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Diallel Analysis of Dry Bean Varieties for Seed Yield and Important Traits for Calcareous Soils

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HIGHLIGHTS

- Beans are an essential food source in the human diet.
- It is the most essential criterion limiting high calcareous yield in beans.
- It would be more appropriate to perform the selection process in later generations by evaluating the seed yield.

Abstract: Five dry beans (Kınalı, Alberto, Great, Göynük and Özmen) were selected for high calcareous soils tolerance and used as parents in a full diallel method in 2019. F_1 and its parents were grown in the experimental field of the Faculty of Agriculture of Selcuk University with high lime content in 2020 with three replications. Variations for seed yield and its component maintenance were detected between parents and F hybrids grown on high calcareous soils, and some crosses were found to outperform their parents. Significant general combination ability (GCA) and special combination ability (SCA) were observed for seed yield per plant and components including plant height, pods per plant, seeds per pod, seeds per plant, hundred seed weight, protein ratio and protein yield per plant. While non-additive gene effects were effective in plant height, pod height, number of seeds per pod, seed yield per plant, protein ratio, and protein yield per plant, it was determined that additive gene effects were effective in other investigated traits. Garrafol was had the highest GCA for seed yield. The “Alberto x Kınalı”, “Özmen x G Northern 59”, “G Northern 59 x Özmen”, Özmen x Kınalı”, “Kınalı x Alberto” and “Göynük x Kınalı” crosses exhibited high SCA effects for seed yield per plant. These hybrids are the most promising combination, and it is appropriate to carry out selection processes by evaluating seed yield and yield components together in future generations.

Keywords: Calcareous soils, Diallel Analysis, Dry Bean, GCA, SCA.

INTRODUCTION

Bean (*Phaseolus vulgaris* L.) is a self-fertile plant with 2n = 22 chromosomes. With a large cultivation area in the world thanks to its great adaptability as a hot climate plant, its genetic center is located in America and South Asia. Dried beans make up 50% of the daily diet of people in many developing countries. In addition to being a cheap food source, they contain about 30% protein and contain 65% energy-giving micronutrients. Moreover, it is one of the most cultivated leguminous products in the world due to its ease of

transportation, storage and processing [1-5]. Dry beans contain dietary fibre, polymeric-non-starch components that are resistant to enzymatic digestion in our digestive system [6,7].

Turkey has high clay, lime, pH and low organic matter contents due to its climate zone, geological structure and geographical position [8]. The pH of Konya region soils in Central Anatolia region is higher than 7 and it is calcareous. Lime is important in the development of annual plants such as beans. However, excess lime also prevents the intake of Mn and some micronutrients by decreasing the presence of N, P, K in soils. Therefore, soils with high lime content and high pH affect the development and yield of species and varieties belonging to the *leguminocea* family, especially the bean plant [9].

Variability is observed in the yield of dry beans in soils with intense lime content. Various breeding programs developed help the development of bean varieties with the desired genetic characteristics. The size and structure of gene effects that determine quantitative traits are essential for the successful development of suitable parent and crop varieties selected by crossbreeding [10-14]. The diallel analysis method is one of the most used breeding methods for the breeding of many crops and for the quantitative determination of plant breeders. It also helps in the analysis of polygenic characters in the genetic and non-genetic components in the predicted variation [15-18].

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. Such variation is 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. With this study, the combination abilities, yield and yield components (plant height, pods per plant, seeds per pod, seeds per plant, 100 seed weight) were determined by the diallel hybridizations between five selected bean parents in the calcareous soils of Konya region.

MATERIAL AND METHODS

In this study, namely Kınalı, Alberto, Great, Göynük, Özmen of five dry beans (*Phaseolus vulgaris* L.) varieties were used as material. The diallel hybridization method (5 x 5) was applied to the varieties planted on March 15, 2019, in the fully controlled plant breeding greenhouse of the Faculty of Agriculture of Selçuk University. The varieties were planted in rows in plots 2 m long with a spacing of 1 m between the rows and in each row the plants had a spacing of 20 cm each. In order to ensure simultaneous flowering, planting was carried out at 4 different times with 10-day intervals [15-18]. The water needs of the plants were met by drip irrigation.

The soil characteristics follow as clay-loam structure, a normal level of organic matter (2.25%) in 0-30 cm depth and low level in 30-60 cm depth. Lime content was high (37,6%, 34,4%, respectively), alkali reaction (pH = 8.05 – 8.00), no salinity problem was seen in the soil. The available phosphorus (17,9 kg ha-1 – 13,4 kg ha-1) and zinc (0.32 ppm – 0.34 ppm) levels were low. These elements were found to be low because the lime rate of the soil was high.

The research took place in Konya province and the weather data for 20 years was recorded. The average temperature was 19.3°C in 2020 when the parent and F_1 plants were grown. In the research, the total precipitation during the twenty-year growing period was determined as 109.6 mm, and the total precipitation during the cultivation period in 2020 was determined as 104.0 mm. In the research, the average relative humidity was determined as 48.0% in the twenty-year growing period and the average relative humidity in the growing period in 2020 was 45.8%.

The 20 F_1 hybrids were planted in the field on May 27, 2020. Parents and F_1's were planted in 1 row 1 m long with 80 cm spacing between rows and 20 cm variety spacing between plants. During the experiment, five number seeds were planted to in one row for each hybrid group. A single row of parent varieties was planted before and after the hybrid groups, with the hybrids between the parents [15-18]. Hybrids with one seed were planted in such a way that the hybrid seed was placed in a row between two parents. The water needs of the plants were met by sprinkler irrigation. Weed control was done by hand and hoe. By looking at the soil properties of the research area, 15 kg of urea 46% N fertilizer was given at planting times both in the greenhouse and field trials. The experiment was done in a randomized complete block design with three replicates in the experimental field of Faculty of Agriculture, Konya, Turkey. The plants were harvested from August 28 to September 23, 2020, depending on maturity.

The parental genotypes were chosen on the basis of their overall lime to highly calcareous resistance as assessed and superior seed yield performance under highly calcareous soils trial conducted by Harmankaya and coauthors (2008), Ceyhan and coauthors (2009) and Varankaya and Ceyhan (2012) at Central Anatolian, Turkey [19-21]. The method specified by Griffing (1956) was taken into consideration and

Model-I and Method -1 were employed in diallel hybrids [22]. In the study, the data on plant characteristics were made according to Ceyhan (2004) and Ceyhan (2006) [1,2].

RESULTS AND DISCUSSION

The diallel analysis was carried out on all the traits where the crossed genotypes had shown significant differences. Most hybrids had higher values than their parents for all traits (Table 1). In the study, the results of full diallel variance analysis and the of squares mean of all the analyzed features were found to be statistically significant (Table 1). Combining ability variance analysis in a full diallel hybrid set revealed significant differences in GCA values for all traits except for pod number and plant protein yield. SCA was found to be important for seed yield, protein ratio and protein yield in the plant (Table 1). The fact that υ^2GCA/υ^2SCA less than one and H/$D^{1/2}$ greater than 1 for plant height, pod height, number of seeds per pod, seed yield per plant, protein ratio, and protein yield per plant indicates non-additive gene effect. Different results have been obtained in studies on the inheritance of these characters. Non-additive gen effects have been reported for plant height [13,14,27,28], the number of seeds per pod [13,14,27,28], seed yield in the plant [13,14,23,24], protein ratio [12,23,24], and protein yield in bean [12,23,24,27]. On the other hand, the additive gene effects determined for plant height [27,29,30], and seed yield in the plant [29,30]. The fact that υ^2GCA/υ^2SCA greater than 1 and H/$D^{1/2}$ 1 for the number of seeds per plant and hundred-seed weight in the plant shows the additive gene effect (Table 2). Additive gene effects for these traits in bean have been reported in previous studies by Arunga and coauthors (2014), Senbetay and Tesfaye (2015) and Gomes and coauthors (2019) [30,32,33]. In contrast to our finding, Ceyhan and coauthors (2014a,b), Kepildek and Ceyhan (2021), Oliveira Junior and coauthors (1997), and Ceyhan and Şimşek (2021) reported that the non-additive gene effect and the dominant gene effect were effective in the inheritance of number of seeds per plant and hundred-seed weight of the bean plant [12-14,25,28].

The means of genotypes and F_1 hybrids with respect to seed yield and its components are shown in Table 2. The parental values, ranged from 26.27 cm (Göynük) to 54.05 cm (G Northern 59) for plant height, varied between 110.05 number/pod (Göynük) to 18.00 number/pod (Kınalı) for number of pods per plant, found between 4.16 number/pod (Kınalı) and 5.22 number/pod (Özmen) for number of seeds per pod, ranged between from 38.28 number/plant (Göynük) to 58.49 number/plant (Özmen) for number of seeds per plant, differed between 14.47 g/plant (G Northern 59) and 21.25 g/plant (Kınalı) for seed yield, ranged between 29.21 g (Özmen) and 40.29 g (Göynük) for between hundred-seed weight, found to be between 25.61% (Kınalı) and 29.88% (G Northern 59) for protein ratio and ranged from 3.84 g/plant (Göynük) to 5.44 g/plant (Kınalı) for protein yield (Table 2). Similar results were reported in previous studies by Ceyhan and coauthors (2014a,b), Kepildek and Ceyhan (2021), Ülker and Ceyhan (2008a,b), Varankaya and Ceyhan (2012), and Tamüksek and Ceyhan (2022) [12-14,23,34-36].

Large variations resulted in statistically different groups with respect to plant height 21.93 cm (Göynük x Alberto) and 57.62 cm (Alberto x Kınalı), number of pods per plant 7.18 number/pod (Göynük x Alberto) and 22.84 number/pod (Alberto x Kınalı), number of seeds per pod 3.52 number/pod (Göynük x Alberto) and 5.28 number/pod (Alberto x Göynük), number of seeds per plant 25.45 number/plant (Göynük x Alberto) and 85.14 number/plant (Alberto x Kınalı), seed yield 13.72 g/plant (G Northern 59 x Göynük) and 32.38 g/plant (Alberto x Kınalı), hundred-seed weight 25.88 g (Özmen x Alberto) and 39.33 g (Göynük x Kınalı), protein ratio 22.55% (Alberto x G Northern 59) and 29.35% (Özmen x Alberto), protein yield 3.58 g/plant (Kınalı x Göynük) to 9.28 g/plant (Özmen x G Northern 59) for F_1 hybrids (Table 2). Ceyhan and coauthors (2014a,b), Kepildek and Ceyhan (2021), Ülker and Ceyhan (2008a,b), Varankaya and Ceyhan (2012), Jou-Nteufa and Ceyhan (2022) and Tamüksek and Ceyhan (2022) reported similar results [12-14,23,24,34-36].

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	DF	Plant Height	Pods per Plant	Seeds per Pod	Seeds per Plant	Seed Yield per Plant	Hundred Seed Weight	Protein Ration	Protein Yield per Plant
Blocks	2	713,584	154,909	2,006	2734,056	102,001	14,058	0,215	6,886
Genotypes	24	226,937*	37,160*	0,530**	564,957*	74,919**	52,7**	10,857**	6,359**
Error	48	114,162	18,269	0,169	286,110	24,065	11,778	0,037	1,797
GCA	4	184,434**	14,534	0,284**	296,100*	11,354	36,917**	3,841**	0,890
SCA	10	51,130	5,386	0,053	99,554	20,323*	5,705	2,747**	1,583*
Reciprocal Effect	10	56,646	18,528	0,258**	233,971*	35,071**	21,700**	4,401**	3,148**
Error	48	38,054	6,090	0,056	95,370	8,021	3,926	0,012	0,599
GCA		29,28	1,69	0,05	40,15	0,67	6,60	0,77	0,06
SCA		39,23	-2,11	-0,01	12,55	36,90	5,34	8,20	2,95
Reciprocal		18,59	12,44	0,20	138,60	27,05	17,77	4,39	2,55
υ^2GCA / υ^2SCA		0,75	---	---	3,20	0,02	1,24	0,09	0,02
$H/D^{1/2}$		116,37	---	---	231,45	65,28	36,31	14,13	5,62
H^2		0,46	0,37	0,54	0,38	0,71	0,75	0,99	0,74
h^2		0,23	0,09	0,17	0,13	0,01	0,27	0,11	0,02

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

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

Parents/ F_1 Hybrids	Plant Height (cm)		Number of Pods per Plant		Number of Seeds per Pod		Number of Seeds per Plant		Seed Yield per Plant (g)		Hundred Seed Weight (g)		Protein Ration (%)		Protein Yield per Plant (g)	
Kınalı	37,99	b-f	18,00	a-d	4,16	bcd	54,16	b-f	21,25	bc	31,25	b-g	25,61	jk	5,44	b-e
Alberto	47,94	abc	14,77	b-e	4,44	abc	47,00	c-g	16,41	bc	35,56	6a-e	26,93	fg	4,42	cde
Göynük	26,27	ef	10,05	ef	4,22	bcd	38,28	efg	14,63	c	40,29	a	26,29	hı	3,84	de
G Northern 59	54,05	ab	11,64	def	5,16	a	43,61	d-g	14,47	c	31,04	b-g	29,88	a	4,32	cde
Özmen	30,16	ef	15,05	b-e	5,22	a	58,49	a-f	16,76	bc	29,21	efg	27,85	e	4,67	cde
Kınalı x Alberto	47,98	abc	14,08	b-f	4,85	ab	58,38	a-f	16,00	bc	27,70	fg	25,02	lm	4,00	de
Kınalı x Göynük	39,71	b-e	12,99	def	4,47	abc	46,43	d-g	14,16	c	30,47	c-g	25,28	kl	3,58	e
Kınalı x G Northern 59	42,87	a-e	16,67	a-e	4,40	a-d	48,29	c-g	18,25	bc	31,43	b-g	24,20	op	4,42	cde
Kınalı x Özmen	47,74	a-d	14,21	b-e	4,47	abc	49,42	b-g	16,38	bc	32,96	a-g	23,34	q	3,82	de
Alberto x Kınalı	57,62	a	22,84	a	4,47	abc	85,14	a	32,38	a	36,76	a-d	25,49	k	8,25	ab
Alberto x Göynük	49,28	ab	20,85	ab	5,28	a	66,71	a-d	25,57	ab	38,34	ab	26,00	ıj	6,65	a-d
Alberto x G Northern 59	39,12	b-f	15,88	a-e	4,50	abc	50,98	b-g	16,70	bc	33,12	a-g	22,55	r	3,77	de
Alberto x Özmen	39,85	b-e	15,24	b-e	4,72	abc	53,01	b-g	18,28	bc	34,52	a-f	23,97	p	4,38	cde
Göynük x Kınalı	28,08	ef	11,99	def	4,58	abc	39,21	d-g	18,86	bc	39,33	a	24,78	mn	4,67	cde
Göynük x Alberto	21,93	f	7,18	f	3,52	d	25,45	g	16,64	bc	39,15	a	26,61	gh	4,42	cde
Göynük x G Northern 59	29,88	ef	13,12	c-f	4,15	bcd	40,20	g	19,24	bc	37,59	abc	27,27	f	5,25	cde
Göynük x Özmen	30,20	def	11,88	def	3,88	cd	36,17	fg	18,95	bc	35,87	a-e	26,30	hı	4,98	cde
G Northern 59 x Kınalı	39,63	b-e	14,23	b-e	4,75	abc	56,28	b-f	16,12	bc	28,64	efg	27,96	e	4,51	cde
G Northern 59 x Alberto	38,19	b-f	15,04	b-e	5,02	ab	58,05	a-f	17,68	bc	30,45	c-g	24,48	no	4,33	cde
G Northern 59 x Göynük	31,63	c-f	13,13	c-f	4,77	abc	45,88	d-g	13,72	c	30,17	c-g	26,43	h	3,63	e
G Northern 59 x Özmen	36,52	b-f	15,42	b-e	4,86	ab	61,35	a-f	18,02	bc	29,59	d-g	25,57	k	4,60	cde
Özmen x Kınalı	41,09	a-e	16,33	a-e	5,00	ab	65,00	a-e	25,40	ab	30,87	b-g	28,17	de	7,19	abc
Özmen x Alberto	37,99	b-f	16,02	a-e	4,88	ab	64,13	a-e	16,73	bc	25,88	g	29,35	b	4,90	cde
Özmen x Göynük	39,92	b-e	20,08	abc	4,78	abc	74,56	abc	22,62	abc	25,99	g	28,57	cd	6,47	a-e
Özmen x G Northern 59	37,08	b-f	20,61	ab	4,90	ab	76,27	ab	32,10	a	34,70	a-f	28,92	c	9,28	a

[1] The same letter for each tested traits aren't significantly different by LSD

Table 3. Estimates of GCA and SCA for investigated traits in a full-diallel hybrid set.

Parents/ F_1 Hybrids	Plant Height	Pods per Plant	Seeds per Pod	Seeds per Plant	Seed Yield per Plant	Hundred Seed Weight	Protein Ration	Protein Yield per Plant
Kınalı	3,161	0,842	-0,087	1,949	0,912	-0,769	-0,726**	0,100
Alberto	3,875	0,575	-0,006	1,887	0,188	0,869	-0,540**	-0,078
Göynük	-6,592*	-1,961*	-0,231*	-8,581*	-1,191	2,912**	0,109*	-0,297
G Northern 59	1,393	-0,354	0,149	-1,247	-1,016	-1,058	0,442**	-0,189
Özmen	-1,837	0,897	0,174	5,991	1,107	-1,954*	0,715**	0,465
Kınalı x Alberto	6,852*	1,952	0,135	14,229*	4,001*	-0,702	0,247**	1,073*
Kınalı x Göynük	-1,585	-1,483	0,225	-4,248	-2,304	-0,082	-0,626**	-0,708
Kınalı x G Northern 59	-2,214	-0,129	-0,106	-2,117	-1,806	-0,974	0,094	-0,480
Kınalı x Özmen	4,184	-1,560	0,031	-4,430	-0,225	1,803	-0,507**	-0,091
Alberto x Kınalı	4,820	4,377**	-0,193*	13,380*	8,190**	4,530**	0,238**	2,124**
Alberto x Göynük	-0,588	0,308	0,020	-0,923	3,015	2,126	0,463**	0,877*
Alberto x G Northern 59	-5,522	0,146	-0,001	0,176	-1,075	-0,861	-2,657**	-0,717
Alberto x Özmen	-2,025	-0,937	0,010	-3,007	-2,886*	-1,552	0,210**	-0,777*
Göynük x Kınalı	-5,813*	-0,503	0,058	-3,612	2,353*	4,430**	-0,254**	0,545
Göynük x Alberto	-13,675**	-6,837**	-0,878**	-20,628**	-4,465**	0,403	0,307**	-1,114**
Göynük x G Northern 59	-2,955	0,347	-0,077	-0,827	-0,408	-0,812	0,029	-0,104
Göynük x Özmen	4,580	1,949	-0,231	4,258	1,778	-2,861*	0,335**	0,529
G Northern 59 x Kınalı	-1,618	-1,220	0,173	3,997	-1,063	-1,395	1,878**	0,045
G Northern 59 x Alberto	-0,465	-0,422	0,260*	3,535	0,487	-1,337	0,964**	0,279
G Northern 59 x Göynük	0,875	0,003	0,308*	2,840	-2,758*	-3,708**	-0,419**	-0,813*
G Northern 59 x Özmen	-1,664	2,381	-0,063	10,366*	5,876**	2,324	-0,186*	1,630**
Özmen x Kınalı	-3,327	1,063	0,267*	7,788*	4,510**	-1,048	2,416**	1,688**
Özmen x Alberto	-0,928	0,390	0,080	5,557	-0,775	-4,322**	2,688**	0,261
Özmen x Göynük	4,857*	4,100**	0,453**	19,197**	1,837	-4,940**	1,136**	0,745*
Özmen x G Northern 59	0,283	2,595*	0,018	7,462	7,037**	2,555*	1,675**	2,341**
Gi	3,044	6,888	0,004	7,630	0,642	0,314	0,001	0,048
Sij	12,938	29,275	0,019	32,426	2,727	1,335	0,004	0,204
Rij	19,027	43,052	0,028	47,685	4,011	1,963	0,006	0,300

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

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

Parents/ F_1 Hybrids	Plant Height	Pods per Plant	Seeds per Pod	Seeds per Plant	Seed Yield per Plant	Hundred Seed Weight	Protein Ration	Protein Yield per Plant
Kınalı x Alberto	11,66	-14,05	12,82**	15,43	-15,02	-17,08	-4,78**	-18,78*
Kınalı x Göynük	23,57	-7,34	6,60**	0,45	-21,09	-14,83	-2,57**	-22,82*
Kınalı x G Northern 59	-6,86	12,50	-5,61**	-1,22	2,16	0,90	-12,76**	-9,51
Kınalı x Özmen	40,11	-14,03	-4,69**	-12,26	-13,84	9,03	-12,69**	-24,46*
Alberto x Kınalı	34,09	39,38	3,84**	68,33	71,96	10,04	-2,97**	67,42**
Alberto x Göynük	32,80	67,99	21,89**	56,46	64,74	1,09	-2,30**	60,91**
Alberto x G Northern 59	-23,29	20,24	-6,32**	12,53	8,16	-0,54	-20,59**	-13,81
Alberto x Özmen	2,04	2,17	-2,38**	0,51	10,18	6,58	-12,49**	-3,62
Göynük x Kınalı	-12,61	-14,52	9,39**	-15,17	5,15	9,94	-4,53**	0,67
Göynük x Alberto	-40,90	-42,18	-18,66**	-40,30	7,20	3,22	0,01*	6,97
Göynük x G Northern 59	-25,60	20,98	-11,55**	-1,80	32,20	5,38	-2,89**	28,65*
Göynük x Özmen	7,04	-5,38	-17,87**	-25,25	20,73	3,23	-2,86**	17,06*
G Northern 59 x Kınalı	-13,89	-3,97	1,82**	15,13	-9,75	-8,05	0,78**	-7,65
G Northern 59 x Alberto	-25,11	13,86	4,51**	28,14	14,46	-8,57	-13,81**	-1,05
G Northern 59 x Göynük	-21,24	21,04	1,60**	12,07	-5,72	-15,41	-5,88**	-11,15
G Northern 59 x Özmen	-13,27	15,53	-6,39**	20,17	15,40	-1,78	-11,42**	2,20
Özmen x Kınalı	20,58	-1,16	6,68**	15,39	33,62	2,09	5,38**	42,33**
Özmen x Alberto	-2,71	7,40	0,93**	21,58	0,83	-20,10	7,14**	7,87
Özmen x Göynük	41,46	59,95	1,34**	54,10	44,13	-25,20	5,53**	52,06**
Özmen x G Northern 59	-11,93	54,42	-5,68**	49,40	105,51	15,19	0,19**	106,31**
Mean	0,80	11,64	-0,39	13,68	18,55	-2,24	-4,68	13,98

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

The fact that the GCA effect is significant indicates that a cultivar will increase more traits than the other cultivar in crossings in terms of the relevant trait. An estimate of GCA of the five cultivars for seed yield and its components showed that Garrafol was the best combiner for seed yield (Table 3). Apart from grain yield and protein yield, Göynük 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. G. Northern 59 and Özmen can be used in breeding studies as parents with positive effecting to increase the number of seeds per pod, It is thought that it will be used in breeding studies to increase the number of seeds in the plant for Özmen, Kınalı and Alberto genotypes, which have positive effects, Kınalı, Alberto, Özmen parents, who have a positive effect, can considered as parents to be developed in breeding studies, G Northern 59, Özmen cultivars were positive and significant. Özmen and Kınalı, had a positive effect and therefore are suggested as genotypes that can be used in breeding studies. This line can be used as a breeding material in terms of seed yield and its components in breeding for dry bean.

The fact that the effect of SCA is significant indicates that the effect of GCA of the cultivars does not play an important role in the formation of the related trait of the hybrid. Estimates of SCA of 20 F_1 crosses for the seed yield and its components are showed in Table 3. The “Alberto x Kınalı”, “Özmen x G Northern 59”, “G Northern 59 x Özmen”, Özmen x Kınalı”, “Kınalı x Alberto” and “Göynük x Kınalı” hybrid exhibited high SCA effects for seed yield per plant. Cross with high SCA for plant heigth included “Kınalı x Alberto” and “Göynük x Alberto”. The “Alberto x Kınalı”, “Özmen x Göynük” and “Özmen x G Northern 59” cross combination was good combiner for pods per plant. Good specific combiners for seeds per pod was “Özmen x Göynük”, “G Northern 59 x Göynük”, “Özmen x Kınalı” and “G Northern 59 x Alberto” crosses. The “Özmen x Göynük”, “Kınalı x Alberto”, “Alberto x Kınalı” and “G Northern 59 x Özmen” and “Özmen x Kınalı” crosses combination was a good combiner for seeds per plant. The two crosses “Alberto x Kınalı” and “Göynük x Kınalı” had best combiner for hundred seed weight. Crosses “Özmen x Alberto”, “özmen x Kınalu”, “G Northern 59 x Kınalı”, “Özmen x G Northern 59”, “Özmen x Göynük”, “G Northern 59 x Alberto”, “Alberto x Göynük”, “Göynük x Özmen”, “Kınalı x Alberto”, “Alberto x Kınalı” and “Alberto x Özmen” showed high SCA for protein ratio. The crosses “Özmen x G Northern 59”, “Alberto x Kınalı”, “Özmen x Kınalı “, “G Northern 59 x Özmen”, “Alberto x Göynük”, “Alberto x Özmen” and “Özmen x Göynük” exhibited high SCA effets for protein yield per plant. SCA values provide important information about the performance of the hybrid relative to its parents. The most promising specific combiner for seed yield and its components was “Alberto x Kınalı”, “Özmen x G Northern 59”, “G Northern 59 x Özmen”, Özmen x Kınalı” and “Kınalı x Alberto” crosses for further utilization in hybrid development in dry bean.

In breeding studies, determining the genetic variance that the hybrid population may have in the shortest time ensures that the appropriate parent is selected, and the breeding is more effective. At the end of the study, the desired characteristics can be obtained from which parent and hybrids, by determining the effects of GCA and SCA. GCA and SCA effects are determined according to the differences between parents and crosses from the general average. The results we obtained are largely similar to the results obtained in the studies of Ceyhan and coauthors (2014a,b), Kepildek and Ceyhan (2021), Oliveira Junior and coauthors (1997), Ceyhan and Şimşek (2021), Arunga and coauthors (2014), Senbetay and Tesfaye (2015), Gomes and coauthors (2019), and Tamüksek and Ceyhan (2022) [12-14,23,25,28,30,32,33].

According to the averages of the F_1 hybrids in the study, the heterosis values were varied between -40.90% (Göynük x Alberto) and 40.11% (Kınalı x Özmen) in plant height, -42.18% (Göynük x Alberto) and 67.99% (Alberto x Göynük) in pods per plant, -18.66% (Göynük x Alberto) and 21.89% (Alberto x Göynük) in seeds per pod, -40.30% (Göynük x Alberto) and 68.33% (Alberto x Kınalı) in seeds per plant, -21.09% (Kınalı x Göynük) and 105.51% (Özmen x G Northern 59) in seed yield per plant, -25.20% (Özmen x Göynük) and 15.19% (Özmen x G Northern 59) in hundred seed weight, -20.59% (Alberto x G Northern 59) and 7.14% (Özmen x Alberto) in protein ration, and -24.46% (Kınalı x Özmen) and 106.31% (Özmen x G Northern 59) in protein yield per plant (Table 4). The results we obtained in this study have been reported by Ceyhan and coauthors (2014a,b), Kepildek and Ceyhan (2021), Oliveira Junior and coauthors (1997) and Ceyhan and Şimşek (2021) with both positive and negative heterosis values obtained in hybrid combinations [12-14,25,28].

In terms of the characteristics examined in the study, hybrids with higher phenotypic values than the average of both parents were determined. This shows us that superior dominance gene effects are effective on these characters. In terms of grain yield per plant, an increase was observed in 15 hybrids compared to the parental average. Therefore, these hybrids are recommended to be used in hybrid breeding programs in the future.

CONCLUSION

As a result, there is a sufficient level of genetic variation in the studied population in terms of agricultural characteristics. Non-additive and dominant genes were found to be more effective on the plant height, pod height, number of seeds per pod, seed yield per plant, protein ratio, and protein yield per plant in this study. In this population, it would be more appropriate to perform the selection process in later generations by evaluating the seed yield.

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