INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 18, No. 6, p. 77-86, 2021
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

Combining ability studies for yield and related traits in garden pea

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Article published on June 30, 2021

Key words: F_1 hybrids, Garden pea, Combining ability, Gene actions

Abstract

Combining ability potential of the eight parents crossed in 8 × 8 full-diallel fashion and their 56 derived F_1 hybrids were estimated to identify superior parents, desirable cross combinations and to fig. out mode of gene action for yield and related traits. Parental pea genotypes and F_1 hybrids were planted in randomized complete block design with three replications at The University of Agriculture Peshawar-Pakistan during 2018-2019 pea-crop growing season. Mean squares due to general combining ability (GCA) and specific combining ability (SCA) effects were observed significant ($p \leq 0.01$) for most of the studied traits which indicated the importance of both additive and non-additive gene actions in controlling their expression. The SCA variances were observed higher in magnitude than those of corresponding GCA variances, resultantly with GCA/SCA ratio of lesser than unity for seeds pod^{-1}, 100-green seed weight and green pod yield depicting the importance of non-additive gene action in the inheritance of these characters. Leena Pak was identified as the good general combiner for days to first picking (-11.52) and plant height (-27.25) while UAP-29 appeared as the good general combiner for pods plant^{-1} (7.57). Highest GCA effects for seeds pod^{-1} (0.53), and green pod yield (10.16) were manifested by UAP-47. F_1 cross combination UAP-47 × UAP-29 manifested the highest SCA effects for seeds pod^{-1} (1.31) and green pod yield (14.10). The genetic potential of the parental genotypes Leena Pak, UAP-29 and UAP-47 while F_1 cross UAP-47 × UAP-29 for the desired traits could be exploited in pea hybridization programs.

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Introduction

Garden pea is a well-known winter vegetable which is cultivated in the temperate regions of the world (Ceyhan and Avci, 2005). It belongs to family Leguminoseae (Fabaceae). The genus *Pisum* has five species namely *fulvum, abyssinicum, sativum, humile* and *elatius*. Cultivated forms of *P. sativum* have different morphological intra-specific types, which have been developed for different end-uses. Some types (field pea) are used for livestock feeding as above ground mass or dry seed, while other (garden pea) are used for human consumption as immature pods (Cupic *et al.*, 2009). Garden pea ranks third in production among food legumes after soybean and beans in the world. Asia is the largest pea producing sub-continent, contributing about 88.3% of global production in green peas. It is one of the prominent winter vegetables grown in Pakistan and is cultivated on 27.0 thousand hectares with production of 178.23 thousand tons. The cultivars grown in Pakistan are having low yield and quality. Average green pod yield of peas in Pakistan is quite low (6.60 t ha^{-1}) when compared with other pea producing countries where the average production is above 10 t ha^{-1} (FAOSTAT, 2018).

It is self-pollinated crop and diploid with 2n chromosome number of 14. The inflorescence is a raceme arising from the leaf axil. Shoot apical meristem on transitionn to flowering bears lateral compound leaves with leaflets and tendrils producing an axillary inflorescence meristem. Once plant initiates flowering, the first node is called as first blossom node, whereas the subsequent nodes are termed floral nodes (Sinjushin and Belyakova, 2015). First blossom node is constant for a given genotype and is used in characterizing cultivars. The flowers per raceme are genetically controlled and may vary from variety to variety. Most garden pea varieties bear one or two flowers per node (Bassett, 1986).

Development of superior crop varieties needs selection of parental genotypes capable of transferring their desirable characters to their progenies. A rational approach for crop breeding is to select parents based on their combining ability potential rather than phenotypic performance *per se*. Combining ability studies provide valuable details about the selection of parental genotypes to be used in hybridization programs. General combing ability (GCA) provides information on the importance of genes with largely additive effects while specific combining ability (SCA) depicts the significance of non-additive effects (Ceyhan and Avci, 2005). The knowledge about the nature and extent of genetic diversity within a crop species is crucial for an effective crop breeding program.

It is useful for the genotypes characterization and parent's selection for the hybridization program to have sufficient genetic diversity within a crop (Dharmendra *et al.*, 2018). Genetic variability for the desired traits plays an essential role in the crop improvement programs to develop desired commercial cultivars (Tiwari and Lavanya, 2012; Pallavi and Pandey, 2013). Development of superior crop varieties needs selection of parental genotypes capable of transferring their desirable characters to their progenies. Combining ability studies provide valuable information for the identification of superior parental genotypes to be used in hybridization programs. General combing ability (GCA) provides information on the importance of genes with largely additive effects while specific combining ability (SCA) depicts the importance of non-additive effects (Ceyhan and Avci, 2005). High GCA estimates depicts superior parental potential for particular traits and indicates the flow of desirable genes from parents to progeny at greater intensity (Franco *et al.*, 2001).

Desirable GCA effects for traits imply that parental genotypes possess favorable alleles for the traits and would transmit their favorable characters to their progenies. The significance of SCA effect depicts the predominance of non-additive gene action which indicates genetic variations in F_1 crosses due to the non-fixable components (Pandey and Singh, 2010). For non-additive gene effects selection should therefore be delayed till later segregating generations when these effects are fixed in the segregating lines (Ertiro *et al.*, 2013).

Crop improvement with respect to yield and other desired traits can be achieved through development of new crop cultivars using appropriate crop breeding strategies. However, crop breeders should have sufficient knowledge about the mode of inheritance for important maturity, yield and yield related traits (Jawar *et al.*, 2019). Breeding for superior varieties also needs information about the combining potential of the genotypes for desired traits termed as GCA facilitates crop breeders to use appropriate parental genotypes capable of transferring their desired characters to their progenies. Another form of combining ability known as SCA helps in identification of superior cross combinations to be used in crop breeding programs.

Griffing (1956) Diallel Analysis Approach facilitates crop breeders to identify best parental genotypes as well as superior cross combinations through GCA and SCA effects. Moreover, combining ability analysis provides very useful genetic information about the inheritance of quantitative traits that helps to determine the type of crop breeding methods and selection schemes to be employed in segregating generations (Senbetay *et al.,* 2015). GCA includes both additive effect as well as additive x additive interactions as suggested by Griffing (1956a). It is not necessary for the high yielding genotypes to able to transfer their superiority to their resulting hybrids.

Hence, an estimate of GCA and SCA effects is considered a more reliable approach than the per se performance of the genotypes. Combining ability study provides useful information about the inheritance of quantitative traits which in turn helps to determine the type of breeding methodology to be employed for crop improvement (Senbetay *et al.,* 2015).There is a worldwide problem of scarcity of high yielding pea varieties affecting the productivity of the pea crop. Most of the times farmers are relying on the low yielding indigenous cultivars, while the extensive use of narrow genetic makeup germplasm prone the pea crops susceptible to pests and diseases. Pea cultivars grown in Pakistan are low yielding. Limited information is available about the pea germplasm. There is lack of knowledge regarding the pea parental genotypes to be used in hybridization programs and also lack of organized pea breeding program in the country. Thus there is an urgent need to broaden the genetic base of pea germplasm through systematic pea breeding program and develop high yielding pea cultivars. For development of new high yielding cultivars, there is a dire need to start an organized pea breeding program. For this we need to use mating system which could identify desirable parents for use in hybridization program, fig. out the cross combinations for advancement in segregating generations to derive high yielding pea cultivars and give information about mode of inheritance of yield and yield contributing traits. The present study was carried out with the aim to assess general combining ability potential of parents and specific combining ability potential of F_1 hybrids derived from crossing of eight parental genotypes in all possible combinations for yield and related traits in garden pea.

Materials and methods

Eight pea genotypes namely UAP-7, UAP-35, UAP-47, UAP-32, UAP-29, UAP-31, Green Gold and Leena Pak were used as parental genotypes. They were crossed in 8 × 8 diallel fashion during 2017-18 pea growing season and 56 F_1 hybrids were obtained. Fifty six F_1 hybrids along with their 8 parents were sown during 2018-19 pea growing season. Ridge method was used with plant-plant distance of 15 cm while row-row distance of 45 cm was maintained. Data were recorded on five randomly selected plants from each treatment on maturity and yield parameters.

Data Analysis

Analyses of variance technique as proposed by Steel and Torrie (1980) was used to analyze the data. Griffing approach (1956) was used to compute combining ability effects for the studied material. Combining ability analysis was carried out using Method I, Model II of Griffing (1956) i.e., including parents, F_1s and reciprocals.

Results and discussion

First blossom node

Mean squares due to GCA, SCA and RCA were observed significant ($p \leq 0.01$) for first blossom node

(Table 1). Significance of variances showed the importance of additive, non-additive and maternal effects in the inheritance of first blossom node. The variance due to GCA was observed greater than that of SCA, indicating that additive genetic effects were having predominating effects in comparison with non-additive effects (Table 2). Similar results were reported by Sharma *et al.* (2013) and Sharma and Sharma (2012). They also observed the prevalence of additive gene action for node number at which first flower appears.

Table 1. Combining ability mean squares of pea parental genotypes and F_1 hybrids for yield and yield related traits at Peshawar during 2018-19 pea growing season.

Traits	GCA (df=7)	SCA (df=28)	reciprocals (df=28)	Error (df=126)
First blossom node	104.4**	5.3 **	0.1**	0.7
Days to first picking	464.3**	21.3 **	7.3 **	1.0
Plant height	8457.1**	851.6 **	142.4 **	9.5
Pods plant^{-1}	403.7 **	18.6 **	4.8 **	1.5
Pod length	545.7 **	35.6**	2.2 **	1.2
Seeds pod^{-1}	2.4 **	3.2 **	0.4 ns	0.2
100-green seed weight	140.0 **	141.2 **	17.554 **	3.4
Green pod yield	15.1 **	2.6 **	0.034 ns	0.02

ns = non-significant ** = Significant at 1% level of probability

GCA= General combining ability effects

SCA= Specific combing ability effects

RCA= Reciprocal effects

Table 2. Variance components of combining ability effects for yield and yield related traits of pea genotypes and F_1 hybrids at Peshawar during 2018-19 pea growing season.

Traits	σ^2 GCA	σ^2 SCA	σ^2 GCA/ σ^2 SCA
First blossom node	6.20	2.54	2.45
Days to first picking	27.7	11.4	2.44
Plant height	24.8	10.3	2.39
Pods plant^{-1}	24.1	9.63	2.50
Pod length	31.9	19.3	1.65
Seeds pod^{-1}	0.05	1.69	0.03
Hundred green seeds weight	0.04	77.6	0.01
Green pod yield	0.78	1.45	0.54

GCA= General combining ability effects
SCA= Specific combing ability effects
RCA= Reciprocal effects

Fist blossom node determines the time of floral initiation and hence the time of picking (Truong, 1993). Negative combining ability is desirable for first blossom node for early maturing pea varieties. Two parents namely Leena Pak and Green Gold were found best general combiners with GCA effects of (-4.23) and (-3.72), respectively for earliness as these genotypes exhibited high negative GCA effects for first blossom node (Table 3). However, UAP-32 was recorded the best general combiner for lateness, showing high positive GCA effects (2.84) for the trait. Among 28 F_1 direct crosses, 17 hybrids had desirable negative SCA effects. Maximum negative SCA effects (-2.25) were recorded for cross combination UAP-29 × UAP-31, followed by UAP-32 × Leena Pak (-2.13) while maximum positive SCA effects (2.69) were observed for cross Green Gold × Leena Pak. Among reciprocals, the highest negative effects (-0.75) were recorded for F_1 cross Leena Pak × UAP-7 while maximum positive effects (0.75) were recorded for UAP-29 × UAP-32.

Table 3. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for first blossom node of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	1.75	-0.84	0.00	0.41	0.56	0.94	-1.78	-1.28
UAP-35	-1.25	0.84	-0.34	0.56	1.22	-1.41	-0.88	-0.63
UAP-47	-1.75	-0.50	1.00	0.66	0.06	-0.31	-1.03	-0.53
UAP-32	0.00	0.25	1.50	2.84	0.47	0.34	-1.63	-2.13
UAP-29	0.75	0.00	0.50	0.75	0.94	-2.25	-0.97	-1.22
UAP-31	0.25	0.50	0.25	0.25	4.25	0.56	-0.84	-0.84
Green Gold	-0.25	0.25	0.25	0.50	-0.25	0.50	-3.72	2.69
Leena Pak	-0.75	-0.50	0.25	-0.50	-0.50	-0.50	-0.25	-4.22

S.E. (g_j) = 0.20 S.E. (g_i-g_j) = 0.30 S.E. $(s_{ij}-s_{ik})$ = 0.80

S.E. (s_{ii}) = 0.75 S.E. $(s_{ii}-s_{ji})$ = 1.05 S.E. $(s_{ij}-s_{ki})$ = 0.74

S.E. (s_{ij}) = 0.54 S.E. $(s_{ii}-s_{ij})$ = 1.00 S.E. $(r_{ij}-r_{ki})$ = 0.86

S.E. (r_{ij}) = 0.61 S.E. $(s_{ii}-s_{jk})$ = 0.91

S.E. = Standard error

Days to first picking

Combining ability effects were observed significant ($p \leq 0.01$) for days to first picking (Table 1). It depicted that additive, non-additive and maternal effects played roles in controlling the expression of days to first picking. Additive gene action, however, was having a pivotal role in the genetic control of days to first picking. It was evident from GCA/SCA variance ratio (2.44) which was observed higher than 1 (Table 2). Kosev (2013) also observed the role of additive gene action for earliness character in pea. Kumar and Jain (2002), El-Shabrawy (2006), Sharma and Sharma (2012) and Sharma and Bora (2013) also reported the importance of additive gene action through higher estimates of GCA than SCA for days to first picking.

Data regarding combining ability effects (Table 4) showed that, two parents Leena Pak and Green Gold appeared as the good general combiners for earliness by exhibiting maximum negative GCA effects of (-11.52) and (-4.39), respectively for days to first picking. Katoch *et al.* (2017) also reported early maturity character as desirable character for short duration pea varieties. Out of 28 cross combinations, 18 F_1 hybrids showed negative SCA effects for days to first picking. The best specific combining ability was observed for cross combination UAP-7 × Leena Pak with the highest negative SCA effects (-3.67) indicating the genetic potential of early maturity for this cross. Highest negative reciprocal effects were observed for F_1 cross combination Leena Pak × UAP-31 (-3.25) for days to first picking.

Table 4. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for days to first picking of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	4.02	-1.70	-1.08	2.67	-2.05	2.83	-3.05	-3.67
UAP-35	-2.25	1.02	-1.33	1.92	-1.80	1.33	-0.55	-1.42
UAP-47	-1.50	-2.25	1.64	-1.95	-0.67	-1.55	-2.67	1.45
UAP-32	2.00	2.25	-1.00	4.39	1.33	0.70	-2.67	-1.30
UAP-29	-0.25	-1.50	-1.25	0.50	2.86	-1.27	-1.64	-1.77
UAP-31	4.25	-1.25	3.00	2.00	0.50	1.98	-1.02	-2.14
Green Gold	-0.50	0.50	0.50	-0.25	1.75	0.50	-4.39	-0.27
Leena Pak	0.25	-1.00	-3.00	-3.00	-3.00	-3.25	0.75	-11.52

S.E. (g_j) = 0.23 S.E. (g_i-g_j) = 0.35 S.E. (s_{ij}-s_{ik}) = 0.93

S.E. (s_{ii}) = 0.87 S.E. (s_{ii}-s_{ji}) = 1.22 S.E. (s_{ij}-s_{ki}) = 0.87

S.E. (s_{ij}) = 0.62 S.E. (s_{ii}-s_{ij}) = 1.17 S.E. (r_{ij}-r_{ki}) = 1.00

S.E. (r_{ij}) = 0.71 S.E. (s_{ii}-s_{jk}) = 1.06

S.E. = Standard error

Plant height (cm)

Significant (p ≤ 0.01) GCA, SCA and reciprocal effects were revealed for plant height (Table 1). High GCA/SCA variance ratio (Table 2) was also identified for plant height. This depicted predominance of additive genetic effects. Same results have also been observed by Enrique *et al.* (2013), Sharma and Bora (2013), Suman *et al.* (2017), and Singh *et al.* (2019).

The development of short-statured plants is considered desirable in pea as these plants can be grown without any physical support (Sharma and Dhar, 2015). Among the parents, 4 parental genotypes showed desirable negative GCA effects (Table 5). Parental genotypes namely, Leena Pak (-27.25), UAP-35(-22.03), Green Gold (-17.89) and UAP-7 (-16.71) were observed as the good general combiners for plant height. The highest positive GCA effects (27.14) were noted for UAP-29. Out of 28 direct F_1 crosses, 11 F_1 cross combinations showed desirable negative SCA effects. The specific performance was best for the cross UAP-35 × UAP-47 with the highest negative SCA effects (-35.52) followed by the cross UAP-7 × UAP-32 (-29.66). Maximum positive SCA effects (31.51) were observed for cross combination UAP- 32 × Green Gold followed by UAP-7 × UAP-31 (27.42). The highest negative reciprocal effects (-17.88) were observed for Leena Pak × UAP-32.

Table 5. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for plant height (cm) of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	-16.71	5.12	-25.33	-29.66	27.20	27.42	-3.52	-6.66
UAP-35	1.63	-22.03	-35.52	21.65	-20.74	20.48	-28.58	-1.97
UAP-47	-1.00	-14.50	18.05	9.45	8.06	1.53	13.71	19.70
UAP-32	1.13	10.63	2.25	13.75	-20.27	3.45	31.51	-12.13
UAP-29	4.38	-16.88	1.25	-5.63	27.14	-26.69	20.25	20.98
UAP-31	-1.63	9.63	-6.50	13.88	10.13	24.93	-3.29	1.95
Green Gold	5.63	-7.50	-6.38	-0.88	14.00	-4.75	-17.89	-15.36
Leena Pak	-0.38	8.75	-4.50	-17.88	10.13	3.38	-3.50	-27.25

S.E. (g_j) = 0.72 S.E. (g_i-g_j) = 1.09 S.E. (s_{ij}-s_{ik}) = 2.89

S.E. (s_{ii}) = 2.70 S.E. (s_{ii}-s_{ji}) = 3.78 S.E. (s_{ij}-s_{ki}) = 2.67

S.E. (s_{ij}) = 1.09 S.E. (s_{ii}-s_{ij}) = 3.62 S.E. (r_{ij}-r_{ki}) = 3.09

S.E. (r_{ij}) = 2.18 S.E. (s_{ii}-s_{jk}) = 3.27

Pods plant^{-1}

Data analysis (Table 1) revealed that GCA, SCA and RCA effects were observed significant ($p \leq 0.01$) for pods plant^{-1}. Similar findings were also achieved by Kumar *et al.* (2019) in the expression of pods plant^{-1}. The variance components also revealed GCA/SCA ratio of greater than unity (Table 2). Kalia and Sood (2009) and Brar *et al.* (2012) also observed significant GCA and SCA variances and GCA/SCA ratio of > 1 implying the role of additive gene action in controlling the expression of pods plant^{-1}.

Among parental genotypes, three parents showed positive GCA effects (Table 6). The UAP-29 had highest GCA effects (7.57) and was found the best general combiner followed by UAP-47 (6.35). Nineteen cross combinations showed desirable positive SCA effects. The best cross combination was Green Gold × Leena Pak (4.37) followed by UAP-29 × UAP-31(3.87). Positive reciprocal effects were observed highest for F_1 cross combination UAP-32 × UAP-7 (2.75) followed by UAP-35 × UAP-7 (2.50).

Table 6. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for pods plant^{-1} of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	-0.84	2.24	3.21	1.12	1.99	-1.48	-0.41	-0.82
UAP-35	2.50	0.57	2.06	0.46	3.84	-0.13	-1.57	0.77
UAP-47	-0.75	1.50	6.35	1.18	0.81	1.84	0.90	-0.26
UAP-32	2.75	0.00	-1.50	-0.56	1.96	0.74	-0.45	0.40
UAP-29	-0.75	-0.50	-3.25	1.00	7.57	3.87	-3.07	-2.73
UAP-31	-0.50	-0.25	-2.00	0.50	-1.25	-0.71	1.21	0.06
Green Gold	-0.50	-0.25	2.50	-0.75	1.25	-1.75	-5.77	4.37
Leena Pak	-1.25	-2.25	2.50	0.25	-0.25	-2.25	1.00	-6.62

S.E. (g_i) = 0.28 S.E. $(g_i\text{-}g_j)$ = 0.43 S.E. $(s_{ij}\text{-}s_{ik})$ = 1.13

S.E. (s_{ii}) = 1.06 S.E. $(s_{ii}\text{-}s_{ji})$ = 1.48 S.E. $(s_{ij}\text{-}s_{ki})$ = 1.04

S.E. (s_{ij}) = 0.75 S.E. $(s_{ii}\text{-}s_{ij})$ = 1.41 S.E. $(r_{ij}\text{-}r_{ki})$ = 1.21

S.E. (r_{ij}) = 0.85 S.E. $(s_{ii}\text{-}s_{jk})$ = 1.28

S.E. = Standard error

Pod length (cm)

Significant ($p \leq 0.01$) differences among the parents for GCA, crosses for SCA and reciprocals for RCA were observed (Table 1). The variance of GCA was greater in magnitude than SCA (Table 2) which showed additive gene action in the inheritance of pod length. Sofi *et al.* (2006), Singh *et al.* (2010), Brar *et al.* (2012) and Kumar *et al.* (2017) reported same results for pod length while conducting genetic study in garden pea.

Among the parental genotypes, desirable GCA effects were observed for Green Gold with maximum positive GCA effects (11.81), followed by UAP-47 (3.09) (Table 7). Among direct F_1 crosses, cross combination UAP-32 × Green Gold was revealed as the best specific combiner, showing the highest SCA effects (5.42) followed by UAP-31 × Green Gold (4.33). F_1 cross combination UAP-32 × UAP-31exhibited the maximum negative SCA effects (-7.07) and was found the poorest cross combination for pod length. Among the reciprocals, Green Gold × UAP-31 showed the highest positive reciprocal effects (2.48) for pod length.

Table 7. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for pod length of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	-3.93	0.94	1.27	0.47	0.84	-2.35	3.55	1.62
UAP-35	-1.66	0.30	-0.26	3.82	-0.79	2.64	0.86	-2.01
UAP-47	-0.05	0.74	3.09	3.35	1.59	3.35	-0.89	-1.27
UAP-32	1.29	0.22	0.51	-6.05	2.89	-7.07	5.42	4.10
UAP-29	0.92	0.41	0.58	0.11	1.49	4.20	-0.95	-2.49
UAP-31	-1.18	-0.43	0.19	0.79	0.75	-5.89	4.33	2.85
Green Gold	1.33	0.31	-0.64	1.14	-0.30	2.48	11.81	-0.30
Leena Pak	-0.05	-1.62	-0.26	0.82	-1.46	0.94	-2.40	-0.82

S.E. (g_j) = 0.26 S.E. $(g_i\text{-}g_j)$ = 0.39 S.E. $(s_{ij}\text{-}s_{ik})$ = 1.03

S.E. (s_{ii}) = 0.97 S.E. $(s_{ii}\text{-}s_{ji})$ = 1.35 S.E. $(s_{ij}\text{-}s_{ki})$ = 0.96

S.E. (s_{ij}) = 0.69 S.E. $(s_{ii}\text{-}s_{ij})$ = 1.29 S.E. $(r_{ij}\text{-}r_{ki})$ = 1.10

S.E. (r_{ij}) = 0.78 S.E. $(s_{ii}\text{-}s_{jk})$ = 1.17

S.E. = Standard error

Seeds pod^{-1}

Mean squares showed significant ($p \leq 0.01$) GCA and SCA effects while non-significant reciprocal effects for seeds pod^{1} (Table 1). The SCA was also observed greater in magnitude than GCA (Table 2). This indicated that the genetic control of seeds pod^{-1} was due to involvement of dominance gene actions. Similar results were documented by Espinosa and Ligarreto (2005), Uddin *et al.* (2006), Singh *et al.* (2012), Motamedi *et al.* (2014) and Suman *et al.* (2017).

Among parental genotypes UAP-47 (0.53) was observed the best general combiner followed by Green Gold (0.34) (Table 8) while Leena Pak was the poorest general combiner for seeds pod^{-1} with highest negative GCA effects (-0.60). Twenty five out of 28 F_1 direct crosses showed positive SCA effects. F_1 cross combination UAP-47 × UAP-29 (1.31) was observed the best for SCA effects followed by UAP-7 × UAP-35 (1.13). Cross combination UAP-35 × Green Gold was found the poorest cross for seeds pod^{-1} which showed maximum negative SCA effects (-0.78) for the trait.

Table 8. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for seeds pod^{-1} of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	<u>-0.06</u>	1.13	-0.19	0.22	0.16	0.34	0.25	0.94
UAP-35	0.25	<u>0.22</u>	1.03	-0.06	0.38	0.31	-0.78	0.41
UAP-47	0.25	-0.25	<u>0.53</u>	0.13	1.31	0.50	0.41	0.34
UAP-32	-0.25	-0.75	-0.25	<u>-0.38</u>	0.72	0.66	1.06	0.50
UAP-29	-0.25	-0.75	0.00	0.00	<u>0.19</u>	0.09	0.00	0.69
UAP-31	0.50	-0.25	-0.75	0.00	-0.50	<u>-0.25</u>	0.69	0.38
Green Gold	0.50	0.25	-0.25	0.00	-0.50	-0.25	<u>0.34</u>	0.03
Leena Pak	-0.25	-1.00	-0.75	0.50	-0.75	-0.50	-0.25	<u>-0.59</u>

S.E. (g_j) = 0.41 S.E. (g_i-g_j) = 0.17 S.E. (s_{ij}-s_{ik}) = 0.44

S.E. (s_{ii}) = 0.30 S.E. (s_{ii}-s_{ji}) = 0.58 S.E. (s_{ij}-s_{ki}) = 0.41

S.E. (s_{ij}) = 0.33 S.E. (s_{ii}-s_{ij}) = 0.55 S.E. (r_{ij}-r_{ki}) = 0.47

S.E. (r_{ij}) = 0.41 S.E. (s_{ii}-s_{jk}) = 0.50

S.E. = Standard error

Hundred green seeds weight (g)

GCA, SCA and reciprocal effects were observed significant ($p \leq 0.01$) for hundred green seeds weight (Table 1). Variance due to SCA was greater in magnitude than that of GCA (Table 2) which pointed towards dominance effect of genes in the expression of hundred green seeds weight. Enrique Luis Cointry *et al.* (2013) have also reported significant GCA and SCA effects for 100-green seed weight in garden pea. The present findings were also similar to those of Kumar *et al.* (2017) and Tampha *et al.* (2018).

Parental genotype Green Gold showed the highest positive GCA effects (5.75) which were considered desirable, while UAP-47 had the highest negative GCA effects (-2.25) for 100-green seed weight (Table 9). Positive SCA effects were recorded in 19 out of 28 F_1 crosses. The highest positive SCA effects (9.03) were observed for F_1 cross combination UAP-47 × UAP-31 followed by UAP-47 × Leena Pak (7.38), while the highest negative SCA effects (-3.50) were recorded for F_1 cross combination Green Gold × Leena Pak. Positive reciprocal effects were indicated in 10 F_1 crosses. Cross combination Leena Pak × UAP-32 showed the highest positive reciprocal effects (5.60) followed by UAP-47 × UAP-35 (4.75).

Table 9. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for 100-green seed weight of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	<u>-0.75</u>	2.03	3.19	5.59	-0.03	2.78	-1.13	0.63
UAP-35	-3.00	<u>2.00</u>	4.69	-1.56	5.31	4.38	5.47	-0.53
UAP-47	-4.75	4.75	<u>-2.25</u>	-1.47	0.47	9.03	1.13	7.38
UAP-32	-2.25	-1.25	0.25	<u>1.75</u>	2.16	3.91	3.50	-0.75
UAP-29	3.50	-2.75	4.50	-2.50	<u>-1.50</u>	-0.16	4.31	-0.19
UAP-31	-1.25	-3.25	1.50	1.00	-2.00	<u>-1.00</u>	0.25	5.41
Green Gold	-1.25	-2.25	-3.25	-0.50	-5.50	-4.75	<u>5.75</u>	-3.50
Leena Pak	-0.75	2.03	3.19	5.59	-0.03	2.78	-1.13	<u>0.63</u>

S.E. (g_j) = 0.43 S.E. (g_i-g_j) = 0.66 S.E. (s_{ij}-s_{ik}) = 1.74

S.E. (s_{ii}) = 1.62 S.E. (s_{ii}-s_{ji}) = 2.27 S.E. (s_{ij}-s_{ki}) = 1.61

S.E. (s_{ij}) = 1.16 S.E. (s_{ii}-s_{ij}) = 2.18 S.E. (r_{ij}-r_{ki}) = 1.86

S.E. (r_{ij}) = 1.31 S.E. (s_{ii}-s_{jk}) = 1.97

S.E. = Standard error

Green pod yield (t ha^{-1})

Combining ability for green pod yield indicated significant ($p \leq 0.01$) differences among parents for GCA effects and among F_1crosses for SCA effects. Reciprocal effects, however, were observed non-significant (Table 1). Singh *et al.* (2010), Kumar *et al.* (2017), Katoch *et al.* (2018), Pathak and Gahalain (2018) have also reported the same results. The GCA variance was observed greater in magnitude than SCA variance. The ratio of GCA/SCA was observed greater than 1 (Table 2). This suggested the predominance of additive gene actions in the inheritance of green pod yield. Similar results have also been reported by Kalia and Sood (2009), Singh *et al.* (2010) and Sharma and Bora (2013). In contrast, Singh *et al.* (2010) and Katoch *et al.* (2017) have reported the importance of non-additive gene actions in the expression of pod yield in pea.

The parental genotype UAP-47 with the highest positive GCA effects (10.16) was the best general combiner, followed by UAP-29 (9.31). Parental genotype Leena Pak was the poorest general combiner with minimum GCA effects (5.62) (Table 10). Among F_1 direct crosses, the highest positive SCA effects (14.10) were recorded for F_1 cross UAP-47 × UAP-29 followed by UAP-35 × UAP-47(12.67) while SCA effects were observed minimum (8.79) for cross Green Gold × Leena Pak. F_1 cross combination UAP-29 × UAP-47 displayed the highest positive reciprocal effects (13.96) followed by UAP-47 × UAP-35(13.09).

Table 10. General combining ability effects (diagonal values), specific combining ability effects (above diagonal) and reciprocal effects (below diagonal) for green pod yield of parents and their F_1s at Peshawar during 2018-19 pea growing season.

Parents	UAP-7	UAP-35	UAP-47	UAP-32	UAP-29	UAP-31	Green Gold	Leena Pak
UAP-7	7.22	10.75	12.50	10.93	12.15	10.99	9.83	9.21
UAP-35	10.46	7.80	12.67	10.69	11.71	10.35	9.11	9.17
UAP-47	12.90	13.09	10.16	12.55	14.10	11.75	10.43	9.88
UAP-32	10.42	10.62	11.98	7.76	11.27	9.89	9.24	8.93
UAP-29	12.19	12.29	13.96	11.26	9.31	11.15	10.21	9.87
UAP-31	10.93	10.48	11.52	9.86	11.49	7.11	9.89	9.37
Green Gold	9.54	9.17	10.49	9.19	9.97	9.76	6.12	8.79
Leena Pak	9.21	9.22	9.87	8.89	9.62	9.15	8.59	5.62

S.E. (g_j) = 0.03 S.E. (g_i-g_j) = 0.05 S.E. (s_{ij}-s_{ik}) = 0.13

S.E. (s_{ii}) = 0.12 S.E. (s_{ii}-s_{ji}) = 0.16 S.E. (s_{ij}-s_{ki}) = 0.12

S.E. (s_{ij}) = 0.08 S.E. (s_{ii}-s_{ij}) = 0.16 S.E. (r_{ij}-r_{ki}) = 0.13

S.E. (r_{ij}) = 0.09 S.E. (s_{ii}-s_{jk}) = 0.14

S.E. = Standard error

Conclusions

Both additive and non-additive gene actions were found important in controlling the expression of maturity and yield traits of garden pea. GCA effects were observed higher than the SCA effects for days to first picking, plant height, pods plant^{-1}and pod length depicting the major role of additive gene action in the expression of these traits. SCA variances were observed higher than the GCA variances with GCA/SCA ratio of lesser than unity for seeds pod^{-1}, 100-green seed weight and green pod yield, which indicated the importance of non-additive gene action in the inheritance of these characters.

The parental genotypes namely Leena Pak for days to first picking and plant height, Green Gold for pod length and 100-green seed weight, UAP-7 and UAP-47 for seeds pod^{-1} and green pod yield were identified as good general combiners. Desirable negative SCA effects were manifested by F_1 cross combinations UAP-35 × Green Gold, UAP-7 × Leena Pak and UAP-35 × UAP-47 for early picking and plant height.

F_1 hybrid Green Gold × Leena Pak was observed as the best specific cross combination for pods plant^{-1} while F_1 hybrid UAP-47 × UAP-31 was manifested as the best cross for 100-green seed weight with highest SCA effects. Highest SCA effects for seeds pod^{-1} and green pod yield were displayed by F_1 cross combination UAP-47 x UAP-29. Parental genotypes Leena Pak, Green-Gold and UAP-47 and F_1 crosses Green Gold × Leena Pak, UAP-47 × UAP-31 and UAP-47 × UAP-29 could serve as useful genetic resources for the desired maturity, yield and yield related traits in pea hybridization program

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