

FULL DIALLEL ANALYSIS OF PEA CULTIVARS FOR SEED WEIGHT AND ITS COMPONENTS UNDER KURDISTAN REGION-IRAQ CONDITION

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ABSTRACT

The present study was carried out at Grjan Agricultural Research Station and Qaladze Agricultural Research Station, College of Agricultural Engineering Sciences-University of Raparin, Kurdistan Region-Iraq, during the growing seasons 2020 and 2021. According to the full diallel mating system using five pea (*Pisum sativum* L.) cultivars (Legacy, Rainer, Topaz, P₁₁, P₁₃) with 20 F₁ crosses. The genotypes were planted in a RCBD with 3 replicates. Highly significant mean squares due to genotypes for all traits were recorded in both locations. The mean squares due to the GCA were highly significant for all of the traits except for number of days to 50% flowering which was significant at Grjan, but at Qaladze it was highly significant for number of days to maturity, pod length, seeds weight pod⁻¹, and 100-seed weight. The mean squares due to SCA were highly significant for all of the traits except for 100-seed weight which was significant and was not significant for number of seeds pod⁻¹ and seeds weight pod⁻¹ at Grjan, but at Qaladze it was highly significant for all of the traits except for significant pod length, and it was not significant for seeds weight pod⁻¹. The highest positive heterosis value for seeds weight plant⁻¹ at Grjan was 177.445% recorded by the diallel cross 3×4, while at Qaladze it was 210.431% recorded by the diallel cross 1×3. The reciprocal cross 5×3 had the maximum heterosis value for seeds weight plant⁻¹ at 78.300%, while at Qaladze it was 199.713% recorded by the reciprocal cross 5×2. The maximum positive GCA effect values for most of the traits were recorded by the parent P₁₃ at both locations. The dominance gene effect controlled the inheritance of most of the traits of both locations.

Keywords: Combining ability, heterosis, heritability, gene action, *Pisum sativum*, genetic analysis.

احمد وآخرون

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التضريب التبادلي الكامل للباذلاء المزروعة لوزن البذور ومكوناتها في بيئة إقليم كردستان العراق

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باحث

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المستخلص

أجريت هذه الدراسة في محطة كرجان للبحوث الزراعية ومحطة قلعة دزة للبحوث الزراعية، كلية علوم الهندسة الزراعية – جامعة رابرين، إقليم كردستان العراق، خلال موسمي النمو 2020 و2021. وفقاً لنظام التزاوج الكامل باستعمال خمسة أصناف من البازلاء (Legacy, Rainer, Topaz, P₁₁, P₁₃) مع 20 هجن من الجيل الأول. زرعت الطرز الوراثية في RCBD بثلاث مكررات. تم تسجيل مجموع مربعات عالية المعنوية بسبب الأنماط الجينية لجميع الصفات في كلا الموقعين. كان متوسط المربعات بسبب GCA معنوياً جداً لجميع الصفات باستثناء عدد الأيام إلى 50% من التزهير الذي كان معنوياً في كرجان، ولكن في قلعة دزة كان معنوياً جداً لعدد الأيام حتى النضج وطول القرون ووزن البذور قرنة⁻¹، ووزن 100 بذرة. كان متوسط المربعات الناتجة عن SCA معنوياً للغاية لجميع الصفات باستثناء وزن 100 بذرة والذي كان معنوياً ولم يكن معنوياً لعدد البذور قرنة⁻¹ ووزن البذور قرنة⁻¹ في كرجان، ولكنه كان معنوياً جداً لجميع الصفات باستثناء طول القرون حيث كان معنوياً، ولم يكن معنوياً لوزن البذور قرنة⁻¹. أعلى قيمة تغاير موجبة لوزن البذور نبات⁻¹ في كرجان كانت 177.445% سجلت بواسطة الهجين 3×4 بينما في قلعة دزة كانت 210.431% سجلت بواسطة الهجين 1×3. أعطى الهجين العكسي 3×5 أقصى قيمة تغايرية لوزن البذور نبات⁻¹ عند 78.300% بينما في قلعة دزة كانت 199.713% مسجلة بواسطة الهجين العكسي 5×2. تم تسجيل القيم القصوى لتأثير GCA الإيجابي لمعظم الصفات بواسطة الأب P₁₃ في كلا الموقعين. يتحكم تأثير الجين السائد في وراثية معظم الصفات كلا الموقعين.

الكلمات المفتاحية: القدرة على الأكتلاف، التغاير الوراثي، درجة التوريث، الفعل الجيني، *Pisum sativum*، التحليل الوراثي.



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INTRODUCTION

Pea (*Pisum sativum* L.) is the second most important legume crop for seed production in the world after dry beans. Seed Pea has high-level protein, amino acids, minerals, and vitamins and it is used for canning or baking. Pea is also an important grain legume for crop rotation because of providing nitrogen and organic matter to the soil (2, 5, 23, 39). For any breeding program, genetic variability plays an important role as it provides an opportunity to plant breeders to the selection of high-yielding genotypes (8). The most important aim for pea breeding is developing high-yielding cultivars with stable productivity. Its improvement is mainly based on exploiting natural germplasm sources by selection or hybridization followed by selection. Heritability is the portion of phenotypic variation that is transmitted from parent to progeny. Highly heritable variation leads to great possibility of fixing trait by selection methods (1, 31, 32, 34). Diallel analysis provides a systematic approach for the identification of superior parents and crosses which are the basic material on which the success of the breeding program rests (20). The diallel analysis helps intersect the suspect of the GCA and SCA. This analysis is very helpful to predict the additive and dominant effects of a population which can then be used to predict genetic variability and heritability (37). Heterosis in the F_1 generation is of great importance in vegetable crops as heterotic crosses may give transgressive segregants for economic traits in advanced generations (16). The study of heterosis in self-pollinated crops offers an opportunity to breeders for identifying promising crosses in the early generation that can give transgressive segregants in later segregating generations. Nowadays, the utilization of hybrid vigour and selection of parents based on combining ability has opened new vistas in plant breeding (20). The most important phenomena in plants are hybrid vigour, which is not clearly understood (3). Combining ability analysis on the basis of a diallel mating system is one of the most appropriate methods to recognize the best combiners, which could be utilized for a hybridization program. It gives information about the nature of gene action and the relative

magnitudes of fixable (additive) and non-fixable (non-additive/dominance) genetic variations (20). Therefore, the present investigations were carried out to obtain information regarding general and specific combining ability effects and finding out heterotic combinations for yield and yield attributing traits in garden peas (16). The gene combination effects are a pointer for evaluating the selection value of the parental components and is used widely in breeding and applied genetic research. A diallel method of crossing based on the data of F_1 hybrids is an accurate method for its determination (6, 12, 13). Plant breeding is a continuous process and the knowledge of the genetic constitution of the population handled is quite essential for the breeder in a hybridization program to decide on suitable parents. Among the several biometrical methods developed to identify superior parents for heterosis breeding, the diallel analysis has received considerable attention. It is a technique employed to gain information on hybrid vigour, combination ability and nature of gene action from the study of the first generation itself. Combining ability refers to the capacity or ability of a genotype to transmit its superior performance to its crosses. The GCA was attributed to the additive effect of gene and SCA to dominant deviations and epistatic interactions (4, 10, 14). The main objective of the present investigation is to estimate the degree of heterosis for seeds weight and its components for different cross combinations, find the combination having high yield potential to be used in the further breeding program, and develop high-yielding varieties with stable yields.

MATERIALS AND METHOD

This study was conducted in two growing seasons (2020 and 2021). At the first season (2020), the hybridization was carried out at experimental fields of the Grjan Research Station, Agricultural Research Station, (Lat. $36^{\circ} 12' 11''$; N, Lon. $44^{\circ} 47' 03''$; E, 543 MASL) 115 km north-west of Sulaimani city, at Kurdistan Region-Iraq in three planting dates with ten days intervals in order to overcome the differences in flowering time between parents to succeed in the hybridization during the suitable duration. The

varieties have been crossed to produce 20 F_0 crosses according to the Full Diallel Mating System. In the second growing season (2021), The seeds of twenty crosses along with their parents were seeded at Grjan Research Station and Qaladze Agricultural Research Station, College of Agricultural Engineering Sciences-University of Raparin in Randomized Complete Block Design (RCBD) with three replicates (Table 1). Each plot consisted of two rows of each genotype with 3 m long, 50 cm between the rows, 20 cm between the plants within the row, 1m between the plots within each replicate, and 2.5 m between the replicates. Five plants from each plot were took in random for recording the observations

to evaluate studied traits, number of days to 50% flowering, number of days to maturity, number of pods plant⁻¹, weight of pods plant⁻¹, pod length, number of seeds pod⁻¹, seeds weight pod⁻¹, 100-seed weight and weight of seeds plant⁻¹. The analysis of variance and combining ability analysis were computed using the methods suggested by Kempthorne (22). Heterosis was worked out over better parent and standard variety (Rachna) and their significance was determined by t-test as suggested by Mohamad and Ahmad (27) and Rai and Rai (28) Least significant difference (LSD) test was used to compare the genotype means.

Table 1. Parents and the crosses details

No.	Crosses, and Parental No.	Parentage
1	1	Legacy
2	2	Rainer
3	3	Topaz
4	4	P ₁₁
5	5	P ₁₃
6	1×2	Legacy × Rainer
7	2×1	Rainer × Legacy
8	1×3	Legacy Topaz
9	3×1	Topaz × Legacy
10	1×4	Legacy × P ₁₁
11	4×1	P ₁₁ × Legacy
12	1×5	Legacy × P ₁₃
13	5×1	P ₁₃ × Legacy
14	2×3	Rainer × Topaz
15	3×2	Topaz × Rainer
16	2×4	Rainer × P ₁₁
17	4×2	P ₁₁ × Rainer
18	2×5	Rainer × P ₁₃
19	5×2	P ₁₃ × Rainer
20	3×4	Topaz × P ₁₁
21	4×3	P ₁₁ × Topaz
22	3×5	Topaz × P ₁₃
23	5×3	P ₁₃ × Topaz
24	4×5	P ₁₁ × P ₁₃
25	5×4	P ₁₃ × P ₁₁

RESULTS AND DISCUSSION

The analysis of variance displayed in Table (2) was carried out to determine the genotypes' significant differences. Both General and specific combining ability variances and their effects were identified. Highly significant differences among the genotypes were recorded for all of the studied traits, which showed a wide range of diversity among the genotypes in both locations (Grjan and Qaladze). This demonstrates that genotypes exhibit sufficient genetic variability. Additive and non-additive gene effects were significant for the inheritance of various traits according to the estimations of GCA and SCA variances. Other researchers (40) obtained significant and highly significant mean squares for all the yield and its components for the different

genotypes. The mean squares due to the GCA were highly significant for all of the traits except for number of days to 50% flowering which were significant at Grjan location, but at Qaladze location the mean squares due to the GCA were highly significant for the traits number of days to maturity, pod length, seeds weight pod⁻¹, and 100-seed weight while showing significant differences for number of days to 50% flowering, number of pods plant⁻¹, weight of pods plant⁻¹, number of seeds pod⁻¹ and seeds weight plant⁻¹. The mean squares due to the SCA were highly significant for all of the traits except for 100-seed weight which was significant and was not significant for number of seeds pod⁻¹ and seeds weight pod⁻¹ at Grjan location, while at Qaladze location it was highly significant for all of the traits

except for pod length which was significant and it was not significant for seeds weight pod^{-1} . The mean square of SCA values for number of days to 50% flowering at both locations as well as for number of pods plant^{-1} , number of seeds pod^{-1} and seeds weight plant^{-1} , at Qaladze location was higher than the GCA mean squares values. Joshi *et al.* (20) recorded that the mean squares due to GCA and SCA were found to be significant for all of the traits except for the mean squares due to GCA for days to maturity and number of primary branches. The GCA has been equated with additive gene action and SCA with non-

additive gene action (15). Regarding the mean squares due to the RCS, they were highly significant for number of days to 50% flowering, number of days to maturity, and seeds weight pod^{-1} , but it was significant for number of seeds pod^{-1} and 100-seed weight, and it was not significant for number of pods plant^{-1} , weight of pods plant^{-1} , pod length and seeds weight plant^{-1} at Grjan location, while at Qaladze location number of days to 50% flowering, number of days to maturity, number of pods plant^{-1} and seeds weight plant^{-1} were highly significant and it was not significant for the others.

Table 2. Mean squares of variance analysis across locations

S.O.V	d.f	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant^{-1}	Weight of pods plant^{-1} (g)	Pod length (cm)	Number of seeds pod^{-1}	Seeds weight pod^{-1} (g)	100-seed weight (g)	Seeds weight plant^{-1} (g)
Blocks	2	Grjan	32.213	13.293	91.692	345.517	0.088	0.064	0.002	3.454	349.241
		Qaladze	21.613	3.360	2.572	15.004	0.125	0.520	0.006	4.620	16.026
Genotypes	24	Grjan	40.083**	38.337**	418.664**	971.494**	0.905**	0.840**	0.112**	16.883**	731.796**
		Qaladze	44.124**	46.463**	60.655**	254.692**	0.548**	0.644**	0.100**	26.153**	127.710**
GCA	4	Grjan	4.178*	17.774**	270.770**	604.607**	1.285**	0.665**	0.106**	23.739**	397.821**
		Qaladze	8.214*	15.537**	8.361*	106.407*	0.574**	0.218*	0.129**	42.536**	33.664*
SCA	10	Grjan	10.084**	13.460**	188.765**	464.756**	0.138**	0.174 ^{ns}	0.019 ^{ns}	1.987*	359.583**
		Qaladze	8.297**	14.266**	25.757**	96.084**	0.147*	0.328**	0.020 ^{ns}	2.444**	55.614**
RCS	10	Grjan	20.311**	10.100**	37.870 ^{ns}	70.587 ^{ns}	0.015 ^{ns}	0.231*	0.028**	2.024*	66.725 ^{ns}
		Qaladze	23.717**	16.694**	19.423**	65.107 ^{ns}	0.61 ^{ns}	0.100 ^{ns}	0.008 ^{ns}	1.464 ^{ns}	33.088**
Exp. Error	48	Grjan	3.755	11.127	88.222	184.515	0.127	0.267	0.29	2.532	127.031
		Qaladze	7.983	9.818	7.683	97.546	0.203	0.207	0.033	2.537	28.370
MS _e		Grjan	1.252	3.709	29.407	61.505	0.042	0.89	0.010	0.844	42.344
		Qaladze	2.561	3.273	2.561	32.515	0.068	0.069	0.011	0.846	9.457

The mean performance of the genotypes represents in Table (3). At Grjan location, the reciprocal cross 5×4 produced the minimum value for number of days to 50% flowering with 98.667 days, whilst the reciprocal cross 5×2 produced the maximum value for number of days to maturity with 166.000 days. The reciprocal cross 4×1 produced the highest value for number of pods plant^{-1} with 64.200. The cross 1×3 had the maximum pod length of 7.273 cm followed by the reciprocal cross 5×3 with 7.253cm. The cross 2×3 exhibited the highest value for number of seeds pod^{-1} reaching 7.400 followed by the cross 5×3 with 7.300. The reciprocal cross 5×3 produced the highest values for pods weight plant^{-1} , seeds weight pod^{-1} , 100-seed weight, and seeds weight plant^{-1} with 93.990, 2.049, 27.373, and 78.300g respectively. According to the parental value at Grjan location, Topaz recorded the lowest value for number of days to 50% flowering with 109.667 days. Rainer recorded the highest value for number of days to maturity with 166.333 days. Legacy exhibited the highest value for pod length with

6.780 followed by Rainer with 6.627cm. Rainer showed the highest value for number of seeds pod^{-1} with 6.867 seeds. P₁₃ obtained the highest values for number of pods plant^{-1} , pods weight plant^{-1} , seeds weight pod^{-1} , 100-seed weight, and seeds weight plant^{-1} with 34.443, 58.357, 1.579, 26.667, and 47.020 respectively. At Qaladze location, the reciprocal cross 5×4 produced the minimum value for number of days to 50% flowering with 114.000 days. The reciprocal cross 5×3 obtained the highest value for number of days to maturity with 181.333 days. The cross 4×5 produced the highest value for pods weight plant^{-1} with 50.140. The cross 1×5 recorded the maximum values for number of pod plant^{-1} , pod length and seeds weight plant^{-1} with 22.533, 7.173cm and 29.847g respectively. The cross 2×5 exhibited the highest value for number of seeds pod^{-1} recorded 6.667 followed by cross 1×3 with 6.600. The cross 5×4 produced the highest value for seeds weight pod^{-1} , with 1.677 followed by cross 1×5 with 6.676. The cross 5×3 produced the highest value for 100-seed weight with 27.557.

These results were in agreement with the results achieved by (11, 40). Regarding the parental values at Qaladze location, Topaz recorded the lowest value for number of days to 50% flowering with 120.333. Rainer showed the highest value for number of days to maturity recorded 180.000 days. P₁₁ recorded the highest values for number of pods plant⁻¹ and number of seeds pod⁻¹ with 11.689

and 6.667 respectively. Legacy recorded the highest value for pod length with 6.587. P₁₃ gave the highest values for pods weight plant⁻¹, seeds weight pod⁻¹, 100-seed weight, and seeds weight plant⁻¹ with 16.210, 1.684, 29.913, and 11.812 respectively. In the previous investigation, the mean values due to the F₁ hybrids and their parents recorded various values for yield and its components (13, 40).

Table 3. The mean values of the studied traits across locations

Crosses	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Weight of pods plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
1×2	Grjan	112.000	161.333	30.777	41.480	6.760	6.733	1.385	19.627	35.603
	Qaladze	119.667	174.333	13.556	17.260	6.367	5.800	1.183	21.720	14.221
1×3	Grjan	112.667	159.333	34.557	55.373	7.273	6.467	1.729	24.103	47.503
	Qaladze	126.333	171.333	19.167	31.143	6.933	6.600	1.539	22.723	25.747
1×4	Grjan	110.000	161.333	58.890	78.780	6.180	6.100	1.309	21.313	66.870
	Qaladze	118.667	172.667	12.442	15.921	5.880	6.000	1.320	22.750	13.088
1×5	Grjan	112.000	156.333	40.600	63.537	6.800	5.800	1.424	25.603	54.213
	Qaladze	121.333	171.667	22.533	35.247	7.173	6.400	1.676	25.010	29.847
2×3	Grjan	111.333	160.000	38.247	56.250	6.533	7.400	1.611	20.653	51.623
	Qaladze	123.333	172.333	17.780	20.657	6.660	6.200	1.341	20.133	11.722
2×4	Grjan	114.333	155.667	51.000	60.277	5.907	6.400	1.341	21.410	51.780
	Qaladze	123.667	170.333	14.663	18.490	6.153	5.933	1.271	19.733	15.080
2×5	Grjan	111.667	157.667	49.557	79.777	6.800	6.333	1.613	23.043	71.807
	Qaladze	123.333	171.667	21.110	31.960	6.633	6.667	1.675	24.897	27.100
3×4	Grjan	112.333	155.333	54.833	85.583	6.067	6.700	1.687	23.460	74.360
	Qaladze	119.667	170.667	17.677	24.263	5.987	6.033	1.457	21.553	20.023
3×5	Grjan	117.333	164.333	47.833	74.987	6.533	6.533	1.673	24.637	64.130
	Qaladze	125.667	174.667	14.000	26.587	6.033	6.467	1.641	25.424	19.937
4×5	Grjan	116.667	161.667	63.557	83.680	5.600	5.800	1.331	20.497	72.487
	Qaladze	127.000	173.333	20.223	50.140	6.473	5.767	1.552	25.593	23.067
2×1	Grjan	117.667	162.667	41.443	49.283	6.853	7.267	1.467	18.930	41.510
	Qaladze	134.000	182.333	16.220	23.193	7.040	6.200	1.325	19.500	19.267
3×1	Grjan	113.333	163.333	43.780	61.753	6.773	6.800	1.407	21.307	52.053
	Qaladze	121.000	177.000	11.112	16.146	6.547	6.200	1.423	20.943	12.969
4×1	Grjan	113.333	160.333	64.200	81.493	5.867	6.267	1.220	20.703	70.027
	Qaladze	120.333	178.333	22.443	28.243	5.920	6.400	1.390	21.527	23.452
5×1	Grjan	110.000	156.000	50.390	77.280	7.100	7.267	1.761	23.613	65.977
	Qaladze	121.333	176.333	9.284	20.157	6.847	5.600	1.585	26.077	11.781
3×2	Grjan	108.333	157.667	31.000	51.557	6.653	6.967	1.463	20.320	44.087
	Qaladze	118.000	173.667	15.667	20.340	5.973	6.400	1.269	19.593	17.017
4×2	Grjan	113.000	162.333	47.223	57.517	5.900	5.800	1.331	20.860	58.503
	Qaladze	121.667	179.333	13.999	18.197	5.993	6.000	1.421	22.187	14.479
5×2	Grjan	110.667	166.000	47.860	69.770	6.213	5.867	1.433	24.170	58.580
	Qaladze	119.667	179.000	22.110	33.320	6.633	6.267	1.454	22.687	28.150
4×3	Grjan	113.333	158.333	39.510	62.633	5.953	5.867	1.359	22.943	50.240
	Qaladze	124.333	170.333	14.890	21.510	5.947	5.467	1.468	23.227	19.180
5×3	Grjan	112.667	160.000	48.623	93.990	7.253	7.300	2.049	27.373	78.300
	Qaladze	124.667	181.333	14.110	22.117	5.973	6.000	1.487	27.557	17.923
5×4	Grjan	98.667	155.667	52.180	73.867	5.907	5.867	1.495	24.787	64.057
	Qaladze	114.000	171.667	15.003	24.983	6.387	6.133	1.677	25.523	20.833
1	Grjan	115.667	163.333	29.333	38.290	6.780	6.333	1.304	20.703	31.703
	Qaladze	126.333	168.667	11.558	14.669	6.587	6.133	1.213	19.793	11.640
2	Grjan	113.000	166.333	27.057	34.743	6.627	6.867	1.335	18.823	29.310
	Qaladze	122.333	180.000	8.554	8.843	6.100	6.000	1.069	20.247	6.972
3	Grjan	109.667	152.000	16.533	22.773	5.707	6.267	1.404	21.077	20.103
	Qaladze	120.333	169.000	5.778	6.274	5.533	6.067	1.105	18.167	4.948
4	Grjan	114.333	160.667	32.067	39.863	5.133	6.000	1.254	20.053	33.500
	Qaladze	121.000	175.333	11.689	14.790	5.787	6.667	1.273	19.413	11.687
5	Grjan	112.667	158.000	34.443	58.357	6.193	5.867	1.579	26.667	47.020
	Qaladze	121.000	171.667	11.112	16.210	6.380	4.400	1.684	29.913	11.812
Diallel mean	Grjan	113.033	159.300	46.985	67.972	6.445	6.427	1.510	22.435	59.038
	Qaladze	122.867	172.300	17.315	27.167	6.429	6.187	1.466	22.954	19.983
The reciprocal mean	Grjan	111.100	160.233	46.621	67.914	6.447	6.527	1.499	22.501	58.333
	Qaladze	121.900	176.933	15.484	22.821	6.326	6.067	1.450	22.882	18.505
General mean	Grjan	112.267	159.827	43.020	62.116	6.375	6.435	1.479	22.267	53.414
	Qaladze	122.347	174.280	15.067	22.426	6.318	6.072	1.420	22.636	17.278
LSD (p≤0.05)	Grjan	3.181	5.476	15.420	22.300	0.585	0.848	0.884	2.612	18.503
	Qaladze	4.638	5.144	4.550	16.214	0.740	0.747	0.298	2.615	8.744
LSD (p≤0.01)	Grjan	4.244	7.305	20.570	29.748	0.780	1.132	1.179	3.485	24.683
	Qaladze	6.188	6.862	6.070	21.630	0.987	0.996	0.398	3.488	11.665

The estimation of heterosis values for the traits is calculated as the percentage of F_1 s deviation from mid-parental values for both diallel and the reciprocal crosses represent in Table (4). At Grjan location, the cross 3×5 produced the maximum positive heterosis values for number of days to 50% flowering and number of days to maturity reached 5.547 and 6.022%, while the cross 3×4 showed the highest positive heterosis values for the trait's number of pods plant⁻¹, pods weight plant⁻¹ and seeds weight plant⁻¹ with 125.652, 173.269 and 177.445% respectively. The cross 1×3 recorded the highest positive heterosis values for pod length, seeds weight pod⁻¹, and 100-seed weight with 16.498, 27.671, and 15.382 % respectively. Number of seeds pod⁻¹ recorded 12.690% by the cross 2×3. The previous study recorded significant positive and negative heterosis according to cross for all of the traits, while some of the crosses were observed as superior for the heterosis (16). Regarding the reciprocal crosses, 2×1 produced the maximum positive heterosis value for number of days to 50% flowering reached 2.915%. The reciprocal cross 3×1 exhibited the highest heterosis value for number of days to maturity reaching 3.594%. The reciprocal cross 4×1 produced the maximum positive heterosis value for number of pods plant⁻¹ with 109.121%. The highest heterosis values for the trait's pods weight plant⁻¹, pod length, number of seeds pod⁻¹, seeds weight pod⁻¹, 100-seed weight, and seeds weight plant⁻¹ were 131.702, 21.905, 20.330, 37.416, 14.669, and 133.302% produced by the reciprocal cross 5×3 respectively. The maximum negative heterosis values at Grjan location, the reciprocal cross 5×2 showed the highest negative heterosis value for pod length with -3.068, and the cross 4×5 gave -6.048 and -12.257 for seeds weight pod⁻¹ and 100-seed weight respectively. The reciprocal cross 4×2 obtained -9.845 for number of seeds pod⁻¹. Concerning Qaladze location, the cross 4×5 showed the maximum positive heterosis values for number of days to 50% flowering and pods weight plant⁻¹ with 4.959% and 223.484% respectively. The cross 3×5 showed the maximum positive heterosis value for number of days to maturity with 2.544%. Also, the maximum positive heterosis values for number of pods plant⁻¹ and pod

length were 148.110 and 14.499% respectively recorded by the cross 2×3. The highest heterosis value for number of seeds pod⁻¹ was 28.205% produced by the cross 2×5. The cross 1×3 gave the highest positive heterosis values for seeds weight pod⁻¹ and 100-seed weight and seeds weight plant⁻¹ with 32.816, 19.723, and 210.431% respectively. Regarding to the reciprocal crosses, the cross 2×1 showed the maximum positive heterosis value for number of days to 50% flowering and pod length were 7.775 and 10.983% respectively, while for number of days to maturity, it was 6.458 % produced by the cross 5×3. The maximum positive heterosis values number of pods plant⁻¹, number of seeds pod⁻¹, and seeds weight plant⁻¹ were recorded by the cross 5×2 with 124.847, 20.513, and 199.713% respectively. The cross 3×2 obtained the highest positive heterosis value for pods weight plant⁻¹ with 169.089%. The cross 4×3 showed the maximum positive heterosis values for seeds weight pod⁻¹ and 100-seed weight with 23.465 and 23.612% respectively. The positive heterosis values reveal the effect of the over-dominance gene actions for the parent of the higher value (17, 25, 39). Regarding the negative heterosis value at Qaladze location, the cross 1×4 obtained the highest negative heterosis value for pod length with -4.957, the reciprocal cross 4×3 recorded the highest negative heterosis value for number of seeds pod⁻¹ with -14.136 and the reciprocal cross 5×2 recorded the highest negative heterosis value for 100-seed weight with -9.543. For number of days to 50% flowering the maximum negative heterosis values were recorded by the cross 1×4 with -4.348 and -4.043% at Grjan and Qaladze locations respectively, and the reciprocal cross 5×4 the maximum negative heterosis values were recorded by the with -13.069 and -5.785% at Grjan and Qaladze locations respectively, indicating the early flowering for this cross. Moreover, for number of days to maturity, the cross 2×4 exhibited the maximum negative heterosis value of -4.791 and -4.128% at Grjan and Qaladze locations respectively, indicating that the early maturity can be exploited for the early yield for this cross. In addition, the negative heterosis values reflect the partial dominance genes effect for the parent with a

lower value. These results agree with those found by Abo-Hamda (1), Askander *et al.* (7), Galal *et al.* (11), Gharib (13), Zyada and Bardisi (40) who estimated heterosis in some

studied crosses for yield and its components. Other researchers reported the behavior of negative and positive heterosis values for pea yield and its components (18, 19, 21).

Table 4. Heterosis percentage of the diallel and the reciprocal crosses across locations

Crosses	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Pods weight plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
1×2	Grjan	-2.041	-2.123	9.156	13.592	0.845	2.020	5.003	-0.692	16.707
	Qaladze	-3.753	0.000	34.802	46.817	0.368	-4.396	3.710	8.492	52.813
1×3	Grjan	0.000	1.057	50.683	81.364	16.498	2.646	27.671	15.382	83.387
	Qaladze	2.432	1.481	121.124	197.406	14.411	8.197	32.816	19.723	210.431
1×4	Grjan	-4.348	-0.412	91.824	101.604	3.749	-1.081	2.320	4.588	105.112
	Qaladze	-4.043	0.388	7.046	8.089	-4.957	-6.250	6.223	16.052	12.212
1×5	Grjan	-1.898	-2.697	27.319	31.482	4.830	-4.918	-1.203	8.099	37.731
	Qaladze	-1.887	0.881	98.794	128.289	10.643	21.519	15.719	0.630	154.530
2×3	Grjan	0.000	0.524	75.484	95.595	5.946	12.690	17.624	3.525	108.945
	Qaladze	1.648	-1.242	148.110	173.279	14.499	2.762	23.299	4.825	96.683
2×4	Grjan	0.587	-4.791	72.521	61.585	0.454	-0.518	3.580	10.143	64.878
	Qaladze	1.644	-4.128	44.871	56.474	3.533	-6.316	8.511	-0.487	61.638
2×5	Grjan	-1.034	-2.775	61.160	71.378	6.084	-0.524	10.709	1.312	88.148
	Qaladze	1.370	-2.370	114.678	155.136	6.303	28.205	21.695	-0.731	188.533
3×4	Grjan	0.298	-0.640	125.652	173.269	11.931	9.239	26.963	14.077	177.445
	Qaladze	-0.829	-0.871	102.401	130.374	5.771	-5.236	22.568	14.706	140.747
3×5	Grjan	5.547	6.022	87.668	84.856	9.804	7.692	12.159	3.205	91.081
	Qaladze	4.144	2.544	65.775	136.491	1.287	23.567	17.639	5.757	137.908
4×5	Grjan	2.790	1.464	91.119	70.393	-1.118	-2.247	-6.048	-12.257	80.046
	Qaladze	4.959	-0.096	77.387	223.484	6.411	4.217	4.983	3.771	96.320
S.E diallel crosses	Grjan	0.861	0.948	10.717	13.615	1.745	1.780	3.608	2.528	13.703
	Qaladze	0.980	0.609	13.814	21.814	1.957	4.207	3.051	2.304	19.785
2×1	Grjan	2.915	-1.314	46.988	34.961	2.238	10.101	11.218	-4.217	36.069
	Qaladze	7.775	4.589	61.297	97.287	10.983	2.198	16.155	-2.597	107.031
3×1	Grjan	0.592	3.594	90.901	102.260	8.489	7.937	3.890	1.995	100.952
	Qaladze	-1.892	4.837	28.202	54.184	8.031	1.639	22.807	10.344	56.369
4×1	Grjan	-1.449	-1.029	109.121	108.547	-1.511	1.622	-4.613	1.595	114.795
	Qaladze	-2.695	3.682	93.089	91.747	-4.310	0.000	11.856	9.811	101.077
5×1	Grjan	-3.650	-2.905	58.020	59.923	9.455	19.126	22.202	-0.303	67.617
	Qaladze	-1.887	3.624	-18.091	30.553	5.604	6.329	9.459	4.922	0.468
3×2	Grjan	-2.695	-0.942	42.234	79.276	7.892	6.091	6.865	1.855	78.440
	Qaladze	-2.747	-0.478	118.620	169.089	2.693	6.077	16.738	2.013	185.515
4×2	Grjan	-0.587	-0.714	59.745	54.186	0.340	-9.845	2.807	7.314	86.287
	Qaladze	0.000	0.938	38.307	53.992	0.841	-5.263	21.378	11.884	55.196
5×2	Grjan	-1.920	2.364	55.642	49.882	-3.068	-7.853	-1.602	6.265	53.491
	Qaladze	-1.644	1.801	124.847	165.993	6.303	20.513	5.617	-9.543	199.713
4×3	Grjan	1.190	1.279	62.593	99.989	9.840	-4.348	2.232	11.565	87.451
	Qaladze	3.039	-1.065	70.493	104.231	5.065	-14.136	23.465	23.612	130.607
5×3	Grjan	1.349	3.226	90.767	131.702	21.905	20.330	37.416	14.669	133.302
	Qaladze	3.315	6.458	67.078	96.730	0.280	14.650	6.597	14.628	113.882
5×4	Grjan	-13.069	-2.301	56.909	50.411	4.297	-1.124	5.578	6.107	59.107
	Qaladze	-5.785	-1.057	31.600	61.183	4.986	10.843	13.416	3.487	77.313
S.E the reciprocal crosses	Grjan	1.413	0.733	6.918	10.100	2.303	3.310	3.957	1.787	9.298
	Qaladze	1.239	0.850	13.849	14.612	1.373	3.129	2.051	2.952	19.060

The estimation of the reciprocal effect values for the reciprocal crosses in both locations represents in Table 5. At Grjan location, the cross 2×1 produced the maximum positive reciprocal effect values for number of days to 50% flowering and number of pods plant⁻¹ with 5.060 and 34.658% respectively, whilst the maximum negative reciprocal effect values

for number of days to 50% flowering, number of days to maturity and number of pods plant⁻¹ with -15.429, -3.711 and -17.900, also the highest positive value for 100-seed weight with 20.930 recorded by the reciprocal cross 5×4. The reciprocal cross 5×2 produced the maximum positive and negative reciprocal effect for number of days to maturity, pods

weight plant⁻¹, and pod length with 5.285, -12.543, and -8.627 respectively, while for number of seeds pod⁻¹ and seeds weight pod⁻¹, the maximum positive reciprocal effect values was 25.287 and 23.689 % produced by the reciprocal cross 5×1, also the reciprocal cross 4×3 recorded the maximum negative reciprocal effect values for number of pod plant⁻¹, weight of pod plant⁻¹, number of seeds pod⁻¹, seeds weight pod⁻¹ and seeds weight plant⁻¹ with -27.945, -26.816, -12.438, -19.478 and -32.437, while the highest positive values for pods weight plant⁻¹, pod length, and seeds weight plant⁻¹ were 25.342, 11.020 and 22.096% produced by the reciprocal cross 5×3. The reciprocal cross 3×1 produced the maximum negative reciprocal effect value for 100-seed weight reached -11.603%. At Qaladze location, the highest positive reciprocal effect values for number of days to 50% flowering, pod length, number of seeds pod⁻¹ and seed weight pod⁻¹ were 11.978, 10.576, 6.897% and 12.000 produced by the cross 2×1, while for

number of pods plant⁻¹, pods weight plant⁻¹, and seeds weight plant⁻¹ were 80.379, 77.397 and 79.194% exhibited by the cross 4×1, but the cross 4×2 produced the maximum positive reciprocal effect values for number of days to maturity, seeds weight pod⁻¹ and 100-seed weight with 5.284, 11.857 and 12.432% respectively. The presence of the differences between the reciprocal and the diallel crosses for the same trait confirms the presence of the maternal effect due to this trait. Concerning The maximum negative reciprocal effect values for number of days to 50% flowering and pods weight plant⁻¹ which were -10.236 and -50.173 recorded by the cross 5×4, whilst for number of pods plant⁻¹, number of seeds pod⁻¹ and seeds weight plant⁻¹ were -58.797, -12.500 and -60.528 exhibited by the reciprocal cross 5×1. For pod length with -10.310 produced by 3×2, for seeds weight pod⁻¹ was -13.211 recorded by 5×2, and for 100-seed weight with -10.221 exhibited by 2×1.

Table 5. The reciprocal effect values of the reciprocal crosses across locations

The reciprocal crosses	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Pods weight plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
2×1	Grjan	5.060	0.826	34.658	18.812	1.381	7.921	5.919	-3.550	16.590
	Qaladze	11.978	4.589	19.655	34.376	10.576	6.897	12.000	-10.221	35.480
3×1	Grjan	0.592	2.510	26.690	11.522	-6.874	5.155	-18.627	-11.603	9.578
	Qaladze	-4.222	3.307	-42.023	-48.157	-5.577	-6.061	-7.536	-7.833	-49.628
4×1	Grjan	3.030	-0.620	9.017	3.444	-5.070	2.732	-6.775	-2.862	4.721
	Qaladze	1.404	3.282	80.379	77.397	0.680	6.667	5.303	-5.377	79.194
5×1	Grjan	-1.786	-0.213	24.113	21.631	4.412	25.287	23.689	-7.772	21.698
	Qaladze	0.000	2.718	-58.797	-42.813	-4.554	-12.500	-5.410	4.265	-60.528
3×2	Grjan	-2.695	-1.458	-18.947	-8.344	1.837	-5.856	-9.147	-1.614	-14.599
	Qaladze	-4.324	0.774	-11.886	-1.533	-10.310	3.226	-5.321	-2.682	45.165
4×2	Grjan	-1.166	4.283	-7.405	-4.579	-0.113	-9.375	-0.746	-2.569	12.984
	Qaladze	-1.617	5.284	-4.531	-1.586	-2.600	1.124	11.857	12.432	-3.985
5×2	Grjan	-0.896	5.285	-3.424	-12.543	-8.627	-7.368	-11.120	4.889	-18.420
	Qaladze	-2.973	4.272	4.737	4.255	0.000	-6.000	-13.211	-8.877	3.875
4×3	Grjan	0.890	1.931	-27.945	-26.816	-1.868	-12.438	-19.478	-2.202	-32.437
	Qaladze	3.900	-0.195	-15.765	-11.348	-0.668	-9.392	0.732	7.764	-4.212
5×3	Grjan	-3.977	-2.637	1.652	25.342	11.020	11.735	22.519	11.108	22.096
	Qaladze	-0.796	3.817	0.786	-16.813	-0.994	-7.216	-9.386	8.388	-10.099
5×4	Grjan	-15.429	-3.711	-17.900	-11.727	5.476	1.149	12.375	20.930	-11.630
	Qaladze	-10.236	-0.962	-25.812	-50.173	-1.339	6.358	8.033	-0.274	-9.682
S.E	Grjan	1.750	0.944	6.754	5.491	1.906	3.661	4.985	3.010	6.015
	Qaladze	1.854	1.118	12.097	12.594	1.765	2.388	2.896	2.548	13.309

The estimation of the specific combining ability effect ($\hat{s}_{ij}$) for the diallel crosses represent in Table 6. At Grjan location, the maximum positive $\hat{s}_{ij}$ values for number of days to 50% flowering, number of days to maturity, pod length, number of seeds pod⁻¹ and seeds weight pod⁻¹ recorded by the cross 3×5 with 3.700, 4.393, 0.363, 0.445 and 0.167 respectively, while for number of pods plant⁻¹, pods weight plant⁻¹ and seeds weight plant⁻¹ were 12.682, 17.341 and 14.614 respectively

recorded by the cross 1×4. Maximum positive $\hat{s}_{ij}$ values for 100-seed weight recorded by the cross 1×3 with 1.410. The cross 4×5 recorded the highest negative $\hat{s}_{ij}$ effect value for number of days to 50% flowering and 100-seed weight with -3.600 and -1.405. The maximum negative $\hat{s}_{ij}$ value due to number of days to maturity was -4.107 exhibited by the cross 1×5, while for number of seeds pod⁻¹, the cross 2×5 gave the highest negative $\hat{s}_{ij}$ value of -0.365. At Qaladze location, the cross 3×5

produced the maximum positive $\hat{s}_{ij}$ values for number of days to 50% flowering and number of days to maturity, with 3.247 and 5.047 respectively, while the highest positive $\hat{s}_{ij}$ values for number of pods plant⁻¹, number of seeds pod⁻¹ and seeds weight plant⁻¹ they were 5.396, 0.582 and 8.587 respectively. The maximum negative value for 100-seed weight was -0.926 produced by the cross 2×5. The cross 1×5 recorded the maximum positive $\hat{s}_{ij}$ value for pod length with 0.248 but for seeds weight pod⁻¹ it was 0.152 produced by the cross 1×3. The highest positive $\hat{s}_{ij}$ value for

weight of pod plant⁻¹ with 9.162 produced by the cross 4×5, while for 100-seed weight it was 1.185 produced by the cross 3×4. The positive values of $\hat{s}_{ij}$ effect indicated that the contributions of these parents are important in increasing the values of these traits in their crosses. Also, the maximum negative $\hat{s}_{ij}$ values due to number of days to 50% flowering and pod length were -2.820 and -0.402 respectively recorded by 1×4, for number of days to maturity was -1.953 produced by 2×3, whilst for number of seed pod⁻¹ was -0.435 obtained by 3×4.

Table 6. The estimation of specific combining abilities effect ($\hat{s}_{ij}$) for the diallel crosses across locations

$\hat{s}_{ij}$	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Pods weight plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
1×2	Grjan	1.367	-0.507	-2.323	-4.598	-0.023	0.248	0.043	-0.781	-4.957
	Qaladze	2.847	2.180	-0.254	0.878	0.068	-0.221	-0.020	0.168	0.558
1×3	Grjan	-0.733	1.227	1.380	4.988	0.137	-0.225	0.063	1.410	4.096
	Qaladze	-2.087	0.213	0.214	3.922	0.106	0.192	0.152	0.854	3.304
1×4	Grjan	-1.333	0.727	12.682	17.341	-0.083	0.001	-0.046	0.007	14.614
	Qaladze	-2.820	1.913	2.051	-0.289	-0.402	0.019	-0.022	0.698	0.925
1×5	Grjan	-1.467	-4.107	-0.764	0.608	0.149	0.181	0.047	0.509	1.434
	Qaladze	-1.753	-0.153	-0.071	0.770	0.248	0.115	0.052	-0.064	0.500
2×3	Grjan	-2.467	-1.173	1.376	3.712	0.035	0.311	0.006	-0.607	3.807
	Qaladze	-2.153	-1.953	2.973	3.283	0.157	0.075	0.034	-0.344	0.108
2×4	Grjan	1.400	-1.973	3.457	1.117	0.026	-0.195	0.025	1.128	3.812
	Qaladze	1.080	-0.920	-1.295	-2.473	-0.006	-0.215	0.048	0.409	-1.298
2×5	Grjan	-0.567	0.693	5.657	9.989	-0.065	-0.365	-0.023	0.502	9.037
	Qaladze	-0.853	-0.987	5.396	7.263	0.094	0.582	0.065	-0.926	8.578
3×4	Grjan	1.000	-0.773	3.494	11.101	0.175	-0.019	0.065	1.166	7.931
	Qaladze	0.847	-1.887	2.283	2.649	0.141	-0.435	0.089	1.185	4.180
3×5	Grjan	3.700	4.393	7.154	14.477	0.363	0.445	0.167	0.871	12.020
	Qaladze	3.247	5.047	-0.533	-0.446	-0.282	0.345	-0.011	1.118	0.540
4×5	Grjan	-3.600	-0.073	4.387	1.173	-0.096	-0.062	-0.060	-1.405	1.794
	Qaladze	-0.187	-1.253	1.149	9.162	0.225	0.105	0.013	-0.157	1.744
S.E	Grjan	1.001	1.723	4.850	7.015	0.184	0.267	0.088	0.822	5.820
	Qaladze	1.431	1.618	1.431	5.100	0.233	0.235	0.094	0.823	2.751

The estimation of the specific combining ability of the reciprocal crosses is represented in Table 7. At Grjan location, the maximum positive $\hat{r}_{ij}$ values for number of days to 50% flowering and number of days to maturity produced by the cross 5×4 recording 9.000 and 3.000 respectively, while for number of pods plant⁻¹, pods weight plant⁻¹, number of seeds pod⁻¹, seeds weight pod⁻¹ and seeds weight plant⁻¹ they were 7.662, 11.475, 0.417, 0.164 and 12.060 respectively recorded by the cross 4×3. The cross 5×2 showed the maximum positive $\hat{r}_{ij}$ for pod length with 0.293. The cross 3×1 recorded the maximum positive $\hat{r}_{ij}$ value for 100-seed weight with 1.398. The maximum negative $\hat{r}_{ij}$ values for number of

days to 50% flowering, number of pods plant⁻¹ were recorded by the cross 2×1 with -2.833 and -5.333 respectively, whilst the cross 5×3 recorded the maximum negative $\hat{r}_{ij}$ values for pods weight plant⁻¹, pod length, seeds weight pod⁻¹ and seeds weight plant⁻¹ with -9.502, -0.360, -0.188 and -7.085 respectively and for 100-seed weight it was -2.145 recorded by the cross 5×4. Concerning $\hat{r}_{ij}$ values at Qaladze location, the cross 5×4 exhibited the maximum positive $\hat{r}_{ij}$ values for number of days to 50% flowering, number of days to maturity, and pods weight plant⁻¹ with 6.500, 0.833, and 12.578 respectively, but for pod length, it was recorded by the cross 3×2 with 0.343. The maximum positive $\hat{r}_{ij}$ values for number of

pods plant⁻¹, number of seeds pod⁻¹, and seeds weight plant⁻¹ were 6.625, 0.400, and 9.033 respectively, and recorded by the cross 5×1. The cross 2×1 gave the maximum positive $\hat{r}_{ij}$ value for 100-seed weight with 1.110. The maximum negative values due to $\hat{r}_{ij}$ for number of days to 50% flowering and pod length were -7.167 and -0.337 respectively recorded by the cross 2×1, while for number of days to maturity, seeds weight pod⁻¹ and 100-seed weight they were -4.500, -0.075 and -

1.227 recorded by 4×2, and for number of pods plant⁻¹, pods weight plant⁻¹, and seeds weight plant⁻¹ they were -5.001, -6.161 and -5.182 respectively recorded by 4×1. Both crosses 2×1 and 4×1 recorded the same value with -0.200 for number of seeds pod⁻¹. The positive values of $\hat{r}_{ij}$ effect indicated that the contributions of these parents are important in increasing the values of these traits in their crosses.

Table 7. The estimation of specific combining abilities effect of the reciprocal crosses ($\hat{r}_{ij}$) across locations

$\hat{r}_{ij}$	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Pods weight plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
2×1	Grjan	-2.833	-0.667	-5.333	-3.902	-0.047	-0.267	-0.041	0.348	-2.953
	Qaladze	-7.167	-4.000	-1.332	-2.967	-0.337	-0.200	-0.071	1.110	-2.523
3×1	Grjan	-0.333	-2.000	-4.612	-3.190	0.250	-0.167	0.161	1.398	-2.275
	Qaladze	2.667	-2.833	4.027	7.499	0.193	0.200	0.058	0.890	6.389
4×1	Grjan	-1.667	0.500	-2.655	-1.357	0.157	-0.083	0.044	0.305	-1.578
	Qaladze	-0.833	-2.833	-5.001	-6.161	-0.020	-0.200	-0.035	0.612	-5.182
5×1	Grjan	1.000	0.167	-4.895	-6.872	-0.150	-0.733	-0.169	0.995	-5.882
	Qaladze	0.000	-2.333	6.625	7.545	0.163	0.400	0.045	-0.533	9.033
3×2	Grjan	1.500	1.167	3.623	2.347	-0.060	0.217	0.074	0.167	3.768
	Qaladze	2.667	-0.667	1.057	0.158	0.343	-0.100	0.036	0.270	-2.647
4×2	Grjan	0.667	-3.333	1.888	1.380	0.003	0.300	0.005	0.275	-3.362
	Qaladze	1.000	-4.500	0.332	0.147	0.080	-0.033	-0.075	-1.227	0.301
5×2	Grjan	0.500	-4.167	0.848	5.003	0.293	0.233	0.090	-0.563	6.613
	Qaladze	1.833	-3.667	-0.500	-0.680	0.000	0.200	0.111	1.105	-0.525
4×3	Grjan	-0.500	-1.500	7.662	11.475	0.057	0.417	0.164	0.258	12.060
	Qaladze	-2.333	0.167	1.393	1.377	0.020	0.283	-0.005	-0.837	0.422
5×3	Grjan	2.333	2.167	-0.395	-9.502	-0.360	-0.383	-0.188	-1.368	-7.085
	Qaladze	0.500	-3.333	-0.055	2.235	0.030	0.233	0.077	-1.066	1.007
5×4	Grjan	9.000	3.000	5.688	4.907	-0.153	-0.033	-0.082	-2.145	4.215
	Qaladze	6.500	0.833	2.610	12.578	0.043	-0.183	-0.062	0.035	1.117
S.E	Grjan	1.119	1.926	5.423	7.843	0.205	0.299	0.098	0.919	6.507
	Qaladze	1.600	1.809	1.600	5.702	0.260	0.262	0.105	0.920	3.075

The estimation of the general combining ability effect for the parents across locations represents in Table 8. Data respect to $\hat{g}_{ii}$ values for the characters, positive and negative values due to this effect were represented. At Grjan location, the maximum positive GCA effect for pods weight plant⁻¹, seeds weight pod⁻¹, 100-seed weight, and seeds weight plant⁻¹ were 11.244, 0.115, 2.439, and 8.945 respectively produced by P₁₃, while for number of days to 50% flowering and pod length, they were produced by Legacy with 0.967 and 0.342. Rainer showed the maximum positive GCA effect value for number of days to maturity with 1.773. Topaz showed the highest positive value for number of seeds

pod⁻¹ with 0.222, but for number of pods plant⁻¹ exhibited by P₁₁ with 6.533. The maximum negative GCA effect value for most of the traits produced by both Rainer and P₁₁. Rainer exhibited the maximum negative GCA effect value for pods weight plant⁻¹, 100-seed weight, and seeds weight plant⁻¹ with -8.576, -1.601, and -6.203 respectively, while P₁₁ showed the maximum negative GCA effect value for pod length, number of seeds pod⁻¹ and seeds weight pod⁻¹ with -0.610, -0.355 and -0.121 respectively. At Qaladze location, P₁₃ showed the maximum positive GCA effect value for most of the traits including number of pods plant⁻¹, pods weight plant⁻¹, seeds weight pod⁻¹, 100-seed weight, and seeds weight plant⁻¹

with 0.993, 5.267, 0.191, 3.624 and 2.949 respectively, while for number of days to 50% flowering and pod length the maximum positive GCA effect values produced by Legacy with 1.187 and 0.270 respectively. Several negative values were produced by Topaz. The positive value of GCA indicates the tendency of these parents to increase the value of this trait, while the negative GCA value indicates the ability of these parents to

reduce the value of this trait. Previous study recorded high SCA effect due to yield and its components (40). Kumar *et al.* (24); Manjunath *et al.* (26) and Suman *et al.* (36) observed that determined the general and specific combining abilities which were important for horticultural traits. A diallel method of crossing based on the data of F_1 hybrids is an accurate method for it.

Table 8. The estimation of general combining abilities effect ($\hat{g}_{ii}$) of the parents across locations

$\hat{g}_{ii}$	Locations	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Pods weight plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
1	Grjan	0.967	0.907	-0.689	-3.560	0.342	0.102	-0.048	-0.606	-3.698
	Qaladze	1.187	-0.147	-0.080	-0.762	0.270	0.075	-0.033	-0.652	0.087
2	Grjan	0.233	1.773	-3.898	-8.576	0.113	0.215	-0.047	-1.601	-6.203
	Qaladze	0.453	2.020	0.154	-2.316	0.048	0.075	-0.112	-1.541	-1.180
3	Grjan	-0.200	-1.593	-5.875	-3.348	0.071	0.222	0.100	0.428	-3.164
	Qaladze	0.020	-1.347	-1.471	-2.895	-0.206	0.078	-0.036	-0.887	-1.836
4	Grjan	-0.233	-0.627	6.533	4.240	-0.610	-0.355	-0.121	-0.659	4.118
	Qaladze	-1.213	-0.547	0.405	0.706	-0.286	0.035	-0.010	-0.544	-0.020
5	Grjan	-0.767	-0.460	3.929	11.244	0.085	-0.185	0.115	2.439	8.945
	Qaladze	-0.447	0.020	0.993	5.267	0.174	-0.262	0.191	3.624	2.949
S.E	Grjan	0.500	0.861	2.425	3.507	0.092	0.133	0.044	0.411	2.910
	Qaladze	0.716	0.809	0.716	2.550	0.116	0.117	0.047	0.411	1.375

The estimation of the same genetic parameters across locations represents in Table 9. At Grjan location, the ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ for all of the traits was less than unity the except for pod length, seeds weight pod⁻¹, and 100-seed weight. These results indicate the high contribution of the non-additive gene effect controlling the inheritance of all traits except to additive gene effect for the inheritance of pod length, seeds weight pod⁻¹, and 100-seed weight. The ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ was less than unity for all traits in the previous work (33). The average degree of dominance for the diallel crosses for all of the traits was more than unity except for pod length, number of seeds pod⁻¹, seeds weight pod⁻¹, and 100-seed weight. The result confirms the importance of overdominance gene action of almost all of the traits, while for the reciprocal crosses the estimation of the average degree of dominance was less than unity for all of the traits except for number of days to 50% flowering, number of days to maturity and number of seeds pod⁻¹. Heritability in broad sense for the diallel and the reciprocal crosses were high for all of the traits, while for narrow sense due to the diallel crosses it was high for pod length, seeds weight pod⁻¹ and 100-seed weight and it was low for the rest of the traits. Regarding the

reciprocal crosses, heritability in narrow sense was high for all of the traits except for number of days to 50% flowering and number of days to maturity, moderate for number of seeds pod⁻¹. At Qaladze location, the estimation of the ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ was less than unity for all of the traits except for seeds weight pod⁻¹, and 100-seed weight, while the average degree of dominance for the diallel crosses was more than unity for all of the traits except for pod length, seeds weight pod⁻¹, and 100-seed weight. Also, the average degree of dominance for the reciprocal crosses was more than unity for all of the traits except for pod length, seeds weight pod⁻¹, and 100-seed weight. In a previous investigation on field peas, the average degree of dominance showed overdominance for all of the traits except for plant height (35). The average degree of dominance was more than one for all of the traits indicating the importance of the non-additive gene effect in controlling the inheritance of these traits (30). Heritability in broad sense for the diallel crosses was high for all of the traits, while for the reciprocal crosses, it was high for all of the traits except for number of seeds pod⁻¹. Heritability in narrow sense for the diallel crosses was found to be low for all of the traits except for seeds

weight pod⁻¹ and 100-seed weight, while for the reciprocal crosses, it was high for pod length, seeds weight pod⁻¹ and 100-seed weight and low for the other traits. These results indicated the importance of the non-additive gene effect in controlling the inheritance of almost all traits concerning

additive gene effect for inheritance of pod length, seeds weight pod⁻¹ and 100-seed weight. In a previous study heritability in broad sense was found to be high in most studied traits. Heritability in narrow sense was high for the traits number of days to 50% flowering, and physiological maturity (29).

Table 9. The estimation of some genetic parameters across locations

Parameters	Location	Number of days to 50% flowering	Number of days to maturity	Number of pods plant ⁻¹	Weight of pod plant ⁻¹ (g)	Pod length (cm)	Number of seeds pod ⁻¹	Seeds weight pod ⁻¹ (g)	100-seed weight (g)	Seeds weight plant ⁻¹ (g)
MSe ^c	Grjan	1.252	3.709	29.407	61.505	0.042	0.089	0.010	0.844	42.344
	Qaladze	2.561	3.273	2.561	32.515	0.068	0.069	0.011	0.846	9.457
σ_{gca}^2	Grjan	0.293	1.4066	24.133	54.310	0.124	0.058	0.010	2.289	35.548
	Qaladze	0.565	1.2264	0.580	7.389	0.051	0.015	0.012	4.169	2.421
$\sigma_{sca}^2 = \sigma_D^2$	Grjan	8.833	9.751	159.358	403.260	0.096	0.085	0.009	1.143	317.239
	Qaladze	5.736	10.989	23.196	63.568	0.079	0.259	0.009	1.598	46.157
$\sigma_{gca}^2/\sigma_{sca}^2$	Grjan	0.033	0.144	0.151	0.135	1.292	0.675	1.023	2.003	0.112
	Qaladze	0.099	0.112	0.025	0.116	0.638	0.057	1.339	2.608	0.052
σ_A^2	Grjan	0.585	2.813	48.266	108.620	0.249	0.115	0.019	4.579	71.095
	Qaladze	1.131	2.453	1.160	14.778	0.101	0.030	0.024	8.338	4.842
$\sigma_{Dr}^2 = 2\sigma_{rca}^2$	Grjan	9.530	3.196	4.231	4.541	0.015	0.071	0.009	0.590	12.191
	Qaladze	10.578	6.711	8.431	16.296	-0.003	0.016	-0.001	0.309	11.816
$\bar{a}$	Grjan	3.885	1.862	1.817	1.927	0.622	0.861	0.699	0.500	2.112
	Qaladze	2.252	2.117	4.472	2.074	0.885	2.952	0.611	0.438	3.088
$h_{b.s}^2$	Grjan	0.890	0.883	0.772	0.876	0.893	0.891	0.692	0.748	0.871
	Qaladze	0.728	0.804	0.905	0.707	0.727	0.808	0.748	0.922	0.844
$h_{n.s}^2$	Grjan	0.055	0.173	0.204	0.189	0.642	0.398	0.502	0.697	0.165
	Qaladze	0.120	0.147	0.043	0.133	0.408	0.083	0.545	0.773	0.080
$\bar{a}r$	Grjan	5.707	1.507	0.419	0.289	0.344	1.111	0.982	0.508	0.586
	Qaladze	4.326	2.339	3.813	1.485	0.258	1.021	0.345	0.272	2.209
$h_{b.s.r}^2$	Grjan	0.890	0.618	0.641	0.648	0.862	0.676	0.747	0.860	0.663
	Qaladze	0.821	0.737	0.789	0.489	0.591	0.397	0.670	0.911	0.638
$h_{n.s.r}^2$	Grjan	0.051	0.289	0.589	0.622	0.814	0.418	0.504	0.762	0.566
	Qaladze	0.079	0.197	0.095	0.232	0.611	0.261	0.712	0.878	0.185

CONCLUSIONS

In conclusion, the analysis of variance revealed significant differences among the genotypes for all of the study traits, indicating a wide range of genetic diversity among the genotypes in both locations. The study also identified significant effects of both general and specific combining abilities on the inheritance of various traits, with significant differences observed for both additive and non-additive gene effects. The mean squares due to the RCS were also found to be highly significant for some traits, indicating the importance of the environment in the expression of these traits. The cross 5×3 exhibited the highest positive heterosis value for pods weight plant⁻¹, pod length, number of seeds pod⁻¹, seeds weight pod⁻¹, 100-seed weight, and seeds weight plant⁻¹. The results also showed that negative heterosis values were observed in some crosses, indicating the partial dominance genes effect for the parent with a lower value. The study highlights the potential of reciprocal crosses to improve the

yield and quality of pea crops. The non-additive gene effects play a significant role in controlling the inheritance of most of the studied traits, except for pod length, seeds weight pod⁻¹, and 100-seed weight, which are mainly controlled by additive gene effects. The importance of overdominance gene action was confirmed for almost all traits, and the high heritability in broad sense for both diallel and reciprocal crosses suggests that these traits can be successfully improved through selection. However, heritability in narrow sense varied among traits and between diallel and reciprocal crosses, indicating that careful selection strategies need to be employed for each trait. Overall, the study suggests that there is significant genetic variability among the genotypes studied, and both additive and non-additive gene effects play important roles in the inheritance of various traits, these findings provide useful insights for the genetic improvement of field pea cultivar

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

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