% (Ribera x Lida) and 9.72% (Albeni x Garrafol), while heterobeltiosis values varied between -8.66% (Ribera x Lida) and 5.16% (Albeni x Beyzade) (Table 8 and 9). Kepildek and Ceyhan (2021) found positive and negative heterosis and heterobeltiosis values in their study.

Broad and narrow-sense heritability was determined as 0.92 and 0.13, respectively (Table 6). The high level of heritability in the narrow sense indicated that the contribution of the environment was high. Considering the importance of non-additive gene effects in the inheritance of protein ratio, it may be more appropriate to start selection in late generations.

Table 8
Heterosis (%) values for investigated traits in full-diallel hybrid set

F_2 Populations	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
Lida x Beyzade	23,51	20,44	1,69**	22,68*
Lida x Ribera	-22,08	0,50	4,05**	4,88
Lida x Albeni	11,33	-19,92	7,17**	-13,78
Lida x Garrafol	4,56	26,32	-2,16**	23,60*
Beyzade x Lida	23,55	15,08	2,47**	18,44
Beyzade x Ribera	16,15	12,53	4,77**	18,16
Beyzade x Albeni	-9,91	3,75	9,54**	13,13
Beyzade x Garrafol	-17,51	80,20**	7,59**	93,20**
Ribera x Lida	5,09	-7,34	-3,92**	-11,05
Ribera x Beyzade	3,35	14,08	5,49**	20,90
Ribera x Albeni	-9,73	-21,28	3,65**	-17,24
Ribera x Garrafol	-13,17	12,68	-3,38**	9,53
Albeni x Lida	-1,20	-10,02	5,77**	-4,02
Albeni x Beyzade	-4,21	5,17	8,25**	13,29
Albeni x Ribera	2,63	-12,57	6,07**	-5,53
Albeni x Garrafol	-20,52	-7,69	9,72**	1,43
Garrafol x Lida	25,54	60,97*	6,06**	71,07**
Garrafol x Beyzade	10,07	40,39	9,24**	53,20**
Garrafol x Ribera	-5,26	53,31	2,35**	57,94**
Garrafol x Albeni	-15,80	42,50	9,39**	56,46**
Mean	0,32	15,46	4,69	21,32

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

3.8. Protein yield

It was determined that the parent values in terms of protein yield were between 4.68 g/plant (Ribera) and 7.37 g/plant (Albeni), and the protein yields in the F_2 generation ranged between 4.61 g/plant (Ribera x Lida) and 11.87 g/plant (Beyzade x Garrafol) (Table 6). The data of this research were in harmony with each other (Ülker and Ceyhan 2008b; Varankaya and Ceyhan 2012; Kepildek and Ceyhan 2021).

It had been stated that for protein yield, $\upsilon^2GCA/\upsilon^2SCA$ ratios were less than 1, and $(H/D)^{1/2}$ ratio was more than 1, non-additive gene effect and superior dominance were effectively found in the inheritance of protein yield trait (Table 6). Studies have also determined that the non-additive gene effect was effective in the inheritance of protein yield (Ceyhan et al., 2014a; Kepildek and Ceyhan, 2021).

When the GCA value was examined, it was determined that the Garrafol variety, which had a 5% positive and significant GCA value, had parents that can be preferred in breeding studies to be made in terms of protein yield. When the SCA values of the hybrids were examined, it was determined that the "Beyzade x Garrafol" hybrid, which showed a positive and significant SCC value at the 5% level, is the genotype that can be preferred in breeding studies in terms of protein yield (Table 7). Ceyhan et al. (2014a), and Kepildek and Ceyhan (2021) found the effect of GCA and SCA important in their studies.

Table 9
Heterobeltiosis (%) values for investigated traits in full-diallel hybrid set

F_2 Populations	Seed Yield	Hundred Seed Weight	Protein Ration	Protein Yield
Lida x Beyzade	10,41	10,72	-3,95*	18,94
Lida x Ribera	-32,72**	-7,65	3,55*	-4,34
Lida x Albeni	0,14	-33,25*	-0,11	-23,66
Lida x Garrafol	-17,65*	17,71	-4,52*	18,11
Beyzade x Lida	10,45	5,79	-3,21	14,82
Beyzade x Ribera	11,64	-4,21	-0,58	4,80
Beyzade x Albeni	-10,54	-6,86	8,01**	3,00
Beyzade x Garrafol	-28,65**	77,60**	4,04*	90,34**
Ribera x Lida	-9,27	-14,86	-4,39*	-18,87
Ribera x Beyzade	-0,67	-2,89	0,10	7,24
Ribera x Albeni	-13,82	-38,64*	-2,95	-32,33*
Ribera x Garrafol	-22,22**	-2,90	-5,25**	-4,10
Albeni x Lida	-11,13	-25,00	-1,41	-15,02
Albeni x Beyzade	-4,88	-5,59	6,74**	3,14
Albeni x Ribera	-2,02	-31,86*	-0,68	-22,76
Albeni x Garrafol	-31,66**	-18,19	4,67*	-6,39
Garrafol x Lida	-1,12	49,99*	3,51*	63,48**
Garrafol x Beyzade	-4,79	38,36*	5,64**	50,93*
Garrafol x Ribera	-15,14	32,11	0,37	38,28*
Garrafol x Albeni	-27,59**	26,28	4,36*	44,39*
Mean	-10,06	3,33	0,70	11,750

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

The mean heterosis value was 21.32% and the mean heterobeltiosis value was 11.75%. Heterosis values were found to be between -17.24% (Ribera x Allure) and 93.20% (Beyzade x Garrafol), and heterobeltiosis values were found to be between -32.33% (Ribera x Albeni) and 90.34% (Beyzade x Garrafol) (Table 8 and 9).

Broad and narrow sense heritability was found to be 0.66 and 0.25, respectively (Table 6). The fact that the heritability was low in the narrow sense indicated that the contribution of the environment was highly effective in the emergence of the protein yield feature. Considering the importance of non-additive gene effects in the inheritance of protein yield, selection should be started in later generations.

4. Conclusions

As a result of this research, a sufficient level of genetic variation has been determined in the population when we consider it in terms of the evaluated agricultural characteristics. Non-additive genes and dominant genes were determined to be more effective in terms of the features evaluated in this study. Evaluating the selection based on seed yield in this population and starting it in future generations will increase the level of success.

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