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Research Article

Determination of Combining Ability and Heredity Through Diallel Analysis Method in F_2 Populations of Cowpea

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ABSTRACT

Cowpea is an essential economic crop in underdeveloped and developing countries mainly grown by small farmers. The parents and F_2 populations obtained for the F_1 generation were planted, in 3 rows of 2 m in length, with row spacing of 45 cm, row spacing of 10 cm and in the ecological conditions of Konya in 2021. The 20 F_2 populations and 5 parents were evaluated in the 2021 grown season. General combining ability (GCA) effects for various parents differed significantly. "Sırma" gave significant, positive GCA effects for the number of pod per plant, number of seeds per plant, seed yield per plant and protein yield in plant. Significant, positive specific combining ability (SCA) effects were smaller and less significant than GCA effects. The non-additive dominant gene effect was determined for all the traits. Heterosis of the F_2 over the high-parent was observed in five F_2 populations. In the terms of combining ability for yield, the best parent was "Sırma". The heterosis for a yield of F_2 hybrids resulted mainly from an increased number of seeds per plant, hundred seed weight. These results suggest that high yielding F_2 cowpea populations can be developed that may contain acceptable levels of superior agronomic and technological characteristics.

1. Introduction

Cowpea [*Vigla unguiculata (L.) Wap*.] (2n=22) is native and domesticated in Africa; it is widespread and cultivated in tropical and subtropical regions. Cultivated for the collection of immature pods, ripe seeds, leaves, richness in proteins, vitamins (*thiamine, riboflavin*), photo chemicals (*phenolic acids, anthocyanins*) and minerals (potassium, phosphorus iron, calcium (Sert and Ceyhan, 2012; Abdulazeez et al., 2019). The very regular consumption of pulses including cowpeas is associated with poverty (Sert and Ceyhan, 2012; Harmankaya et al., 2016). It is an important component of human and animal nutrition, especially on the African continent, where it is mainly cultivated. Cowpea plays a major role as a concentrated source of cheaper protein like fish, meat, poultry or dairy products. Thus, it combines well with cereals in the human diet hence its name "food of the poor men" (Porch and Hall, 2013). It is one of the favorite crops grown in India for green pods, ripe seeds, and richness in nutrients. The consumption of meat or dairy products in India is sometimes questioned for customary and religious reasons. However, cowpea is consumed for the rational and nutritional balance of these populations (Penchalaraju and Don Bosco, 2022). Cowpea seeds contain substantial amounts of protein (about 25%), carbohydrates (about 64%), vitamins and fiber. When a part of cowpea is combined with three cereal seeds, it provides an almost complete food (Hal, 2012).

The most important function of legumes in nutrition is that they are a source of protein. Legumes are important nutritious sources of proteins, vitamins and above all rich in minerals like potassium, phosphorus, calcium and iron. Legumes are more widely used as a source of protein, especially in less developed and developing third world countries (Sing, 2020). Pulses are important sources that potentially provide the 15 minerals needed by humans, the amount of which varies depending on genetic and environmental factors (Horn and Shimelis, 2020).

Cowpeas are better than other legumes in heat and drought tolerance in semi-arid and tropical regions of the world (Boukar et al., 2019). It is undeniable that crossbreeding studies are necessary to increase the genetic variation of cowpea, which has an important place in the world. However, its importance has not been demonstrated in Turkey and only selection studies have focused on selection by selection. The development of

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cowpea cultivars in these variations can be formed by hybridization, improved productivity and quality in the unit area. Thus, by improving the breeding varieties resistant to the diseases observed in Turkey; the creation of genetic resources would show how much more important the study is in terms of temperature and dry weather (Veeranagappa et al., 2022). However, Turkey's total number of local varieties, especially in extreme and remote areas, is declining Since Turkey is a micro gene for many plants such as cowpea, the demand for protein-rich foods like cowpea is increasing daily, especially in rural areas where malnutrition becomes a problem. These protein-rich varieties are of profitable economic importance, of an undeniable role in the diet of populations. Consequently, their insufficiency could contribute to exacerbate this problem of malnutrition and to lower the economy.

Genotypes with significantly positive general and specific combining ability (GCA and SCA) were reported for plant height, pod lenght, pod width, number of pods per plant, number of seed per pod, seed yield per plant, hundred weight, protein ratio and protein yield of cowpea hybrids (Pejic et al., 2013; Tchiagam et al., 2011; Magar et al., 2016; Kumari and Chauhan, 2018; Kalambe et al., 2019; Walle et al., 2019). But for the number of seeds per plant, GCA was negative and SCA was positive. The genotypes with a high GCA variance can be used as a basic breeding source in such breeding studies (Ayo-Vaughan et al., 2013).

It was found that non-additive genes were effective on pod length (Pallavi and Chaudhary, 2020; Yadji Haman, 2020). Non-additive genes were also effective on number of pod per plant, number of seed per plant, plant height and protein yield per plant (Magar et al., 2016; Kumari and Chauhan, 2018), then effective on the number of seed per pod, protein ratio (Ayo-Vaughan et al., 2013), on hundred-seed weight, seed yield per plant of cowpea (Singh, 2020). Whereas, additive genes were effective in the inheritance of pod width (Umaharan et al., 1997; Tchiagam et al., 2011; Verma et al., 2020).

This study aimed to study the genetic structure of the F_2 hybrids, identify the appropriate parents and combinations, determine the heritability, heterosis, and heterobeltiosis of the characters studied, and finally identify the hybrids with superior agronomic and technological characteristics and available for mechanical agriculture.

2. Materials and Methods

Field experiments were carried out on an apple (In this study, 5 high-yield cowpea varieties of seed collection have been used: Sırma (shows stunted and upright development; Seed shape is rhombic; hilum ring color is yellowish brown; the number of fruit seeds is 8-12), Amazon (It shows stunted and upright development; The shape of the seed is that of a pastry; the color of the hilum ring is black; The number of fruit seeds is 8-12), Karagöz (They are black-eyed peas with cylindrical seeds that are off-white. Fruit color is dark green. The circumference of the hilum is black. Plant height is 60-90 cm. Fruit size is about 16-21 cm long, 10-12 mm in diameter. The number of seeds in the fruit is 10-14), Ülkem (There is no pubescence on the stem and leaves of the plant, which produces abundant vegetative parts, develops spreading, growth type is pole (unlimited), growth type is spreading (creeper); Seeds are reddish brown; flower color is purple violet) and Pekşen (There is a climbing type, which most of lower branches touched the ground).

The soil of research area was clay loam, with pH 8.05 and phosphorous, potassium, iron, zinc, organic matter and $CaCO_3$ contents of 55.9, 17.9 kg ha^{-1}, 14.74, 0.32 ppm and 37.6, 2.25%, respectively. 20 year annual precipitation is 109.6 mm per year, annual mean temperature is 19.5 ^oC and average relative humidity is 48.0%. Total annual precipitation was 134.3 mm, which was more than 20 years on average (109.6 mm) of the site. During the experimental period, average temperature was 19.8 ^0C and average relative humidity was 44.4%.

The parents and F_2 populations obtained for the F_1 generation were planted on 04.29.2021, in 3 rows of 2 m of length, row spacing of 45 cm and row spacing of 10 cm. Mother plants were planted first, then father plants were planted in each row of the hybrid group. In the trial field of Selcuk University Faculty of Agriculture and according to the “Random Blocks Trial Design”, the trials were set up with 3 replicates (Yurtsever, 1984). At the sowing’s time, 15 kg of 46 % DAP (Diammonium phosphate) fertilizer was added per decare. After planting, the plots were irrigated by the sprinkler irrigation method to ensure germination and emergence. Using a hoe, weeding was done manually and mechanically. When the plants reached harvest maturity, they were harvested separately and measurement, weighing, analysis, and evaluation processes were carried out.

Measurements and counts of the properties examined in the research have been carried out in all plants obtained in each parcel in F_2 populations. Plant height, pod length, number of pods per plant, number of seed per pod, number of seed per plant, seed yield per plant, hundred-seed weight, protein ratio, and protein yield were investigated in this study.

The breeding value of the plant material was evaluated by analyzing the data on heterosis or combining ability for all the traits in the F_2. The studied data were analyzed with the program TARPOPGEN PC Program (Ozcan and Acikgoz, 1999).

3. Results and Discussion

In Table 1 are given the results of the mean squares of the initial analysis of variance and the combination of the analysis of variance of the capacities for the characters studied in the complete diallel hybrid set.

The mean squares of the crosses were determined to be statistically significant for all traits in the full diallel analysis of trait variance. Genotypes varied at the 5%

and 1% significance levels for all traits studied (Table 1).

In the F_2 generation, in the full diallel hybrid set, significant differences were determined for all the investigated traits between GCA and SCA for the traits whose combinatory ability variances were examined. Among the variances of the reciprocal effect, it was found to be statistically significant in all properties except pod width and pod length (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	Pod Length	Pod Width	Number of Pods per Plant	Number of Seeds per Pod
Blocks	2	131,745	3,715	0,005	0,549	0,2250
Genotypes	24	1494,545**	10,731**	0,021**	19,248**	3,497**
Error	48	395,064	3,34	0,002	6,448	0,729
GCA	4	935,949**	935,949**	11,927**	0,008**	10,509**
SCA	10	248,160	248,160	2,195	0,004**	5,884**
Reciprocal Effect	10	573,096**	573,096**	1,619	0,009**	5,310*
Error	48	131,688	131,688	1,114	0,001	2,149
Source of Variation	SD	Number of Seed per Plant	Seed Yield	Hundred Seed Weight	Protein Ratio	Protein Yield in Plant
Blocks	2	131,513	6,180	6,737	0,052	0,438
Genotypes	24	3288,605**	244,852**	22,251**	2,234**	19,264**
Error	48	853,570	46,405	3,181	0,074	3,601
GCA	4	2229,474**	181,394**	7,158**	1,177**	12,842**
SCA	10	865,068**	93,441**	10,843**	0,422**	7,391**
Reciprocal Effect	10	874,026**	29,883	4,094**	0,894**	2,882*
Error	48	284,523	15,468	1,060	0,025	1,200

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

3.1. Plant height:

In the F_2 generation, the plant height ranged between 80.52 cm (Karagöz x Amazon) and 153.53 cm (Sırma x Karagöz) (Table 2). In previous studies, some researchers have determined similar results (Peksen et al., 2004; Pekşen, 2012; Sert and Ceyhan, 2012; Kadam et al., 2013; Pekşen, 2013; Walle et al., 2019; Joshi et al., 2022).

The fact that σ^2SCA was greather than σ^2GCA and $H/D^{1/2}$ ratio was also greater than 1 (Table 2), showed us that, the non-additive gene effect and superior dominance are important in the inheritance on plant height. Owusu et al. (2020) determined in their research that the additive gene effect was more dominant in the inheritance of plant height. But contrary to (Magar et al., 2016; Kumari and Chauhan, 2018; Verma et al., 2020) non-additive gene effect was predominant in this trait and these results were in agreement with ours.

In the F_2 generation plant height, while examining the parental GCA, Pekşen, Sırma and Ülkem genotypes had positive and significant GCA values, while Amazon and Karagöz genotypes showed negative and significant GCA values (Table 3). Pekşen, Sırma and Ülkem genotypes with positive and significant GCA effect value can be used to increase plant height, and Amazon and Karagöz genotypes, which are negative and important, can be easily used in the development of Cowpea varieties with less grading. Magar et al. (2016), Kumari and Chauhan (2018), Ravelombola et al. (2018), Owusu et al. (2020), Pallavi et al. (2020), Verma et al. (2020), who studied the plant height feature found the GCA and SCA values of different numbers of parents and crosses to be significant.

While examining the SCA effects of hybrids in the F_2 generation, "Sırma x Karagöz" hybrid combinations are positive and significant, "Pekşen x Sırma", "Ülkem x Pekşen", "Karagöz x Pekşen", "Ülkem x Sırma", "Amazonx Pekşen", "Karagöz x Sırma", hybrid combination showed a negative and significant effect (Table 3). When Table 4.5 sub-diagonal reciprocal effects are examined, "Sırma x Karagöz" was positively significant. This shows us that cytoplasm or cytoplasm x nucleus interactions cause significant changes in this feature.

The average heterosis value determined in the F_2 generation is 4.45%, the heterobeltiosis value is -10.61%.Heterosis values in the F_2 generation ranged between -27.05% (Ülkem x Karagöz) and 54.32% (Pekşen x Ülkem), while heterobeltiosis values ranged between -33.90% (Karagöz x Pekşen) and 22.35% (Sırma x Karagöz) (Table 4). In terms of plant height, the majority of hybrids have negative heterosis and heterobeltiosis values. 16,31. Analyzing the heterosis and heterobeltiosis values for the same trait, Sarath and Reshma (2017), and Joshi et al. (2022) reported that they detected high or low heterosis and heterobeltiosis values for this feature and hybrids that both were desirable and significant.

In the F_2 generation, broad and narrow sense heritability was calculated as 0.74 and 0.21, respectively (Table 2). The high heritability in F_2 generation reveals that genetic factors, as well as the environment, as well as the environment, significantly impact the emergence of this trait. Thereby, it can be said that a selection to be-

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

Parents	Plant Height		Pod Length		Pod Width		Number of Pods per Plant		Number of Seeds per Pod	
Pekşen	121,89	a-d	21,48	a	0,81	c-f	12,91	f	9,41	ab
Sırma	125,49	abc	19,77	abc	0,84	b-e	18,88	a-e	9,60	ab
Ülkem	116,07	a-d	16,51	be	0,73	fgh	16,31	a-f	10,26	ab
Amazon	96,74	b-e	16,58	be	0,85	b-e	13,76	ef	9,96	ab
Karagöz	58,00	e	15,67	de	0,99	a	13,67	ef	5,67	d
F_2 Populations										
Pekşen X Sırma	96,42	b-e	17,26	be	0,87	cd	17,66	a-f	10,07	ab
Pekşen X Ülkem	133,61	ab	19,94	ab	0,81	c-f	17,89	a-f	9,92	ab
Pekşen X Amazon	133,73	ab	21,65	a	0,84	b-e	18,85	a-e	9,67	ab
Pekşen X Karagöz	135,92	ab	18,25	a-e	0,92	ab	18,09	a-f	11,27	a
Sırma X Pekşen	109,63	bcd	18,25	a-e	0,78	d-g	21,10	ab	9,40	b
Sırma X Ülkem	137,06	ab	17,96	a-e	0,86	bcd	17,92	a-f	10,42	ab
Sırma X Amazon	112,84	a-d	16,92	b-e	0,90	abc	18,40	a-f	9,54	ab
Sırma X Karagöz	153,53	a	17,05	b-e	0,69	gh	16,06	a-f	7,43	cd
Ülkem X Pekşen	115,43	a-d	16,84	b-e	0,76	efg	20,40	abc	9,03	bc
Ülkem X Sırma	100,82	b-e	15,82	cde	0,72	fgh	16,76	a-f	10,44	ab
Ülkem X Amazon	103,10	bcd	15,92	cde	0,71	gh	20,06	a-d	10,11	ab
Ülkem X Karagöz	94,44	b-e	16,27	b-e	0,85	b-e	13,13	f	9,93	ab
Amazon X Pekşen	103,67	bcd	19,32	a-d	0,87	abc	14,54	def	9,88	ab
Amazon X Sırma	97,88	b-e	15,01	e	0,86	bcd	21,56	a	9,70	ab
Amazon X Ülkem	88,96	cde	15,75	de	0,84	b-e	13,98	ef	9,13	bc
Amazon X Karagöz	95,17	b-e	15,98	b-e	0,83	b-e	18,15	a-f	10,20	ab
Karagöz X Pekşen	80,57	de	15,81	cde	0,66	h	14,46	ef	9,03	bc
Karagöz X Sırma	83,34	cde	16,22	b-e	0,84	b-e	15,95	b-f	9,22	bc
KaragözX Ülkem	83,91	cde	15,91	cde	0,65	h	14,99	c-f	9,80	ab
KaragözX Amazon	80,52	de	14,85	e	0,85	b-e	16,04	a-f	8,59	bc
GCA	160,85		2,16		0,00		1,67		0,42	
SCA	349,42		3,24		0,01		11,21		2,90	
Reciprocal	441,41		0,51		0,01		3,16		0,41	
σ^2GCA/σ^2SCA	0,46		0,67		0,13		0,15		0,14	
$H/D^{1/2}$	1112,53		8,07		0,02		17,71		4,15	
H^2	0,74		0,71		0,93		0,74		0,85	
h^2	0,21		0,38		0,12		0,14		0,17	

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

made in the direction of plant height should be considered together with seed yield. For this reason, it may be more appropriate to start the selection in future generations. Owusu ve ark. (2020); Verma ve ark. (2020) found the similar results.

3.2. Pod Length:

The parental values in the F_2 generation ranged from 15.67 mm (Karagöz) to 21.48 mm (Pekşen), and the pod length per plant in the F_2 generation was 14.85 mm (Karagöz x Amazon) to 21.65 mm (Pekşen x Amazon) (Table 2). Peksen et al. (2004), Pekşen (2012), Kadam et al. (2013), Pekşen (2013), da Costa et al. (2017), Walle et al. (2019), and Joshi et al. (2022) obtained similar results.

The fact that in F_2 generation σ^2SCA was greather than σ^2GCA in the inheritance of pod length, then σ^2GCA/σ^2SCA ratio was lower than 1 and $H/D^{1/2}$ ratio was greater than 1 showed us the effectivity of non-additive gene effect and superior dominance in the inheritance of this trait. It reveals that selection in future generations would be appropriate because the genes that affect the pod length in the plant are not additive in the examined hybrid generations (Pallavi et al., 2020; Verma et al., 2020), found different results. But Magar et al. (2016), Kumari and Chauhan (2018), and Olunloyo et al. (2019) found similar results.

Considering the SCA effects of hybrids in the F_2 generation, "Pekşen x Amazon" hybrid combinations are positive and significant, "Ülkem x Pekşen", "Amazon x Pekşen", "Karagöz x Pekşen", "Pekşen x Sırma", "Amazon x Sırma" ", "Ülkem x Sırma" hybrids combinations showed a negative and significant effect (Table 2). When the reciprocal effects are examined, in the F_2 generation, "Pekşen x Amazon" was found to be positive and significant. This shows us that cytoplasm or cytoplasm x nucleus interactions cause significant changes in this feature(Table 2). Working on the pod length, Dias et al. (2016), Magar et al. (2016), Kumari and Chauhan (2018), Olunloyo et al. (2019), Owusu et al. (2020), Pallavi et al. (2020), and Verma et al. (2020) found the GCA and SCA values of different numbers of parents and crosses to be important for this trait.

In the F2 generation, the determined mean heterosis value was -5.16%, while the heterobeltiosis value was -12.08%. From this feature, most hybrids have negative values of heterosis and heterobeltiosis. Heterosis values are between -17.42% (Amazon x Sırma) and 13.79% (Pekşen x Amazon), heterobeltiosis values are between -26.39% (Karagöz x Pekşen) and 0.83% (Pekşen x Amazon) (Tables 4 and 8). These findings were supported by Ceyhan (2004), Kadam et al. (2013), Ceyhan et al. (2014), Sarath and Reshma (2017), and Joshi et al. (2022). Moreover, Kadam et al. (2013), and Sarath and

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

Parents	Plant Height	Pod Length	Pod Width	Number of Pods per Plant	Number of Seeds per Pod
Pekşen	8,926	1,789**	0,000	0,020	0,201
Sırma	7,899	0,163	0,006	1,456*	0,036
Ülkem	2,598	-0,497	-0,047**	-0,086	0,423*
Amazon	-5,414	-0,383	0,027*	0,050	0,167
Karagöz	-14,009*	-1,073*	0,015	-1,440*	-0,827**
F_2 Populations					
Pekşen X Sırma	-20,152*	-1,436*	0,007	1,045	-0,006
Pekşen X Ülkem	6,645	-0,140	0,019	2,348*	-0,658*
Pekşen X Amazon	8,836	1,842*	0,015	-0,237	-0,100
Pekşen X Karagöz	6,982	-0,925	-0,037*	0,837	1,265**
Sırma X Pekşen	6,605	0,493	-0,045**	1,723*	-0,336
Sırma X Ülkem	2,095	-0,017	0,016	-0,892	0,464
Sırma X Amazon	-3,475	-1,055	0,034*	1,612	-0,092
Sırma X Karagöz	18,193*	0,302	-0,069**	-0,872	-0,389
Ülkem X Pekşen	-9,092*	-1,550**	-0,022*	1,257*	-0,443*
Ülkem X Sırma	-18,120**	-1,073*	-0,074**	-0,582	0,008
Ülkem X Amazon	-7,501	-0,527	-0,018	0,196	-0,479
Ülkem X Karagöz	-5,764	0,419	-0,029	-1,276	0,762*
Amazon X Pekşen	-15,030**	-1,166*	0,015	-2,157**	0,108
Amazon X Sırma	-7,484	-0,955*	-0,022*	1,584*	0,078
Amazon X Ülkem	-7,072	-0,084	0,061**	-3,037**	-0,492*
Amazon X Karagöz	0,920	-0,368	-0,014	1,626	0,549
Karagöz X Pekşen	-27,675**	-1,223*	-0,132**	-1,816*	-1,120**
Karagöz X Sırma	-35,096**	-0,415	0,076**	-0,051	0,897**
KaragözX Ülkem	-5,263	-0,180	-0,099**-	0,932	-0,067
KaragözX Amazon	-7,323	-0,568	0,009	-1,054	-0,801**
G_i	10,535	0,089	0,000	0,172	0,019
S_{ij}	44,774	0,379	0,000	0,731	0,083
R_{ij}	65,844	0,557	0,000	1,075	0,122

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

Reshma (2017), who examined the heterosis and heterobeltiosis values pod length, reported that heterosis was expressed in hybrids and heterobeltiosis was recorded in crosses. In comparison, Joshi et al. (2022) found that heterosis values were positive and significant.

In the F_2 generation, broad and narrow sense heritability rates were 0.71 and 0.38, respectively (Table 2). The low heritability in both generations indicates that genetic factors are more dominant in the emergence of this trait. With these results, it can be said that it would be more appropriate to start the selection in terms of the pod length after the F_2 generation. Ceyhan (2004), and Owusu et al. (2020) were in harmony.

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

F_2 Populations	Plant Height	Pod Length	Pod Width	Number of Pods	Number of Seed per Pod
Pekşen X Sırma	-15,64	-16,29**	5,87**	11,10	5,98**
Pekşen X Ülkem	54,32**	5,00	4,80**	22,41	0,82
Pekşen X Amazon	9,36	13,79*	1,16**	41,35*	-0,20
Pekşen X Karagöz	-18,91	-1,71	2,35**	36,18*	49,46**
Sırma X Pekşen	5,95	-11,51*	-4,98**	32,78*	-1,08
Sırma X Ülkem	-8,12	-0,99	9,93**	1,83	4,94**
Sırma X Amazon	6,37	-6,91	6,99**	12,70	-2,47*
Sırma X Karagöz	47,68*	-3,79	-24,66**	-1,34	-2,66*
Ülkem X Pekşen	1,14	-11,32*	-0,82**	39,62*	-8,19**
Ülkem X Sırma	-5,43	-12,82*	-8,91**	-4,78	5,09**
Ülkem X Amazon	-13,68	-3,80	-9,77**	33,38*	-0,03
Ülkem X Karagöz	-27,05	1,12	-1,37**	-12,43	24,70**
Amazon X Pekşen	-2,77	1,54	4,82**	9,01	2,03*
Amazon X Sırma	22,82	-17,42**	1,74**	32,10*	-0,88
Amazon X Ülkem	-22,00	-4,82	5,64**	-7,01	-9,77**
Amazon X Karagöz	-8,69	-0,87	-9,74**	32,34*	30,48**
Karagöz X Pekşen	-8,68	-14,88*	-26,84**	8,84	19,74**
Karagöz X Sırma	37,45	-8,48	-8,17**	-1,97	20,83**
KaragözX Ülkem	-14,07	-1,11	-24,24**	0,00	23,01**
KaragözX Amazon	-0,44	-7,91	-7,83**	16,96	9,97**
Mean	4,45	-5.16	-4.20	15.15	8.59

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

3.4. Number of pods:

According to the average number of pods in the F_2 generation, the parental values were between 12.91 per plant (Pekşen) and 18.88 per plant (Sırma), in the F_2 generation the number of pods per plant was 13.13 per plant (Ülkem x Karagöz) and 21.56 per plant (Ülkem x Sırma) (Table 2). These findings were supported by Peksen et al. (2004), Pekşen (2012), Kadam et al. (2013), da Costa et al. (2017), Walle et al. (2019), and Joshi et al. (2022).

For the number of pods per plant in the F_2 generation, the GCA variance was less than SCA, then σ^2GCA/σ^2SCA ratio ratio was also less than 1 and the $H/D^{1/2}$ ratio was greather than 1 The fact that the σ^2GCA/σ^2SCA ratios examined for the number of pods in the plant were found to be less than 1 reveals that the non-additive gene effect is effective in the inheritance of this trait. Likewise, the fact that the $(H/D)^{1/2}$ ratio is greater than 1 in the F_2 generation indicates superior dominance and supports this result. Magar et al. (2016), Gupta et al. (2017), Kumari and Chauhan (2018), and Purnamasari et al. (2019) agreed with these results. Hall et al. (2003), and Verma et al. (2020) stated that additive genes were effective on the number of pods in the plant.

In the F_2 generation, examining the effects of parents and hybrids on GCA and SCA in terms of the number of pods per plant; Magar et al., (2016), Olunloyo et al. (2019), and Pallavi and Chaudhary (2020) obtained similar results to our findings. (Table 2). Considering the reciprocal effect, the hybrid is in F_2 generation, "Pekşen x Ülkem" hybrid has Pekşen cytoplasm. This result shows that cytoplasm and cytoplasm x nucleus interactions cause significant changes in this feature. Increasing the number of pods in the plant is also theoretically increasing the seed yield (Pekşen et al., 2004), examining the effects of parents and hybrids on GCA and SCA in terms of the number of pods per plant. Dias et al. (2016), Magar (2016), Gupta et al. (2017), Kumari and Chauhan (2018), Purnamasari et al. (2019), Owusu et al. (2020), Pallavi et al. (2020), and Verma et al. (2020) obtained similar results to our findings.

While the average heterosis value determined in the F_2 generation was 15.15%, the heterobeltiosis value was 5.57%. Heterosis values varied between -12.43% (Ülkem x Karagöz) and 39.62% (Ülkem x Pekşen), while heterobeltiosis values varied between -19.53% (Ülkem x Karagöz) and 36.96% (Pekşen x Amazon). Likewise, heterobeltiosis values were mostly found to be significant and positive (Tables 4 and 8). These findings were supported by Kadam et al. (2013), Sarath and Reshma (2017), and Joshi et al. (2022), who found significant heterosis and heterobeltiosis values for this feature.

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

F_2 Populations	Plant Height	Pod Length	Pod Width	Number of Pods	Number of Seed per Pod
Pekşen X Sırma	- 22,05	47,48*	41,28**	92,68**	- 18,29
Pekşen X Ülkem	12,30	20,90	21,29	- 34,35*	40,68**
Pekşen X Amazon	22,33	14,65	37,70**	43,80*	51,83**
Pekşen X Karagöz	51,12	- 18,32	15,26	- 52,07**	84,65**
Sırma X Pekşen	- 11,37	19,87	- 19,15	61,29**	5,06
Sırma X Ülkem	13,48	26,58	- 3,40	- 7,03	3,77
Sırma X Amazon	1,56	-5,76	0,00	31,11	- 18,29
Sırma X Karagöz	67,34	-33,89	- 42,21**	- 49,58**	- 42,22**
Ülkem X Pekşen	- 2,99	39,78	33,11*	15,41	5,32
Ülkem X Sırma	- 16,52	20,22	2,55	- 7,07	- 4,86
Ülkem X Amazon	- 3,10	-14,66	0,26	- 1,24	- 37,60*
Ülkem X Karagöz	8,50	1,70	- 25,97*	17,12	- 20,00
Amazon X Pekşen	- 5,17	6,76	- 5,76	8,57	4,39
Amazon X Sırma	-11,92	1,24	- 6,17	57,07**	17,51
Amazon X Ülkem	-16,40	-18,34	- 24,61*	- 17,90	1,32
Amazon X Karagöz	23,00	-26,60	- 50,97**	31,96*	4,60
Karagöz X Pekşen	-10,42	-21,18	- 2,92	1,46	33,87
Karagöz X Sırma	-9,16	- 8,67	- 52,92**	11,94	8,09
KaragözX Ülkem	-3,59	-32,75	- 64,29**	- 18,52	30,60*
KaragözX Amazon	4,07	- 31,35	-60,71**	2,70	-17,76
Mean	-10.61	-12.08	-9.78	5.75	-3.13

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

Heritability in the broad and narrow sense was 0.7 and 0.14, respectively, in the F_2 generation (Table 2). In the study, it was revealed that the heritability in the broad sense was large and the heritability in the narrow sense was low, and the number of pods was also affected by the environment. Working on similar issues, Purnamasari et al. (2019), and Owusu et al. (2020) found high heritability broad and narrow sense. It can be argued that it would be better to start breeding after 3-4 generations, since non-additive genetic effects are important in the generation examined.

3.5. Number of seeds per pod:

According to the number of seeds per pod in the F_2 generation, the parental values were between 5.67 units/pod (Karagöz) and 10.26 units/pod (Ülkem), and in the F_2 generation, the number of seeds per pod was 7.43 units/pod (Sırma x Karagöz) to 11.27 units/pod

(Pekşen x Karagöz) (Table 2). Which are in harmony with our research findings (Peksen and Artık, 2004; Kadam et al., 2013; Kumari and Chauhan, 2018; Walle et al., 2019; Joshi et al., 2022).

When Table 2 is examined, the σ^2GCA was less than The σ^2SCA, σ^2GCA/σ^2SCA ratio was less than 1 and $(H/D)^{1/2}$ ratio was greather than 1. The fact that the σ^2GCA/σ^2SCA ratios are less than 1 and the $H/D^{1/2}$ ratio is greater than 1 for the number of seeds per pod shows us that the non-additive dominant gene effect is effective in the inheritance of this trait (Magar ve ark., 2016; Gupta ve ark., 2017; Kumari ve Chauhan, 2018; Purnamasari ve ark., 2019).

When GCA was examined regarding the number of seeds in the pod, Pekşen, Sırma, Ülkem and Amazon genotypes were found to have significant and positive values in the F_2 generation. In contrast, Karagöz genotype had a significant negative effect (Table 2). As a result, Pekşen, Sırma, Ülkem and Amazon genotypes, which are positively important in increasing the number of seeds per pod, were determined as suitable parents to be used in breeding studies for this purpose.

Looking at the SCA effects of crosses in the F_2 generation, "Ülkem x Karagöz" and "Pekşen x Karagöz", "hybrid have a positive significant SCA effect. Pekşen x Ülkem" and "Ülkem x Pekşen", "x "Karagöz x Pekşen", "Amazon x Ülkem"and "Karagöz x Amazon" hybrids have negative significant SCA effect (Table 2). Considering the reciprocal effect values, "hybrids are positive and have high SCA. They can be considered as suitable combinations that can be used to increase the number of seeds in the pod, as they have the effect of SCA. In many studies, the effects of GCA and SCA for the number of seeds per pod were determined (Dias et al., 2016; Magar et al., 2016; Gupta et al., 2017; Kumari and Chauhan, 2018; Olunloyo et al., 2019; Purnamasari et al., 2019; Owusu et al., 2020; Pallavi et al., 2020; Verma et al., 2020).

In the F_2 generation, the heterosis average value determined for the number of seeds per pod was 8.59%, and the heterobeltiosis value was calculated as -3.13%. Heterosis value was found to be significant and positive, and heterobeltiosis value was found to be significant and negative. Heterosis values varied between -9.77% (Amazon x Ülkem) and 49.46% (Pekşen x Karagöz), while heterobeltiosis values ranged between -22.61% (Sırma x Karagöz) and 19.75% (Pekşen x Karagöz) (Tables 4 and 8). Examining the heterosis and heterobeltiosis values for the seed number feature per pod, Kadam et al. (2013), Sarath and Reshma (2017), and Joshi et al. (2022) reported that in hybrids they detected significate positive and negative performance in heterosis. According to Kadam et al. (2013), Sarath and Reshma (2017), and Joshi et al. (2022), their results were similar to ours.

In the F_2 generation, broad and narrow sense heritability was 0.85 and 0.17, respectively (Table 2). The fact that the heritability in the narrow sense is at medium levels indicates that genetics and the environment influence the number of seeds per pod to a certain extent. Analyzing seed number inheritance in pods Purnamasari et al. (2019), and Owusu et al. (2020) found that broad sense heritabilities were generally largest but varied among crosses. It would be more appropriate to start the selection in advanced generations, since non-additive gene effects are important and hybrid strength is low.

3.6. Number of seeds per plant:

It was determined that the parent values in terms of the number of seeds per plant in the F_2 generation ranged between 76.67 units/plant (Karagöz) and 181.11 units/plant (Sırma), and the number of seeds per pod in the F_2 generation ranged between 119.92 units/plant (Sırma x Karagöz) and 209.13 (Amazon x Sırma) (Table 5). With our research findings, Peksen et al. (2004), Kumari and Chauhan (2018), Walle et al. (2019) are in harmony.

In the F_2 generation, it is seen that the σ^2GCA was less than the σ^2SCA, the σ^2GCA/σ^2SCA ratio was less than 1 and the $H/D^{1/2}$ ratio was greather than 1. These results supports the non-additive gene effect. The gene effect and the superiority of dominance reduce the success of selection for this trait in early generations. Kumari and Chauhan (2018) found the similar results.

When GCA was examined for the number of seeds per plant in the F_2 generation, Pekşen, Sırma, Amazon and Ülkem had significant positive values, while negative and significant GCA values were determined for Karagöz genotype (Table 5). Pekşen, Sırma, Amazon and Ülkem, which were found to be positively significant, were determined as the parents that could be used to increase the number of seeds per plant in crossing studies. Kumari and Chauhan (2018) were in agreement.

Looking at the SCA effects of hybrids in the F_2 generation, "Pekşen x Karagöz", "Karagöz x Sırma", hybrids have positive significant SCA effect and these combinations are genotypes with breeding potential for high seed number (Table 5). When the subdiagonal reciprocal effects are examined in Table 5, in the F_2 generation, Pekşen cytoplasm of "Pekşen x Karagöz" was found to increase the number of seeds per plant. This shows us that cytoplasm or cytoplasm x nucleus interactions cause significant changes in this feature (Table 5). "Pekşen x Karagöz", "Karagöz x Sırma", hybrids have emerged as suitable combinations that can be used to increase the number of seeds per plant, since they have a positive significant SCA effect. Kumari and Chauhan (2018) found the similar results in previous studies.

In the F_2 generation, the average heterosis value was determined as 25.00%, while the heterobeltiosis value was 5.02%. Heterosis values varied between -16.73% (Amazon x Ülkem) and 106.48% (Pekşen x Karagöz), while heterobeltiosis values varied between -33.79% (Sırma x Karagöz) and 68.70% (Pekşen x Karagöz) (Tables 7 and 9).While analysing their results Kumari and Chauhan (2018) found that heterosis and heterobeltiosis were significant in this feature.

Broad and narrow sense heritability was 0.79 and 0.00, respectively in the F_2 generation (Table 2). The high heritability in the broad sense and the low heritability in the narrow sense indicates that the effect of genotype variance on this trait is low. Therefore, it would be more appropriate to start selection in future generations.

3.7. Seed yield per plant

According to the average seed yields in the F_2 generation, the parental values varies between 17.04 g/plant (Karagöz) and 52.06 g/plant (Sırma), and in the F_2 generation, the single-plant seed yields were 24.45 g/plant (Sırma x Karagöz) and 51.41 g/plant (Pekşen x Karagöz) (Table 6). With the findings of this study, Ceyhan (2004), Peksen and Artık (2004), Ceyhan et al. (2008), Borivoj et al. (2013), Kadam et al. (2013), Ceyhan et al. (2014), Rodrigues et al. (2018), Walle et al. (2019), and Joshi et al. (2022) are in harmony.

In the F_2 generation, it was determined that the σ^2GCA was less than the σ^2SCA, the σ^2GCA/σ^2SCA ratio was less than 1 and the $H/D^{1/2}$ ratio was greather than 1 (Table 6). Thus, Dias et al. (2016), Magar et al. (2016), Kumari and Chauhan (2018), Rodrigues et al. (2018), Purnamasari et al. (2019), Owusu et al. (2020), and Verma et al. (2020) reported that additive gene effects are important in seed yield. Olunloyo et al. (2019) stated that cowpea seed yield was influenced by both added and non-added genes.

When we look at the effect value of GCA, it is seen that Pekşen, Sırma, Ülkem and Amazon genotypes among the parent genotypes show significant and positive values in the F_2 generation. Karagöz genotype had a significant negative effect (Table 6). Pekşen, Sırma, Ülkem and Amazon genotypes with positive and significant GCA effect values were determined as promising parents that could be used in terms of plant yield in crossing studies.

In the F_2 generation, "Pekşen x Karagöz", and "Amazon x Karagöz" hybrids were positive and has a significant SCA effect. "Amazon x Pekşen", "Karagöz x Pekşen", "Amazon x Ülkem", "Sırma x Karagöz", hybrids showed high negative significant SCA effect (Table 6). When Table 4.29 is examined, in the F_2 generation "Pekşen x Karagöz" showed a significant negative and positive reciprocal effect. This shows us that cytoplasm or cytoplasm x nucleus interactions cause significant changes in this feature. These results are in agreement with the previous studies of Magar al. (2016), Gupta et al. (2017), Kumari and Chauhan (2018), Rodrigues et al. (2018), Olunloyo et al. (2019), Purnamasari et al. (2019), Owusu et al. (2020), Pallavi et al. (2020), and Verma et al. (2020).

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

Parents	Number of Seeds per Plant		Seed Yield per Plant		Hundred Seed Weight		Protein Ratio		Protein Yield in Plant	
Pekşen	120,91	1fg	27,37	hıj	17,86	fgh	28,49	cde	7,80	hıj
Sırma	181,11	a-f	52,06	a	26,27	a	26,49	k	13,80	abc
Ülkem	168,34	a-f	43,58	a-g	23,65	abc	28,09	efg	12,24	a-g
Amazon	135,83	d-g	30,89	f-j	17,68	fgh	28,37	def	8,76	e-j
Karagöz	76,67	g	17,04	j	17,09	gh	28,12	efg	4,79	j
F_2 Populations										
Pekşen X Sırma	178,15	a-f	46,93		22,29	bcd	26,29	kl	12,33	a-g
Pekşen X Ülkem	177,30	a-f	44,17	a-d	21,31	c-f	28,88	a-d	12,75	a-f
Pekşen X Amazon	182,78	a-f	45,14	a-g	21,48	c-f	29,01	abc	13,10	a-d
Pekşen X Karagöz	203,97	ab	51,41	a-g	22,77	a-d	29,25	a	15,04	a
Sırma X Pekşen	199,41	a-d	41,02	a-h	18,21	e-h	28,37	def	11,64	a-h
Sırma X Ülkem	185,65	a-e	50,80	ab	23,36	abc	28,37	def	14,43	ab
Sırma X Amazon	176,50	a-f	45,88	a-e	23,46	abc	25,87	l	11,87	a-h
Sırma X Karagöz	119,92	fg	24,45	ı j	15,15	h	28,52	cde	6,96	ıj
Ülkem X Pekşen	185,11	a-e	44,14	a-g	20,50	c-g	29,12	ab	12,85	a-e
Ülkem X Sırma	174,99	a-f	46,72	a-d	23,44	abc	27,99	e-h	13,07	a-d
Ülkem X Amazon	202,53	abc	45,70	a-f	19,86	c-g	27,37	ıj	12,51	a-g
Ülkem X Karagöz	130,42	efg	31,71	e-j	21,36	c-f	27,13	j	8,60	f-j
Amazon X Pekşen	143,85	b-f	37,20	a-ı	22,36	bcd	28,53	b-e	10,62	b-ı
Amazon X Sırma	209,13	a	48,57	abc	20,90	c-g	28,48	cde	13,82	abc
Amazon X Ülkem	126,64	efg	33,31	d-ı	23,13	a-d	27,71	g-j	9,22	d-ı
Amazon X Karagöz	185,82	a-e	42,65	a-g	19,30	d-g	28,01	efg	11,95	a-h
Karagöz X Pekşen	131,01	efg	35,69	bc-ı	22,47	a-d	27,40	hıj	9,78	c-ı
Karagöz X Sırma	147,43	a-f	30,36	g-j	17,98	e-h	27,61	g-j	8,38	g-j
KaragözX Ülkem	146,68	a-f	37,13	b-ı	21,79	b-e	28,51	cde	10,59	b-ı
KaragözX Amazon	139,24	c-g	39,39	a-h	25,48	ab	27,82	f-ı	10,96	a-ı
GCA	388,99		33,19		1,22		0,23		2,33	
SCA	1741,63		233,92		29,35		1,19		18,57	
Reciprocal	589,50		14,41		3,03		0,87		1,68	
σ^2GCA/σ^2SCA	0,22		0,14		0,04		0,19		0,13	
$H/D^{1/2}$	3109,12		314,70		34,82		2,52		24,91	
H^2	0,79		0,88		0,91		0,97		0,88	
h^2	0,20		0,18		0,06		0,18		0,16	

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

In the F_2 generation, the average heterosis value determined in this study for seed yield was 25.87%, while the heterobeltiosis value was 1.76%. Heterosis values varied between -29.23% (Sırma x Karagöz) and 131.55% (Pekşen x Karagöz), and heterobeltiosis values ranged between -53.03% (Sırma x Karagöz) and 87.83% (Pekşen x Karagöz) (Tables 7 and 9). In their previous studies, Kadam et al. (2013), Magar et al. (2016), Gupta et al. (2017), Rodrigues et al. (2018), Owusu et al. (2020), and Joshi et al. (2022) reported that heterosis was more significant than herobeltiosis in seed yield.

Broad and narrow sense heritability was 0.88 and 0.18 in the F_2 generation, respectively (Table 5). In the F_2 generation, the low heritability in the narrow sense in the seed yield means that the effect of the environmental variance of this feature may be high. Purnamasari et al. (2019), and Owusu et al. (2020) found high heritability in the broad sense and low heritability in the narrow sense for this trait.

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

Parents	Number of Seeds per Plant	Seed Yield per Plant	Hundred Seed Weight	Protein Ratio	Protein Yield in Plant
Pekşen	3,165	0,311	-0,456	0,390**	0,256
Sırma	14,164*	4,153*	0,569	-0,544**	0,894*
lkem	5,424	2,352	1,039*	0,135*	0,737
Amazon	2,640	0,229	-0,034	-0,038	0,043
Karagöz	-25,392**	-7,045**	-1,118*	0,058	-1,930**
F_2 Populations					
Pekşen X Sırma	10,273	-0,223	-1,028	-0,509**	-0,280
Pekşen X Ülkem	11,444	1,759	-0,845	0,483**	0,693
Pekşen X Amazon	-3,664	0,896	1,244	0,426**	0,446
Pekşen X Karagöz	28,544*	10,551**	3,026**	-0,115	2,969**
Sırma X Pekşen	10,630	-2,956	-2,043**	1,042**	-0,344
Sırma X Ülkem	-0,443	2,521	0,630	0,601**	1,006
Sırma X Amazon	14,838	3,108	0,478	-0,238*	0,791
Sırma X Karagöz	-16,273	-9,432**	-4,050**	0,562**	-2,410**
Ülkem X Pekşen	3,903	-0,015	-0,407	0,117*	0,052
Ülkem X Sırma	-5,332	-2,040	0,040	-0,191*	-0,679
Ülkem X Amazon	-4,657	-2,807	-0,678	-0,549**	-1,029
Ülkem X Karagöz	-2,659	-0,616	0,487	-0,365**	-0,324
Amazon X Pekşen	-19,463*	-3,972*	0,439	-0,243**	-1,244*
Amazon X Sırma	16,313*	1,346	-1,282*	1,305**	0,975*
Amazon X Ülkem	-37,947**	-6,196**	1,637**	0,167*	-1,641**
Amazon X Karagöz	24,111	8,103**	2,377**	-0,094	2,230**
Karagöz X Pekşen	-36,480**	-7,862**	-0,150	-0,922**	-2,628**
Karagöz X Sırma	13,757*	2,956	1,413**	-0,455**	0,706
KaragözX Ülkem	8,129	2,709	0,213	0,693**	0,995*
KaragözX Amazon	-23,290**	-1,627	3,090**	-0,095	-0,495
G_i	22,762	1,237	0,085	0,002	0,096
S_{ij}	96,738	5,259	0,361	0,008	0,408
R_{ij}	142,262	7,734	0,530	0,012	0,600

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

3.8. Hundred seed weight:

The parent values ranged from 17.09 g (Karagöz) to 26.27 g (Sırma), while the hundred-seed weight of the F_2 generation ranged from 15.15 g (Sırma x Karagöz) to 25.48 g (Karagöz x Amazon) (Table 5). Some researchers have obtained similar results (Peksen and Artık, 2004; Sert and Ceyhan, 2012; Kadam et al., 2013; Sarath and Reshma, 2017; Rodrigues et al., 2018; Walle et al., 2019).

The σ^2GCA in the F_2 generation was less than the σ^2SCA, the ratio of σ^2GCA/σ^2SCA was also less than 1, and $H/D^{1/2}$ ratio was greather than 1. The fact that σ^2GCA/σ^2SCA ratios are less than 1 and $H/D^{1/2}$ ratio is greater than 1 shows that the non-additive gene effect is effective and the superior dominance of these genes. Looking at these results selection could be started in the future generations. Contrary to us, Magar et al. (2016), Gupta et al. (2017), Kumari and Chauhan (2018), Rodrigues et al. (2018), Olunloyo et al.(2019), Purnamasari et al.(2019), Owusu et al.(2020), and Verma et al. (2020) found that for the hundred seed weight the additive gene effect was important.

In F_2 generation, Sırma, and Ülkem cultivars have significant and positive values while Pekşen, Karagöz and Amazon genotypes have significant and negative values. (Table 6). Sırma and Ülkem cultivars, which were found to be positively important in increasing the hundred-seed weight in this generation, emerged as suitable parents for breeding studies for this trait. In their previous studies, Dias et al. (2016), Magar et al. (2016), Gupta et al. (2017), Kumari and Chauhan (2018), Rodrigues et al. (2018), Olunloyo et al. (2019), Purnamasari et al. (2019), Verma et al. (2020) were in harmony.

In the F_2 generation, "Karagöz x Sırma", "Amazon x Ülkem", "Karagöz x Amazon", "Pekşen x Karagöz", "Amazon x Karagöz" hybrids were determined to have positive and significant effects and emerge as a promising genotype that can be used in breeding studies for this purpose (Table 6). "Sırma x Pekşen", "Amazon x Sırma", "Sırma x Karagöz" are negative had a significant effect. Dias et al. (2016), Magar et al. (2016), Gupta et al. (2017), Kumari and Chauhan (2018), Rodrigues et al. (2018), Olunloyo et al. (2019), Purnamasari et al. (2019), Owusu et al. (2020), Pallavi et al. (2020), and Verma et al. (2020) found genotypes with significant positive SCA for a hundred seed weight in their studies.

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

F_2 Populations	Number of Seeds per Plant	Seed Yield per Plant	Hundred Seed Weight	Protein Ratio	Protein Yield in Plant
Pekşen X Sırma	17,97	18,16	1,03	-4,37**	14,20
Pekşen X Ülkem	22,60	24,51	2,68	2,10**	27,23*
Pekşen X Amazon	42,39	54,96	20,90**	2,06**	58,27**
Pekşen X Karagöz	106,48	131,55	30,30**	3,33**	138,97**
Sırma X Pekşen	32,05	3,27	-17,49*	3,21**	7,82
Sırma X Ülkem	6,25	6,23	-6,40*	3,97**	10,84
Sırma X Amazon	11,38	10,61	6,76*	-5,70**	5,23
Sırma X Karagöz	-6,96	-29,23	-30,11**	4,47**	-25,06*
Ülkem X Pekşen	28,00	24,42	-1,24	2,92**	28,27*
Ülkem X Sırma	0,15	-2,30	-6,08*	2,58**	0,41
Ülkem X Amazon	33,17	22,75	-3,91	-3,04**	19,08*
Ülkem X Karagöz	6,46	4,64	4,86	-3,49**	1,02
Amazon X Pekşen	12,06	27,69	25,84**	0,35**	28,22*
Amazon X Sırma	31,97	17,10	-4,91	3,82**	22,51*
Amazon X Ülkem	-16,73	-10,54	11,94*	-1,86**	-12,16
Amazon X Karagöz	74,90	77,97	11,03*	-0,82**	76,43**
Karagöz X Pekşen	32,62	60,73	28,58**	-3,18**	55,44**
Karagöz X Sırma	14,39	-12,11	-17,07**	1,13**	-9,87
KaragözX Ülkem	19,73	22,52	6,96*	1,45**	24,38*
KaragözX Amazon	31,06	64,39	46,58**	-1,49**	61,80**
Mean	20.00	25.87	5.51	0.37	26.65

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

3.8. Protein ratio:

According to the average of the protein ratio in the F_2 generation, it was determined that the parental values ranged from 26.69 % (Sırma) to 28.82% (Pekşen), and in the F_2 generation the protein ratio ranged between 25.64% (Sırma x Amazon) and 29.51% (Pekşen x Karagöz) (Table 5). Researching this subject, Hall et al. (2003), Sert and Ceyhan (2012), Kadam et al. (2013), Harmankaya et al. (2016), Joshi et al. (2022) found similar results.

It has been determined that in the F_1 generation, The σ^2GCA was less than The σ^2SCA, the ratio of σ^2GCA/σ^2SCA was also less than 1 and the $H/D^{1/2}$ ratio was greater than 1. The fact that the σ^2GCA/σ^2SCA ratios of the protein ratio were less than 1 shows us that the non-additive gene effect is effective in the inheritance of this trait. Likewise, a ratio of $H/D^{1/2}$ greater than 1 indicates superior dominance. Researching this subject, Sharma and Mehta (2014), Magar et al. (2016), and Purnamasari et al. (2019) determined that the additive gene effect is preponderant for the protein feature in cowpea.

When we examine the effect value of GCA in the F_1 generation, we find that among the genotypes, Pekşen and Ülkem show significant and positive values. It was determined that the Sırma, Amazon and Karagöz genotypes had a negative significant GCA effect (Table 6). Pekşen and Ülkem genotypes, which were found to have a positive and significant GCA effect value, were determined as promising parents that could be used in terms of protein ratio in crossing studies.

Looking at the SCA effects of hybrids in the F_2 generation, "Sırma x Pekşen", "Ülkem x Pekşen", "Amazon x Sırma", "Pekşen x Ülkem", "Sırma x Ülkem", "Pekşen x Amazon", "Sırma x Karagöz" hybrids have positive and significant SCA effect. Hybrids which showed high positive SCA effect with high reproductive potential for protein ratio, which could be used as genotype in future generations. In this study, parents and hybrids with significant positive SCA effect and high positive SCA effect for protein ratio are highlighted as suitable materials that can be used in protein ratio based selection studies Tchiagam et al. (2011), Sharma and Mehta (2014), Magar et al. (2016), Kumari ve Chauhan (2018), Purnamasari et al. (2019), found that the GCA and SCA values of different numbers of parents and crosses were important for the protein ratio in cowpea.

In the F_2 generation, the average heterosis value determined in this study for the protein ratio was -0.46%, while the heterobeltiosis value was -2.33%. Heterosis values varied between -8.17% (Karagöz x Pekşen) and 4.81% (Sırma x Karagöz), while heterobeltiosis values ranged between -9.10% (Karagöz x Pekşen) and 2.78% (Ülkem x Amazon) (Tables 7 and Table 9). More than half of the hybrids showed positive heterosis for this trait and were statistically significant, indicating that suitable

material for high protein is available. Analyzing the heterosis and heterobeltiosis values for the protein ratio, Sharma and Mehta (2014), Sarath and Reshma (2017), Joshi et al. (2022) found low or high mean heterosis and heterobeltiosis values for this feature.

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

F_2 Populations	Number of Seeds perPlant	Seed Yield per Plant	Hundred Seed Weight	Protein Ratio	Protein Yield in Plant
Pekşen X Sırma	-1,63	-9,86	-15,15**	-7,72**	-10,62
Pekşen X Ülkem	5,33	1,36	-9,89	1,39*	4,14
Pekşen X Amazon	34,57*	46,13**	20,29*	1,85*	49,56**
Pekşen X Karagöz	68,70**	87,83**	27,50**	2,67**	92,85**
Sırma X Pekşen	10,10	-21,22*	-30,70**	-0,41	-15,62
Sırma X Ülkem	2,51	-2,43	-11,08*	1,00	4,60
Sırma X Amazon	-2,54	-11,88	-10,71*	-8,82**	-13,97
Sırma X Karagöz	-33,79*	-53,03**	-42,32**	1,43*	-49,53**
Ülkem X Pekşen	9,96	1,29	-13,33*	2,21**	4,99
Ülkem X Sırma	-3,38	-10,26	-10,77*	-0,35	-5,24
Ülkem X Amazon	20,31	4,88	-16,04**	-3,51**	2,16
Ülkem X Karagöz	-22,53	-27,22*	-9,68	-3,53**	-29,73*
Amazon X Pekşen	5,91	20,42	25,21**	0,14	21,17*
Amazon X Sırma	15,47	-6,71	-20,46*	0,38	0,16
Amazon X Ülkem	-24,77*	-23,56*	-2,20	-2,34**	-24,65*
Amazon X Karagöz	36,81*	38,06*	9,18	-1,26*	36,42*
Karagöz X Pekşen	8,36	30,38*	25,82**	-3,80**	25,44*
Karagöz X Sırma	-18,60	-41,68**	-31,57**	-1,80*	-39,29**
KaragözX Ülkem	-12,87	-14,79	-7,88	1,40*	-13,49
KaragözX Amazon	2,52	27,52*	44,14**	-1,93**	25,11*
Mean	5.02	1.76	-3.98	-1.15	3.22

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

The heritability in the broad sense calculated for the protein ratio in the F_2 generation was 0.97, and the heritability in the narrow sense was determined as 0.18 (Table 5). The high heritability in the broad sense and the low heritability in the narrow sense in the protein ratio means that the effect of the environmental variance of this feature may be high. Analyzing the inheritance of the protein ratio, Sharma and Mehta (2014), Purnamasari et al. (2019) found high heritability in narrow and broad in this trait. Since the non-additive gene effects are important in the heritability of protein ratio and the heritability in the narrow sense is low, it is more appropriate to start the selection after a few generations.

3.9. Protein yield in plant:

According to the single plant proteins yields in the F_2 generations, the parental values ranged from 4.79 g/plant (Karagöz) to 13.80 g/plant (Sırma), and the plant proteins yields in the F_2 generation varies between 6.96 g/plant (Sırma x Karagöz) and 15.04 g/plant (Pekşen x Karagöz) (Table 5). The findings of this study are in harmony with the findings of (Kumari and Chauhan, 2018).

For the protein yields in the F_2 generation, it is seen that σ^2GCA was less than σ^2SCA, the ratio of σ^2GCA/σ^2SCA was less than 1 and the $H/D^{1/2}$ ratio was greather than 1 (Table 5). The fact that σ^2GCA/σ^2SCA ratios were less than 1 and $H/D^{1/2}$ ratio was greater than 1 indicates that the non-additive gene effect and superior dominance are effective in the inheritance of this trait. After their analyses Magar et al. (2016), Kumari and Chauhan, (2018) found the similar results.

When GCA is examined, while Pekşen, Sırma, Amazon and Ülkem genotypes have significant and positive values in the F_2 generation, Karagöz genotype has significant and negative values (Table 6). Considering the SCA effects of the hybrids, "Amazon x Sırma", "Karagöz x Ülkem", "Pekşen x Karagöz" and "Amazon x Karagöz" crosses which were positive emerge as a promising genotype that can be used in breeding studies for this purpose(Table 6). Magar et al. (2016), Kumari and Chauhan (2018), in their previous studies were in harmony

Average heterosis value determined for biological yield in F_2 generation was 26.65%, heterobeltiosis value was calculated as 3.22%. Heterosis values varied between -25.06% (Sırma x Karagöz) and 138.97% (Pekşen x Karagöz), while heterobeltiosis values ranged between -49.53% (Sırma x Karagöz) and 92.85% (Pekşen x Karagöz) (Table 4.42), ın conformity with those obtained by Kadam et al. (2013), Joshi et al. (2022).

Broad and narrow sense heritability was 0.88 and 0.16, respectively in the F_2 generation (Table 5). The determination of the non-additive gene effect in terms of this feature and the presence of positive heterosis in the examined generations revealed that selection should be made in advanced generations. Purnamasari et al. (2019) showed high heritability in the broad and narrow senses.

4. Conclusions

Considering the agronomic characteristics of the studied population, we can affirm that this population presented a sufficient variation. This study reveals that the non-additive and dominant genes were more effective in

the traits studied. Thus, in future generations, some selections could be considered.

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