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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(12): 1790-1794
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www.thepharmajournal.com
Received: 09-09-2023
Accepted: 17-11-2023

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Heterosis and inbreeding depression in pigeonpea [*Cajanus cajan* (L.) Millsp.]

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Abstract
In the present investigation, five pigeonpea crosses namely GJP 1 × BRG 14-1, GJP 1 × BDN 2010-1, NTL 740 × BRG 14-1, TDRG 107 × BDN 2010-1 and GJP 1310 × BSMR 853 were studied to understand the extent of heterosis over better-parent (BP) and standard variety (SV) for seed yield and its attributing characters. The cross GJP 1 × BDN 2010-1 exhibited the highest standard heterosis followed by GJP 1 × BRG 14-1 for seed yield per plant. It was observed that crosses GJP 1 × BDN 2010-1 and GJP 1 × BRG 14-1 were heterotic for seed yield per plant and majority of trait in desirable direction. The highest significant and negative inbreeding depression for seed yield per plant was observed in GJP 1 × BDN 2010-1 and followed by GJP 1 × BRG 14-1. High heterosis exhibited by seed yield per plant was due to heterosis for number of primary branches per plant, number of secondary branches per plant, number of pods per plant and number of seeds per pod. Positive and significant heterosis over better parent along with positive inbreeding depression recorded in above traits may be attributed to major contribution from dominance (h) and additive × additive (i) gene effects and selection will be effective only in later generations. Seed yield is controlled by polygenes and is influenced by other component characters.

Keywords: Heterosis, inbreeding depression, pigeonpea [*Cajanus cajan* (L.) Millsp.]

Introduction
Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important leguminous short lived perennial shrub cultivated as annual crop in semi-arid tropical and subtropical regions of the world. Presently, pigeonpea is known by several trade names such as Arhar, Redgram, Tur, Angola pea and Congo pea *etc*. Pigeonpea (2n=2x=22) is a perennial member of the family Leguminosae (Fabaceae).
Heterobeltiosis is the estimate of the superiority of F_1 hybrid over its better parent out of two parents involved in the particular crosses. Standard Heterosis expresses the superiority of F_1 hybrid over its standard commercial check variety or hybrids. Higher yield of hybrid is resulted due to the presence of hybrid vigour (heterosis) for yield and yield components. Exploitation of heterosis and hybrid vigor in pigeonpea by considerable additive and non-additive gene action in heterosis breeding. This specifies that estimation of heterobeltiosis for yield and yield attributes will aid in identifying crosses which can lead to transgressive segregants in segregating generations. Beside this, inbreeding depression indicates whether the vigor observed in segregating generations can be fixed in later generations by selfing. Information obtained from heterosis and inbreeding can be used to design appropriate breeding programs. Therefore, the estimation of heterosis and inbreeding depression especially over commercial variety is of immense importance for the development of hybrid in pigeonpea.

Materials and Methods
Plant materials
Six generations, namely P_1, P_2, F_1, F_2, BC_1 and BC_2 of five crosses of pigeonpea *viz*., GJP 1 × BRG 14-1, GJP 1 × BDN 2010-1, NTL 740 × BRG 14-1, TDRG 107 × BDN 2010-1 and GJP 1310 × BSMR 853 were grown *kharif* 2018 at Pulses Research Station, Junagadh Agricultural University, Junagadh. The experiment was laid out during *kharif*-2018 in Compact Family Block Design with three replications having each row of 4 m length and 90 cm × 20 cm inter and intra row spacing, respectively. Each replication was divided into five compact blocks, each consists of single cross and blocks were consisted of six plots comprised of six basic generations of each cross.

The crosses were assigned to each block and six generations of a cross were relegated to individual plot within the block. The single plot of one row for P_1, P_2, F_1, BC_1 and BC_2 generation and two rows for each F_2 generation was accommodated. All the recommended agronomical practiced were be adopted to raise good crop. The observations were recorded on five randomly selected plants from P_1, P_2 and F_1, twenty plants from F_2 and ten plants from BC_1 and BC_2 generations in each replication for ten characters *viz*., days to flowering, days to maturity, plant height (cm), number of primary branches per plant, number of secondary branches per plant, number of pods per plant, number of seeds per pod, length of pod (cm), 100-seeds weight (g) and seed yield per plant (g) and means were used for statistical analysis.

Statistical analysis

Heterosis was estimated over better parents (heterobeltiosis) and commercial variety of the locality i.e. GJP 1 (economic heterosis) whereas inbreeding depression was analysed as the reduction in F_2 mean.

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Economic heterosis (\%)} = \frac{\overline{F}_1 - \overline{SC}}{\overline{SC}} \times 100$$

The inbreeding depression (ID) in F_2 generation was calculated as

$$\text{Inbreeding depression (\%)} = \frac{\overline{F}_1 - \overline{F}_2}{\overline{F}_1} \times 100$$

Where,

$\overline{F}_1$ = Mean of F_1 generation

$\overline{BP}$ = Mean of better parent

$\overline{F}_2$ = Mean of F_2 generation

$\overline{SC}_2$ = Mean of standard check (GJP 1)

The standard errors for heterosis and inbreeding depression were calculated as

$$\text{S. E. for (BP)} = \sqrt{V_{\overline{F}_1} + V_{\overline{BP}}}$$

$$\text{S. E. for (SC)} = \sqrt{V_{\overline{F}_1} + V_{\overline{SC}}}$$

$$\text{S. E. for inbreeding depression} = \sqrt{V_{\overline{F}_1} + V_{\overline{F}_2}}$$

The test of significance for heterosis and inbreeding depression was done by usual t-test.

Results and Discussion

In case of days to flowering, cross GJP 1310 × BSMR 853 and NTL 740 × BRG 14-1 showed significant and negative heterobeltiosis and standard heterosis, respectively. Khorgade *et al*. (2000) [9], Dheva *et al*. (2008) [7], Parmar and Kathiria (2016) [15], Singh and Singh (2016) [18] and Ashutosh *et al*. (2017) [3] also reported significant heterosis in negative direction for this trait in pigeonpea. Positive and significant inbreeding depression was observed in the cross GJP 1310 × BSMR 853 and is supported by earlier report of Kumar *et al*. (2012) [10] and Ashutosh *et al*. (2017) [3].

With regards days to maturity none of the cross showed negative and significant heterobeltiosis but hybrid GJP 1310 × BSMR 853 showed significant negative standard heterosis in desired direction for earliness. The result was confirmed with findings of earlier workers Narladkar and Khapre (1996) [12], Aher *et al*. (2006) [1], Dheva *et al*. (2008) [7], Kumar *et al*. (2012) [10], Parmar and Kathiria (2016) [15] and Ashutosh *et al*. (2017) [3]. The hybrid TDRG 107 × BDN 2010-1 showed significant and positive inbreeding depression and similar result was reported by Aher *et al*. (2006) [1], Kumar *et al*. (2012) [10] and Ashutosh *et al*. (2017) [3].

The results for plant height indicate that all crosses showed significant and positive heterobeltiosis in desired direction. Plant height is an enviable trait for achieving high yield in pigeonpea as vigour in plant height may lead to increase biomass as well as source-sink capacity for acquiring optimum yield. None of the cross demonstrated standard heterosis in positive direction. The present findings were in close association with results reported by Narladkar and Khapre (1996) [12], Khorgade *et al*. (2000) [9], Aher *et al*. (2006) [1], Ajay *et al*. (2015) [2], Parmar and Kathiria (2016) [15] and Ashutosh *et al*. (2017) [3]. Inbreeding depression for plant height was significant and positive in GJP1 x BDN 2010-1, TDRG 107 x BDN 2010-1 and GJP 1310 x BSMR 853 and supported by Aher *et al*. (2006) [1], Ajay *et al*. (2015) [2], Parmar and Kathiria (2016) [15] and Ashutosh *et al*. (2017) [3].

In a case of number of primary branches per plant, three crosses gave significant positive heterobeltiosis and standard heterosis. The cross showing highest percentage of heterobeltiosis and standard heterosis was GJP 1310 × BSMR 853 and NTL 740 × BRG 14-1, respectively. Narladkar and Khapre (1996) [12], Khorgade *et al*. (2000) [9], Chandirakala and Raveendran (2002) [6], Aher *et al*. (2006) [1], Pandey *et al*. (2013) [13], Ajay *et al*. (2015) [2], Parmar and Kathiria (2016) [15], Singh and Singh (2016) [18] and Ashutosh *et al*. (2017) [3] also have reported similar results for this trait. The inbreeding depression was positive and significant for this trait in cross GJP1 x BRG 14-1, NTL 740 x BRG 14-1 and TDRG 107 x BDN 2010-1. Similar conclusions were drawn by Aher *et al*. (2006) [1] and Ashutosh *et al*. (2017) [3].

Crosses with positive and significant heterobeltiosis and standard heterosis for number of secondary branches per plant, were GJP 1 × BRG 14-1 and GJP 1 × BDN 2010-1, respectively. While remaining crosses expressed negative heterosis for this trait. Present work is in agreement with earlier report of several workers Khorgade *et al*. (2000) [9], Chandirakala and Raveendran (2002) [6], Aher *et al*. (2006) [1], Pandey *et al*. (2013) [13], Ajay *et al*. (2015) [2], Singh and Singh (2016) [18] and Ashutosh *et al*. (2017) [3]. Inbreeding depression was negative and significant in the cross TDRG 107 × BDN 2010-1 and GJP 1310 × BSMR 853 and is supported by earlier repot Ashutosh *et al*. (2017) [3].

For number of pods per plant, four crosses expressed significant positive heterosis over better parent and two crosses expressed significant positive standard heterosis. The cross TDRG 107 × BDN 2010-1 exhibited the highest heterobeltiosis and cross GJP 1 × BRG 14-1 exhibited the highest standard heterosis for this character. The present finding was in close association with the results reported by Patel and Patel (1992) [16], Narladkar and Khapre (1996) [12], Khorgade *et al*. (2000) [9], Chandirakala and Raveendran (2002) [6], Aher *et al*. (2006) [1], Dheva *et al*. (2008) [7], Patel and Tikka (2008) [17], Pandey *et al*. (2013) [13], Ajay *et al*. (2015) [2], Parmar and Kathiria (2016) [15], Singh and Singh (2016) [18] and Ashutosh *et al*. (2017) [3]. All the crosses showed negative and significant inbreeding depression for this trait and similar conclusions were drawn by Aher *et al*. (2006) [1] and Ashutosh *et al*. (2017) [3].

For number of seeds per pod, four crosses expressed significant positive heterosis over better parent and two crosses expressed significant positive standard heterosis. The hybrid GJP 1310 × BSMR 853 exhibited the highest heterobeltiosis and hybrid GJP 1 × BRG 14-1 exhibited the highest standard heterosis for this character. This result is in agreement with the findings of Aher *et al*. (2006) [1], Patel and Tikka (2008) [17], Pandey *et al*. (2013) [13], Parmar and Kathiria (2016) [15] and Ashutosh *et al*. (2017) [3]. Two crosses showed significant and negative inbreeding depression and rest of the crosses had positive and significant inbreeding depression for this trait. Aher *et al*. (2006) [1] and Ashutosh *et al*. (2017) [3] also reported similar results for this trait.

With respect to length of pod, two crosses showed significant positive heterosis over better parent and standard check. The cross TDRG 107 × BDN 2010-1 exhibited the highest heterobeltiosis and cross GJP 1 × BRG 14-1 exhibited the highest standard heterosis for this character. Similar conclusions were drawn by Patel and Tikka (2008) [17], Parmar and Kathiria (2016) [15], Singh and Singh (2016) [18] and Ashutosh *et al*. (2017) [3]. The three crosses showed significant and positive inbreeding depression. This result is in agreement with the findings of Parmar and Kathiria (2016) [15] and Ashutosh *et al*. (2017) [3].

In case of 100 seed weight, none of the crosses showed desirable heterosis while, two crosses showed significant standard heterosis in desired direction. The cross GJP 1 × BRG 14-1 exhibited the highest positive standard heterosis which is supported by earlier workers (Khorgade *et al*., 2000 [9]; Chandirakala and Raveendran, 2002 [6]; Aher *et al*., 2006 [1]; Patel and Tikka, 2008 [17]; Parmar and Kathiria, 2016 [15] and Ashutosh *et al*., 2017) [3]. While two and three crosses showed positive as well as negative and significant inbreeding depression respectively, for this trait. This finding is supported by earlier workers (Parmar and Kathiria, 2016 [15] and Ashutosh *et al*., 2017) [3].

Fairly high degree of heterosis was obtained for seed yield per plant. All the crosses depicted significant positive heterobeltiosis for this character, among them best performing cross for this trait was GJP 1310 × BSMR 853. Two crosses depicted significant positive standard heterosis for this character and GJP 1 × BRG 14-1 was the best performing cross. This result is in agreement with the findings of Patel and Patel (1992) [16], Narladkar and Khapre (1996) [12], Khorgade *et al*. (2000) [9], Chandirakala and Raveendran (2002) [6], Wankhade *et al*. (2005), Aher *et al*. (2006) [1], Patel and Tikka (2008) [17], Kumar *et al*. (2012) [10], Pandey *et al*. (2013) [13], Ajay *et al*. (2015) [2], Parmar and Kathiria (2016) [15] and Ashutosh *et al*. (2017) [3]. All the crosses showed significant and negative inbreeding depression for this trait except GJP 1310 x BSMR 853 and it is in agreement of earlier reports of and Ashutosh *et al*. (2017) [3].

As regards to heterosis over better parent and standard check for different traits, a good number of crosses registered significant heterobeltiosis and standard heterosis in desired direction for different traits. For seed yield per plant (20.27 and 5.46 percent in GJP 1310 × BSMR 853 and GJP 1 × BDN 2010-1, respectively); number of primary branches per plant (5.22 and 19.79 percent in GJP 1310 × BSMR 853 and NTL 740 × BRG 14-1, respectively); number of secondary branches per plant (5.47 and 8.87 percent in GJP 1 × BDN 2010-1); number of pods per plant (16.98 and 11.85 percent in TDRG 107 × BDN 2010-1 and GJP 1 × BRG 14-1 respectively); number of seeds per pod (1.05 and 1.71 percent in GJP 1310 × BSMR 853 and GJP 1 × BRG 14-1, respectively) and length of pod (2.28 and 6.70 percent in TDRG 107 × BDN 2010-1 and GJP 1 × BRG 14-1 respectively) exhibited fairly high magnitude of heterosis as compared to rest of the characters. In addition to the above crosses, for plant height (4.54 percent in TDRG 107 × BDN 2010-1) and 100-seed weight (7.57 percent in GJP 1 × BRG 14-1) also expressed significant and positive heterobeltiosis and standard heterosis, respectively. Magnitude of negative heterobeltiosis and standard heterosis in desirable direction was observed for days to flowering (-3.97 and -9.63 percent in GJP 1310 × BSMR 853 and NTL 740 × BRG 14-1, respectively). For days to maturity, significant and negative standard heterosis was expressed by only one cross GJP 1310 × BSMR 853.

Conclusion

In the present study, expression of fairly high heterosis for seed yield per plant was due to heterosis for number of primary branches per plant, number of secondary branches per plant, number of pods per plant and number of seeds per pod. Similar inference between seed yield per plant and number of primary branches per plant, number of secondary branches per plant, number of pods per plant and number of seeds per pod was made by Narladkar and Khapre (1996) [12], Ajay *et al*. (2015) [2], Bhanu *et al*. (2016) and Ashutosh *et al*. (2017) [3]. Positive and significant heterosis over better parent along with positive inbreeding depression recorded in above traits may be attributed to major contribution from dominance (h) and additive × additive (i) gene effects and selection will be effective only in later generations. Seed yield is controlled by polygenes and is influenced by other component characters.

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Appendices

Table A.1: Heterosis over better parent (BP), heterosis over standard check (SC) and Inbreeding Depression (ID) for days to flowering, days to maturity, plant height (cm), no. of primary branches per plant and no. of secondary branches per plant of five crosses in medium duration pigeonpea

Crosses	Heterosis (%) over		
	BP	**SP**	**ID (%)**
Days to flowering			
GJP1 x BRG 14-1	0.35±0.47	0.35±0.47	0.53±0.49
GJP1 x BDN 2010-1	1.66*±0.27	0.76±0.36	0.44±0.29
NTL 740 x BRG 14-1	-0.65±0.54	-9.63**±0.51	0.05±0.51
TDRG 107 x BDN 2010-1	1.42*±0.34	0.70±0.39	0.03±0.36
GJP 1310 x BSMR 853	-3.97*±0.45	-4.76*±0.48	5.09*±0.49
Days to maturity			
GJP1 x BRG 14-1	0.07±0.40	0.07±0.40	-1.01±0.46
GJP1 x BDN 2010-1	0.29±0.38	0.25±0.36	0.34±0.39
NTL 740 x BRG 14-1	3.24*±0.76	-0.65±0.64	1.32±0.71
TDRG 107 x BDN 2010-1	3.45*±0.91	2.25*±0.71	2.79*±0.76
GJP 1310 x BSMR 853	-0.33±0.50	-1.67*±0.37	-0.55±0.44
Plant height (cm)			
GJP1 x BRG 14-1	3.18*±0.38	-4.72*±0.45	-0.89±0.44
GJP1 x BDN 2010-1	1.31*±0.42	-5.97**±0.48	1.7*±0.49
NTL 740 x BRG 14-1	4.05*±0.51	-8.94**±0.48	-0.35±0.49
TDRG 107 x BDN 2010-1	4.54*±0.48	-3.64*±0.49	2.56*±0.50
GJP 1310 x BSMR 853	0.91±0.54	-13.94**±0.51	2.77*±0.51
No. of primary branches per plant			
GJP1 x BRG 14-1	2.67*±0.35	2.67*±0.35	1.43*±0.40
GJP1 x BDN 2010-1	2.72*±0.45	1.07*±0.42	-1.59*±0.45
NTL 740 x BRG 14-1	0.45±0.36	19.79*±0.38	9.49**±0.41
TDRG 107 x BDN 2010-1	0.57±0.43	-6.42**±0.40	2.43*±0.47
GJP 1310 x BSMR 853	5.22**±0.42	-35.29**±0.36	-6.4**±0.44
No. of secondary branches per plant			
GJP1 x BRG 14-1	4.03*±0.35	4.03*±0.35	0.45±0.37
GJP1 x BDN 2010-1	5.47**±0.39	8.87**±0.45	-0.19±0.48
NTL 740 x BRG 14-1	0.66±0.44	-18.28**±0.46	0.41±0.50
TDRG 107 x BDN 2010-1	-3.62*±0.43	-28.49**±0.41	-9.3**±0.45
GJP 1310 x BSMR 853	-2.87*±0.43	-45.43**±0.41	-18.1**±0.45

*and **Significant at 5 and 1 percent levels respectively

Table A.2: Heterosis over better parent (BP), heterosis over standard check (SH) and Inbreeding Depression (ID) for no. of pods per plant, no. of seeds per pod, length of pod (cm), 100 seed weight and seed yield per plant (g) of five crosses in medium duration pigeonpea

Crosses	Heterosis (%) over		ID (%)
	BP	SP	
No. of pods per plant			
GJP1 x BRG 14-1	11.85**±0.39	11.85**±0.39	-14.89**±0.43
GJP1 x BDN 2010-1	8.28**±0.42	7.19**±0.43	-8.88**±0.43
NTL 740 x BRG 14-1	-2.02*±0.49	-20.73**±0.45	-12.38**±0.49
TDRG 107 x BDN 2010-1	16.98**±0.50	-14.79**±0.49	-7.09**±0.51
GJP 1310 x BSMR 853	7.96**±0.42	-38.58**±0.44	-2.44*±0.45
No. of seeds per pod			
GJP1 x BRG 14-1	0.68*±0.07	1.71**±0.08	8.00*±0.06
GJP1 x BDN 2010-1	0.69**±0.05	0.34*±0.07	-0.60*±0.06
NTL 740 x BRG 14-1	-1.02**±0.08	-0.34*±0.09	5.93**±0.07
TDRG 107 x BDN 2010-1	0.74*±0.07	-6.51**±0.08	-2.20**±0.07
GJP 1310 x BSMR 853	1.05**±0.07	-1.20**±0.08	2.73**±0.07
Length of pod (cm)			
GJP1 x BRG 14-1	-6.69**±0.05	6.7**±0.05	2.55**±0.05
GJP1 x BDN 2010-1	1.43**±0.07	1.91**±0.07	3.46**±0.07
NTL 740 x BRG 14-1	-18.01**±0.09	-7.42**±0.07	-3.75**±0.07
TDRG 107 x BDN 2010-1	2.28**±0.05	-3.35**±0.06	8.17**±0.08
GJP 1310 x BSMR 853	-4.86**±0.08	-11.00**±0.08	-0.54*±0.08
100 seed weight (g)			
GJP1 x BRG 14-1	-9.04**±0.28	7.57**±0.24	-11.73**±0.27
GJP1 x BDN 2010-1	-3.33**±0.26	1.58*±0.22	-7.77**±0.25
NTL 740 x BRG 14-1	-24.22**±0.35	-10.34**±0.34	-4.21**±0.34
TDRG 107 x BDN 2010-1	-6.83**±0.36	-1.45*±0.31	3.67*±0.31
GJP 1310 x BSMR 853	0.30±0.35	0.14±0.32	7.44**±0.33
Seed yield per plant (g)			
GJP1 x BRG 14-1	3.50*±0.43	3.50*±0.44	-2.96*±0.47
GJP1 x BDN 2010-1	6.62**±0.38	5.46**±0.44	-2.63*±0.43
NTL 740 x BRG 14-1	2.80*±0.36	-6.36**±0.42	-4.3*±0.45
TDRG 107 x BDN 2010-1	18.95**±0.32	-7.14**±0.38	-5.53**±0.38
GJP 1310 x BSMR 853	20.27**±0.41	-31.62**±0.43	-0.55±0.42

*and **Significant at 5 and 1 percent levels respectively