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Genetic analysis of seed yield and some traits in cowpea using diallel analysis

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Abstract: Cowpea is an essential economic crop in underdeveloped and developing countries mainly grown by small farmers. In terms of seed yield and some agricultural characteristics, this study was carried out to determine the genetic structures and the general and specific adaptability of the genotypes. The trial, which included F_1 hybrids and parents, was established under Konya ecological conditions with 3 replications in 2020 in the "Random Blocks Trial" design. Based on the results of the preliminary analysis of variance, it was determined that there was sufficient variation in the hybrid populations formed in terms of all traits examined. Nonadditive and dominant genes were found to be important in all traits examined. In the study, general adaptability was found to be important for the other traits examined, except the seed number per pod, seed number per plant, seed yield per plant, and protein yield per plant, and the effects of special adaptability were significant for all traits examined. Considering their general combining abilities, it was found that Ülkem, Sırma, and Pekşen cultivars should be used as rootstocks in breeding programs aimed at increasing yield and Pekşen and Ülkem cultivars in breeding programs to increase protein levels. When the specific combining abilities, heterosis and heterobeltiosis values are evaluated together, the hybrid combinations "Pekşen × Sırma", "Ülkem × Pekşen" and "Karagöz × Sırma" with the best performance in terms of, seed yield per plant and "Pekşen × Amazon", "Sırma × Pekşen", "Sırma × Karagöz" and "Ülkem × Pekşen" with the most outstanding give better performance in terms of protein ratio were found to be promising.

Key words: Diallel analysis, cowpea, GCA, SCA, heterosis, heterobeltiosis

1. Introduction

Cowpea [*Vigla unguiculata* (L.) WAP.] (2n = 2x = 22) is native and domesticated in Africa, it is widespread and cultivated in tropical as well as 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) (Abdulazeez et al., 2019). Cowpea plays a major role as a concentrated source of cheaper protein like fish, meat, poultry, or dairy products (Timko and Singh, 2008; Sert and Ceyhan, 2012). Thus, it combines well with cereals in the human diet hence its name "food of the poor men" (Porch and Hall, 2013; Harmankaya et al., 2016). Marketing stems, seeds and cowpea leaves is also a financial and vital source for farmers (Ketema et al., 2021). In Turkey, cereals, pulses, and many other production volumes are important for products rich in genetic diversity. Cowpea (*Vigna unguiculata* (L.) Walp), who has no certainty about its homeland, is of African origin. In Turkiye, cowpea was spread throughout the country long before it was cultivated.

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

It was found that nonadditive genes were effective on pod length (Pallavi and Chaudhary, 2020; Yadji Haman, 2020). Nonadditive genes were also effective on the number of pods per plant, number of seeds per plant, plant height, and protein yield per plant (Badhe et al., 2016; Kumari and Chauhan, 2018), then effective on the number of seeds per pod, protein ratio (Ayo-Vaughan et al., 2013), on hundred seed weight, seed yield per plant of cowpea (Singh, 2020).

Many studies were more focused on breeding selections in the previous research. It will therefore be a question for us during this work of improving the agricultural qualities and characteristics of cowpea genotypes. These genetic characteristics are previously determined. To this end, hybridization studies will be carried out. Thus, the

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objective would be to discover and find genotypes adapted to efficient environmental conditions and of high quality. It would be undeniable for the sake of developing new lines or eliminating the insufficient aspects of the population or existing varieties. Therefore, features such as high efficiency, high quality, high temperature, and resistance to drought, disease, and many more are expected from these new varieties. This plant improvement is also intended to be useful for the studies to be carried out in order to determine such characteristics and to transfer them to new varieties via selection methods. In other words, high yield, high temperature, resistance to drought, disease, and the quality of cowpeas are important agricultural problems sought by farmers. Thus, the development of new varieties will therefore help solve economic problems as well as improve the nutrition and nutritional quality of our populations. In this study, hybridizations were carried out between 5 cowpea genotypes with superior agronomic and technological characteristics. The aim of this study was to study the genetic structure of the F_1 hybrids, to identify the appropriate parents and combinations, to determine the heritability, heterosis, and heterobeltiosis of the characters studied, and finally to identify the hybrids with superior agronomic and technological characteristics and available for mechanical agriculture.

2. Materials and methods

In this study, 5 high-yield cowpea varieties of seed collection have been used: Sırma, Amazon, Karagöz, Ülkem, and Pekşen (Table 1).

In the fully controlled plant breeding greenhouse of the Faculty of Agriculture of Selçuk University, 5 cowpea cultivars (Pekşen, Karagöz, Sırma, Ülkem, Amazon) were planted at 10-day intervals over 4 sowing times different on March 15, 2019. The crossbreeding process has been performed as specified below according to Ceyhan (2004). The flower required for a total of 25 (5 × 5) combinations has been castrated and powdered, and at least 30 F_1 seeds were obtained for each combination from the hybridized flowers.

The soil of the 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 years' annual precipitation is 109.6 mm per year, the annual mean temperature is 19.5 °C and the average relative humidity is 48.0%. Total annual precipitation was 104,0 mm, which was less than 20 years on average (109.6 mm) of the site. During the experimental period, the average temperature was 19.3 °C and the average relative humidity was 45.8%.

A good seed bed has been prepared by timely and duly tillage. In the soil buried in the tray, 20 seeds of parents and F_1's were sown. Each seed row was 1m long and spaced 80 cm apart. The seeds sown had a spacing of 20 cm each. In the experiment, we planted 5 parent varieties in each hybrid group, with a maximum of 5 consecutive seeds, before and after planting each hybrid group. The experiment was set up in a randomized block design with 3 replications at the Selçuk University Faculty of Agriculture. During planting, 150 kg of DAP (Diammonium phosphate (18%–46%)) fertilizer was given per hectare. If necessary, irrigation was made to the parcels after planting in order to ensure germination and emergence. Weed control was done mechanically by hand and hoe in the research. Irrigation was carried out when deemed necessary according to the climate and soil conditions. Other cultural procedures were done in accordance with the technique. When the plants were at harvest maturity (August 2020), they were harvested and evaluated separately.

Measurements and counts of the properties examined in the research have been carried out in all plants obtained in each parcel in F_1. The features and methods of obtaining

Table 1. Cowpea parentages used in the research.

Parents	Distinctive features
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. The pod color is dark green. The circumference of the hilum is black. Plant height is 60–90 cm. Pod size is about 16–21 cm long, 10–12 mm in diameter. The number of seeds in the pod 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.
Pekşen	There is a climbing type in which most of the lower branches touch the ground.

data were performed on parents and hybrids of 5 plants of each plot. Plant height, 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 investigated in this study (Ceyhan, 2004).

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_1. The studied data were analyzed with the program TARPOPGEN PC Program (Ozcan and Acikgoz, 1999).

3. Results and discussion

Mean squares of initial variance analysis and combining ability variance analysis for investigated traits in a full-diallelhybrid set for investigated traits are given in the full-diallel hybrid set in Table 2.

The mean squares of the crosses were determined to be statistically significant for all traits in the full diallel analysis of trait variance. Genotypes had variations at the 5% and 1% significance levels for all traits studied (Table 2). In the F_1 generation, in the full diallel cross set, the combinatory ability variances of the investigated traits were found to be significantly different for all traits examined among the GCA. On the other hand, very significant differences were found among SCA in all properties except plant height. Among the variances of the reciprocal effect, it was found to be statistically significant in all properties (Table 2). Concerning the variances of the reciprocal effect, it was found to be statistically significant in all properties.

3.1. Plant height

Among the morphological characteristics of cowpeas, one of the important components is the height of the plant, because of the role it plays in the components of resistance to lodging and yield. In the breeding of edible cowpeas, medium-sized varieties are generally tried to be developed. In addition to these, excessive shortening of the plant height is also undesirable as it causes problems in machine harvesting. According to the plant height averages of the F_1 generation, it was determined that the parental values were between 64.93cm (Sırma) and 135.23cm (Pekşen), while the plant heights in the F_1 generation ranged between 88.17 cm (Ülkem × Karagöz) and 208.69 cm (Pekşen ×

Table 2. Mean squares of initial variance analysis and combining ability variance analysis for investigated traits in a full diallel analysis.

Source of Variation	SD	Plant height	Number of pods per plant	Number of seeds per pod	Number of seeds per plant
Blocks	2	1837.282	13.363	4.678	739.524
Genotypes	24	2302.595**	116.236**	11.804**	10,564.172**
Error	48	936.797	27.296	2.773	3347.870
Variance of Combination Abilities					
GCA	4	2291.223**	36.752**	1.159	1103.081
SCA	10	563.417	35.252**	4.214**	3437.115**
Reciprocal Effect	10	362.169	43.036**	4.765**	4572.989**
Error	48	312.266	9.099	0.924	1115.956
Source of Variation	SD	Seed yield	Hundred seed weight	Protein ratio	Protein yield in plant
Blocks	2	16.458	15.814	0.247	0.480
Genotypes	24	748.393**	78.958**	4.035**	59.295**
Error	48	182.838	9.183	0.107	14.392
Variance of Combination Abilities					
GCA	4	76.371	9.787*	2.479**	7.608
SCA	10	343.849**	47.034**	0.499**	26.836**
Reciprocal Effect	10	224.317**	12.217**	1.736**	17.556**
Error	48	60.946	3.061	0.035	4.797

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

Ülkem) (Table 3). In previous studies, some researchers have determined similar results (Peksen and Artık, 2004; Pekşen and Pekşen, 2012; Sert and Ceyhan, 2012; Kadam et al., 2013; Pekşen and Pekşen, 2013; Walle et al., 2019; Joshi et al., 2022; Küçük and Ceyhan, 2022).

GCA was lower than SCA and $H/D^{1/2}$ ratio was greater than 1. Thus, revealing that the nonadditive gene effect and superior dominance are important in the inheritance of plant height. These results were not in agreement with our results by 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 (Badhe et al., 2016; Kumari and Chauhan, 2018; Verma et al., 2020) nonadditive gene effect was predominant in this trait and these results were in agreement with ours (Table 3).

When the parental GCA was examined, Pekşen and Ülkem genotypes had positive and significant GCA values, while Sırma, Amazon and Karagöz genotypes showed negative and significant GCA values. Pekşen and Ülkem genotypes with positive and important GCA effect values

Table 3. Mean values and estimates of variance components for investigated traits in a full-diallel hybrid set.

Parents	Plant height		Number of pods per plant		Number of seeds per pod		Number of seeds per plant	
Pekşen	135.23	bc	15.40	efg	4.44	h	70.36	ef
Sırma	64.93	d	13.83	fg	8.57	a–g	117.97	def
Ülkem	120.87	bcd	24.50	a–f	8.33	b–g	196.83	a–e
Amazon	99.44	bcd	14.07	fg	7.90	c–h	112.10	def
Karagöz	79.00	cd	26.78	a–e	5.78	e–h	155.33	b–f
F_1 Hybrids								
Pekşen × Sırma	114.08	bcd	29.67	abc	7.00	d-h	208.33	a–d
Pekşen × Ülkem	208.69	a	16.08	d–g	11.72	ab	187.81	a–f
Pekşen × Amazon	147.89	ab	22.14	b–g	12.00	a	249.93	abc
Pekşen × Karagöz	109.67	bcd	12.83	g	10.67	abc	134.83	c–f
Sırma × Pekşen	143.28	abc	24.83	a–f	9.00	a–e	220.17	a–d
Sırma × Ülkem	111.06	bcd	22.78	b–g	8.89	a–e	206.53	a–d
Sırma × Amazon	105.78	bcd	18.45	c–g	7.00	d–h	133.46	c–f
Sırma × Karagöz	116.67	bcd	13.50	fg	4.95	Gh	67.60	f
Ülkem × Pekşen	136.78	bc	28.28	abc	8.78	a–f	248.34	abc
Ülkem × Sırma	114.30	bcd	22.77	b–g	8.15	b-g	177.69	a–f
Ülkem × Amazon	104.33	bcd	24.20	a–g	5.20	fgh	126.57	c–f
Ülkem × Karagöz	88.17	bcd	31.36	ab	6.67	d–h	213.77	a–d
Amazon × Pekşen	131.48	bcd	16.72	d–g	8.25	b–g	138.63	c–f
Amazon × Sırma	122.13	bcd	22.10	b–g	10.07	a–d	222.55	a–d
Amazon × Ülkem	94.28	bcd	20.11	b–g	8.44	a–g	171.07	a–f
Amazon × Karagöz	90.80	bcd	35.33	a	8.27	b–g	292.60	a
Karagöz × Pekşen	123.50	bcd	27.17	a–d	7.73	cdef	213.93	a–d
Karagöz × Sırma	108.58	bcd	29.97	ab	9.26	a–e	280.82	ab
Karagöz × Ülkem	103.87	bcd	21.82	b–g	10.88	abc	225.56	a–d
Karagöz × Amazon	99.00	bcd	27.50	a–d	6.50	d–h	180.08	a–f
GCA	395.79		5.53		0.05		–2.57	
SCA	753.45		78.46		9.87		6963.48	
Reciprocal	49.90		33.94		3.84		3457.03	
$\upsilon^2GCA / \upsilon^2SCA$	0.53		0.07		0.00		0.00	
$H/D^{1/2}$	1594.94		123.46		13.80		10,415.36	
H^2	0.62		0.82		0.83		0.76	
h^2	0.31		0.07		0.01		0.00	

GCA: General Combining Ability; SCA: Specific Combining Ability; $H/D^{1/2}$: Mean Degree of Dominance; H^2: Broad Sense Heritability; h^2: NarrowSense can be used to increase plant height, and Sırma, Amazon and Karagöz genotypes, which are negative and important, can be easily used in the development of less-height cowpea cultivars (Table 4).

Considering the SCA effects of hybrids, in the F_1 generation, "Pekşen × Ülkem", "Sırma × Pekşen", hybrid combinations are positive and significant "Ülkem × Pekşen", hybrid combination showed a negative and significant ($p < 0.05$) effect. When Table 4 reciprocal effects are examined, "Pekşen × Ülkem", was found significant. This shows us that cytoplasm or cytoplasm × nucleus interactions cause significant changes in this feature (Table 4).

It is not desired that the plant height is too high, as it will cause the plant to lie down. Medium-length lines are important in this regard. For this reason, it has been determined that parents with negative and important SCA values can be used in shortening the plant height, and parents with positive GCA values can be easily used in extending the plant height. Combinations with positive and significant SCA effects from hybrids are for high plant height, and hybrids with negative and significant SCA effects are combinations that can be used to obtain short or medium plant size. Badhe et al. (2016); Kumari and Chauhan (2018); Owusu et al. (2020); Pallavi et al. (2020) and Verma et al. (2020) who studied the plant height features found the GCA and SCA values of different numbers of parents and crosses to be significant.

The average heterosis value determined in the F_1 generation is 20.04%, and the heterobeltiosis value is 1.98%, in terms of plant height, the majority of hybrids have positive heterosis values but negative heterobeltiosis values. In the F_1 generation, heterosis values varied

Table 4. Estimates of general combining ability (GCA) effects and special combining ability (SCA) effects for investigated traits in a full-diallel hybrid set.

Parents	Plant height	Number of pods per plant	Number of Seeds per Pod	Number of Seeds per Plant
Pekşen	23.632**	−1.636	0.225	−7.846
Sırma	−8.377	−1.314	−0.033	−6.806
Ülkem	5.368	1.152	0.362	12.985
Amazon	−5.495	−1.018	−0.024	−8.205
Karagöz	−15.127*	2.817*	−0.530	9.871
F_1 Hybrids				
Pekşen × Sırma	−1.523	7.713**	−0.370	46.786*
Pekşen × Ülkem	28.783*	0.177	1.485*	30.818
Pekşen × Amazon	6.597	−0.404	1.747*	28.218
Pekşen × Karagöz	−6.873	−3.668	1.327*	−9.757
Sırma × Pekşen	14.600*	−2.417*	1.000*	5.917
Sırma × Ülkem	0.735	0.447	0.013	3.813
Sırma × Amazon	12.875	0.119	0.413	10.902
Sırma × Karagöz	21.177	−2.253	−0.510	−10.971
Ülkem × Pekşen	−35.958**	6.097**	−1.473**	30.264*
Ülkem × Sırma	1.622	−0.005	−0.370	−14.420
Ülkem × Amazon	−15.519	−0.466	−1.694*	−38.077
Ülkem × Karagöz	−9.177	0.133	0.765	14.696
Amazon × Pekşen	−8.203	−2.712*	−1.875**	−55.651**
Amazon × Sırma	8.178	1.827	1.533**	44.547**
Amazon × Ülkem	−5.027	−2.042	1.622**	22.252
Amazon × Karagöz	0.570	7.131**	−0.240	52.560*
Karagöz × Pekşen	6.917	7.167**	−1.467**	39.550*
Karagöz × Sırma	−4.042	8.237**	2.155**	106.609**
Karagöz × Ülkem	7.850	−4.772**	2.108**−	5.897
Karagöz × Amazon	4.100	−3.917*	0.883*	−56.258**
G_i	16.03	1.858	0.553	40.886
S_{ij}	46.79	4.229	1.181	133.132
R_{ij}	63.586	5.328	1.451	185.91

G_i : GCA, S_{ij}: SCA; R_{ij}: Reciprocal effect, ** : significant at 1% level; * : significant at 5% level between −14.41% (Amazon × Ülkem) and 62.98% (Pekşen × Ülkem), and heterobeltiosis values ranged between −16.52% (Ülkem × Sırma) and 67.34% (Sırma × Karagöz) (Table 5, 6).

The heterobeltiosis values were majority negative in F_1 and heterosis values were positive in the majority of F_1 hybrids. This fact indicates that this material can be a source for obtaining medium-sized plants. Similar results were obtained for the trait plant height by Kadam et al. (2013); Sarath and Reshma (2017) and Joshi et al. (2022). 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 both were desirable and significant.

Heritability in the broad and narrow sense was 0.62 and 0.32 in the F_1 generation, respectively (Table 3). The high heritability in this generation reveals that genetic factors as well as the environment have a great impact on the emergence of this trait. With these results, it can be said that a selection to be made in the direction of plant height should be considered together with seed yield, and for this reason, it may be more appropriate to start the selection after the F_3 generation. Owusu et al. (2020) and Verma et al. (2020) found similar results.

3.2. Number of pods

High seed yield in cowpea depends on environmental conditions as well as yield components. One of the yield components is the number of pods per plant (Peksen and Artık, 2004; Badhe et al., 2016). According to the average number of pods, the parental values were between 13.83 number/plant (Sırma) and 26.78 number/plant (Karagöz), and the number of pods per plant in the F_1 generation was 12.83 number/plant (Pekşen × Karagöz) and 35.33 number/plant (Amazon × Karagöz) (Table 3). These findings were supported by Peksen and Artık (2004); Ülker and Ceyhan (2008); Pekşen and Pekşen (2012); Kadam et al. (2013); da Costa et al. (2017); Walle et al. (2019); Joshi et al. (2022).

The GCA was less than the SCA, υ^2GCA/ υ^2SCA ratio which was less than 1 and $(H/D)^{1/2}$ ratio was greater than 1. The fact that the υ^2GCA/ υ^2SCA ratios examined for the number of pods in the plant were found to be less than 1 reveals that the nonadditive gene effect is effective in the inheritance of this trait (Table 3). Badhe et al. (2016); Gupta et al. (2017); Kumari and Chauhan (2018) and Purnamasari et al. (2019) were in agreement 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.

When GCA is examined, Ülkem and Karagöz have positive significant values. The Ülkem and Karagöz genotypes, which have a high positive effect and a positive and significant GCA effect value, can be recommended as parents that can be used to increase the number of pods in cowpeas (Table 4).

Looking at the SCA effects of hybrids, "Pekşen × Sırma", "Ülkem × Pekşen", "Amazon × Karagöz", "Karagöz × Pekşen" and the combination of "Karagöz × Sırma" has a positive and significant SCA effect. When looking at the reciprocal effect of the hybrids, there is a significant difference between a combination of normal F_1 hybrid and responsive. Pekşen cytoplasm in the "Pekşen × Sırma" hybrid, and Amazon cytoplasm in the "Amazon × Karagöz" hybrid were determined to increase the number of pods. Pekşen and Amazon genotypes can be used as main parents to increase the number of cowpeas (Table 4).

As in all plants, it is extremely important to increase seed yield in cowpeas. The number of pods per plant is one of the most important characteristics determining the seed yield in cowpeas. Increasing the number of pods in the plant is also theoretically increasing the seed yield (Pekşen and Artık, 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); Badhe et al. (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.

The heterosis average value is 26.79%, while the heterobeltiosis value is 9.37%. Heterosis values varied between −39.14% (Pekşen × Karagöz) and 102.99% (Pekşen × Sırma), while heterobeltiosis values ranged between −52.07% (Pekşen × Karagöz) and 92.68% (Pekşen × Sırma) (Tables 5, 6).

Seed yield in cowpeas is a quantitative character dependent on many factors. However, the factors that determine the yield depend on the different characteristics of the genotype and the environmental conditions effective in development. The desired yield level can be achieved only if the varieties are grown under optimum conditions. The number of seeds in the pod is also more affected by environmental conditions. The variation of heterosis and heterobeltiosis values of hybrids within very wide values shows that this feature is greatly affected by environmental conditions. 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. On another side, Joshi et al. (2022) reported that in certain hybrids heterosis and heterobeltiosis were found highest positive and significant in terms of this feature. But in almost all heterosis, hybrids showed varying positive and negative significant performances.

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 (Table 3). Working on similar issues, Purnamasari et al. (2019) and Owusu et al. (2020) found

Table 5. Heterosis (%) values for investigated traits in a full-diallel hybrid set.

F_1 Hybrids	Plant height	Number of pods	Number of seeds per pod	Number of seeds per plant
Pekşen × Sırma	13.99	102.99	7.66	121.24
Pekşen × Ülkem	62.98	–19.38	83.61**	40.58
Pekşen × Amazon	26.04	50.27	94.49**	173.96
Pekşen × Karagöz	2.38	–39.14	108.88**	19.49
Sırma × Pekşen	43.16	69.92	38.43**	133.81
Sırma × Ülkem	19.54	18.83	5.21	31.21
Sırma × Amazon	28.70	32.22	–15.00	16.01
Sırma × Karagöz	62.11	–33.51	–30.98*	–50.53
Ülkem × Pekşen	6.82	41.75	37.46*	85.89
Ülkem × Sırma	23.04	18.78	–3.55	12.89
Ülkem × Amazon	–5.28	25.47	–35.95*	–18.06
Ülkem × Karagöz	–11.77	22.32	–5.50	21.40
Amazon × Pekşen	12.06	13.46	33.71*	51.96
Amazon × Sırma	48.60	58.40	22.24*	93.46
Amazon × Ülkem	–14.41	4.30	4.00	10.75
Amazon × Karagöz	1.77	73.00	20.86*	118.82
Karagöz × Pekşen	15.30	28.83	51.44**	89.58
Karagöz × Sırma	50.88	47.62	29.12*	105.50
Karagöz × Ülkem	3.94	14.91	54.26**	28.10
Karagöz × Amazon	10.96	34.65	–4.97	34.68
Mean	20.04	26.79	24.77	56.04

Table 6. Heterobeltiosis (%) values for investigated traits in a full-diallel hybrid set.

F_1 Hybrids	Plant Height	Number of Pods	Number of Seeds per Pod	Number of Seeds per Plant
Pekşen × Sırma	–22.05	92.68**	–18.29	76.59*
Pekşen × Ülkem	12.30	–34.35*	40.68**	–4.59
Pekşen × Amazon	22.33	43.80*	51.83**	122.95**
Pekşen × Karagöz	51.12	–52.07**	84.65**	–13.20
Sırma × Pekşen	–11.37	61.29**	5.06	86.62**
Sırma × Ülkem	13.48	–7.03	3.77	4.92
Sırma × Amazon	1.56	31.11	–18.29	13.13
Sırma × Karagöz	67.34	–49.58**	–42.22**	–56.48*
Ülkem × Pekşen	–2.99	15.41	5.32	26.17
Ülkem × Sırma	–16.52	–7.07	–4.86	–9.73
Ülkem × Amazon	–3.10	–1.24	–37.60*	–35.70
Ülkem × Karagöz	8.50	17.12	–20.00	8.60
Amazon × Pekşen	–5.17	8.57	4.39	23.67
Amazon × Sırma	–11.92	57.07**	17.51	88.65**
Amazon × Ülkem	–16.40	–17.90	1.32	–13.09
Amazon × Karagöz	23.00	31.96*	4.60	88.37**
Karagöz × Pekşen	–10.42	1.46	33.87	37.73
Karagöz × Sırma	–9.16	11.94	8.09	80.79**
Karagöz × Ülkem	–3.59	–18.52	30.60*	14.60
Karagöz × Amazon	4.07	2.70	–17.76	15.94
Mean	1.98	9.37	6.63	27.80

high heritability in the broad and narrow sense. It can be argued that it would be better to start breeding after 3–4 generations, since nonadditive genetic effects are important in the generation examined.

3.3. Number of seeds per pod

According to the number of seeds per pod, the parental values were between 4.44 number/pod (Pekşen) and 8.57 number/pod (Sırma), and in the F_1 generation the number of seeds per pod was 4.95 number/pod (Sırma x Karagöz) and 12.00 number/pod (Pekşen × Amazon) (Table 3). 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) (Table 2).

When Table 2 is examined, the GCA variance is less than SCA; then υ^2GCA/υ^2SCA ratio is also less than 1 and the $H/D^{1/2}$ ratio is greater than 1. The fact that the υ^2GCA/ υ^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 nonadditive dominant gene effect is effective in the inheritance of this trait (Table 3). Under the influence of the nonadditive pod number factor gene (Badhe et al., 2016; Gupta et al., 2017; Kumari and Chauhan, 2018; Purnamasari et al., 2019), despite (Hall et al., 2003; Olunloyo et al., 2019; Verma et al., 2020) stated that this feature is under the influence of additive and dominant genes.

In terms of the number of seeds in the pod, Pekşen and Ülkem genotypes were found to have significant and positive values, while Sırma, Amazon and Karagöz genotypes had a significant negative effect. Pekşen and Ülkem genotypes, which are positively important in increasing the number of seeds in the pod, were determined as suitable parents to be used in breeding studies to be carried out for this purpose (Table 4).

Considering the SCA effects of crosses in the F_1 generation, "Sırma × Pekşen", "Pekşen × Ülkem", "Pekşen × Amazon", and "Pekşen × Karagöz", "Amazon × Sırma", "Amazon × Ülkem", "Karagöz × Sırma" and "Karagöz × Ülkem" hybrids have a positive significant SCA effect. "Ülkem × Amazon" and "Karagöz × Amazon", "Ülkem × Pekşen", "Amazon × Pekşen", "Karagöz × Pekşen" hybrids have a significant negative SCA effect (Table 3). Considering the reciprocal effect values, it was determined that the cytoplasm of Pekşen in hybrid "Pekşen × Ülkem", the cytoplasm of Pekşen in hybrid "Pekşen × Amazon", the cytoplasm of Pekşen in hybrid "Pekşen × Karagöz", the cytoplasm of Ülkem in hybrid "Ülkem × Amazon" and cytoplasm × nucleus interactions increased the number of seeds per pod. "Sırma × Pekşen", "Pekşen × Ülkem", "Pekşen × Amazon", and "Pekşen × Karagöz" hybrids can be considered as suitable combinations that can be used to increase the number of seeds in the pod, as they have positive and high SCA effect (Table 4). In many studies, the effects of GCA and SCA for the number of seeds per pod were determined (Badhe et al., 2016; Dias 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).

The heterosis average value determined for the number of seeds per pod was calculated as 24.77%, heterobeltiosis value was calculated as 6.63%. Heterosis and heterobeltiosis values were found significant and positive. Heterosis values varied between –35.95% (Ülkem × Amazon) and 108.88% (Pekşen × Karagöz). The reason why heterosis and heterobeltiosis values are positive in almost all hybrids in F_1 generations is that the effect of the nonadditive gene is insignificant in terms of seed number per pod (Tables 5,6). According to Kadam et al. (2013); Sarath and Reshma (2017) and Joshi et al. (2022) their results were similar to ours.

The fact that the heritability in the narrow sense is at medium levels indicates that the number of seeds per pod is influenced by genetics as well as the environment to a certain extent (Table 3). Analyzing seed number inheritance in pods by Purnamasari et al. (2019) and Owusu et al. (2020) found that broad sense heritabilities were generally the largest but varied among crosses. If it is theoretically thought that the yield will increase with the increase in the number of seeds per pod, it would be more appropriate to start the selection in advanced generations, since nonadditive gene effects are important and hybrid strength is low.

3.4. Number of seeds per plant

The parental values were between 70.36 number/plant (Pekşen) and 196.83 number/plant (Ülkem) in terms of the number of seeds per plant, and F_1 hybrids were between 67.60 number/plant (Sırma × Karagöz) and 292.60 number/plant (Amazon × Karagöz) (Table 3). With our research findings, Peksen and Artık (2004); Kumari and Chauhan (2018), and Walle et al. (2019) are in harmony.

The GCA was less The SCA is 6963,48, the υ^2GCA/ υ^2SCA ratio was less than 1 and the $H/D^{1/2}$ ratio was greater than 1. The fact that the υ^2GCA/υ^2SCA ratios belonging to the number of seeds per plant in both generations were less than 1, shows us that the nonadditive gene effect is effective in the inheritance of this trait. Likewise, if the $H/D^{1/2}$ ratios are greater than 1, it reveals superior dominance. This supports the nonadditive gene effect (Table 3). The gene effect and the superiority of dominance reduce the success of selection for this trait in early generations. Kumari and Chauhan (2018) found similar results.

In the F_1 generation, Ülkem and Karagöz were found to have significant positive values, while negative and significant GCA values were determined for Pekşen, Sırma, and Amazon genotypes. Ülkem and Karagöz, which have a positive effect value of GCA, were determined as parents that can be used to increase the number of seeds per plant in crossing studies (Table 4). Some researchers (Kumari and Chauhan, 2018; Tamüksek and Ceyhan, 2022) found similar results.

Looking at the SCA effects of hybrids, in the F_1 generation, "Pekşen × Sırma", "Ülkem × Pekşen", "Karagöz × Pekşen", "Amazon × Karagöz" and "Karagöz × Sırma" hybrids have positive significant SCA effect, and these combinations are genotypes with breeding potential for high seed number. When we look at the reciprocal effect values, the cytoplasm of Amazon in hybrid "Amazon × Karagöz" increased the number of seeds per plant. "Pekşen × Sırma", "Ülkem × Pekşen", "Karagöz × Pekşen", "Amazon × Karagöz" and "Karagöz × Sırma", hybrids have emerged as suitable combinations that can be used to increase the number of seeds per plant, as they have a positive significant SCA effect. Thus, Kumari and Chauhan (2018); Tamüksek Ceyhan (2022), and Tekin Ceyhan (2022) found similar results in previous studies (Table 4).

The average heterosis value in the F_1 generation was determined as 56.04%, while the heterobeltiosis value was –27.80%. Heterosis values varied between –50.53% (Sırma ×Karagöz) and 173.96% (Pekşen × Amazon), heterobeltiosis values ranged between –56.48% (Sırma × Karagöz) and 122.95% (Pekşen × Amazon) (Tables 5, 6).

In the F_1 generation, heritability in the broad and narrow sense calculated for the number of seeds per plant was 0.76 and 0.00 respectively. The high heritability in the broad sense and the low heritability in the narrow sense shows that the nonadditive gene effect is important for this trait (Table 3). Therefore, it would be more appropriate to start selection in future generations.

3.5. Seed yield in plant

Although seed yields are used to determine the seed yield of genotypes, the fact that environmental conditions have a great effect on this trait makes it difficult to make a precise evaluation (Peksen and Artık, 2004; Pekşen and Pekşen, 2012; Sert and Ceyhan, 2012; Pekşen and Pekşen, 2013). According to the average seed yields in the F_1 generation, the parental values were 14.72 g/plant (Pekşen) and 47.36 g/plant (Ülkem), the single-plant seed yields in the F_1 generation were determined to vary between 24.35 g/plant (Pekşen × Karagöz) and 73.63 g/plant (Pekşen × Sırma) (Table 7). With the findings of this study, Ceyhan (2004); Peksen and Artık (2004); Ceyhan et al. (2008); Kadam et al. (2013); Ceyhan et al. (2014a); Rodrigues et al. (2018); Walle et al. (2019) and Joshi et al. (2022) are in harmony.

It has been determined that in the F_1 generation, GCA was 3.08 and the SCA was 848.71, the ratio of υ^2GCA/υ^2SCA was 0.00 and the $H/D^{1/2}$ ratio was 1018.25. The fact that the υ^2GCA/υ^2SCA ratios belonging to the single plant seed yield trait were less than 1 in the F_1 generation shows us that the nonadditive gene effect is effective in the inheritance of this trait. Likewise, if the ratio of $H/D^{1/2}$ is greater than 1 in the trial year, it reveals superior dominance (Table 7). Thus, Badhe et al. (2016); Dias 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 seed yield was under the influence of both added and nonadded genes in F_1 generations. If the inheritance of seed yield is managed by the additive gene effect in cowpeas as in other plants, selection can be started in early generations and the chance of success can be increased by identifying superior genotypes. However, the superiority of dominance instead of additive genes in seed yield reduces the success chance of selection for this trait in early generations. In this case, the chance of success will depend on the type of effective epistasis. Selection for plant seed yield in cowpea breeding should be done in future generations and it should be possible to transfer superior genotypes to the next generation and the chance of success should be increased.

When we look at the effect value of GCA, it is seen that Pekşen, Sırma, and Ülkem genotypes show significant and positive values among parental genotypes in the F_1 generation. Amazon and Karagöz genotypes were determined to have a significant negative effect. Pekşen, Sırma, and Ülkem genotypes, which were found to have positive and significant GCA effect values, were determined as promising parents that could be used in terms of plant yield in crossing studies (Table 8).

Considering the SCA effects of hybrids, "Ülkem × Pekşen", "Pekşen × Sırma", and "Karagöz × Sırma" hybrids have positive and significant SCA effects in the F_1 generation. In the research, "Amazon × Pekşen", "Ülkem × Sırma", "Karagöz × Ülkem", "Karagöz × Amazon" and "Pekşen × Karagöz" hybrids showed a high negative significant SCA effect. "Ülkem × Pekşen", "Pekşen × Sırma", and "Karagöz × Sırma" hybrids show high positive SCA effect and genotype with breeding potential for seed yield in future generations (Table 8).

Many studies have been carried out on the effect of GCA and SCA in cowpea, and researchers have determined different numbers of parent and hybrid combinations showing significant GCA and SCA effects on seed yield in the generations they examined (Ceyhan et al. 2014a; Dias 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; Verma et al., 2020; Kepildek and Ceyhan 2021).

In the F_1 generation, the average heterosis value determined in this study for seed yield was 60.97%, while the heterobeltiosis value was 29.39%. Positive significant values for heterosis were detected in most

Table 7. Mean values and estimates of variance components for investigated traits in a full-diallel hybrid set.

Parents	Seed yield per plant		Hundred seed weight		Protein ratio		Protein yield in plant	
Pekşen	14.72	h	13.43	fg	28.82	a–d	4.25	g
Sırma	23.40	gh	15.89	d–g	26.69	lm	6.23	fg
Ülkem	47.36	a–g	22.72	bc	28.59	cde	13.56	a–f
Amazon	20.99	gh	12.74	fg	27.53	g–j	5.77	fg
Karagöz	38.58	b–h	22.50	bcd	28.24	d–g	10.90	b–g
F_1 Hybrids								
Pekşen × Sırma	73.63	a	31.77	a	26.79	klm	19.61	a
Pekşen × Ülkem	32.39	d–h	13.21	fg	29.17	abc	9.44	c–g
Pekşen × Amazon	57.23	a–e	20.63	b–e	29.31	ab	16.76	a–d
Pekşen × Karagöz	24.35	fgh	14.31	efg	29.51	a	7.19	efg
Sırma × Pekşen	65.80	ab	26.88	ab	28.87	a–d	19.01	ab
Sırma × Ülkem	44.27	a–h	18.02	c–f	28.37	def	12.59	a–f
Sırma × Amazon	31.64	d–h	20.51	b–e	25.64	n	8.11	efg
Sırma × Karagöz	18.49	gh	18.03	c–f	28.78	b–e	5.31	fg
Ülkem × Pekşen	59.90	a–d	20.46	b–e	29.49	ab	17.70	abc
Ülkem × Sırma	24.90	fgh	10.73	g	28.27	def	7.04	efg
Ülkem × Amazon	34.70	c–h	23.31	bc	29.38	ab	10.18	c–g
Ülkem × Karagöz	53.94	a–f	22.22	bcd	28.07	e–h	15.14	a–e
Amazon × Pekşen	33.79	d–h	20.64	b–e	27.72	f–ı	9.37	d–g
Amazon × Sırma	44.68	a–g	18.08	c–f	27.22	ı–l	12.16	a–g
Amazon × Ülkem	34.57	d–h	18.21	c–f	26.89	j–m	9.30	d–g
Amazon × Karagöz	43.76	b–h	12.57	fg	27.50	h–k	12.02	a–g
Karagöz × Pekşen	31.37	d–h	11.80	fg	26.20	mn	8.21	efg
Karagöz × Sırma	64.24	abc	22.23	bcd	26.54	lm	17.06	abc
Karagöz × Ülkem	38.36	b–h	14.74	efg	26.59	lm	10.17	a–d
Karagöz × Amazon	30.04	4e–h	14.32	efg	26.59	lm	7.99	efg
GCA	3.08		1.35		0.49		0.56	
SCA	848.71		131.92		1.39		66.12	
Reciprocal	163.37		9.16		1.70		12.76	
υ^2GCA/υ^2SCA	0.00		0.01		0.35		0.01	
$H/D^{1/2}$	1018.25		143.77		4.07		80.00	
H^2	0.85		0.94		0.97		0.85	
h^2	0.01		0.02		0.23		0.01	

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

Table 8. Estimates of general combining ability (GCA) effects and special combining ability (SCA) effects for investigated traits in a full-diallel hybrid set.

Parents	Seed yield per plant	Hundred seed weight	Protein ratio	Protein yield in plant
Pekşen	1.305	0.259	0.599**	0.576
Sırma	1.961	1.405*	–0.486**	0.333
Ülkem	2.292	0.236	0.471**	0.865
Amazon	–4.246	–1.024	–0.340**	–1.260
Karagöz	–1.312	–0.876	–0.244*	–0.515
F_1 Hybrids				
Pekşen × Sırma	26.963**	9.265**	–0.156	7.397**
Pekşen × Ülkem	3.065	2.060	0.388**	1.126
Pekşen × Amazon	8.965	3.002*	0.386**	2.748
Pekşen × Karagöz	–11.616*	–4.726**	–0.369**	–3.365*
Sırma × Pekşen	–3.915	–2.446**	1.042**	–0.298
Sırma × Ülkem	–9.150	–5.664**	0.466**	–2.385
Sırma × Amazon	0.960	0.511	–0.619**	0.058
Sırma × Karagöz	1.231	1.205	0.520**	0.366
Ülkem × Pekşen	13.758**	3.624**	0.161*	4.131**
Ülkem × Sırma	–9.683*	–3.644**	–0.052	–2.775*
Ülkem × Amazon	–2.897	3.149*	0.136	–0.867
Ülkem × Karagöz	5.687	0.723	–0.765**	1.302
Amazon × Pekşen	–11.721**	0.008	–0.797**	–3.695**
Amazon × Sırma	6.523	–1.215	0.790**	2.024*
Amazon × Ülkem	–0.065	–2.549**	–1.245**	–0.444
Amazon × Karagöz	2.975	–3.051*	–0.242	0.774
Karagöz × Pekşen	3.514	–1.252	–1.657**	0.513
Karagöz × Sırma	22.876**	2.098*	–1.123**	5.873**
Karagöz × Ülkem	–7.786*	–3.739**	–0.740**	–2.484
Karagöz × Amazon	6.857*	0.878	–0.455**	–2.015*
G_i	5.557	1.034	0.107	1.314
S_{ij}	14.142	2.265	0.219	2.917
R_{ij}	18.465	2.813	1.072	3.64

G_i : GCA, S_{ij}: SCA; R_{ij}: Reciprocal effect, ** : significant at 1% level; * : significant at 5% level of the crosses. Heterosis values varied between –40.35% (Sırma × Karagöz) and 286.33% (Pekşen × Sırma), while heterobeltiosis values varied between –52.08% (Sırma × Karagöz) and 214.65% (Pekşen × Sırma) (Tables 9, 10). In their previous studies (Ceyhan, 2004; Ceyhan et al., 2008; Kadam et al., 2013; Sarath and Reshma, 2017; Joshi et al., 2022), reported that heterosis was more significant than herobeltiosis in seed yield.

In cases where nonadditive gene effects are important, attempts are made to identify combinations of parents and hybrids that show heterosis. In many studies on this subject, it has been determined that F_1 hybrids obtained from different origins and high-yielding parents give high yields (Kadam et al., 2013; Badhe et al., 2016; Gupta et al., 2017; Rodrigues et al., 2018; Owusu et al., 2020; Joshi et al., 2022), showed the similar results.

Analyzing the inheritance of seed yield in cowpea, (Purnamasari et al., 2019; Owusu et al., 2020) found high heritability in the broad sense and low heritability in the narrow sense for this trait. The low heritability in the narrow sense for seed yield (Table 7) and the determination of nonadditive gene effects in the inheritance of this trait reduce the success chance of selection in early generations for seed yield. For these reasons, selecting high heritable and obvious traits instead of seed yield in early generations can increase the chances of success.

3.6. Hundred seed weight

One hundred seed weight in cowpea is an important yield factor that directly affects the yield (Peksen and Artık, 2004; Pekşen and Pekşen, 2012; Sert and Ceyhan, 2012; Pekşen and Pekşen, 2013). In terms of the hundred seed weight of the F_1 generation, the parent values ranged from 12.74 g (Amazon) to 22.72 g (Ülkem), the hundred-seed weight in the F_1 generation ranged from 10.73 g (Ülkem × Sırma) to 31.77 g (Pekşen × Sırma) (Table 7). 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 GCA in the F_1 generation was less than the SCA, the ratio of υ^2GCA/υ^2 SCA was also less than 1, and the H/$D^{1/2}$ ratio was greater than 1. The fact that υ^2GCA/υ^2SCA ratios are less than 1 and the H/$D^{1/2}$ ratio is greater than 1 shows that the nonadditive gene effect is effective in the inheritance of this trait. Likewise, the H/$D^{1/2}$ ratio being greater than 1 reveals the superior dominance of these genes (Table 7). However, selection could be started in the future generations. In a study they carried out, (Badhe 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; Verma et al., 2020), found that the additive gene effect was important for the hundred seed weight.

Table 9. Heterosis (%) values for investigated traits in a full-diallel hybrid set.

F_1 Hybrids	Seed yield per plant	Hundred seed weight	Protein ratio	Protein yield in plant
Pekşen × Sırma	286.33	116.69**	−3.49**	274.11*
Pekşen × Ülkem	4.34	−26.93	1.61**	6.02
Pekşen × Amazon	220.56	57.61*	4.03**	234.61
Pekşen × Karagöz	−8.64	−20.36	3.44**	−5.11
Sırma × Pekşen	245.24	83.32*	4.02**	262.72
Sırma × Ülkem	25.12	−6.67	2.66**	27.23
Sırma × Amazon	42.54	43.24*	−5.44**	35.11
Sırma × Karagöz	−40.35	−6.04	4.81**	−37.97
Ülkem × Pekşen	92.99	13.16	2.73**	98.81
Ülkem × Sırma	−29.62	−44.42*	2.29**	−28.86
Ülkem × Amazon	1.53	31.45	4.71**	5.38
Ülkem × Karagöz	25.51	−1.72	−1.20**	23.81
Amazon × Pekşen	89.25	57.74*	−1.62**	87.09
Amazon × Sırma	101.31	26.26	0.39*	102.57
Amazon × Ülkem	1.15	2.70	−4.16**	−3.80
Amazon × Karagöz	46.91	−28.66	−1.38**	44.21
Karagöz × Pekşen	17.73	−34.30*	−8.17**	8.45
Karagöz × Sırma	107.28	15.82	−3.38**	99.19
Karagöz × Ülkem	−10.72	−34.79*	−6.41**	−16.81
Karagöz × Amazon	0.87	−18.69	−4.65**	−4.15
Mean	60.97	11.27	−0.46	60.63

Table 10. Heterobeltiosis (%) values for investigated traits in a full-diallel hybrid set.

F_1 Hybrids	Seed yield per plant	Hundred seed weight	Protein ratio	Protein yield in plant
Pekşen × Sırma	214.65**	99.93**	−7.06**	214.56**
Pekşen × Ülkem	−31.62	−41.87**	1.20	−30.38
Pekşen × Amazon	172.66**	53.53**	1.71*	190.50**
Pekşen × Karagöz	−36.90	−36.40**	2.40**	−34.05
Sırma × Pekşen	181.19**	69.15**	0.17	204.98**
Sırma × Ülkem	−6.53	−20.70*	−0.75	−7.14
Sırma × Amazon	35.20	29.03*	−6.89**	30.09
Sırma × Karagöz	−52.08*	−19.83*	1.93*	−51.24*
Ülkem × Pekşen	26.48	−9.97	2.32**	30.56
Ülkem × Sırma	−47.42*	−52.77**	−1.11	−48.07*
Ülkem × Amazon	−26.74	2.57	2.78**	−24.88
Ülkem × Karagöz	13.88	−2.22	−1.81*	11.66
Amazon × Pekşen	60.97*	53.66**	−3.82**	62.43*
Amazon × Sırma	90.95**	13.74*	−1.14	95.05*
Amazon × Ülkem	−27.02	−19.86*	−5.93**	−31.43
Amazon × Karagöz	13.41	−44.13**	−2.62**	10.29
Karagöz × Pekşen	−18.68	−47.53**	−9.10**	−24.63
Karagöz × Sırma	66.50*	−1.18	−6.03**	56.57*
Karagöz × Ülkem	−19.00	−35.12**	−6.98**	−24.98
Karagöz × Amazon	−22.13	−36.32**	−5.84**	−26.70
Mean	29.39	−2.31	−2.33	30.16

In F_1 generation, when GCA is examined in terms of hundred seed weight, Pekşen, Sırma, and Ülkem cultivars have significant and positive values while Karagöz, Amazon genotypes have significant and negative values (Table 8). Sırma and Ülkem cultivars, which were found to be positively important in increasing the hundred-seed weight, emerged as suitable parents to be used in breeding studies for this trait. In their previous studies, Badhe et al. (2016); Dias et al. (2016); Gupta et al. (2017); Kumari and Chauhan (2018); Rodrigues et al. (2018); Olunloyo et al. (2019); Purnamasari et al. (2019) and Verma et al. (2020) were in harmony.

Considering the SCA effects of the hybrids, it was determined that twelve crosses showed statistically significant SCA effects in the F_1 generation. "Pekşen × Sırma", "Pekşen × Amazon", "Ülkem × Pekşen", "Ülkem × Amazon" and "Karagöz × Sırma" hybrids showing positive and significant SCA effects are promising genotypes that can be used in breeding studies for this purpose (Table 8). Badhe et al. (2016); Dias 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.

The average of heterosis value determined for hundred seed weight in the F_1 generation was 11.27%, and the average heterobeltiosis value was −2.31%. Heterosis values varied between −44.42% (Ülkem × Sırma) and 116.69% (Pekşen × Sırma), while heterobeltiosis values ranged between −52.77% (Ülkem × Sırma) and 99.93% (Pekşen × Sırma). Most of the hybrids show negative heterosis and heterobeltiosis, which shows that there is a low rate of hybrids suitable for high hundred seed weight (Tables 9, 10). Kadam et al. (2013); Sarath and Reshma (2017) and Joshi et al. (2022) stated that they determined different heterosis and heterobeltiosis values for a hundred seed weights.

The high heritability in the broad sense and the low heritability in the narrow sense in a hundred seed weight means that the effect of the environmental variance of this trait may be low (Table 7). Analyzing the hundred seed weight inheritance, Purnamasari et al. (2019) and Owusu et al. (2020) obtained high heritability in broad and narrow sense. Considering the importance of additive gene effects in the inheritance of hundred seed weight, selection can be started in early generations.

3.7. Protein content

According to the average of the protein ratio in the F_1 generation, it was determined that the parental values ranged from 26.69% (Sırma) to 28.82% (Pekşen), and in the F_1 generation the protein ratio ranged between 25.64% (Sırma × Amazon) and 29.51% (Pekşen × Karagöz) (Table 7). Conducting research on this subject, Hall et al. (2003); Sert and Ceyhan (2012); Kadam et al. (2013); Harmankaya et al. (2016), and Joshi et al. (2022) found similar results.

It has been determined that in the F_1 generation, The GCA was less than The SCA, the ratio of υ^2GCA/υ^2SCA was also less than 1 and the $H/D^{1/2}$ ratio was greater than 1. The fact that the υ^2GCA/υ^2SCA ratios of the protein ratio were less than 1 shows us that the nonadditive gene effect is effective in the inheritance of this trait. Likewise, a ratio of $H/D^{1/2}$ greater than 1 indicates superior dominance (Table 7). Conducting research on this subject, Sharma and Mehta (2014); Badhe 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. 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 (Table 8).

Looking at the SCA effects of hybrids in the F_1 generation, "Sırma × Pekşen", "Ülkem × Pekşen", "Amazon × Sırma", "Pekşen × Ülkem", "Sırma × Ülkem", "Pekşen × Amazon", "Sırma × Karagöz" hybrids have positive and significant SCA effect. Hybrids which showed a high positive SCA effect with high reproductive potential for protein ratio, which could be used as genotypes 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 (Table 8). Tchiagam et al. (2011); Ceyhan et al. (2014b); Sharma and Mehta (2014); Badhe et al. (2016); Kumari and Chauhan (2018); Purnamasari et al. (2019) and Ceyhan et al. (2014b) 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_1 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 × Pekşen) and 4.81% (Sırma × Karagöz), while heterobeltiosis values ranged between –9.10% (Karagöz × Pekşen) and 2.78% (Ülkem × Amazon) (Tables 9, 10).

The fact that the heterosis and heterobeltiosis values are generally positive depending on the hybrids, and the average heterosis and heterobeltiosis values are low, shows that the nonadditive gene effect is important in terms of the protein ratio. The fact that more than half of the hybrids showed positive heterosis for this trait and was statistically significant indicates 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) and Joshi et al. (2022) found low or high mean heterosis and heterobeltiosis values for this feature.

The low heritability in the narrow sense indicates that the contribution of the environment is at a certain level in addition to the genotypic variance in the emergence of the protein ratio (Table 7). Analyzing the inheritance of the protein ratio, Sharma and Mehta (2014), and Purnamasari et al. (2019) found high heritability in narrow and broad in this trait. Since the nonadditive 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.

3.8. Protein yield in plant

In the F_1 generations, the parental values were between 5.77 g/plant (Amazon) and 13.56 g/plant (Ülkem), and the plant proteins yields in the F_1 generation were 5.31 g/plant (Sırma × Karagöz) and 19.61 g/plant (Pekşen × Sırma) (Table 7). The findings of this study are in harmony with the findings of Kumari and Chauhan (2018).

The lower GCA than SCA indicated that nonadditive gene effect and superior dominancy were effective on the heredity of protein ratio (Table 6). After their analyses (Badhe et al., 2016; Kumari and Chauhan, 2018), found similar results.

When the GCA is examined in terms of this feature, Pekşen, Sırma, and Ülkem genotypes have significant and positive values in the F_1 generation, while Amazon and Karagöz genotypes have significant and negative values. Pekşen, Sırma, and Ülkem genotypes, which were positively important in increasing protein yield, were determined as suitable parents to be used in breeding studies for this purpose (Table 8).

Looking at the SCA effects of hybrids, in the F_1 generation, "Ülkem × Pekşen", "Pekşen × Sırma", "Amazon × Sırma" and "Karagöz × Sırma" hybrids showed positive and significant SCA effect. These positive hybrids have emerged as suitable combinations that can be used to increase protein yield, as they have positive and significant SCA effects. Contrary, "Amazon × Pekşen", "Ülkem × Sırma", "Karagöz × Ülkem", "Karagöz × Amazon" and "Pekşen × Karagöz" hybrids have a significant negative SCA effect (Table 8). Badhe et al. (2016) and Kumari and Chauhan (2018) in their previous studies, were in harmony.

The average heterosis value determined for protein yield in F_1 generation was 60.63%, heterobeltiosis value was calculated as 30.16%. Heterosis values varied between −37.97% (Sırma × Karagöz) and 274.11% (Pekşen × Sırma) and heterobeltiosis values ranged between −51.24% (Sırma × Karagöz) and 214.56% (Tables 9, 10). In conformity with those obtained by Kadam et al. (2013) and Joshi et al. (2022).

The high heritability in the broad sense and the low heritability in the narrow sense in protein yield in F_1 hybrids that the effect of genotype variance on this trait is low (Table 7). The determination of the nonadditive 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. The results of Purnamasari et al. (2019), showed high heritability in the broad and narrow sense.

4. Conclusions

Having reached the end of our investigation, it is clear that for the agronomic characters studied, the population studied presented a sufficient variation. Nonadditive genes and dominant genes were more effective on the studied traits. And for this, some selections could be considered by future generations.

Conflicts of interest

The authors declare no conflict of interest. Conceptualization of research (EC); designing of the experiments (EC, CJN); contribution of experimental materials (EC); execution of field/lab experiments and data collection (CJN); analysis of data and interpretation (EC, CJN); preparation of the manuscript (EC, CJN). All authors read and approved the final manuscript.

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