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Generation mean analysis to estimate genetic parameters for desirable horticultural traits in garden pea (*Pisum sativum*)

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ABSTRACT

Generation means analysis was carried out to estimate the nature and magnitude of gene action in order to formulate breeding strategy for identifying the segregants with desirable horticultural traits and resistance to powdery mildew disease. Two commercially grown powdery mildew susceptible varieties Azad P-I and Green Pearl and three resistant lines DPP 9411, DPP 9418-06 and Sugar Giant were used to develop three crosses, viz. Green Pearl × Sugar Giant, DPP 9411 × DPP 9418-06, and Azad P-I × Sugar Giant to achieve the objectives. The presence of epistatic interaction for majority of the traits in all three crosses was observed as reflected by the significance of simple additive-dominance model. The results revealed that the nature and magnitude of gene effects differed in different crosses and showed the importance of additive as well as non-additive gene effects in the inheritance of different characters with preponderance of the latter. In view of the parallel role of additive and non-additive gene effects, selection in the segregating generations should be delayed to later generations to diminish the dominance gene effects. Duplicate type of epistasis was also found for some of the traits in certain cross combinations whose effect can be eliminated by following sophisticated selection procedure such as reciprocal recurrent selection and/or biparental mating in early segregating generations for the development of high-yielding garden pea varieties with desirable horticultural traits.

Key words: Epistasis, Garden pea, Gene action, Powdery mildew

Garden pea (*Pisum sativum* L.) is a leading vegetable crop in the north-western Himalayan region of India comprising Himachal Pradesh, Jammu and Kashmir and Uttrakhand (Sharma *et al.* 2010). Owing to diverse agro-climatic conditions in Himachal Pradesh, the crop is grown year round, generating lucrative returns to the growers. In the high altitude areas of Himachal Pradesh, pea is grown as an off-season cash crop during summer, whereas in winter, it is cultivated in low and mid hills. Garden pea is vulnerable to a number of diseases of which, the powdery mildew disease (*Erysiphie pisi*) is the most important disease affecting fresh pea production all over the world (Warkentin *et al.* 1996). All popular commercial varieties including Azad P-1 are highly susceptible to powdery mildew. On the other hand, the prevalent resistant varieties are not being preferred by the farmers on account of light-green and medium sized pods. Therefore, it is pertinent to develop suitable variety possessing sweet, long and dark green pods coupled with high yield and resistance to powdery mildew disease.

Garden pea is an autogamous crop and thus recombinant breeding is the most appropriate approach to combine various traits of interest. Earlier workers suggested that there would be no separate gene system for yield *per se* and the yield is an end product of the multiplicative interaction between the various components of yield (Sharma and Sain 2002). To study the nature of gene action governing quantitative traits, various mating designs have been developed. The most frequent used designs namely, diallel and line × tester analysis do not provide the estimates of epistasis. It is important to identify and estimate non-allelic interactions which could otherwise inflate the measures of additive and dominance components. The mating designs such as generation mean analysis, triple test cross and biparental cross provide information about all the three components of variance *viz.*, additive, dominance and epistatic. The generation mean analysis is based on first order statistics, whereas triple test cross and biparental cross are based on second degree statistics. Estimates based on first order statistics are statistically more robust and reliable than those based on second degree statistics (Singh and Narayanan 1993). The six parameter generation mean analysis provides information about all the six parameters (mean effects, additive, dominance, additive × additive gene interaction, additive × dominance gene interaction and dominance × dominance gene interaction) and thereby help in formulating the guidelines for handling the segregating material in the subsequent generations by the exploitation of fixable component. Keeping in view, the major drawback that only limited number of crosses can be evaluated at a time, three crosses were studied in the present investigation to estimate the gene action for yield and its component traits in garden pea in order to formulate breeding strategy to identify powdery mildew resistant and high-yielding segregants with desirable pod characteristics.

MATERIALS AND METHODS

The present investigation was carried out at the experimental farm of the Department of Vegetable Science and Floriculture, HPAU, Palampur, Himachal Pradesh. The experimental farm is situated at 32°8' N latitude and 76°3' E longitude at an elevation of 1 290.8 m above sea level. Agro-climatically, the location represents the mid-hill zone of Himachal Pradesh (Zone-II) and is characterized by humid sub-temperate climate with high rainfall (2 500 mm). The soil is clay loam with *p*H 5.6 and is classified as an alfisols typic hapludalf clay. The experimental material comprise of two powdery mildew susceptible (Green Pearl and Azad P-I) and three resistant (DPP 9411, DPP 9418–06 and Sugar Giant) lines. The lines were used to develop three F_1's, viz. Green Pearl × Sugar Giant, DPP 9411 × DPP 9418–06 and Azad P-I × Sugar Giant during winter 2004-05. The F_1 seed of these three crosses along with their parents were sown during winter season of 2005–06 to develop back cross progenies by crossing each F_1 to both of its parents to obtain backcross generations (BC_1 and BC_2). Simultaneously F_2 seed was obtained by selfing the $F_{1's}$. The parents and $F_{1's}$ were further raised at Highland Agricultural Research and Extension Centre, Kukumseri (Lahaul and Spiti) during summer 2006 to obtain more number of seeds of back cross progenies and F_2's. Hence, the experimental material comprising of six generations of above mentioned three crosses (two parents P_1 and P_2, F_1, F_2, BC_1 and BC_2) were sown on 4 November 2006 in randomized complete block design with three replications. Two rows each of parents and F_1's, 12 rows of F_2 and 4 rows of BC_1 and BC_2 were sown with inter- and intra-row spacing of 45 cm and 10 cm. The standard cultural practices were followed for the growth and development of crop. The observations were recorded on ten randomly taken plants in each of P_1, P_2 and F_1's, 40 plants of F_2's and 20 plants of BC_1 and BC_2 in each of the replication between November 2006 and April 2007 on days to 50% flowering, days to first picking, pod length (cm), seeds/pod, pods/plant, shelling (%), plant height(cm), pods/plant, pod yield/plant, powdery mildew incidence (%), total soluble solids (°brix), and protein content (%). To test the adequacy of additive dominance model, the individual scaling tests given by Mather (1949) as well as joint scaling tests by Cavalli (1952) were applied. First, simple additive – dominance model consisting of mean (m), additive (d) and dominance (h) gene effects were tried and the adequacy of the model was tested by the chi-square test. When this model failed to explain variation among generation means, successively non-allelic interaction parameters *i.e.* additive × additive (i), additive × dominance (j) and dominance × dominance (l) were included in this model. Thus, all possible models with different combinations of epistatic parameters were tried to identify the best fit model with minimum/non-significant value of chi-square with maximum number of significant parameters as suggested by Mather and Jinks (1982).

RESULTS AND DISCUSSION

The mean performance of first parent for majority of the traits was better than the F_1 and other segregating generations because the male parent has an advantage of resistance to powdery mildew disease (Table 1). It has been observed that on utilizing Sugar Giant (tall, small poded and powdery mildew resistant) as male parent and Green Pearl and Azad P-1 (medium in height, long poded and susceptible to powdery mildew) as female parents, seeds/pod, shelling (%), pods/plant, pod yield/plant and total soluble solids increased, whereas incidence of powdery mildew disease was comparatively less in F_1.

Simple additive-dominance model (Table 2) was adequate as depicted with the non-significance of A, B, C and D simple scaling tests and chi-square for all the three crosses (DPP9411 × DPP9418-06, Azad P1 × Sugar Giant and Green Pearl × Sugar Giant) for days to first picking and pod length, Green Pearl × Sugar Giant for days to 50% flowering, Azad P1 × Sugar Giant and Green Pearl × Sugar Giant for seeds/pod, Azad P1 × Sugar Giant for shelling (%), DPP9411 × DPP9418-06 for plant height and powdery mildew incidence, and Green Pearl × Sugar Giant for total soluble solids. This indicates that majority of the cross combinations in the present study exhibited non-allelic interactions for various traits.

All the three crosses for pods/plant and pod yield/plant and DPP 9411× DPP 9418-06 and Green Pearl × Sugar Giant exhibited additive × additive, additive × dominance and dominance × dominance type of interactions. On the other hand, DPP 9411 × DPP 9418-06 for seeds/pod and Azad P-1 × Sugar Giant for total soluble solids and protein content manifested dominance × dominance interaction. The desirable plant type in garden pea is one with dwarf growth habit which does not require staking and results in saving resources both in terms of money and labour. Accordingly, negative additive × additive interaction was observed for plant height in the crosses Azad P-1 × Sugar Giant and Green Pearl × Sugar Giant suggesting thereby the selection can be done in the early generation for dwarf plants. Similarly, Azad P-1 × Sugar Giant and Green Pearl × Sugar Giant exhibited all the three (i,j,l) types of interactions with desirable negative sign for powdery mildew incidence.

Earliness is a highly desirable attribute in garden pea as

Table 1 Mean values of six generations for yield and associated traits

Cross	Parameter					
	P_1	P_2	F_1	F_2	BC_1	BC_2
Days to 50% flowering						
DPP 9411× DPP 9418-06	87.0±0.58	83.0±0.58	86.0±0.58	82.43±0.52	87.63±0.92	82.33±0.54
Azad P-1 × Sugar Giant	89.0±0.58	91.0±0.58	90.67±0.88	92.0±0.27	91.53±0.85	92.03±0.79
Green Pearl× Sugar Giant	90.67±0.33	89.33±0.33	88.67±1.33	90.03±1.47	87.9±1.71	91.63±1.37
Days to first picking						
DPP 9411× DPP 9418-06	124±0.0	125.33±1.33	126.3±2.33	123.0±1.0	125.33±1.33	124±0.00
Azad P-1 × Sugar Giant	121±0.0	133±1.0	123.3±1.76	124±0.0	125.33±1.33	125.33±1.3
Green Pearl× Sugar Giant	128.67±2.3	130±3.21	129.7±1.33	129.33±1.7	126.33±2.33	127±2.08
Seeds/pod						
DPP 9411× DPP 9418-06	4.77±0.19	4.90±0.25	5.17±0.2	5.7±0.15	5.03±0.18	5.6±0.36
Azad P-1 × Sugar Giant	5.73±0.93	4.13±0.34	5.83±0.35	5.87±0.2	6.03±0.32	5.03±0.27
Green Pearl× Sugar Giant	5.8±0.05	5.23±0.08	6.63±0.03	6.1±0.5	6.26±0.17	6.0±0.1
Pod length						
DPP 9411× DPP 9418-06	10.17±0.09	10.0±0.15	10.07±0.12	10.1±0.26	10.07±0.26	10.0±0.21
Azad P-1 × Sugar Giant	10.60±0.31	7.95±0.45	8.97±0.3	8.77±0.29	9.26±0.39	8.33±0.38
Green Pearl× Sugar Giant	10.57±0.03	6.93±0.55	8.93±0.37	8.63±0.37	9.86±0.13	8.19±0.49
Shelling percentage						
DPP 9411× DPP 9418-06	39.53±0.47	40.0±0.98	47.77±2.23	51.23±0.63	39.6±0.40	45.0±2.55
Azad P-1 × Sugar Giant	37.23±2.28	45.0±2.89	51.83±1.83	45.46±2.92	42.5±1.44	45.0±2.89
Green Pearl× Sugar Giant	42.53±0.86	49.2±2.15	43.83±1.16	46.36±1.88	38.27±0.93	42.23±1.22
Plant height						
DPP 9411× DPP 9418-06	76.2±2.9	46.0±0.67	62.53±2.8	62.47±3.17	67.37±0.91	55.9±1.06
Azad P-1 × Sugar Giant	49.73±2.17	96.8±1.87	88.53±1.2	80.6±0.69	78.93±0.26	101.3±5.11
Green Pearl× Sugar Giant	65.33±0.2	96.1±2.86	94.76±4.31	80.1±2.67	94.86±3.9	92.23±3.91
Pods/plant						
DPP 9411× DPP 9418-06	13.57±0.27	11.7±0.91	10.47±0.82	7.33±0.22	6.78±0.41	9.8±0.72
Azad P-1 × Sugar Giant	8.23±0.58	9.23±0.23	10.23±0.52	10.4±0.32	8.08±0.29	10.37±0.33
Green Pearl× Sugar Giant	8.8±0.57	13.06±0.64	13.73±0.73	11.04±0.59	9.3±0.7	7.82±0.13
Pod yield/plant						
DPP 9411× DPP 9418-06	78.59±1.5	61.24±1.76	59.18±2.33	39.61±1.56	36.96±1.39	59.79±3.37
Azad P-1 × Sugar Giant	52.19±2.29	40.95±1.7	52.78±1.7	47.89±1.74	43.55±2.04	46.92±2.92
Green Pearl× Sugar Giant	62.91±5.38	58.23±2.18	73.0±1.78	52.03±4.47	56.44±2.29	39.84±1.4
Powdery mildew incidence						
DPP 9411× DPP 9418-06	4.68±0.25	4.38±0.16	4.67±0.16	7.33±0.35	4.31±0.27	4.1±0.26
Azad P-1 × Sugar Giant	68.17±2.87	0.57±0.00	60.77±2.0	51.67±1.25	47.01±1.83	42.69±1.23
Green Pearl× Sugar Giant	62.83±2.04	0.57±0.0	55.79±0.93	39.61±0.98	42.49±2.26	50.97±0.73
Total soluble solids						
DPP 9411× DPP 9418-06	16.87±0.24	16.8±0.31	16.4±0.4	17.7±0.38	17.9±0.26	17.63±0.42
Azad P-1 × Sugar Giant	17.27±0.18	16.8±0.40	18.13±0.52	18.6±0.23	17.37±0.38	18.8±0.61
Green Pearl× Sugar Giant	17.93±0.17	17.33±0.13	18.63±0.15	17.83±0.43	17.7±0.4	17.53±0.35
Protein content						
DPP 9411× DPP 9418-06	7.95±0.13	7.13±0.42	6.4±0.21	6.97±0.52	7.73±0.12	2.1±5.55
Azad P-1 × Sugar Giant	6.2±0.12	7.23±0.15	7.13±0.03	7.17±0.09	6.2±0.06	6.7±0.06
Green Pearl× Sugar Giant	7.03±0.03	6.7±0.05	6.5±0.05	6.36±0.03	6.9±0.05	6.8±0.11

the market prices are invariably high early in the season. The days to flowering and first picking of a particular genotype are the only indicators of earliness. The significance of the estimates of simple and joint scaling tests indicated that all the three types of epistatic interaction had contributed in controlling the inheritance of days to 50% flowering in cross DPP9411 × DPP9418-06 and that of dominance × dominance (l) in Azad P1 × Sugar Giant for both days to flowering and days to first picking (Table 2). The role of epistasis in the inheritance of days to flowering was also advocated by Dixit *et al*. (2006) and Singh *et al*. (2006) with different set of breeding material. Further, significant and negative additive gene effects indicated earliness in cross Azad P1 × Sugar Giant for both these characters though the opposite signs of [h] and[l] indicated duplicate gene action for days to flowering. This indicates that pedigree method should be followed for effective selection of segregants with early picking (Tyagi and Srivastava 2001).

Genic interactions for pod length and seeds/pod in the crosses Azad P-1 × Sugar Giant and Green Pearl × Sugar Giant showed significant additive (d) component, respectively (Table 2) revealing thereby selection of desirable plants in the early generations. On the other hand, dominance gene effect in Green Pearl × Sugar Giant and negative additive × additive epistatic gene interaction (presence of decreaser alleles) in DPP-9411 × DPP-9418-06 for seeds/pod suggests

Table 2 Scaling tests and estimates of components of generation mean for pod yield and various related horticultural traits

Cross	Parameter										
	A	B	C	D	m	d	h	i	j	l	χ^2
Days to 50% flowering											
DPP 9411× DPP 9418-06	2.27	–4.33*	–12.27*	–5.10*	79.37	2.00*	6.85*	5.74*	5.12*		2.69
	± 2.02	± 1.35	± 2.53	± 1.49	±1.16	±0.41	±1.55	±1.24	±2.10		
Azad P-1 × Sugar Giant	3.40	2.40	6.67*	0.43	90.0	–0.94*	7.71*			–6.51*	0.30
	± 2.00	± 1.90	± 2.21	±1.28	±0.41	±0.39	±1.79			±2.17	
Green Pearl × Sugar Giant	–3.53	5.27	2.80	0.53	90.03	–3.73*	2.40				5.03
	± 3.69	± 3.06	±6.46	± 3.66	±1.47	±2.19	±7.44				
Days to first picking											
DPP 9411× DPP 9418-06	0.33	–3.67	–10.0	–3.33	123.0	1.33	8.33				7.75
	± 3.54	± 2.69	±6.29	±2.40	±1.00	±1.33	±5.39				
Azad P-1 × Sugar Giant	3.33	–5.67	–7.67*	–2.67	89.52	–4.50*	3.17				5.24
	± 3.20	±3.35	±3.67	±1.89	±0.28	±0.50	±11.55				
Green Pearl× Sugar Giant	–5.67	–5.67	–0.67	5.34	129.33	–0.67	–10.33				2.53
	± 5.39	± 5.43	±8.21	±4.57	±1.67	±3.13	±9.45				
Seeds/pod											
DPP 9411 × DPP 9418-06	0.13	1.13	2.80*	0.77	6.16		–1.05*	–1.38*			3.35
	± 0.45	± 0.79	±0.80	±0.50	±0.36		±0.51	±0.39			
Azad P-1 × Sugar Giant	0.50	0.10	1.93	0.66	5.87	1.0*	–0.43				2.97
	± 0.83	± 0.73	±1.19	±0.58	±0.20	±0.42	±1.25				
Green Pearl× Sugar Giant	0.10	0.13	0.10	–0.07	6.10	0.27	1.25*				0.51
	± 0.36	± 0.22	±0.26	±0.23	±0.15	±0.20	±0.47				
Pod length											
DPP 9411 × DPP 9418–06	–0.10	–0.07	0.10	0.13	10.10	0.07	–0.28				1.32
	±0.54	±0.46	±1.10	±0.63	±0.06	±0.33	±1.26				
Azad P-1 × Sugar Giant	–1.03	–0.25	–1.42	–0.07	8.77	0.93	–0.18				2.80
	±0.89	±0.94	±1.42	±0.80	±0.29	±0.55	±1.65				
Green Pearl × Sugar Giant	0.23	0.47	–0.83	–0.77	8.63	1.70*	1.72				1.85
	±0.46	±1.18	±1.73	±0.89	±0.37	±0.51	±1.84				
Shelling percentage											
DPP 9411 × DPP 9418-06	–8.10*	2.23	29.87*	17.87*	75.35		–68.89*	–35.73*	–10.80*	41.31*	0.18
	±2.42	±5.66	±5.25	±2.88	±5.77		±16.52	±5.76	±5.17	±11.57	
Azad P-1 × Sugar Giant	–4.07	–6.83	–4.03	3.43	45.47	–2.50	3.85				1.80
	±4.11	± 6.71	± 12.79	±6.68	±2.92	±3.23	±13.61				
Green Pearl × Sugar Giant	–9.83*	–8.57*	6.07	12.23*	70.71	–3.56*	–70.49*	–24.49*		43.62*	0.11
	±2.37	±3.46	±8.21	±4.06	±8.13	±0.93	±17.70	±8.10		±9.99	

Contd.

Table 2 *Concluded*

Cross	Parameter										
	A	B	C	D	m	d	h	i	j	l	χ^2
Plant height											
DPP 9411× DPP 9418-06	–4.00	3.27	2.60	1.67	62.27	11.47*	–1.90				6.19
	±4.42	±3.57	±14.17	±6.49	±3.17	±1.39	±13.35				
Azad P-1 × Sugar Giant	19.60*	17.27	–1.20	–19.03*	33.06	–23.45*	134.6*	40.22*		–79.21*	0.05
	±2.53	±10.54	±4.65	±5.29	±4.41	±1.38	±11.74	±4.04		±7.77	
Green Pearl × Sugar Giant	29.63*	–6.40	–30.57*	–26.90*		–15.15*	212.31*	80.48*	36.45*	–117.54*	3.14
	±8.93	±8.96	±14.02	±7.56		±1.43	±8.73	±1.43	±11.08	±11.49	
Pods per plant											
DPP 9411× DPP 9418-06	–10.47*	–2.57	–16.87*	–1.92*	6.22	10.7*		6.25*	–9.21*	4.08*	1.85
	±1.20	±1.89	±2.09	±0.94	±0.40	±0.46		±0.62	±1.65	±1.13	
Azad P-1 × Sugar Giant	–2.30*	1.27	3.67*	2.35*	13.80		–10.02*	–4.70*	–4.57*	6.4*	2.53
	±0.97	±0.87	±1.77	±0.77	±1.57		±3.77	±1.56	±0.88	±2.44	
Green Pearl × Sugar Giant	–3.93*	–11.17*	–5.17*	4.96*	10.93	–2.13*	–9.63*		9.72*	12.43*	13.06*
	±1.68	±1.01	±2.90	±1.37	±0.43	±0.43	±1.92		±1.52	±2.08	
Pod yield per plant											
DPP 9411 × DPP 9418-06	–63.84*	0.85	–99.77*	–17.54*	32.89	8.68*		36.99*	–63.91*	26.25*	0.04
	±3.92	±7.37	±8.12	±4.79	±2.01	±1.16		±2.38	±6.19	±3.67	
Azad P-1 × Sugar Giant	–17.88*	0.11	–7.17	5.31	45.76	5.39*			–20.53*	6.64*	1.95
	±4.98	±6.32	±8.24	±4.97	±1.11	±1.41			±7.44	±2.17	
Green Pearl × Sugar Giant	–23.03*	–51.56*	–59.01*	7.78	58.90		–55.96*		33.91*	70.06*	1.35
	±7.30	±3.63	±19.14	±9.30	±2.03		±8.02		±5.05	±7.31	
Powdery mildew incidence											
DPP 9411× DPP 9418-06	–0.72	–0.84	–1.07	0.25	4.33	–0.21	–0.35				4.97
	±0.61	±0.56	±1.46	±0.79	±0.35	±0.37	±1.59				
Azad P-1 × Sugar Giant	–34.93*	24.05*	16.37	13.63*	46.64	32.99*		–13.08*	–54.41*	13.61*	5.09
	±5.08	±3.17	±7.02	±3.33	±1.56	±1.39		±2.24	±4.87	±3.07	
Green Pearl × Sugar Giant	–33.62*	45.60*	–16.53*	–14.25*	3.19	31.04*	101.39*	31.61*	–77.56*	–45.60*	0.26
	±5.05	±1.73	±4.81	±3.08	±6.25	±1.01	±3.20	±1.01	±4.02	±3.58	
Total soluble solids (⁰Brix)											
DPP 9411 × DPP 9418-06	2.53*	2.07*	4.33*	–0.13	16.84		3.99*			–4.43*	0.68
	±0.71	±0.65	±1.77	±0.83	±0.19		±0.91			±1.07	
Azad P-1 × Sugar Giant	0.67	2.67	4.07*	1.03	18.50			–1.31*	–3.02*		1.88
	±0.95	±1.39	±1.46	±0.85	±0.19			±0.25	±1.33		
Green Pearl × Sugar Giant	–1.17	–0.90	–1.20	0.43	17.68	0.17*	–0.13				3.57
	±0.99	±0.90	±2.05	±1.02	±0.10	±0.54	±2.11				
Protein content (%)											
DPP 9411 × DPP 9418-06	1.12*	–9.33	–0.02	4.10	7.88		–1.49*		2.43*		4.25
	±0.34	±11.11	±2.18	±5.65	±0.12		±0.24		±0.67		
Azad P-1 × Sugar Giant	–0.90*	–0.97*	0.97*	1.43*	9.58	–0.51*	–7.21*	–2.87*		4.76*	0.02
	±0.17	±0.19	±0.40	±0.19	±0.39	±0.06	±0.90	±0.39		±0.52	
Green Pearl × Sugar Giant	0.27*	0.40	–1.27*	–0.97*	5.01	0.16*	3.94*	1.86*		–2.45*	0.25
	±0.13	±0.25	±0.19	±0.15	±0.25	±0.03	±0.69	±0.25		±0.46	

*Significant at P =0.05, 't' test

that selection should be deferred to the later generations.

Further, digenic interactions in the crosses Azad P-1 × Sugar Giant and Green Pearl × Sugar Giant manifested duplicate epistasis for plant height, pods/plant and protein content, whereas Green Pearl × Sugar Giant exhibited the same for pod yield/plant and powdery mildew incidence. Also, for the crosses DPP9411 × DPP9418-06 and Green Pearl × Sugar Giant for shelling (%) and DPP9411 × DPP9418-06 for total soluble solids, duplicate epistasis was observed. This kind of epistasis generally hinders the improvement through selection as the presence of duplicate epistasis decrease the variation in F_2 and subsequent generations. Therefore, the selection should be delayed until a high level of gene fixation is attained. Tyagi and Srivastava (2001) and Singh *et al*. (2006) also observed the role of duplicate epistasis in the inheritance of shelling (%), plant height, pods/plant and pod yield/plant in their respective studies.

High yield is the basic objective of all the crop improvement programmes. It is of immense importance to develop a genotype, which has a potential to surpass the commercially adopted/adapted cultivar(s) otherwise the genotype will be of no significance even if it has excellent quality and resistance to various pests. Number of pods/plant has a direct bearing on the total productivity of pea crop. Significant estimates of additive component (d) along with significance of additive × additive (i) gene interaction with positive sign in DPP-9411 × DPP-9418-06 for both pods per plant and pod yield/plant indicated the presence of increaser alleles and associated pair of genes. This suggested the increased manifestation can be achieved through single progeny selection (Narain *et al*. 2007). The yield and quality of pea is greatly affected by the incidence of powdery mildew disease and therefore there is necessity to develop resistant lines with high yield. Azad P-1 × Sugar Giant had significant additive × dominance (j) interaction with negative sign for pod yield and additive × additive (i) and additive × dominance (j) for powdery mildew incidence implied thereby to follow one or two cycles of restricted recurrent selection or multiple crosses in the early segregating generations.

It can be concluded that the nature and magnitude of gene effects vary with different crosses character-wise. Hence, specific breeding strategy has to be adopted for a particular cross to get improvement in pod yield along with desirable pod attributes and high quality parameters. The presence of non-allelic interaction for most of the characters in different cross combinations signifies to adopt biometrical approach like generation mean that provides the estimates of epistasis which could otherwise inflate the measure of additive and dominance components. Epistasis must be included in a model for the unbiased estimation of genetic components. The results showed that as a consequence of higher magnitude of interactions, the non-fixable gene effects were higher than the fixable. Further, duplicate type of epistasis was also found in majority of traits in one or the other cross combinations. In such crosses, the selection intensity should be mild in the earlier and intense in the later generations because it marks the progress through selection (Sharma and Sain, 2002). Therefore, normal breeding methods would not be fruitful and the methods which will exploit non-additive gene effect and take care of non-allelic interactions such as restricted recurrent selection by way of intermating the most desirable segregates, followed by selection (Joshi 1979) or diallel selective mating (Jensen 1970) or multiple crosses or biparental mating in early segregating generations (Singh *et al.* 2008) could be promising for genetic improvement of yield and associated traits. In addition, few cycles of recurrent selection, followed by pedigree method may also be useful for the effective utilization of all three type of gene effects simultaneously. It will lead towards an increased variability in later generations for effective selection by maintaining considerable heterozygosity through mating of selected plants in early segregating generations. These breeding approaches could be helpful in developing garden pea populations, which upon selection will result in the most desirable horticulture traits along with high quality to develop new plant types. Such new plant types could stand better under high production management conditions to get maximum yield in garden pea.

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