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Combining Ability, Genetic Diversity and Their Association with Heterosis for Seed Yield in Pigeonpea [*Cajanus cajan* (L.) Millspaugh]

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ABSTRACT

Background: In pigeonpea, very less information is available on the interrelationship between combining ability, parental genetic diversity and heterosis.

Methods: The experiment was conducted using randomized block design during *kharif* 2017-18 at GBPUAT, Pantnagar with 36 genotypes (8 parents and 28 F_1 hybrids). The combining ability was estimated by using the Griffing's, Method II, Model I. The genetic diversity (GD) was estimated by using the D^2 statistics. The correlation between heterosis and different parameters *viz.,* parental mean (PM), specific combining ability (SCA), mean of general combining ability (MGCA) and genetic diversity (GD) were estimated by using Pearson's correlation.

Result: The hybrids *viz.,* Pant A 441 × AH 09-47 (65.33 g), Pant A 441 × Pusa 2013-2 (64.33 g), Pusa 992 × Pant A 441 (62.67 g), UPAS 120 × Pant A 441 (59.67 g) and UPAS 120 × Pusa 992 (58 g) were found as most promising hybrids for seed yield while the parents Pant A 441 can be used as donor for high seed yield. The estimation of genetic diversity among parents revealed that three different clusters were present. PM, MGCA and SCA were found to be reliable parameters to predict the heterosis.

Key words: Combining ability, Genetic diversity, Heterosis, Parental mean, Pigeonpea.

INTRODUCTION

Heterosis breeding resulted in quantum jump in productivity of several crops but in case of pulses it has not yet been properly exploited. Exploitation of heterosis by developing hybrids resulted in significant yield (>60%) advantage (Vaghela *et al.,* 2011). Heterosis is explained as the high-ranking performance of the hybrid, in comparison to their parents (Shull, 1948). Several workers proposed different theories to explain its genetic basis but the genetic mechanism of heterosis still remains unclear to al large extent (Sinha *et al.,* 2020). The magnitude of heterosis depends on the relative performance of the inbred parents. One of the most important steps in hybrid breeding programmes is to identify the parents having good GCA and hybrids having good SCA. Heterosis may increase with increase in genetic diversity but greater divergence between parents not always results in heterosis (Moll *et al.,* 1965). In pigeonpea, very less information is available on the interrelationship between heterosis, combining ability and parental genetic diversity for yield. Thus the present study was conducted with the aim to assess the relationship between combining ability, *per se* performance of parents, genetic diversity and heterosis.

MATERIALS AND METHODS

Plant materials and field experiments

The eight elite pigeonpea genotypes were crossed in half diallel fashion during the *kharif* 2016-17 to produce 28 F_1's.

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These 28 F_1's and eight parents were grown together during *kharif* season of 2017-18 at N.E.B. Crop Research Centre of GBPUAandT, Pantnagar in randomized block design with three replications. The observations were recorded for eight characters including days to 50 per cent flowering, days to maturity, plant height (cm), number of primary branches per plant, number of pods per plant, number of seeds per pod, 100-seed weight (g) and seed yield per plant (g).

Statistical analysis

The combining ability was evaluated by using Method II, Model I (Fixed effects) of Griffing's (1956). If the GCA and SCA effects were significant in desirable direction than these effects were considered as good (G) and those significant towards undesirable direction were considered as poor (P) while non-significant effects were designated as average (A). In case of *per se* (PM) performance if mean of line is found above overall parental mean than such lines were considered as good (G) but if mean of a parental line was below the overall parental mean than these lines were classified as poor (P). The heterosis over mid parent (MPH) and better parent (BPH) were estimated for seed yield. The GCA effects obtained from both parental lines of a hybrid were averaged to determine the mean GCA (MGCA) effect of the parents (Kumar *et al.,* 2015). The genetic diversity was estimated for various yield and related traits by using the Mahalanobis D^2 statistics (Mahalanobis, 1928) and Tocher's method was used as proposed by Rao (1952) for cluster formation. By using the method of Arunachalam (1984), the parents were classified into three genetic diversity classes *i.e.* low, medium and high. The Pearson's correlation coefficients were used to estimate the relation between PM, SCA, MGCA, GD, MPH and BPH. The regression analysis along with coefficient of determination (R^2) was also performed to obtain regression graphs showing the relationship among PM, SCA, MGCA, GD, MPH and BPH (Snedecor and Cochran, 1989).

RESULTS AND DISCUSSION

Estimation of combining ability and genetic diversity

The results revealed that seed yield in hybrids ranged from 28 g to 65.33 g with mean value of 45.80 g while in parents it ranged from 32 g to 53.33 g with mean value of 40.57 g (Fig 1 and Fig 2). The hybrids *viz.,* Pant A 441 × AH 09-47, Pant A 441 × Pusa 2013-2, Pusa 992 × Pant A 441, UPAS 120 × Pant A 441 and UPAS 120 × Pusa 992 were the top five yielder hybrids while parent Pant A 441 was found to be highest yielder and can be used as donor. ANOVA for different traits (Table 1) indicated significant genotypic differences for all characters under study. The diallel ANOVA indicated that MSS due to GCA and SCA effects were highly significant (p<0.01) for all characters. For the days to maturity, plant height and primary branches the estimates of SCA variance were found to be higher than the corresponding GCA variance while for rest of characters

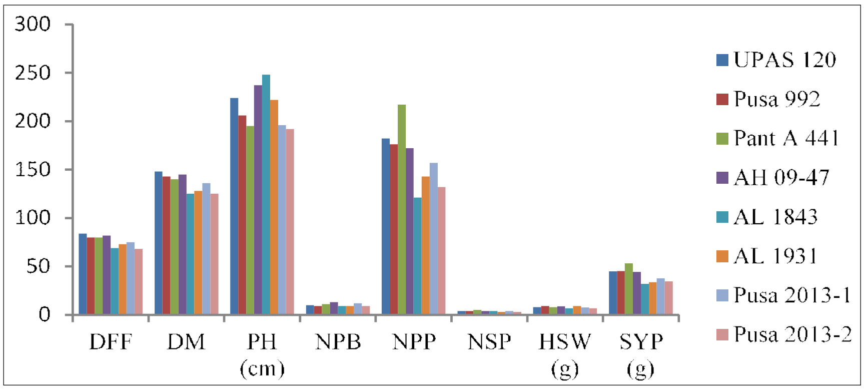

Fig 1: Mean performance of parents for different biometrical traits where, DFF, DM, PH, NPB, NPP, NSP, HSW and SYP refers to days to 50% flowering, days to maturity, plant height, number of primary branches/plant, number of pods/plant, number of seed/pod 100- seed weight and seed yield/plant.

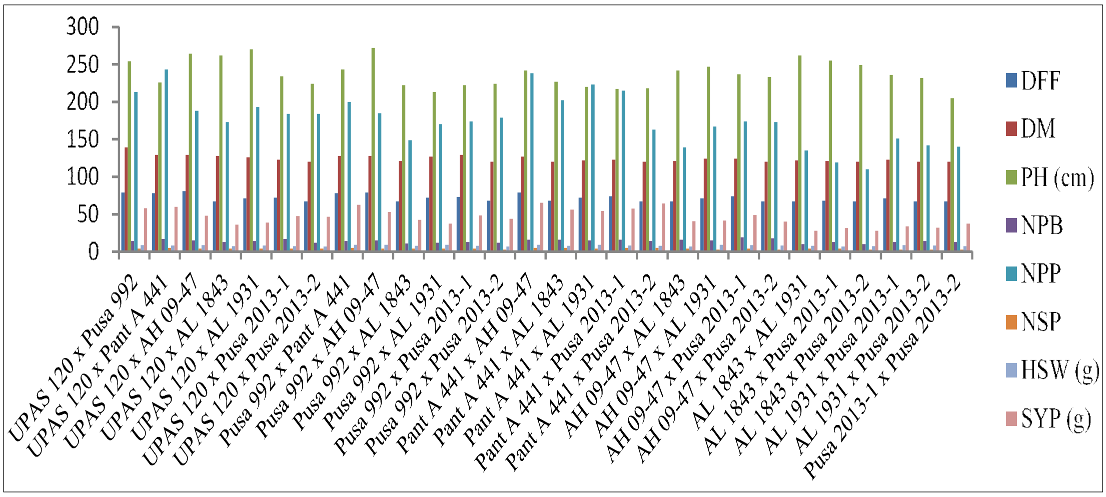

Fig 2: Mean performance of hybrids for different biometrical traits.

GCA variance was found to be higher than SCA variance. Average degree of dominance was found to be more than unity for the characters *viz.,* days to maturity, plant height, number of primary branches which indicated the presence of over dominance. The parent Pant A 441 was ranked as the best parent as it had a good GCA effects for maximum four characters including seed yield (Table 2). Genotype Pusa 992 also exhibited good GCA effect for seed yield along with number of pods and 100 seed weight. Only one hybrid *i.e.* Pant A 441 × Pusa 2013-2 exhibited good SCA effects for seed yield along with days to 50% flowering, days to maturity, number of seed per pods and 100 seed weight (Table 3). The estimation of genetic diversity revealed that three different clusters were present (Table 4). The cluster I contain three parents while the cluster II contains two parents and cluster III contains three parents. The intercluster distance was greater than the intra cluster distance indicating sufficient genetic diversity among the genotypes. The maximum inter cluster distance was found between cluster I and II (118.95) and minimum between cluster I and III (50.53).

Relationship between PM, SCA, MGCA, MPH and BPH for seed yield

The perusals of Table 5 indicated that three hybrids *viz.,* UPAS 120 × Pusa 992, Pant A 441 × AH 09-47 and Pant A 441 × Pusa 2013-2 exhibited significant and positive MPH and BPH for seed yield. Both MPH and BPH (r=0.89*) were significantly and positively correlated with each other (Table 6). The PM was positively and significantly correlated with the MPH (r= 0.82**) and BPH (r= 0.82**). The significant linear regression of PM on MPH and BPH and very high R^2 value further revealed that PM was a good determinant of heterosis (Fig 3). A critical insight of Table 7 and 8 indicated that in case of mid parent highest frequency of heterotic hybrids (50%) was observed when parents having high × high and high × low combinations were crossed. In case of BPH highest frequency of heterotic hybrids (66.66%) was reported when parents having high and high mean were crossed *i.e.* high × high combination. These results indicated that parental mean can be used as reliable parameters for heterosis estimation. Mohammadi *et al.* (2008) also suggested that the *per se* performance of parents can be

Table 1: Diallel analysis of variance for different biometrical characters.

Source of variation	*df*	MSS							
		DFF	DM	PH	NPB	NPP	NSP	HSW	SYP
Replication	2	0.04	0.06	3.18	1.56	167.53	0.01	0.01	13.03
Genotypes	35	32.84**	63.44**	1381.43**	15.29**	2756.77**	0.51**	2.49**	333.02**
Error	70	0.03	0.03	82.27	0.97	52.6	0.05	31.75	9.29
Parents	7	108.92**	257.42**	1310.47**	8.64**	2848.098	0.75**	2.49	164.35**
Hybrids	27	66.46**	57.82**	999.63**	14.09**	3363.36**	0.74**	1.95	386.08**
Parents *vs* Hybrid	1	442.54**	2733.54**	9620.76**	276.00**	3363.11**	0.080**	0.01	475.59**
GCA	7	104.59**	125.36**	1078.92**	14.73**	4444.54**	1.05**	2.75**	432.75**
SCA	27	9.56**	41.23**	275.31**	4.85**	247.32**	0.03**	0.15**	28.83**
		Variances							
σ^2GCA		10.45	12.52	100.05	1.31	436.05	0.09	0.27	41.51
σ^2SCA		9.48	41.11	196.98	3.28	163.33	0.01	0.15	11.19
$\sqrt{\sigma^2SCA/2\sigma^2GCA}$		0.67	1.28	0.99	1.12	0.43	0.24	0.53	0.37

Where, DFF, DM, PH, NPB, NPP, NSP, HSW and SYP refers to days to 50% flowering, days to maturity, plant height, number of primary branches/plant, number of pods/plant, number of seed/pod 100- seed weight and seed yield/plant; *Significant at 5% level, ** Significant at 1% level.

Table 2: General combining ability effects of parents.

Parents	DFF	DM	PH	NPB	NPP	NSP	HSW	SYP
UPAS 120	3.15**(P)	4.78**(P)	9.02**(G)	0.41(A)	18.68**(G)	0.10(A)	-0.13**(P)	2.25(A)
Pusa 992	2.38**(P)	3.75**(P)	-3.01(A)	-1.15**(P)	6.48*(G)	0.033(A)	0.40**(G)	3.45**(G)
Pant A 441	2.31**(P)	0.75**(P)	-11.05**(P)	-0.91*(P)	36.11**(G)	0.63**(G)	0.30**(G)	12.45**(G)
AH 09-47	2.95**(P)	2.25**(P)	11.85**(G)	2.05**(G)	5.11(A)	0.00(A)	0.45**(G)	2.42(A)
AL 1843	-4.31**(G)	-3.88**(G)	12.12**(G)	-1.25**(P)	-28.78**(P)	0.033(A)	-0.77**(P)	-7.50**(P)
AL 1931	-1.51**(G)	-2.08**(G)	3.09(A)	-0.75*(P)	-8.95**(P)	-0.36**(P)	0.60**(G)	-6.90**(P)
Pusa 2013-1	-0.21**(G)	-0.51**(G)	-9.50**(P)	-0.78*(P)	-8.41**(P)	0.00(A)	-0.22(A)	-2.20(A)
Pusa 2013-2	-4.75(A)	-5.05**(G)	-12.37**(P)	-1.01**(P)	-20.25**(P)	-0.43**(P)	-0.62**(P)	-3.97**(P)

Where; G = Good, P= Poor and A= Average.

used as an important parameter for heterosis prediction. The MGCA effects were found to be positively and significantly correlated with MPH (r=0.86**) and BPH (r=0.83**), respectively. The significant linear regression of MGCA on MPH and BPH along with high R^2 value revealed that MGCA was also a good determinant of heterosis (Fig 4). A close perusal of Table 8 indicated that in case of MPH highest heterotic frequency (50.00%) was observed by crossing parents having good × average GCA effects combination. The good × good and good × average combination each produced 12.50% heterotic frequency while good × poor produced 37.50% heterotic frequency. In case of BPH the good × average and good × poor showed a heterotic frequency of 66.66 and 33.33% respectively. These

Table 3: Specific combining ability effects of hybrids.

Hybrids	DFF	DM	PH	NPB	NPP	NSP	HSW	SYP
1	1.00**(P)	3.34**(P)	15.26(A)	1.49(A)	15.19(A)	-0.06(A)	0.22**(G)	7.61(A)
2	0.07(A)	-3.66**(G)	-4.74 (A)	2.43*(G)	15.55(A)	0.01(A)	0.15(A)	0.27(A)
3	2.10**(P)	-5.16**(G)	10.96(A)	-0.71(A)	-8.78(A)	-0.03(A)	0.30**(G)	-1.36(A)
4	-3.96**(G)	0.30(A)	8.36(A)	0.93(A)	10.45(A)	-0.06(A)	-0.07(A)	-3.43(A)
5	-2.76**(G)	-3.50**(G)	25.73**(G)	1.43(A)	10.29(A)	0.01(A)	-0.22**(P)	-1.36(A)
6	-3.06**(G)	-8.06**(G)	2.33(A)	2.23(A)	1.09(A)	-0.03(A)	-0.32**(P)	2.94(A)
7	-3.86**(G)	-6.53**(G)	-5.47(A)	-0.31(A)	12.92(A)	0.41(A)	-0.44**(P)	3.71(A)
8	1.17**(P)	-3.30**(G)	25.06**(G)	0.99(A)	-15.25(A)	0.07(A)	0.38**(G)	2.07(A)
9	1.20**(P)	-4.80**(G)	30.43**(G)	0.53(A)	0.09(A)	0.04(A)	0.20**(G)	2.44(A)
10	-3.20**(G)	-5.33**(G)	-19.84*(P)	-0.17(A)	-2.01(A)	0.01(A)	0.16*(G)	2.04(A)
11	-1.33**(G)	-1.46**(G)	-19.14*(P)	0.66(A)	-0.51(A)	0.07(A)	0.15*(G)	-3.89(A)
12	-1.30**(G)	-0.70*(G)	2.13(A)	0.13(A)	2.95(A)	0.04(A)	-0.56**(P)	2.41(A)
13	-2.43**(G)	-5.16**(G)	7.33(A)	0.93(A)	19.45*(G)	-0.19(A)	-0.91**(P)	-0.16(A)
14	0.94**(P)	-2.46**(G)	8.43(A)	0.13(A)	23.79**(G)	0.11(A)	0.17*(G)	5.77(A)
15	-2.46**(G)	-3.66**(G)	-6.84(A)	2.76*(G)	21.69*(G)	0.07(A)	0.29**(G)	6.71(A)
16	-1.26**(G)	-3.13**(G)	-4.81(A)	1.26(A)	22.85*(G)	0.14(A)	0.32**(G)	4.11(A)
17	-0.23(A)	-4.03**(G)	4.79(A)	0.73(A)	14.65(A)	0.11(A)	-0.06(A)	2.41(A)
18	-3.36**(G)	-2.50**(G)	8.66(A)	0.53(A)	-26.18**(P)	0.54*(G)	0.16*(G)	11.17**(G)
19	-3.76**(G)	-4.16**(G)	-14.14(A)	1.63(A)	-10.65(A)	0.04(A)	-0.89**(P)	1.07(A)
20	-2.90**(G)	-2.63**(G)	-0.44(A)	0.46(A)	-2.15(A)	-0.23(A)	-0.04(A)	1.47(A)
21	-1.20**(G)	-4.20**(G)	2.49(A)	2.59*(G)	4.32(A)	0.07(A)	0.29**(G)	3.77(A)
22	-3.66**(G)	-4.00**(G)	1.36(A)	3.39**(G)	15.15(A)	-0.16(A)	0.21**(G)	-2.79(A)
23	0.37(A)	0.84*(P)	13.96(A)	-0.91(A)	-0.25(A)	0.07(A)	-0.31**(P)	-2.26(A)
24	0.07(A)	-1.73**(G)	20.23*(G)	0.56(A)	-16.78(A)	0.04(A)	-0.25**(P)	-3.63(A)
25	3.27**(P)	2.47**(P)	16.43(A)	-1.31(A)	-14.28(A)	-0.19(A)	0.54**(G)	-5.19(A)
26	0.27(A)	-1.20**(G)	9.59(A)	-0.27(A)	-4.61(A)	-0.23(A)	0.37**(G)	-1.89(A)
27	0.47(A)	0.34(A)	9.13(A)	2.19(A)	-1.45(A)	-0.13(A)	0.03(A)	-1.79(A)
28	-0.50(A)	-1.23**(G)	-5.94(A)	-0.34(A)	-3.98(A)	-0.16(A)	0.19*(G)	-0.83(A)

1 to 28 refers to hybrid UPAS 120 × Pusa 992 to Pusa 2013-1 × Pusa 2013-2, respectively; G = Good, P= Poor and A= Average.

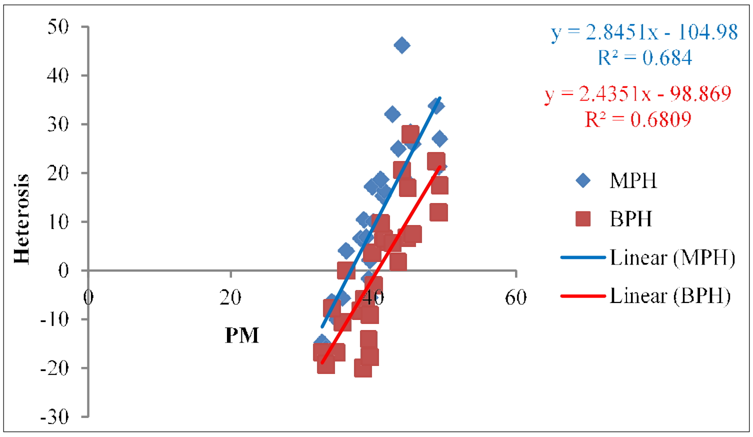

Fig 3: Relation between PM and heterosis.

Table 4: Average intra (diagonal) and inter cluster distance (D^2 values).

Clusters	I	II	III
I (UPAS 120, Pusa 992 and AH 09-47)	19.71	118.95	50.53
II (AL 1843 and Pusa 2013-2)		17.57	75.31
III (Pant A 441, AL 1931 and Pusa 2013-1)			29.28

Table 5: The estimates of PM, MGCA, GD, MPH and BPH for seed yield.

Hybrids	PM	MGCA	GD	MPH	BPH
1	45.17	2.85	19.71	28.41**	27.94*
2	49.17	7.35	50.53	21.36*	11.88
3	44.67	2.33	19.71	7.46	6.67
4	38.50	-2.62	118.95	-6.49	-20.00
5	39.33	-2.32	50.53	-1.69	-14.07
6	41.33	0.02	50.53	15.32	5.93
7	39.83	-0.86	118.95	17.15	3.70
8	49.33	7.95	50.53	27.03**	17.50
9	44.83	2.93	19.71	18.22	16.91
10	38.67	-2.02	118.95	10.34	-5.88
11	39.50	-1.72	50.53	-5.49	-17.65
12	41.50	0.62	50.53	16.47	6.62
13	40.00	-0.26	118.95	10	-2.94
14	48.83	7.43	50.53	33.79**	22.50*
15	42.67	2.47	75.31	32.03**	5.63
16	43.50	2.77	29.28	24.90*	1.88
17	45.50	5.12	29.28	26.01*	7.50
18	44.00	4.24	75.31	46.21**	20.63*
19	38.17	-2.54	118.95	6.55	-8.27
20	39.00	-2.24	50.53	6.84	-6.02
21	41.00	0.11	50.53	18.7	9.77
22	39.50	-0.77	118.95	2.11	-9.02
23	32.83	-7.2	75.31	-14.72	-16.83
24	34.83	-4.85	75.31	-10.05	-16.81
25	33.33	-5.73	17.57	-16	-19.23
26	35.66	-4.55	29.28	-5.61	-10.62
27	34.16	-5.43	75.31	-6.34	-7.69
28	36.16	-3.08	75.31	4.15	0

1 to 28 refers to hybrid UPAS 120 × Pusa 992 to Pusa 2013-1 × Pusa 2013-2, respectively.

results further indicated that if the parents had good × average GCA effects, it results in yielding high heterosis frequency in both MPH and BPH. However, the parents having good × poor GCA effects produced a moderate level of heterotic hybrids. The present study revealed that the GCA effects of parental lines have potential application in hybrid development programmes and supported the earlier findings of Saxena and Sawargaonkar (2014). The SCA effects were positively and significantly correlated with the MPH (r=0.92**) and BPH (r=0.82**), respectively. The significant linear regression of SCA effects on MPH and BPH and very high R^2 value further revealed that SCA was a good determinant of heterosis (Fig 5). In case of MPH, out of 8 heterotic hybrids, 7 hybrids (87.50%) exhibited average SCA and one hybrids (12.50%) exhibited good SCA effects. In case of BPH, out of three heterotic hybrids, 2 hybrids had average SCA (66.66%) while one hybrid (33.33%) had good SCA. Present finding indicated that high frequency of heterotic hybrids was obtained if crosses possessed average or good SCA. These results further indicated that SCA is the most important factor for determination of heterosis. Pandey *et al.* (2015) also reported similar findings. This strong relationship may be due to the reason that both SCA and heterosis are function of non-additive gene action. The presence of genetic diversity between the parents used in hybridization is considered as an important parameter for obtaining significant heterosis in hybrids (Tecklewold and Becker, 2006). However, negligible correlation between heterosis and parental diversity was also reported (Devi and Singh, 2011). Heterosis may increase with increase in genetic diversity but greater divergence between parents

Table 6: The Pearson's correlation between different parameters

	PM	SCA	MGCA	GD	MPH	BPH
PM	1					
SCA	0.60**	1				
MGCA	0.98**	0.63**	1			
GD	-0.31	-0.09	-0.28	1		
MPH	0.82**	0.92**	0.86**	-0.14	1	
BPH	0.82**	0.82**	0.83**	-0.34	0.89**	1

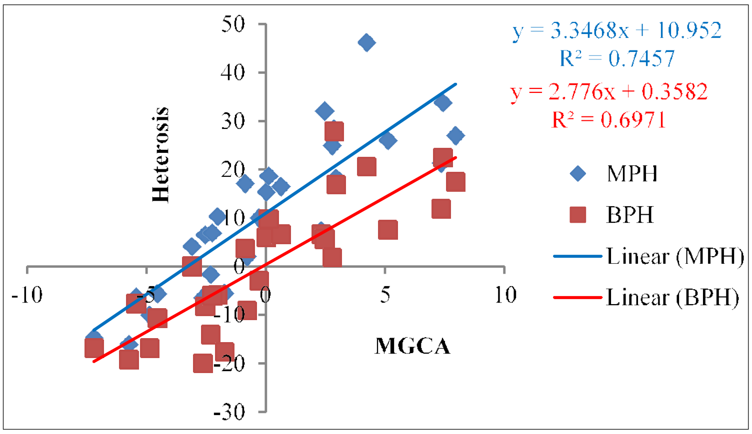

Fig 4: Relation between MGCA and heterosis.

Table 7: The GCA effects, diversity class and parent mean class in pigeonpea.

Hybrids	GCA	Cluster	Diversity class	PM class
1	A × G	I × I	L	H × H
2	A × G	I × III	M	H × H
3	A × A	I × I	L	H × H
4	A × P	I × II	H	H × L
5	A × P	I × III	M	H × L
6	A × A	I × III	M	H × L
7	A × P	I × II	H	H × L
8	G × G	I × III	M	H × H
9	G × A	I × I	L	H × H
10	G × P	I × II	H	H × L
11	G × P	I × III	M	H × L
12	G × A	I × III	M	H × L
13	G × P	I × II	H	H × L
14	G × A	III × I	M	H × H
15	G × P	III × II	H	H × L
16	G × P	III × III	L	H × L
17	G × A	III × III	L	H × L
18	G × P	III × II	H	H × L
19	A × P	I × II	H	H × L
20	A × P	I × III	M	H × L
21	A × A	I × III	M	H × L
22	A × P	I × II	H	H × L
23	P × P	II × III	H	L × L
24	P × A	II × III	H	L × L
25	P × P	II × II	L	L × L
26	P × A	III × III	L	L × L
27	P × P	III × II	H	L × L
28	A × P	III × I	H	L × L

1 to 28 refers to hybrid UPAS 120 × Pusa 992 to Pusa 2013-1 × Pusa 2013-2, respectively while P, A, G, H, M, L refers to Poor, Average, Good, High, Medium, Low.

not always results in heterosis (Cress, 1966). In present study, GD was found to be negatively and non- significantly correlated with MPH (r=-0.14) and BPH (r=-0.34). The linear regressions of GD on heterosis were found to be non-significant (Fig 6). In case of MPH the highest frequency of heterotic hybrids were produced when parents having moderate (37.50%) or low (37.50%) amount of diversity were crossed while the parents having high level of GD results in 25% heterotic hybrids. In case of better parent heterosis equal frequency (33.33%) of heterotic hybrids were produced when parents having high, moderate and low amount of diversity were crossed together. These results indicated that high genetic diversity did not lead to heterosis in pigeonpea. Similar findings was also reported by Pandey *et al.* (2015).

Table 8: The heterotic frequency obtained in different class.

Parameters	Classes	Number of heterotic hybrids		Heterotic frequency per cent	
		MPH	BPH	MPH	BPH
SCA	P	0	0	0	0
	A	7	2	87.5	66.66
	G	1	1	12.5	33.33
GCA	G × G	1	0	12.5	0
	G × A	4	2	50	66.66
	G × P	3	1	37.5	33.33
	P × P	0	0	0	0
	P × A	0	0	0	0
Genetic diversity class	H	2	1	25	33.33
	M	3	1	37.5	33.33
	L	3	1	37.5	33.33
Per se performance of parents	H × H	4	2	50	66.66
	H × L	4	1	50	33.33
	L × L	0	0	0	0

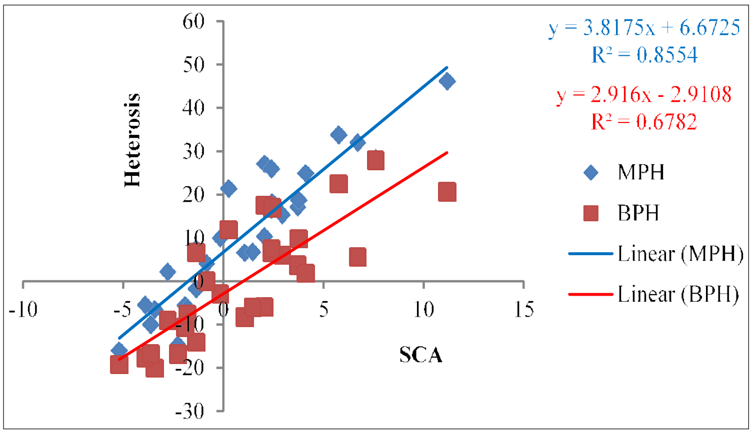

Fig 5: Relation between SCA and heterosis.

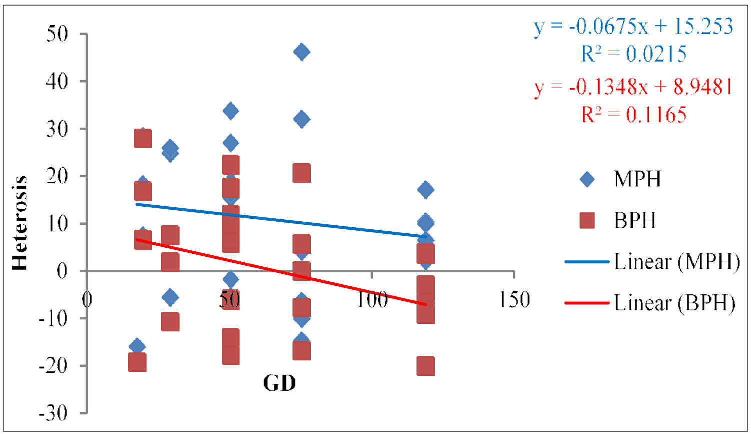

Fig 6: Relation between GD and heterosis.

CONCLUSION

In case of yield the hybrids *viz.,* Pant A 441 × AH 09-47 (65.33 g), Pant A 441 × Pusa 2013-2 (64.33 g), Pusa 992 × Pant A 441 (62.67 g), UPAS 120 × Pant A 441 (59.67 g) and UPAS 120 × Pusa 992 (58 g) were found as most promising. The PM, MGCA and SCA were found to be reliable parameters to predict the heterosis.

Conflict of interest: None.

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