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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Heterosis, heterobeltiosis and dominance effect on yield, total soluble solid and dry matter of red pepper [*Capsicum annuum* L. var. *conoides* (Mill.) Irish] hybrids

Kırmızı biber [*Capsicum annuum* L. var. *conoides* (Mill.) Irish] hibritlerinde verim, toplam çözünebilir madde ve kuru madde yönünden heterosis, heterobeltiosis ve dominans etkisinin belirlenmesi

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Ö Z E T / A B S T R A C T

Aims: The aim of this study is to estimate heterosis, heterobeltiosis and dominance effect on yield, total soluble solid and dry matter of capia type red pepper.
Methods and Results: In this study 11 capia type red pepper parents and 47 hybrids obtained from crosses of these parents were used as materials. Heterosis in fresh fruit yield ranged from -48.23 to 80.68. The highest heterosis were recorded for 209 YKB (80.68%), 239 YKB (60.35%), 225 YKB (56.97%) and 195 YKB (55.30%), respectively. Heterosis rates of F1 changed between -33.70 and 30.98 in terms of total soluble solid. The highest heterosis rates was found in 218 YKB. In terms of dry matter, highest heterosis rate was calculated as 66.67% in 195 YKB. As a result of the study, 39-H-2, 43-H-6 and 45-H-5 were determined as the best parents giving the highest heterosis rates in crosses.
Conclusions: In this study, heterosis rates were highly positive direction in terms of all three characteristics. The use of heterosis can be indicated as a practical method to increase yield and other economic characteristics in peppers.
Significance and Impact of the Study: These results can be used to determine the varieties that become prominent in terms of desired characteristics.

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INTRODUCTION

Pepper (*Capsicum annum*, L.) is an important vegetable crop that is widely grown in Turkey. Turkey is the fourth major pepper producer after China, Mexico and Indonesia in the world (Anonymous, 2020). Pepper used in many forms, such as fresh or cooked vegetables, herbs or spices, and various kinds of processed products. The level of phenotypic diversity within pepper populations is quite high. The factors that reveal the diversity are due to features such as fruit shape, color, bitterness rate in fruit, fruit flesh thickness, fruit flesh color, fruit size and number of seeds etc. (Kanal and Balkaya, 2021).

Heterosis is expressed as an agricultural phenomenon, in which growth, productivity, earliness, quality and other features of hybrid genotypes are superior compared to their parents. While heterosis is defined as the hybrids having higher average values than their parents, heterobeltiosis is the superiority of hybrids over the parents with the highest values. Heterosis may also occur in negative sense depending on the used features which are highlighted (Yılmaz and Sarı, 2002). Heterosis has been widely used in agriculture to increase yield and to broaden adaptability of hybrid varieties and applied to increasing number of crop species (Shresta et al., 2011). High yielding pepper varieties are very important in increasing crop productivity to meet consumer demands (Ganefianti and Fahrurrozi, 2018). It has also been applied to the expression of adaptive traits such as increased fertility and resistance to biotic and abiotic stress. Maximum heterosis is observed in the F1, but the superiority of the progeny over their parents is progressively lost in subsequent generations obtained through successive selfing (Khalil and Hatem, 2014). Hybridization breeding also has the advantage of combining desirable horticultural and resistance traits faster than conventional pure line and pedigree selection, as it allows the combination of dominantly inherited traits (Naves et al., 2022)

The manifestation of heterosis can be due to different factors like: heterozygosity; different allelic interaction (dominance or over dominance); non-allelic or epistasis interactions. Information regarding the inheritance of different traits is very important to design the suitable breeding programs and orientation of selection in different segregant populations. In this regard, dominance effect (potence ratio) can be an effective tool in determining the type and direction of dominance (Soames et al., 2021)

Several studies have been conducted on heterosis in F1 hybrids of pepper in recent years. Pérez-Grajales et al . (2009) were found the highest heterosis relative to the best parent in the cross 'Zongolica x Puebla' for fruit yield (51%). Shresta et al. (2011) used 23 hybrid and their parents to determine heterosis. For fruit number per plant, out of 23 tested hybrids, 20 hybrids showed superiority to their parents. Out of 23 hybrids tested, 8 hybrids showed the negative heterobeltiosis on fruit number per plant. Bhutia et al. (2015), found that five genetically diverse parents selected out of twenty two genotypes of diverse origin through multivariate analysis. They were crossed in diallel fashion without reciprocals to produce 10 F1 hybrids to determine mode of gene action,extent of heterosis and dominance effect, and to estimate combining ability for 14 quantitative characters. The predictability ratio revealed overwhelming response of non-additive gene action in controlling theexpression of fresh fruit yield per plant and most of the yield components. Rao et al. (2017) determined heterosis rates in terms of yield and some characteristics affecting yield in 33 hybrids obtained by using 3 lines and 11 testers in bell pepper. Accordingly, the highest heterosis rates were determined as 77.27% for fruit number per plant, 131.82% for fruit weight per plant, and 43.72% for average fruit weight. Abrham et al. (2017) found mid and better parent heterosis of the fresh fruit yield ranging from -38.63 to 97.66% and from -47.24 to 80.44%, respectively. Chakrabarty et al. (2019), stated that the highest heterosis rate of fresh fruit yield as 121.68%.

The aim of this study is to estimate heterosis, heterobeltiosis and dominance effect on yield, total soluble solid and dry matter of capia type red pepper.

MATERIALS and METHODS

Material

Eleven parents from different heterotic groups with high general adaptability in the Black Sea Agricultural Research Institute pepper breeding gene pool and 47 hybrid combinations that obtained from these parents were used as material. Morphological features of parents presented in Table 1. Hybrid combination and parents listed in Table 2. The study was carried out in 2018 on the research plots of Black Sea Agricultural Reseach Institute (Samsun, Turkey). Seeds of all studies carried out in the trial area were sown in the first week of April. Peat and perlite mixture was prepared at a ratio of 3:1 as seedling growing medium and vermiculite was used as covermedium. Cultural processes such as fertilization and spraying were applied during the seedling growing period. Experimental areas were prepared with mulch, embankment and drip irrigation system, and plantings were generally done at the end of May in 100X50X40 cm double row plots with 20 plants. In all the studies carried out, the maintenance procedures (fertilization, weed control, irrigation etc.) were carried out regularly during the vegetation period.

Analytical methods

Total soluble solids (TSS) were determined by an refractometer at 20 °C and expressed with °Brix. For this, the puree obtained by crushing the pieces taken from different parts of the similar fruits taken from each line was measured in a refractometer. In the determination of dry matter, 5 similar fruits taken from each line were kept in an oven at 55 °C until dry. Dry matter was determined as [100 × (dry weight/fresh weight)] and expressed with %. For the average yield (kg da^{-1}), the yields of the plants harvested once a week were recorded. The yields of the parcels were determined cumulatively after harvest. The yield per decare was calculated from the yield per parcel, and the yield per decare was taken into account in the analysis of the data.

Table 1. Morphological features of parents
Tablo 1. Ebeveynlerin morfolojik özellikleri

Parent	*Fruit weight (g)*	*Fruit diameter (mm)*	*Fruit length (cm)*	*Pericarp thickness (mm)*	*Fruit color at mature stage*
39 H-1	162.00	48.29	23.62	4.25	Red
39 H-2	97.70	46.53	16.62	3.15	Red
39 H-16	91.70	44.61	12.5	3.59	Red
43-H-3	171.30	60.14	20.75	3.59	Red
43-H-6	123.9	55.70	13.7	5.00	Red
45 H-5	104.80	38.9	18.84	3.58	Red
66 YM-8	124.00	44.68	13.8	5.39	Red
29-2-2-3	81.11	31.84	16.37	5.01	Red
29-2-2-3-1	104.30	50.48	14.87	3.48	Red
10 YM-4-2	106.10	46.76	13.0	5.51	Red
12YM-3-2	109.65	42.42	13.20	3.34	Red

Table 2. Hybrid combination and hybrid codes obtained from crosses
Tablo 2. Melezlemelerden elde edilen hibrit kombinasyonları ve kodları

Hybrid code	*Hybrid combination*	*Hybrid code*	*Hybrid combination*
180 YKB	39-H-1 X 29-2-2-3	210 YKB	43-H-6 X 39-H-2
181 YKB	39-H-1 X 29-2-2-3-1	211 YKB	43-H-6 X 43-H-3
182 YKB	39-H-1 X 39-H-2	215 YKB	45-H-5 X 66 YM-8
183 YKB	39-H-1 X 39-H-16	216 YKB	45-H-5 X 10 YM-4-2
185 YKB	39-H-1 X 45-H-5	218 YKB	45-H-5 X 39-H-16
188 YKB	39-H-1 X 66 YM-8	219 YKB	45-H-5 X 12 YM-3-2
189 YKB	39-H-2 X 10 YM-4-2	220 YKB	66 YM-8 X 39 H-16
190 YKB	39-H-2 X 12 YM-3-2	221 YKB	29-2-2-3 X 66 YM-8
191 YKB	39-H-2 X 29-2-2-3	223 YKB	29-2-2-3 X 39-H-16
192 YKB	39-H-2 X 29-2-2-3-1	224 YKB	29-2-2-3-1 X 10 YM-4-2
193 YKB	39-H-2 X 43-H-3	225 YKB	29-2-2-3-1 X 12 YM-3-2
194 YKB	39-H-2 X 43-H-6	226 YKB	29-2-2-3-1 X 29-2-2-3
195 YKB	39-H-2 X 45-H-5	227 YKB	29-2-2-3-1 X 39 H-1
197 YKB	39-H-16 X 45-H-5	228 YKB	29-2-2-3-1 X 39 H-2
198 YKB	39-H-16 X 39-H-1	229 YKB	29-2-2-3-1 X 39 H-16
199 YKB	43-H-3 X 10 YM-4-2	230 YKB	29-2-2-3-1 X 43 H-3
200 YKB	43-H-3 X 12 YM-3-2	231 YKB	29-2-2-3-1 X 43 H-6
201 YKB	43-H-3 X 29-2-2-3-1	233 YKB	29-2-2-3-1 X 66 YM 8
202 YKB	43-H-3 X 39-H-1	239 YKB	10-YM-4-2 X 12 YM-3-2
203 YKB	43-H-3 X 39-H-16	240 YKB	10-YM-4-2 X 29-2-2-3-1
205 YKB	43-H-3 X 43-H-6	241 YKB	10-YM-4-2 X 43-H-3
207 YKB	43-H-3 X 66-YM-8	242 YKB	10-YM-4-2 X 45-H-5
208 YKB	43-H-6 X 10 YM-4-2	243 YKB	10-YM-4-2 X 43-H-6
209 YKB	43-H-6 X 29-2-2-3-1		

Determination of heterosis, heterobeltiosis and dominance effect

Heterosis (H1) and heterobeltiosis (H2) were calculated with the formula below.

a) H1 (%) = F1-MP/MP*100, where F1= mean value of the hybrid population; MP = mid-parent

b) H2 (%) = F1-BP/BP*100, where F1= mean value of the hybrid population; BP = better-parent

The dominance estimates (D.E.) also referred as "potence ratio" was computed using the following formula as suggested by Bhutia et al. (2015).

c) D.E. = F1− MP/0.5 × P2– P1, where F1= mean value of the hybrid population; MP = mid-parent; P2= mean of the highest parent; P1= mean of the lowest parent.

Evaluation of data and statistical analysis

Trials were set up in randomized blocks with 3 replications. The data obtained by examining the yield and technological properties of the materials used were evaluated by subjecting them to the SAS-JMP 5.0.1 statistical program and the statistically significant criteria were grouped with the Duncan multiple comparison test.

RESULTS and DISCUSSION

Yield

Heterosis, heterobeltiosis and dominance effect data on yield of pepper are presented in Table 3.

Table 3. Heterosis, heterobeltiosis and dominance effect on yield of pepper
Tablo 3. Biberde verim yönünden heterosis, heterobeltiosis oranları ve dominans etkisi

Hybrid code	Yield (kg da^{-1})						
	P1	P2	F1	MP	Heterosis	Heterobeltiosis	DE
180 YKB	5735.21	4809.50	6359.96 c-m	5272.35	20.63	10.89	2.35
181 YKB	5735.21	4342.91	6897.24 a-h	5039.06	36.88	20.26	2.67
182 YKB	5735.21	6160.04	7416.68 a-d	5947.62	24.70	20.40	6.92
183 YKB	5735.21	6982.92	6988.28 a-g	6359.06	9.89	0.08	1.01
185 YKB	5735.21	6733.02	7434.53 a-d	6234.11	19.26	10.42	2.41
188 YKB	5735.21	5164.01	6384.95 c-l	5449.61	17.16	11.33	3.28
189 YKB	6160.04	5358.93	6358.17 c-m	5759.48	10.39	3.22	1.49
190 YKB	6160.04	2334.78	6379.59 c-l	4247.41	50.20	3.56	1.11
191 YKB	6160.04	4809.50	4494.63 q-w	5484.77	-18.05	-27.04	-1.47
192 YKB	6160.04	4342.91	6845.48 a-ı	5251.47	30.35	11.13	1.75
193 YKB	6160.04	5308.59	7580.72 abc	5734.31	32.20	23.06	4.34
194 YKB	6160.04	6733.02	5417.48 j-s	6446.53	-15.96	-19.54	-3.59
195 YKB	6160.04	3096.98	7188.20 a-e	4628.51	55.30	16.69	1.67
197 YKB	6982.92	6733.02	7984.31 a	6857.97	16.42	14.34	9.01
198 YKB	6982.92	5735.21	7081.10 a-f	6359.06	11.35	1.41	1.16
199 YKB	5308.59	5358.93	6772.29 a-ı	5333.76	26.97	26.37	57.16
200 YKB	5308.59	4342.91	5633.46 h-q	4825.75	16.74	6.12	1.67
201 YKB	5308.59	4342.91	5938.70 e-o	4825.75	23.06	11.87	2.30
202 YKB	5308.59	5735.21	7013.27 a-g	5521.90	27.01	22.28	6.99
203 YKB	5308.59	6982.92	5829.81 f-p	6145.76	-5.14	-16.51	-0.38
205 YKB	5308.59	3096.98	5431.76 j-s	4202.78	29.24	2.32	1.11
207 YKB	5308.59	5164.01	4730.25 o-v	5236.30	-9.66	-10.89	-7.00
208 YKB	3096.98	5358.93	4944.45 n-v	4227.95	16.95	-7.73	0.63
209 YKB	3096.98	4342.91	6721.24 a-ı	3719.94	80.68	54.76	4.82
210 YKB	3096.98	6160.04	6072.57 e-n	4628.51	31.20	-1.42	0.94
211 YKB	3096.98	5308.59	5369.28 k-s	4202.78	27.76	1.14	1.05
215 YKB	6733.02	5164.01	6646.45 b-k	5948.51	11.73	-1.29	0.89
216 YKB	6733.02	5358.93	6176.10 d-n	6045.97	2.15	-8.27	0.19
218 YKB	6733.02	6982.92	6254.64 d-m	6857.97	-8.80	-10.43	-4.83
219 YKB	6733.02	2334.78	5883.36 f-p	4533.90	29.76	-12.62	0.61
220 YKB	5164.01	6982.92	3953.78 u-y	6073.46	-34.90	-43.38	-2.33
221 YKB	4809.50	5164.01	4274.72 s-y	4986.75	-14.28	-17.22	-4.02
223 YKB	4809.50	6982.92	6288.56 d-m	5896.21	6.65	-9.94	0.36
224 YKB	4342.91	5358.93	4081.94 t-y	4850.92	-15.85	-23.83	-1.51
225 YKB	4342.91	2334.78	5241.12 l-t	3338.84	56.97	20.68	1.89
226 YKB	4342.91	4809.50	6240.36 d-m	4576.20	36.37	29.75	7.13
227 YKB	4342.91	3096.98	5083.68 m-u	3719.94	36.66	17.06	2.19
228 YKB	4342.91	5358.93	4655.28 p-w	4850.92	-4.03	-13.13	-0.39
229 YKB	4342.91	6982.92	5706.65 h-q	5662.91	0.77	-18.28	0.02
230 YKB	4342.91	5308.59	4487.49 q-w	4825.75	-7.01	-15.47	-0.70
231 YKB	4342.91	3096.98	4289.36 s-y	3719.94	15.31	-1.23	0.91

Table 3 (devamı). Heterosis, heterobeltiosis and dominance effect on yield of pepper
Tablo 3 (continued). Biberde verim yönünden heterosis, heterobeltiosis oranları ve dominans etkisi

233 YKB	4342.91	5164.01	4205.46 s-y	4753.46	-11.53	-18.56	-1.33
239 YKB	5358.93	2334.78	6168.42 d-n	3846.85	60.35	15.11	1.54
240 YKB	5358.93	4342.91	2511.50 z	4850.92	-48.23	-53.13	-4.61
241 YKB	5358.93	5308.59	4734.53 o-v	5333.76	-11.23	-11.65	-23.81
242 YKB	5358.93	3096.98	3082.34 xyz	4227.95	-27.10	-42.48	-1.01
243 YKB	5358.93	3096.98	5403.20 k-s	4227.95	27.80	0.83	1.04

P1: Parent 1, P2: Parent 2, MP: Mid parent, DE: Dominance effect

Total soluble solid

Heterosis, heterobeltiosis and dominance effect data on total soluble solid of pepper are shown in Table 4.

Table 4. Heterosis, heterobeltiosis and dominance effect on total soluble solid (TSS) of pepper
Table 4. Biberde toplam kuru madde yönünden heterosis, heterobeltiosis oranları ve dominans etkisi

	TSS (Brix^o)						
Hybrid code	P1	P2	F1	MP	Heterosis	Heterobeltiosis	DE
180 YKB	6.80	6.08	6.13 d-s	6.44	-4.85	-9.93	-0.86
181 YKB	6.80	7.05	6.85 b-j	6.93	-1.08	-2.84	-0.60
182 YKB	6.80	5.70	6.55 b-n	6.25	4.80	-3.68	0.55
183 YKB	6.80	5.70	5.95 g-s	6.25	-4.80	-12.50	-0.55
185 YKB	6.80	7.05	7.70 ab	6.93	11.19	9.22	6.20
188 YKB	6.80	6.35	7.10 b-g	6.58	7.98	4.41	2.33
189 YKB	5.70	6.33	6.85 b-j	6.01	13.93	8.30	2.68
190 YKB	5.70	5.85	6.00 f-s	5.78	3.90	2.56	3.00
191 YKB	5.70	6.08	6.75 b-k	5.89	14.65	11.11	4.60
192 YKB	5.70	7.05	5.20 o-t	6.38	-18.43	-26.24	-1.74
193 YKB	5.70	6.60	4.98 st	6.15	-19.11	-24.62	-2.61
194 YKB	5.70	4.95	5.08 q-t	5.33	-4.69	-10.96	-0.67
195 YKB	5.70	7.05	6.13 d-s	6.38	-3.92	-13.12	-0.37
197 YKB	5.70	7.05	5.43 m-t	6.38	-14.90	-23.05	-1.41
198 YKB	5.70	6.80	6.20 c-r	6.25	-0.80	-8.82	-0.09
199 YKB	6.60	6.33	6.65 b-l	6.46	2.90	0.76	1.36
200 YKB	6.60	5.85	5.95 g-s	6.23	-4.42	-9.85	-0.73
201 YKB	6.60	7.05	6.40 c-o	6.83	-6.23	-9.22	-1.89
202 YKB	6.60	6.80	7.18 a-f	6.70	7.09	5.51	4.75
203 YKB	6.60	5.70	6.63 b-m	6.15	7.72	0.38	1.06
205 YKB	6.60	4.95	7.00 bg	5.78	21.21	6.06	1.48
207 YKB	6.60	6.35	6.40 c-o	6.48	-1.16	-3.03	-0.60
208 YKB	4.95	6.33	7.10 b-g	5.64	25.94	12.25	2.13
209 YKB	4.95	7.05	6.45 c-n	6.00	7.50	-8.51	0.43
210 YKB	4.95	5.70	5.53 l-t	5.33	3.76	-3.07	0.53
211 YKB	4.95	6.60	5.55 k-t	5.78	-3.90	-15.91	-0.27
215 YKB	7.05	6.35	6.28 c-q	6.70	-6.34	-10.99	-1.21
216 YKB	7.05	6.33	7.35 abc	6.69	9.91	4.26	1.83
218 YKB	7.05	5.70	8.35 a	6.38	30.98	18.44	2.93
219 YKB	7.05	5.85	6.35 c-p	6.45	-1.55	-9.93	-0.17
220 YKB	6.35	5.70	6.73 b-l	6.03	11.62	5.91	2.15
221 YKB	6.08	6.35	6.65 b-l	6.21	7.04	4.72	3.18

Table 4 (devamı). Heterosis, heterobeltiosis and dominance effect on total soluble solid (TSS) of pepper
Table 4 (continued). Biberde toplam kuru madde yönünden heterosis, heterobeltiosis oranları ve dominans etkisi

223 YKB	6.08	5.70	5.70 ı-t	5.89	-3.18	-6.17	-1.00
224 YKB	7.05	6.33	6.48 c-n	6.69	-3.18	-8.16	-0.59
225 YKB	7.05	5.85	6.90 b-ı	6.45	6.98	-2.13	0.75
226 YKB	7.05	6.08	6.23 c-q	6.56	-5.14	-11.70	-0.69
227 YKB	7.05	6.80	6.70 b-l	6.93	-3.25	-4.96	-1.80
228 YKB	7.05	5.70	5.18 p-t	6.38	-18.82	-26.60	-1.78
229 YKB	7.05	5.70	6.10 d-s	6.38	-4.31	-13.48	-0.41
230 YKB	7.05	6.60	4.53 t	6.83	-33.70	-35.82	-10.22
231 YKB	7.05	4.95	5.95 g-s	6.00	-0.83	-15.60	-0.05
233 YKB	7.05	6.35	6.60 b-n	6.70	-1.49	-6.38	-0.29
239 YKB	6.33	5.85	5.65 j-t	6.09	-7.19	-10.67	-1.84
240 YKB	6.33	7.05	6.30 c-p	6.69	-5.79	-10.64	-1.07
241 YKB	6.33	6.60	6.88 b-ı	6.46	6.38	4.17	3.00
242 YKB	6.33	7.05	7.30 a-d	6.69	9.16	3.55	1.69
243 YKB	6.33	4.95	5.40 n-t	5.64	-4.21	-14.62	-0.35

P1: Parent 1, P2: Parent 2, MP: Mid parent, DE: Dominance effect

When the trial was examined in terms of total soluble solid (TSS), the °Brix values changed between 8.35 and 4.52, and the difference was statistically significant (Table 4). The highest brix value was measured at the rate of 8.35% in 218 YKB F1. The °Brix of these varieties was within the range commonly reported for sweet peppers. This result is similar to Ferreira et al. (2012) who stated that the total soluble solids of sweet pepper ranged between 6.37 and 8.45°Brix in their study. Heterosis rates of F1 changed between -33.70 and 30.98%. The highest heterosis rates was found in 218 YKB. These heterosis rates are similar to AlBallat et al. (2019). Rodrigues et al. (2012) were found the highest heterosis rate as 12.93% in terms of TSS. While the number of heterosis in the negative direction was determined as 27, the number of heterosis in the positive direction was determined as 20 in terms of TSS. Considering the standard heterotic effects, the number of crosses having significant heterosis in desired direction is more than that of the crosses with heterosis in undesired direction for most of the traits is strongly suggesting that the genes with desired effect were dominating. The negative heterosis are seen in some of the crosses may be based to non-allelic interaction which can either increase or decrease the expression of heterosis (Rao et al., 2017). Heterobeltiosis rates for TSS on F1 changed from -35.82 to 18.44%. Heterosis compares the mean values of the two parents, whereas heterobeltiosis compares the best performance value of the parents (Sahid et al., 2020). Therefore, it is expected that heterobeltiosis rates are lower than heterosis rates. The over dominance has been associated with positive alleles in hybrids that exceed +1 and with negative alleles in hybrids that exceed -1.

Dry matter

Heterosis, heterobeltiosis and dominance effect data on dry matter of pepper are presented in Table 5.

Table 5. Heterosis, heterobeltiosis and dominance effect on dry matter of pepper
Table 5. Biberde kuru madde yönünden heterosis, heterobeltiosis oranları ve dominans etkisi

	Dry Matter (%)						
Hybrid code	P1	P2	F1	MP	Heterosis	Heterobeltiosis	DE
180 YKB	7.48	6.03	7.80 h-n	6.75	15.44	4.21	1.43
181 YKB	7.48	7.95	7.91 g-n	7.72	2.53	-0.50	0.83
182 YKB	7.48	5.28	10.52 a-ı	6.38	64.88	40.57	3.75
183 YKB	7.48	6.83	7.72 h-n	7.15	7.93	3.21	1.73
185 YKB	7.48	6.49	11.02 a-f	6.98	57.82	47.33	8.12
188 YKB	7.48	8.90	11.38 a-d	8.19	38.99	27.94	4.51
189 YKB	5.28	8.23	7.77 h-n	6.75	14.99	-5.65	0.69

Table 5 (devamı). Heterosis, heterobeltiosis and dominance effect on dry matter of pepper
Table 5 (continued). Biberde kuru madde yönünden heterosis, heterobeltiosis oranları ve dominans etkisi

190 YKB	5.28	9.95	9.21 d-m	7.61	20.99	-7.44	0.68
191 YKB	5.28	6.03	7.72 h-n	5.65	36.64	28.13	5.52
192 YKB	5.28	7.95	7.61 ı-n	6.61	15.09	-4.28	0.75
193 YKB	5.28	14.64	12.38 ab	9.96	24.36	-15.41	0.52
194 YKB	5.28	10.46	8.80 d-n	7.87	11.79	-15.92	0.36
195 YKB	5.28	6.49	9.80 b-k	5.88	66.67	51.12	6.48
197 YKB	6.83	6.49	9.30 c-m	6.66	39.74	36.26	15.56
198 YKB	6.83	7.48	6.63 lmn	7.15	-7.38	-11.43	-1.61
199 YKB	14.64	8.23	9.32 c-m	11.43	-18.48	-36.32	-0.66
200 YKB	14.64	9.95	9.68 b-k	12.29	-21.29	-33.89	-1.12
201 YKB	14.64	7.95	7.79 h-n	11.29	-31.06	-46.81	-1.05
202 YKB	14.64	7.48	10.01 b-j	11.06	-9.47	-31.60	-0.29
203 YKB	14.64	6.83	10.47 a-ı	10.73	-2.47	-28.49	-0.07
205 YKB	14.64	10.46	11.35 a-d	12.55	-9.58	-22.48	-0.58
207 YKB	14.64	8.90	7.15 j-n	11.77	-39.27	-51.18	-1.61
208 YKB	10.46	8.23	8.37 e-n	9.35	-10.49	-20.03	-0.88
209 YKB	10.46	7.95	10.52 a-ı	9.21	14.23	0.53	1.04
210 YKB	10.46	5.28	10.87 a-g	7.87	38.16	3.92	1.16
211 YKB	10.46	14.64	13.22 a	12.55	5.36	-9.67	0.32
215 YKB	6.49	8.90	8.75 d-n	7.69	13.72	-1.69	0.88
216 YKB	6.49	8.23	7.92 g-n	7.36	7.65	-3.77	0.64
218 YKB	6.49	6.83	9.33 c-m	6.66	40.12	36.63	15.71
219 YKB	6.49	9.95	9.03 d-n	8.22	9.89	-9.25	0.47
220 YKB	8.90	6.83	8.37 e-n	7.86	6.42	-5.96	0.49
221 YKB	6.03	8.90	7.85 h-n	7.46	5.16	-11.80	0.27
223 YKB	6.03	6.83	7.46 j-n	6.43	16.11	9.30	2.59
224 YKB	7.95	8.23	6.92 k-n	8.09	-14.52	-15.98	-8.39
225 YKB	7.95	9.95	7.07 j-n	8.95	-21.01	-28.94	-1.88
226 YKB	7.95	6.03	7.13 j-n	6.99	2.04	-10.31	0.15
227 YKB	7.95	7.48	9.69 b-k	7.72	25.60	21.89	8.40
228 YKB	7.95	5.28	6.51 o	6.61	-1.63	-18.18	-0.08
229 YKB	7.95	6.83	7.99 g-n	7.39	8.16	0.50	1.07
230 YKB	7.95	14.64	9.59 b-k	11.29	-15.08	-34.47	-0.51
231 YKB	7.95	10.46	7.47 j-n	9.21	-18.85	-28.59	-1.38
233 YKB	7.95	8.90	10.63 a-h	8.42	26.15	19.45	4.66
239 YKB	8.23	9.95	9.51 b-l	9.09	4.62	-4.42	0.49
240 YKB	8.23	7.95	9.22 d-m	8.09	13.97	12.03	8.07
241 YKB	8.23	14.64	10.44 a-ı	11.43	-8.73	-28.70	-0.31
242 YKB	8.23	6.49	8.92 d-n	7.36	21.17	8.32	1.79
243 YKB	8.23	10.46	8.69 d-n	9.35	-7.01	-16.92	-0.59

P1: Parent 1, P2: Parent 2, MP: Mid parent, DE: Dominance effect

Fruit dry matter is very important for pepper processing industry and best materials for processing purposes should show the highest percentage of dry matter (Singh et al. 2015). Results of the current experiment on dry matter ratios varied between 6.13% and 13.22% ($p<0.01$). The hybrid with the highest value in terms of dry matter was determined to be 211 YKB. Heterosis rates varied from -39.27 to 66.67% (Table 5). While heterosis rate was determined in positive direction in 31 combinations, it was detected in negative direction in 16 combinations. Highest heterosis rate was calculated as 66.67% of 195 YKB. Singh et al. (2015) were determined heterosis of a low magnitude (−9.65% to 2.19%) for dry matter in pepper. They revealed that the some hybrids with high heterosis rate involved low × low GCA parents, revealing the importance of complementary gene action in heterosis expression whereas the other ones involved either one or both good combiner parents. Heterobeltiosis rates were calculated as lower than heterosis rates as in other features. Heterobeltiosis rates ranged between -51.18 and 51.12%. Data presented in Table 5 show that 16 crosses in dry matter had positive values with significant or highly significant heterosis over the midparents. The estimated values of dominance effect for dry matter changed from -8.39 to 15.71. In hybrids with high heterosis and heterobeltiosis rates, the estimates of dominance effect generally exceeded +1. These results show the over dominance effect in these combinations. These results also are in agreement with the studies of Bhutia et al. (2015) and Kumar et al. (2017). Generally, 39-H-2 X 45-H-5, 39-H-1 X 39-H-2, 39-H-1 X 45-H-5 were identified as the best heterotic cross combinations in terms of dry matter.

In conclusion, heterosis and heterobeltiosis for selection should also be considered in the assembly of hybrid cultivars through breeding activities. If hybrid cultivars have the best heterosis and heterobeltiosis values but poor performance, they cannot be easily utilized as hybrid cultivars (Sahid et al. 2020). On the other hand parent lines showing low performance are able to produce hybrids with high degree of heterosis (Andrade Júnior et al. 2018). Heterobeltiosis helps in identifying the superior cross combinations and their exploitation to get better transgressive segregants. In the utilization of hybrid vigor in commercial crops, only that vigor in excess of the better parent is of significance (Rohini and Lakshmanan, 2017). In this study, heterosis rates were highly positive direction in terms of all three characteristics. The highest rates of heterosis and heterobeltiosis occurred in terms of yield. As a result of the study, 39-H-2, 43-H-6 and 45-H-5 were determined as the best parents giving the highest heterosis rates in crosses.

ÖZET

Amaç: Bu çalışmanın amacı, kapya tipi kırmızı biberin verim, toplam çözünür madde ve kuru maddesi üzerine heterosis, heterobeltiosis ve dominans etkisini belirlemektir.

Yöntem ve Bulgular: Çalışmada 11 kapya tipi kırmızı biber ebeveyni ve bu ebeveynlerin melezlerinden elde edilen 47 hibrit materyal olarak kullanılmıştır. Meyve verimi yönünden heterosis oranları -48.23 ile 80.68 arasında değişmiştir. En yüksek heterosis sırasıyla 209 YKB (%80.68), 239 YKB (%60.35), 225 YKB (%56.97) ve 195 YKB'de (%55.30) tespit edilmiştir. Toplam çözünür madde açısından heterosis oranları -33.70 ile 30.98 arasında değişmiştir. En yüksek heterosis oranı 218 YKB'de belirlenmiştir. Kuru madde bakımından en yüksek heterosis oranı ise 195 YKB'de %66,67 olarak hesaplanmıştır. Çalışma sonucunda hibritlerde en yüksek heterosis oranları veren ebeveynler genel olarak 39-H-2, 43-H-6 ve 45-H-5 olarak belirlenmiştir.

Genel Yorum: Bu çalışmada heterosis oranları her üç özellik açısından da yüksek oranda pozitif yönde tespit edilmiştir. Heterosis kullanımı biberlerde verim ve diğer ekonomik özelliklerin artırılmasında pratik bir yöntem olarak gösterilebilir.

Çalışmanın Önemi ve Etkisi: Elde edilen bu sonuçlar istenen özellikler bakımından öne çıkan çeşitlerin belirlenmesinde kullanılabilecektir.

Anahtar Kelimeler: Biber, heterosis, heterobeltiosis, dominans etkisi, verim.

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STATEMENT OF CONFLICT OF INTEREST

The author(s) declare no conflict of interest for this study.

AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

REFERENCES

Abrham S, Mandefro N, Sentayehu A (2017) Heterosis and heterobeltiosis study of hot pepper (*Capsicum annuum* L.) genotypes in Southern Ethiopia. Int. J. Plant Breed. 11: 63-70.

AlBallat IA, Ahmed ME, Ommran S, Alkadah KAG (2019) Heterosis, combining ability and heritability of fruit yield and quality traits in blocky yellow sweet pepper. Egypt. J. Plant Breed. 23(6): 1267-1297.

Andrade Junior VC, Pedrosa CE, Miranda TG, Valadares NR, Pereira SL, Azevedo AM (2018) Biometric evaluation of morpho-agronomic traits in pepper lines and hybrids. Hortic. Bras. 36: 357-361.

Anonymous (2020) FAO Crops and livestock products. Retrieved February 15, 2022 from https://www.fao.org/faostat/en/#data/QCL

Bhutia ND, Seth T, Shende VD, Dutta S, Chattopadhyay, A (2015) Estimation of heterosis, dominance effect and genetic control of fresh fruit yield, quality and leaf curl disease severity traits of chilli pepper (*Capsicum annuum* L.). Sci. Hortic. 182: 47-55.

Chakrabarty S, Islam AKM, Mian MA, Ahamed T (2019) Combining ability and heterosis for yield and related traits in chili. Open Agric. 13(1).

Ferreira TAPC, Valadares KO, Souza MJF, Santana JQ, Balbino MP, Ferreira RC (2012) Yellow and red sweet pepper quality under photoselective screens and field crop conditions. In VII International Symposium on Light in Horticultural Systems 956: 473-479.

Ganefianti DW, Fahrurrozi F (2018) Heterosis and combining ability in complete diallel cross of seven chili pepper genotypes grown in ultisol. Agrivita Journal of Agricultural Science 40(2): 360-370.

al A, Balkaya A (2021) *Capsicum baccatum* türüne ait biber popülasyonunun karakterizasyonu ve morfolojik varyasyon düzeyinin belirlenmesi. MKU. Tar. Bil. Derg. 26(2): 278-291.

Khalil MR, Hatem MK (2014) Study on combining ability and heterosis of yield and its components in pepper (*Capsicum annum* L.). Alex. J. Agric. Res. 59(1): 61-71.

Kumar S, Kumar R, Kumar D, Gautam N, Singh N, Parkash C, Shukla YR (2017) Heterotic potential, potence ratio, combining ability and genetic control of yield and its contributing traits in cucumber (*Cucumis sativus* L.). N. Z. J. Crop Hortic. Sci. 45(3): 175-190.

Naves ER, Scossa F, Araújo WL, Nunes-Nesi A, Fernie AR, Zsögön A (2022) Heterosis and reciprocal effects for agronomic and fruit traits in *Capsicum* pepper hybrids. Sci. Hortic. 295: 110821.

Pérez-Grajales M, González-Hernández VA, Peña-Lomelí A, Sahagún-Castellanos J (2009) Combining ability and heterosis for fruit yield and quality in manzano hot pepper (*Capsicum pubescens* R & P) landraces. Revista Chapingo. Serie Horticultura 15(1): 103-109.

Rao PG, Reddy KM (2017) Exploitation of mid parent heterosis in bell pepper (*Capsicum annuum* L.) for yield and yield attributing traits. Agric. Res. J. 54(1): 117-119.

Rodrigues R, Gonçalves LS, Bento CDS, Sudré CP, Robaina RR, do Amaral Júnior AT (2012) Combining ability and heterosis for agronomic traits in chili pepper. Hortic. Bras. 30: 226-233.

Rohini N, Lakshmanan V (2017) Heterotic expression for dry pod yield and its components in chilli (*Capsicum annuum* var. *annuum*). J. Anim. Plant Sci. 27(1).

Sahid ZD, Syukur M, Maharijaya A (2020) Combining ability and heterotic effects of chili pepper (*Capsicum annuum* L.) genotypes for yield components and capsaicin content. Sabrao J. Breed. Genet. 52(4): 390-401.

Shrestha SL, Luitel BP, Kang WH (2011) Heterosis and heterobeltiosis studies in sweet pepper (*Capsicum annuum* L.). Hortic. Environ. Biotechnol. 52(3): 278-283.

Singh P, Cheema DS, Dhaliwal MS, Garg N, Jindal SK, Chawla N (2015) Combining ability and heterosis for quality and processing traits in chili pepper (*Capsicum annuum* L.) involving male sterile lines. J. Crop Improv. 29(4): 379-404.

Soames I, Cıulca A, Madosa E, Cıulca S (2021) Estimation of heterosis and potence ratio for plant yield in hot pepper. Life Science and Sustainable Development 2(2): 82-87.

Yilmaz N, Sari N (2012) Heterosis effect on plant growth fruit, yield and quality in single, triple and double crosses of melon (*Cucumis melo* var. *cantalupensis*) Hybrids. In Yilmaz N, Sari N, editors. Proceeding of the Xth EUCARPIA Meeting on Genetics and Breeding of Cucurbitaceae (pp. 535-543).