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Study of heterosis and inbreeding depression for yield and quality traits in garden pea [*Pisum sativum* var. (L.) hortense]

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Abstract
F_1 and F_2 generations of fifteen cross combinations developed from 6 X 6 diallel analysis excluding reciprocals were evaluated along with parents to know the magnitude of heterosis over better parent and standard check and inbreeding depression for yield and quality traits in garden pea. Pant Uphar × Nepal Pea, PSM-4 × Nepal Pea and Nepal Pea × PEVAR-6 were the crosses which exhibited negative and significant standard heterosis (in desirable direction) for D 50%F, NNFF and DFGPP. These crosses showing high negative heterosis can be exploited for recovering early recombinants in advance generations. For NPPP, crosses Pant Uphar × Nepal Pea and PSM-4 × Arka Ajit expressed positive and significant heterobeltiosis whereas Pant Uphar × Nepal Pea and Nepal Pea × PEVAR-6 expressed the maximum positive and significant heterosis over the check variety. Pant Uphar × PSM-4 exhibited desired significant economic heterosis NSPP whereas for NPBPP, PSM-4 × NDVP-250 followed by Pant Uphar × PSM-4 expressed positive and significant standard heterosis. These findings can be further utilized to develop and enhance the yield potential of pea cultivars.
For protein content %, PSM-4 × NDVP-250 expressed positive heterobeltiosis along with desirable non-significant inbreeding depression whereas for TSS % PSM-4 × PEVAR-6 and Pant Uphar × PSM-4 showed desired (positive) heterosis over BP and SV with desirable non-significant inbreeding depression. Hence, these crosses could be useful in future breeding programme for improvement in quality traits of garden pea.

Keywords: *Pisum sativum*, heterosis, indreding depression, F_1 and F_2, yield and quality traits

Introduction
Pea (*Pisum sativum* L.) a member of family fabaceae is an important vegetable crop grown temperate and subtropical areas of the world. It is native of Europe and West Asia, while its wild prototype came from Ethiopia. Peas are processed (canned, frozen or dehydrated) for consumption in the off season. It is a highly nutritive legume and used in the form of green vegetables, soup, dal etc. Pea ranks next to tomato among processed vegetables. In India, it occupies 498 thousands ha area with a production of 4811 thousands metric tonne (MT) and productivity of 96.6 q/ha. Its share is about 2.84 % and 4.92 % in total vegetable production and area, respectively (NHB, 2016) [2]. In Uttarakhand, garden pea, has become a leading vegetable crop, especially in hilly region where it is expected to cover more than 80 per cent area under vegetables. Increasing trend of garden pea cultivation in high hills during summer months is because of the high remuneration that the farmers of the area get by selling their quality pea produce in metropolitan cities and other ready markets in the adjoining states. Statistics exhibits that it has covered an area of 11.82 thousands ha with an annual production of 83.01 thousands metric tonne and productivity of 70.23 q/ha in the state of Uttarakhand (NHB, 2016) [2].
The production and productivity of garden pea in India is low when we compare it with world scenario due to stagnation. Therefore, development of germplasm with enhanced production and productivity becomes essential. For which, adequate variability in the material and utilization of heterosis can be the potential tools (Singh, 2012) [31]. Though, the development of hybrid varieties does not seem to be economically feasible in legume vegetables. The development of pure lines from hybrid is the common practice. Aim is generally, to identify the best combinations of parents giving the high degree of useful heterosis (Kumar *et al.*, 2000) [24]. Inbreeding is the basic mechanism for providing the base materials for selection. The information regarding nature and magnitude of inbreeding depression is helpful in

determining the effectiveness of selection (Elangaimannan *et al.*, 2008) [15]. The present study was, therefore, undertaken to study heterosis and inbreeding depression in garden pea.

Materials and Methods

Diallel analysis excluding reciprocals was carried out with six genetically diverse parent lines viz., (5 susceptible and 1 resistant) Pant Uphar, PSM-4 (leafless and resistant to powdery mildew), NDVP-250 (leafless and resistant to powdery mildew), Arka Ajit (powdery mildew and rust resistant) used as check variety, PEVAR-6 and Nepal Pea (early) were grown during rabi season of 2015-2016 in crossing block of pea breeding block at VRC, GBPUA&T, Pantnagar. In the rabi season of 2016-2017, part of each F_1 seed raised and selfed to obtain F_2 generation. Thus, the experimental materials finally consisted of four generations viz., P_1, P_2, F_1 and F_2. All these generations was shown in randomized block design (RBD) with three replications on in rabi season of 2017-18 at Vegetable Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar. The row length was kept as 4.0 m with spacing between and within rows as 40.0 cm and 10.0 cm, respectively. A single row of non-experimental line was planted on either side of each block so as to minimize variation due to environment and border effect and to raise the normal crop, all the recommended package of practices were followed. Five plants (twenty in F_2 generation) were randomly selected from each plot in all the three replications passing up the border plants. The tagging was done before flowering. On the basis of per se performances of fourteen yield and quality traits viz., days to 50 % flowering, node number to first flower, days to first green pod picking, pod length (cm), pod weight (g), number of pods per plant, pod yield per plant (g), number of seeds per pod, number of primary branches per plant, plant height (cm), shelling %, protein content %, TSS % and 100 seed weight (g), heterosis and inbreeding depression for individual traits were calculated as suggested by Kempthorne (1957) [22] and Griffing (1950) [18], respectively. The analysis of variance (ANOVA) for RBD was done as suggested by Panse and Sukhtame (1967) [25]. All the statistical analysis was performed using MS excel 2007.

Results and Discussion

The analysis of variance (Table 1 and 2) showed that significant differences existed among the parents and the progenies. It was found that the mean squares due to genotypes for all the traits were highly significant except trait viz., number of primary branches per plant in F_1 generation while genotypes of F_2 generation showed highly significant values for all the traits except number of seed per pod which was found significant. Similar results also have been reported by Bisht and Singh (2010) [9], Brar *et al*., (2012) [11] and Esposito *et al*., (2013) [16].

The objective of analyzing the heterosis in the present investigation was to find out the best crosses which gave high magnitude of useful heterosis for use in future breeding programmes. From the study, it was noticed that from trait to trait the number of heterotic crosses varied and the direction and extent of heterosis likewise differed from cross to cross for all the traits. Considerably, high heterosis in certain cross combinations and low in others reflected that nature of gene action varied with genetic architecture of the parents. Such nature as well as magnitude of heterosis helps in distinguishing superior cross combinations and thus their exploitation to get better transgressive segregants in future segregating generations (Ashokbhai 2012) [3].

While, the estimation of inbreeding depression gives information about the nature of gene actions involved in the expression of yield and its component traits. Inbreeding depression indicates whether the vigour observed in the F_1 generation can be fixed or not in later generations through selfing. The information of such estimates is essential to plan efficient breeding programmes as well as selection of parents in order to get good segregants for improvement of the crop yields.

Foregoing results of heterosis over BP as well as SV reflected that the frequency of crosses manifesting desired heterosis was, in general, low for pod length, pod weight, number of seeds per pod, number of primary branches per plant, plant height, shelling % and protein content %. The cross combinations Nepal Pea × PEVAR-6, NDVP-250 × PEVAR-6, Arka Ajit × Nepal Pea exhibited significant and desired negative heterobeltiosis for earliness whereas PSM-4 × PEVAR-6, Nepal Pea × PEVAR-6, PSM-4 × Nepal Pea exhibited significant and desired negative economic heterosis. In F_2 generation, NDVP-250 × Arka Ajit, PSM-4 × Arka Ajit, NDVP-250 × Nepal Pea were the cross combinations which exhibited significant and positive (desirable) inbreeding depression for days to 50 % flowering. For node number to first flower, PSM-4 × PEVAR-6 followed by Pant Uphar × Nepal Pea, NDVP-250 × PEVAR-6 showed maximum significant heterosis over better parent in desired direction whereas Nepal Pea × PEVAR-6 followed by PSM-4 × PEVAR-6 and Arka Ajit × Nepal Pea exhibited desired negative and significant standard heterosis. PSM-4 × Arka Ajit followed by Arka Ajit × PEVAR-6 exhibited the desired positive and significant inbreeding depression for this trait. For days to first green pod picking, Nepal Pea × PEVAR-6, Pant Uphar × Nepal Pea and NDVP-250 × Arka Ajit showed negative significant and desirable heterobeltiosis whereas Pant Uphar × Nepal Pea followed by NDVP-250 × Nepal Pea, Nepal Pea × PEVAR-6 exhibited negative significant standard heterosis in desired direction whereas in F_2 generation, desirable inbreeding depression in for this trait was recorded in PSM-4 × NDVP-250 followed by Pant Uphar × PSM-4 and Pant Uphar × Arka Ajit.

Earliness is a highly desirable attribute in vegetables in the fact that prevailing prices in the market are higher in early season. Pant Uphar × Nepal Pea, PSM-4 × Nepal Pea and Nepal Pea × PEVAR-6 were the crosses which exhibited negative and significant standard heterosis (in desirable direction) for D 50%F, NNFF and DFGPP. These crosses showing high negative heterosis can be exploited for recovering early recombinants in advance generations. These results were in close agreement with those reported by Bhardwaj *et al.,* (2005) [6], Ceyhan and Avci (2005) [13], Sharma *et al*., (2007) [28], Bisht and Singh (2010) [9], Daheriya (2012) [14], Buckseth (2013) [12] and Sharma (2013) [30].

Table 1: Analysis of variance for different traits in parents and their F_1'S in garden pea

S.V.	d.f.	Mean squares													
		D 50%F	NNFF	DFGPP	PL	PW	NPPP	PYPP	NSPP	NPB	PH	Shelling %	Protein content %	TSS %	100 seed weight
Replication	2	5.29	0.823	45.71	0.114	1.70	1.84	137.62	1.21	0.836	62.60	11.05	0 .439	0.290	4.77
Treatment	20	91.02**	2.85**	156.48**	2.98**	3.10**	6.51**	238.70**	1.13**	0.479	278.23**	60.08**	7.40**	32.26**	16.75**
Error	40	2.42	0.330	10.30	0.380	0.374	1.52	27.74	0.342	0.295	22.99	5.72	0.314	1.10	1.96
SEm±		0.907	0.331	1.85	0.356	0.353	0.710	3.04	0.338	0.314	2.77	1.38	0.323	0.606	0.809
CD (at 1%)		3.47	1.27	7.089	1.36	1.35	2.72	11.63	1.30	1.20	10.59	5.28	1.23	2.32	3.09
CD (at 5%)		2.59	0.947	5.30	1.01	1.01	2.03	8.69	0.966	0.897	7.91	3.95	0.924	1.73	2.32
CV (%)		2.55	4.59	3.90	7.26	10.42	14.69	10.96	7.29	17.19	5.88	4.91	2.27	5.63	8.09

Table 2: Analysis of variance for different traits in parents and their F_2'S in garden pea

S.V.	d.f.	Mean squares													
		D 50%F	NNFF	DFGPP	PL	PW	NPPP	PYPP	NSPP	NPBPP	PH	Shelling %	Protein content %	TSS %	100 seed weight
Replication	2	12.35	0.155	6.58	0.650	0.222	0.124	7.08	0.407	0.062	16.03	3.99	0.264	0.640	2.33
Treatment	20	66.87**	1.89**	86.20**	3.00**	2.42**	2.63**	76.34**	1.08*	0.545**	142.58**	50.89**	8.10**	25.19**	9.00**
Error	40	3.61	0.120	13.38	0.209	0.212	0.335	22.37	0.46	0.190	22.44	2.08	0.379	0.784	1.91
SEm±		1.10	0.259	2.11	0.264	0.266	0.334	2.73	0.391	0.252	2.735	0.832	0.355	0.511	0.797
CD (at 1%)		4.20	0.987	8.07	1.01	1.02	1.28	10.45	1.50	0.963	10.46	3.18	1.36	1.96	3.05
CD (at 5%)		3.13	0.738	6.03	0.755	0.760	0.955	7.80	1.12	0.720	7.82	2.38	1.01	1.46	22.79
CV (%)		3.13	3.53	4.50	5.66	8.78	7.78	12.30	8.460	14.04	6.10	3.15	2.48	4.85	8.62

D 50%F=Days to 50 % flowering, NNFF=Node number to first flower, DFGPP= Days to first green pod picking, PL=Pod length, PW= Pod Weight, NPPP=Number of pods/plant, PYPP= Pod yield/plant, NSPP= Number of seeds/pod, NPBPP= Number of primary branches per plant, PH= Plant height, TSS %= Total soluble solids %.

Table 3: Percent increase or decrease of the F_1 over mid parent (relative heterosis (RH)), better parent (heterobeltiosis (HB)) and check variety (economic heterosis (EH)) and Inbreeding depression (ID) for yield and quality traits

No of crosses	Days to 50 % flowering					Node number to first flower					Days to first green pod picking				
	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID
Pant Uphar × PSM-4	65.00	63.20	2.63	0.00	2.77	13.27	12.63	-1.97	5.29	4.77	86.50	78.42	9.04**	-1.30	9.34**
Pant Uphar × NDVP-250	66.33	64.65	4.74*	2.05	2.54	13.47	13.03	-2.42	6.88	3.22	85.16	81.34	7.36*	-2.83	4.49
Pant Uphar × Arka Ajit	66.00	65.00	1.54	1.54	1.52	13.40	14.17	-0.99	6.35	-5.72	91.43	85.43	4.33	4.33	6.57*
Pant Uphar × Nepal Pea	62.33	60.00	-1.58	-4.10*	3.74	11.33	12.27	-16.26**	-10.05**	-8.24*	70.74	74.54	-10.82**	-19.28**	-5.37
Pant Uphar × PEVAR-6	65.00	63.85	-5.34**	0.00	1.77	12.40	12.90	-8.37*	-1.59	-4.03	88.67	85.72	-1.95	1.18	3.32
PSM-4 × NDVP-250	67.33	68.99	22.42**	3.59	-2.46	13.33	13.63	-3.38	5.82	-2.25	84.09	75.32	6.48	-4.06	10.42**
PSM-4 × Arka Ajit	68.33	63.45	5.13*	5.13*	7.15**	13.47	12.03	0.50	6.88	10.64**	83.97	83.46	-4.19	-4.18	0.61
PSM-4 × Nepal pea	55.67	57.33	3.09	-14.36**	-2.99	11.53	11.70	-13.93**	-8.47*	-1.45	70.56	75.33	-10.65**	-19.49**	-6.76
PSM-4 × PEVAR-6	53.67	55.33	-21.84**	-17.44**	-3.11	10.80	13.23	-19.40**	-14.29**	-22.53**	92.33	88.90	2.10	5.36	3.72
NDVP-250 × Arka Ajit	67.00	59.33	3.08	3.08	11.44**	13.13	13.23	-4.83	4.23	-0.76	78.17	77.92	-10.81**	-10.81**	0.32
NDVP-250 × Nepal pea	61.33	57.67	11.52**	-5.64**	5.98*	12.07	11.60	-12.56**	-4.23	3.87	71.93	75.64	-4.89	-17.93**	-5.16
NDVP-250 × PEVAR-6	57.00	59.33	-16.99**	-12.31**	-4.09	11.80	12.70	-14.49**	-6.35	-7.63*	87.79	84.11	-2.92	0.17	4.20
Arka Ajit × Nepal pea	58.00	59.67	-10.77**	-10.77**	-2.87	11.20	11.77	-11.11**	-11.11**	-5.06	84.71	83.61	-3.34	-3.34	1.30
Arka Ajit × PEVAR-6	65.33	62.33	-4.85*	0.513	4.59*	12.73	11.67	1.06	1.06	8.38*	90.63	88.74	0.22	3.41	2.08
Nepal Pea × PEVAR-6	54.67	54.67	-20.39**	-15.90**	0.00	10.67	11.53	-13.51**	-15.34**	-8.13*	75.40	84.67	-16.62**	-13.97**	-12.29**

Contd….

No of crosses	Pod length (cm)					Pod weight (g)					Number of pods per plant				
	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID
Pant Uphar × PSM-4	8.07	7.67	-0.66	-10.67	4.96	5.92	5.43	9.16	-13.20	8.23	6.89	7.32	-13.40	-14.79	-6.19
Pant Uphar × NDVP-250	7.24	8.47	-16.14**	-19.82**	-16.94**	5.03	4.55	1.13	-26.19**	9.61	8.13	7.98	2.14	0.49	1.85
Pant Uphar × Arka Ajit	8.57	7.70	-5.17	-5.13	10.12*	7.10	5.09	4.06	4.06	28.28**	8.89	8.47	9.93	9.89	4.72
Pant Uphar × Nepal Pea	7.93	6.77	5.31	-12.14*	14.71**	5.20	4.07	4.45	-23.77**	21.70*	10.74	8.70	31.93*	32.80*	19.00**
Pant Uphar × PEVAR-6	9.43	8.03	-16.25**	4.43	14.81**	6.76	4.88	-16.18*	-0.94	27.77**	8.13	7.39	2.09	0.45	9.08
PSM-4 × NDVP-250	8.73	7.73	1.16	-3.29	11.45*	5.92	4.69	9.22	-13.15	20.82**	7.28	7.46	-7.42	-10.05	-2.52
PSM-4 × Arka Ajit	9.37	8.93	3.69	3.73	4.63	7.13	5.37	4.50	4.50	24.60**	10.44	8.12	29.06*	29.01*	22.20**
PSM-4 × Nepal pea	8.00	7.20	-1.48	-11.41*	10.00	5.13	4.71	-5.35	-24.73**	8.17	10.09	7.98	23.86	24.68	20.89**
PSM-4 × PEVAR-6	9.40	8.03	-16.52**	4.10	14.54**	6.22	5.42	-22.77**	-8.73	12.94	8.08	7.37	8.83	-0.16	8.71
NDVP-250 × Arka Ajit	8.77	8.33	-2.95	-2.92	4.94	5.88	5.61	-13.76	-13.76	4.65	7.46	7.09	-7.75	-7.79	4.96
NDVP-250 × Nepal pea	7.83	7.37	-9.27	-13.25*	5.96	4.50	4.41	-0.656	-34.02**	2.02	9.68	7.09	18.85	19.63	26.74**
NDVP-250 × PEVAR-6	9.61	8.54	-14.65**	6.42	11.10*	6.29	5.43	-21.99**	-7.81	13.67	7.00	7.08	-10.94	-13.47	-1.14
Arka Ajit × Nepal pea	8.03	7.70	-11.07	-11.04	4.15	5.07	4.83	-25.66**	-25.66**	4.75	10.08	7.54	23.78	24.60	25.20**
Arka Ajit × PEVAR-6	8.43	9.00	-25.10**	-6.61	-6.72	7.05	5.73	-12.52	3.39	18.74**	8.53	7.07	5.48	5.44	17.12
Nepal Pea × PEVAR-6	7.73	7.23	-31.32**	-14.36*	6.47	6.01	5.76	-25.46**	-11.90	4.15	10.49	5.33	28.78*	29.63*	49.19**

Contd….

No of crosses	Pod yield per plant (g)					Number of seeds per pod					Number of primary branches per plant				
	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID
Pant Uphar × PSM-4	40.71	39.84	0.716	-26.08**	2.14	9.00	8.00	7.96	14.03*	11.08	3.67	4.03	0.164	43.46*	-9.74
Pant Uphar × NDVP-250	40.81	35.73	2.65	-25.89**	12.45	8.11	8.33	5.78	2.79	-2.75	2.83	2.82	-17.33	10.49	0.35
Pant Uphar × Arka Ajit	63.08	43.20	14.55	14.55	31.51**	8.25	8.22	4.60	4.60	0.40	2.99	3.16	-12.75	16.61	-5.91
Pant Uphar × Nepal Pea	55.28	35.29	39.03**	0.381	36.16**	7.78	7.78	6.05	-1.44	0.00	3.15	2.84	-7.93	23.05	9.99
Pant Uphar × PEVAR-6	54.85	35.94	37.94**	-0.406	34.46**	8.20	8.67	-13.14*	3.89	-5.73	2.98	2.77	-21.41	16.22	6.90
PSM-4 × NDVP-250	44.05	34.87	8.97	-20.02*	20.84*	7.67	8.11	-8.00	-2.83	-5.83	3.71	3.02	1.09	44.79*	18.58
PSM-4 × Arka Ajit	56.08	43.48	1.84	1.83	22.46**	8.44	8.67	1.32	7.01	-2.65	2.81	3.52	-23.29	9.87	-24.98
PSM-4 × Nepal pea	51.66	37.50	27.80*	-6.20	27.41**	8.33	8.44	0.00	5.62	-1.32	3.55	2.43	-3.30	38.50*	31.37**
PSM-4 × PEVAR-6	51.99	39.82	28.63*	-5.59	23.40**	8.33	8.11	-11.69*	5.62	2.68	3.02	3.20	-20.28	17.89	-6.03
NDVP-250 × Arka Ajit	43.95	39.52	-20.18*	-20.18*	10.09	7.67	8.33	-2.83	-2.83	-8.70	3.52	2.67	17.17	37.31*	23.97*
NDVP-250 × Nepal pea	43.36	31.30	21.35	-21.26**	27.81**	7.33	8.00	-4.35	-7.06	-9.09	3.02	3.55	0.601	17.89	-17.48
NDVP-250 × PEVAR-6	44.01	38.82	15.00	-20.08*	11.81	8.33	8.33	-11.69*	5.62	0.00	2.85	3.02	-24.75*	11.27	-5.95
Arka Ajit × Nepal pea	51.88	36.46	-5.79	-5.79	29.72**	8.67	7.00	9.84	9.84	19.23**	3.01	3.21	0.178	17.40	-6.76
Arka Ajit × PEVAR-6	60.72	40.55	10.27	10.27	33.22**	8.00	7.33	-15.22**	1.39	8.33	3.50	2.83	-7.67	36.53*	19.07
Nepal Pea × PEVAR-6	63.21	30.80	65.15**	14.78	51.27**	7.00	7.33	-25.82**	-11.28	-4.76	2.35	2.67	-38.05**	-8.39	-13.78

Contd….

No of crosses	Plant height (cm)					Shelling %					Protein content %				
	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID
Pant Uphar × PSM-4	77.84	77.41	1.96	-8.58	0.555	49.02	44.64	-5.49	-7.97*	8.94**	24.83	24.89	-4.05*	-13.61**	-0.266
Pant Uphar × NDVP-250	75.94	99.26	-0.535	-10.82*	-30.71**	49.27	46.37	-5.02	-7.52*	5.88	24.15	24.20	-6.66**	-15.96**	-0.175
Pant Uphar × Arka Ajit	93.43	82.47	9.73*	9.73*	11.73**	54.26	53.01	1.86	1.86	2.30	22.97	23.69	-20.08**	-20.09**	-3.16
Pant Uphar × Nepal Pea	77.25	70.16	1.19	-9.27*	9.18	51.38	43.87	-0.94	-3.54	14.62**	25.94	25.04	0.245	-9.75**	3.46
Pant Uphar × PEVAR-6	85.67	77.00	12.05*	0.624	10.13*	48.56	44.39	-6.38	-8.84*	8.59**	24.23	23.77	-10.24**	-15.68**	1.91
PSM-4 × NDVP-250	106.88	73.28	46.89**	25.52**	31.43**	46.32	42.54	0.99	-13.05**	8.16*	24.64	24.30	4.71*	-14.26**	1.38
PSM-4 × Arka Ajit	82.86	77.08	-2.69	-2.69	6.97	50.53	46.96	-5.14	-5.14	7.07*	23.40	25.46	-18.59**	-18.60**	-8.82**
PSM-4 × Nepal pea	72.62	72.60	1.90	-14.72**	0.034	55.72	49.99	33.95**	4.59	10.28**	25.43	23.70	5.25**	-11.52**	6.81**
PSM-4 × PEVAR-6	80.54	80.21	5.34	-5.41	0.415	45.42	44.00	-7.09	-14.74**	3.13	24.88	22.87	-7.85**	-13.43**	8.08**
NDVP-250 × Arka Ajit	97.39	79.77	14.38**	14.38**	18.09**	50.23	45.82	-5.70	-5.71	8.78**	25.55	23.92	-11.10**	-11.11**	6.39**
NDVP-250 × Nepal pea	73.44	71.47	0.935	-13.75**	2.68	49.52	46.28	7.96	-7.05	6.54*	24.72	26.49	2.31	-13.99**	-7.17**
NDVP-250 × PEVAR-6	88.73	74.19	16.05**	4.21	16.39**	47.29	44.08	-3.26	-11.22**	6.79*	23.84	25.59	-11.71**	-17.06**	-7.37**
Arka Ajit × Nepal pea	88.08	83.69	3.44	3.44	4.98	48.73	46.42	-8.52*	-8.52*	4.74	26.08	23.83	-9.25**	-9.25**	8.65**
Arka Ajit × PEVAR-6	86.05	84.14	1.06	1.06	2.22	55.39	43.62	3.99	3.98	21.25**	22.96	27.20	-20.13**	-20.13**	-18.51**
Nepal Pea × PEVAR-6	74.61	75.63	-2.42	-12.38*	-1.37	40.43	36.92	-17.30**	-24.10**	8.68*	23.92	25.15	-11.42**	-16.79**	-5.14*

Contd….

No of crosses	TSS %					100 seed weight (g)				
	Mean F_1	Mean F_2	HB	EH	ID	Mean F_1	Mean F_2	HB	EH	ID
Pant Uphar × PSM-4	22.26	22.20	17.16**	13.17**	0.275	17.23	16.68	7.49	6.29	3.19
Pant Uphar × NDVP-250	20.50	20.43	20.12**	4.22	0.345	20.11	15.37	22.03**	24.04**	23.56**
Pant Uphar × Arka Ajit	21.33	18.52	8.43	8.41	13.15**	17.96	16.70	10.79	10.79	7.01
Pant Uphar × Nepal Pea	18.17	19.00	6.47	-7.62	-4.57	18.84	16.34	17.53*	16.22*	13.27*
Pant Uphar × PEVAR-6	20.80	20.20	1.96	5.74	2.88	17.66	17.08	10.17	8.95	3.29
PSM-4 × NDVP-250	19.46	20.00	2.43	-1.06	-2.77	21.32	18.22	29.38**	31.50**	14.53**
PSM-4 × Arka Ajit	16.79	15.30	-14.63**	-14.64**	8.86	17.59	16.54	8.51	8.51	5.97
PSM-4 × Nepal pea	12.20	13.52	-35.79**	-37.98**	-10.79	20.73	18.09	41.31**	27.88**	12.73*
PSM-4 × PEVAR-6	24.00	23.75	17.65**	22.01**	1.05	18.52	17.97	17.07*	14.25	2.97
NDVP-250 × Arka Ajit	20.80	19.52	5.76	5.74	6.16	20.43	18.05	23.99**	26.03**	11.65*
NDVP-250 × Nepal pea	17.17	16.26	15.50*	-12.71**	5.31	16.37	14.34	-0.626	1.01	12.42
NDVP-250 × PEVAR-6	13.79	15.32	-32.39**	-29.88**	-11.08	17.00	16.33	3.18	4.87	3.95
Arka Ajit × Nepal pea	17.20	15.59	-12.54**	-12.56**	9.39*	18.12	16.47	11.78	11.78	9.11
Arka Ajit × PEVAR-6	16.67	15.98	-18.30**	-15.27**	4.09	17.46	15.47	7.71	7.71	11.40
Nepal Pea × PEVAR-6	24.80	22.55	21.57**	26.08**	9.06**	13.33	12.05	-15.74*	-17.77*	9.60

Table 4: Ranking of parents and crosses based on per se performance

Si. No.	Trait	Mean basis		Range of heterosis over better parent (BP)	Range of heterosis over standard parent (SP)	Range of Inbreeding Depression
		Promising parent	Promising F_1			
1	Days to 50 % flowering	PSM-4 (53.00) Nepal Pea (54.00) NDVP-250 (55.00)	PSM-4 × PEVAR-6 (53.67) Nepal Pea × PEVAR-6 (54.67) PSM-4 × Nepal Pea (55.67)	-21.84 to 22.42	-17.44 to 5.13	-2.46 to 11.44

2	Node number to first flower	Nepal Pea (12.27) PEVAR-6 (12.33) Arka Ajit (12.60)	Nepal Pea × PEVAR-6 (10.67) PSM-4 × PEVAR-6 (10.80) Arka Ajit × Nepal Pea (11.20)	-19.40 to 1.06	-15.34 to 6.88	-22.53 to 10.64
3	Days to first green pod picking	Nepal Pea (73.44) NDVP-250 (75.63) PSM-4 (78.97)	PSM-4 × Nepal Pea (70.56) Pant Uphar × Nepal Pea 70.74) NDVP-250×Nepal Pea (71.93)	-16.62 to 9.04	-19.49 to 5.36	-12.29 to 10.42
4	Pod length (g)	PEVAR-6 (11.26) Arka Ajit (9.03) NDVP-250 (8.63)	NDVP-250×PEVAR-6 (9.61) Pant Uphar × PEVAR-6 (9.43) PSM-4 × PEVAR-6 (9.40)	-31.32 to 5.31	-19.82 to 6.42	-16.94 to 14.81
5	Pod weight (g)	PEVAR-6 (8.60) Arka Ajit (6.82) PSM-4 (5.42)	PSM-4 × Arka Ajit (7.13) Pant Uphar × Arka Ajit (7.10) Arka Ajit × PEVAR-6 (7.05)	-25.66 to 9.22	-34.02 to 4.50	2.02 to 28.28
6	Number of pods per plant	Nepal Pea (8.14) Arka Ajit (8.09) Pant Uphar (7.96)	Pant Uphar × Nepal Pea (10.74) Nepal Pea × PEVAR-6 (10.49) PSM-4 × Arka Ajit (10.44)	-13.40 to 31.93	-14.79 to 32.80	-6.19 to 49.19
7	Pod yield per plant (g)	Arka Ajit (55.07) PSM-4 (40.42) Pant Uphar (39.76)	Nepal Pea × PEVAR-6 (63.21) Pant Uphar × Arka Ajit (63.08) Arka Ajit × PEVAR-6 (60.72)	-20.18 to 65.15	-26.08 to 14.78	2.14 to 51.27
8	Number of seeds per pod	PEVAR-6 (9.44) PSM-4 (8.33) Arka Ajit (7.89)	Pant Uphar × PSM-4 (9.00) Arka Ajit × Nepal Pea (8.67) PSM-4 × Arka Ajit (8.44)	-25.82 to 9.84	-11.28 to 14.03	-9.09 to 19.23
9	Number of primary branches per plant	PEVAR-6 (3.79) PSM-4 (3.67) Pant Uphar (3.42)	PSM-4 × NDVP-250 (3.71) Pant Uphar × PSM-4 (3.67) PSM-4 × Nepal Pea (3.55)	-38.05 to 17.17	-8.39 to 44.79	-24.98 to 31.37
10	Plant height (cm)	Nepal Pea (68.11) PSM-4 (71.26) NDVP-250 (72.76)	PSM-4 × Nepal Pea (72.62) NDVP-250 × Nepal Pea (73.44) Nepal Pea × PEVAR-6 (74.61)	-2.69 to 46.89	-14.72 to 25.52	-30.71 to 31.43
11	Shelling %	Arka Ajit (53.27) Pant Uphar (51.87) PEVAR-6 (48.89)	PSM-4 × Nepal Pea (55.72) Arka Ajit × PEVAR-6 (55.39) Pant Uphar × Arka Ajit (54.26)	-17.30 to 33.95	-24.10 to 4.59	2.30 to 21.25
12	Protein content %	Arka Ajit (28.74) PEVAR-6 (27.00) Pant Uphar(25.88)	Arka Ajit × Nepal Pea (26.08) Pant Uphar × Nepal Pea (25.94) NDVP-250 × Arka Ajit (25.55)	-20.13 to 5.25	-20.13 to -9.25	-18.51 to 8.65
13	TSS %	PEVAR-6 (20.40) Arka Ajit (19.67) PSM-4 (19.00)	Nepal Pea × PEVAR-6 (24.80) PSM-4 × PEVAR-6 (24.00) Pant Uphar × PSM-4 (22.26)	-35.79 to 21.57	-37.98 to 26.08	-11.08 to 13.15
14	100 seed weight	NDVP-250 (16.48) Arka Ajit (16.21) Pant Uphar (16.03)	PSM-4 × NDVP-250 (21.32) PSM-4 × Nepal Pea (20.73) NDVP-250 × Arka Ajit (20.43)	-15.74 to 41.31	-17.77 to 31.50	2.97 to 23.56

None of the cross combinations exhibited desired significant heterosis over better parent and over check variety for pod length and pod weight. The number of pods per plant contributes directly towards increase in the fresh pod yield; therefore more number of pods per plant is always a desirable trait. Therefore, for number of pods per plant, crosses Pant Uphar × Nepal Pea, PSM-4 × Arka Ajit and Nepal Pea × PEVAR-6 expressed positive and significant heterobeltiosis whereas Pant Uphar × Nepal Pea, Nepal Pea × PEVAR-6 and PSM-4 × Arka Ajit expressed the maximum positive and significant heterosis over the check variety. Maximum undesirable inbreeding depression for this trait was expressed by Nepal Pea × PEVAR-6, NDVP-250 × Nepal pea, Arka Ajit × Nepal pea. Bhuvaneshwari and Muthiah (2005) [7], Ganesh *et al*., (2008) [17], Bora *et al.*, (2009) [10], Bishnoi (2015) [8] and Joshi *et al.*, (2016) [19] also reported similar finding for this trait.

For pod yield per plant, the maximum heterobeltiosis was observed in Nepal Pea × PEVAR-6 followed by Pant Uphar × Nepal Pea and Pant Uphar × PEVAR-6 however none of cross combination expressed desired positive and significant economic heterosis and inbreeding depression for this trait. Present findings are in conformity with those of reported by Bisht and Singh (2010) [9] and Buckseth (2013) [12] for heterosis, Daheriya (2012) [14], Ajay *et al.*, (2015) [1].

Number of seeds per pod is an important green pod yield contributing trait in garden pea and is also important trait from consumer's as well as seed production point of view. For number of seeds per pod, Pant Uphar × PSM-4 exhibited desired significant economic heterosis where none of crosses showed desired inbreeding depression for this trait. Increase in yield has always been the first and foremost objectives for pea breeders. The crosses which reflected high heterotic values are likely to produce high yielding segregants in advance generations. These results were in corroboration with earlier reports of Bhuvaneshwari and Muthiah (2005) [7], Karnwal and Khushwah (2010) [20], Bassam and Souhaeel (2011) [5], Ashokbhai (2012) [3].

More number of primary branches is related with more yield, therefore it is a desirable trait for the improvement of yield. Therefore, for number of primary branches per plant, PSM-4 × NDVP-250 followed by Pant Uphar × PSM-4 and PSM-4 × Nepal Pea expressed positive and significant standard heterosis whereas none of the crosses exhibited desired negative and significant inbreeding depression for this trait. PSM-4 × Nepal Pea followed by NDVP-250 × Nepal Pea and Nepal Pea × PEVAR-6 showed the negative (desired) and significant standard heterosis whereas the desired positive and significant inbreeding depression was expressed by PSM-4 × NDVP-250 followed by the cross NDVP-250 × Arka Ajit and NDVP-250 × PEVAR-6 for plant height (dwarf plants). The dwarf and medium plants are considered desirable as they can be grown without providing any support, thus making commercial pea growing a remunerative venture. The negative heterosis is considered desirable for plant height (Bisht and Singh, 2010) [9].

For shelling % which is an important trait from consumer's point of view, PSM-4 × Nepal pea exhibited the maximum positive and significant heterobeltiosis whereas none of the cross combination exhibited desired and significant heterosis and inbreeding depression. These results are in close agreement with the results reported by Brar *et al.*, (2012) [11], Sharma and Bora (2013) [30].

PSM-4 × Nepal Pea followed by PSM-4 × NDVP-250 reflected maximum positive and significant heterosis over better parent whereas none of the crosses showed desired significant heterosis for protein content % while the crosses Arka Ajit × PEVAR-6 and PSM-4 × Arka Ajit reflected the desired negative and significant inbreeding depression for this trait. For TSS %, Nepal Pea × PEVAR-6 followed by Pant Uphar × NDVP-250 and PSM-4 × PEVAR-6 revealed maximum positive and significant heterobeltiosis whereas Nepal Pea × PEVAR-6 followed by PSM-4 × PEVAR-6 and Pant Uphar × PSM-4 showed maximum positive and significant heterosis over the check variety. None of the crosses exhibited the desired negative and significant inbreeding depression for this trait.

The maximum heterobeltiosis for 100 seed weight was observed in PSM-4 × Nepal Pea followed by PSM-4 × NDVP-250 and NDVP-250 × Arka Ajit whereas PSM-4 × NDVP-250 followed by PSM-4 × Nepal Pea and NDVP-250 × Arka Ajit expressed positive and significant heterosis over the check variety while none of the crosses exhibited the desired negative and significant inbreeding depression for this trait. Significant desirable heterosis for this trait was also observed by Patel (2000) [26], Tyagi and Srivastava (2001) [32] and Kumar *et al.*, (2017) [23].

Further, perusal of data from the table 3 showed that for pod yield per plant, five crosses viz., Nepal Pea × PEVAR-6 (65.15) followed by Pant Uphar × Nepal Pea (39.03), Pant Uphar × PEVAR-6 (37.94), PSM-4 × PEVAR-6 (28.63) and PSM-4 × Nepal Pea (27.80) expressed positive and significant heterosis over BP although these crosses also exhibited high positive and significant inbreeding depression which is undesirable for this trait, hybrid vigour in such cases is largely due to non-additive type of gene effects. These results are in harmony with Kaur *et al.*, (2003) [21], Bhardwaj *et al.*, (2005) [6], Awasthi *et al*., (2009) [4], Sharma *et al*., (2010) [29] and Buckseth (2013) [12].

Whereas, for quality traits like protein content %, only two crosses viz., PSM-4 × NDVP-250 (4.71) and PSM-4 × Nepal Pea (5.25) manifested desired (positive) heterosis over BP. Non-significant or negative inbreeding depression is desirable for this trait so out of these two crosses, only one cross i.e. PSM-4 × NDVP-250 is comparably more useful as it expressed positive heterosis over BP along with non-significant inbreeding depression. For TSS %, four crosses viz., Nepal Pea × PEVAR-6, PSM-4 × PEVAR-6, Pant Uphar × NDVP-250 (over BP only) and Pant Uphar × PSM-4 showed desired (positive) heterosis over BP and SV although, out of them, three cross combination i.e. PSM-4 × PEVAR-6, Pant Uphar × NDVP-250 and Pant Uphar × PSM-4 expressed the desirable non-significant inbreeding depression. Hence, these crosses could be more useful in future breeding programme for improvement in quality traits of garden pea.

Conclusion

With the results of heterosis, it may be concluded that for the improvement of yield and quality traits in garden pea, heterosis breeding would be advantageous and the crosses which showed the desirable values (either positive or negative direction) of economic or standard heterosis for different yield and quality traits may be advanced for improvement in quantitative traits.

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