© 2016 RELS
http://rels.comxa.com
rel_sci@yahoo.com

ISSN: 0974-4908
Res. Environ. Life Sci.
9(1) 107-110 (2015)

Study of heterosis and pollen fertility in CGMS based pigeonpea [*Cajanus cajan*(L.) Millspaugh] hybrids

Sudhir Kumar*[1,3], M. K. Debnath[2], C.V. Sameer Kumar[1], P.K. Singh[3] and R. Sultana[3]
[1]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru-502324, India
[2]International Rice Research Institute, Patancheru-502324, India
[3]Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour-813210, India
***e-mail:** sudhirk121@gmail.com

(Received: June 14, 2015; Revised received: November 20, 2015; Accepted: November 24, 2015)

Abstract: Twenty CGMS-based pigeonpea [*Cajanus cajan*(L.) Millspaugh] hybrids were synthesized manually by crossing five CMS lines (A lines) with 11 male lines (R lines) and these hybrids wereevaluated to studyyield potential with the performance of their R- lines. The results showed that the restoring capacities of restorer linesare very important to quality seed production and for yield potential.Result from the study indicated thatmost of the R- line acts as good restorer and it ranged from98.50% (ICPL 20108) to 59.22%(ICPL 2009.In present study most of the hybrids showed standard heterosis towards in desirable direction for yield and yield contributing characters over the checks so these cross combination of parent may be exploited to developed the hybrid in pigeonpea for obtaining higher grain yield.The range of standard heterosis over Asha for grain yield per plant was ranged from -13.06 (ICPA 2092 x ICPL 20123) to 40.91% (ICPA 2047 x ICPL 20126).

Key words:CMS, Heterosis, Hybrids, Pigeonpea, Restorer

Introduction

Pigeonpea [*Cajanus cajan*(L.) Millsp.] is an important food legume crop grown mainly in tropics and sub-tropics under rainfedagriculture by resource-poor farmers because crop is cultivated with low inputs.As world population increasing demand of protean also increasesspecially in India, where most of the people are vegetarian.Pigeonpea seeds have 20-22% protein and are used as green peas, whole grain or split peas (Saxena *et al*., 2002). Globally pigeonpea is cultivated on 4.64 mha with an annual production of 3.43 mt. The average productivity of 780 kg ha^{-1} (http:// faostat.fao.org/2010) indicates further need for improving its yield potential.Recently, 25 to 156% of seed yield over the best inbred variety have been reported by Saxena and Nadarajan (2010). Pollen fertility (%) is an important character to evaluate the restoration of fertility and amount of viable pollens produced by particular hybrid which is a basic need for the successful production of high yielding CMS-based hybrids of pigeonpea.Thus, main objective of this investigation was to estimate the extent of heterosis for seed yield and its component characters including restoring capacities of R- lines forbetter yield potential by using CGMS lines.

Materials and Methods

Germplasm used in the present study consists of five cytoplasmic-nuclear male sterile (CMS) lines, viz., ICPA 2092, ICPA 2078, ICPA 2048, ICPA 2047 and ICPA 2043 which were derived from A_4 cytoplasm of *Cajanus cajanifolius,* and 11 male lines of pigeonpea, such as ICPL 87119, ICPL 20093, ICPL 20096, ICPL 20098, ICPL 20106, ICPL 20108, ICPL 20111, ICPL 20123, ICPL 20126, ICPL 20129 and ICPL 20186, were derived from diverse inbred lines.In *kharif* 2012-13, a total of 20 hybrids were generated by manually pollination of these five cytoplasmic-nuclear male sterile (CMS) lines with 11 male lines at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (17^{o}53'N, 78^{o}27'E, 545.5 MSL), India and sufficient quantity of crossed seeds were produced. 20 F_1 hybrids along with two standard checks, Asha and Maruti were sown in a randomized block design withtwo replications during *kharif* 2013-14. Each entry was sown in four rows of 4 meters length with a spacing of 75 x 30cm row to row and plant to plant. Observations on five randomlyselected competitive plants were recorded for days to 1stflowering, days to 50 per cent flowering, days to maturity, plant height(cm), number of primary branches/plant, number of secondary branches/plant, number of pods/plant, number of grains/pod, 100-seed weight(g), pollen viability (per cent) and grain yield (kg/ha). To identify fertility/sterility of pollen grains, 2% aceto-carmine solution was used. Five well developed flower buds were collected randomly from different parts of each plant at the time of anthesis (9-10 AM). From each bud, the anthers were collected on a glass slide and crushed with a drop of 2% aceto-carmine stain and examined under a light microscope. The mean value of pollen fertility/sterility of five plants was considered as pollen fertility/sterility (%) for that genotype(Saxena *et al.* 2011).

Results and Discussion

In table 1, the ANOVA showed that the mean sum of squares were significant for all characters except for plant height. These results indicated highly significant genotypic differences in all the F_1 hybrids and standard checks.All the twenty hybrids were compared with both checks, Maruti and Asha for estimation of standard heterosis. Early flowering and maturity is one of the desirable traits in hybrid pigeonpea as it helps in escaping drought. Two hybrids viz., ICPA 2043 x ICPL 87119 (-11.81%) and ICPA 2078 x ICPL 87119 (-8.02%) were showed significant negative standard heterosis over Asha and its range was –11.81(ICPA 2043 x ICPL87119) to 3.80% (ICPA 2048 x ICPL 20106) for days to 1st flowering. The range of standard heterosis over Maruti was -0.95 (ICPA 2043 x ICPL 87119) to 16.59% (ICPA 2048 x ICPL 20106) and no any hybrids were showed significant negative standard heterosis over Maruti for days to 1st flowering. Sarode *et al.* (2009) showed significant negative heterosis for this trait in long duration pigeonpea. Similarly,significant negative heterosis in CMS based hybrids was reported by Shoba and Balan (2010) and Sameer Kumar *et al.* (2012).

For days to 50% flowering, nine hybrids viz., ICPA 2043 x ICPL 87119 (-11.28%), ICPA 2078 x ICPL 87119 (-8.27%), ICPA 2047 x ICPL 20108 (-7.14%), ICPA 2047 x ICPL 87119 (-6.02%), ICPA 2047 x ICPL 20098 (-4.89%), ICPA 2092 x ICPL 87119 (-4.51%),ICPA 2047 x ICPL 20126 (-3.76%), ICPA 2092 x ICPL 20108 (-3.76%) and ICPA 2048 x ICPL 87119(-3.38%) were showed significantly early with respect to Asha and its range was –11.28 (ICPA 2043 x ICPL 87119) to 0.75% (ICPA 2048 x ICPL20106). The range of standard heterosis over Maruti was 5.36% (ICPA 2043 x ICPL 87119) to 19.64% (ICPA 2048 x ICPL 20106) and no any hybrids were showed significant negative standard heterosis over Maruti for days to 50% flowering. Similarly,Wankhade *et al*. (2005) reported significant negative heterosis in the hybrids based on genetic male-sterility system for days to 50% flower. The significant negative heterosis for earliness was earlier reported by Singh *et al*. (1989) and Pandey and Singh (2002) for flowering. For days to maturityno any hybrids were showed significant negative standard heterosis over both checks (Asha and Maruti). Among the twenty hybrids, Ten hybrids, ICPA 2048 x ICPL 20108 (17.68%), ICPA 2048 x ICPL 20098(15.66%), ICPA 2048 x ICPL 20111 (14.14%), ICPA 2092 x ICPL 20123 (11.36%), ICPA 2048 x ICPL 20096 (10.86%), ICPA 2047 x ICPL 20108 (10.61%), ICPA 2048 x ICPL 20106 (10.10%), ICPA 2092 x ICPL 20106 (9.60%), ICPA2092 x ICPL 20108 (9.60%) and ICPA 2047 x ICPL 20129 (9.34%) were showed significant standard heterosis over the check variety Asha for plant height. Solomon *et al*. (1957), Singh (1971)and Sharma *et al*. (1973) also reported similar results.

For number of primary branches plant^{-1}**,** six hybrids, ICPA 2048 x ICPL 87119 (76.09%), ICPA 2092 x ICPL 20108 (60.14%), ICPA 2092 x ICPL 20108 (44.93%), ICPA 2047 x ICPL 20098 (44.93%), ICPA 2048 x ICPL 20098 (42.03%) and ICPA 2047 x ICPL 20126 (36.23%)were showed significant positive standard heterosis over Maruti with the range of -26.81 (ICPA 2047 x ICPL 87119) to76.09% (ICPA 2048 x ICPL 87119)and twelve hybrids were showed significant positive standard heterosis over Asha with the range of -12.93 (ICPA 2047 x ICPL 87119) to109.48% (ICPA 2048 x ICPL 87119). For number of secondary branchesplant^{-1},hybrids viz.,ICPA 2078 x ICPL 87119, ICPA 2047 x ICPL 20126, ICPA 2047 x ICPL 20108, ICPA 2048 x ICPL 20096, ICPA 2047 x ICPL 20129 and ICPA 2092 x ICPL 20106 showed significant standard heterosis over Maruti whereas ICPA 2078 x ICPL 87119 showed significant standard heterosis over Asha. The present study showed both positive and negative standard heterosis for number ofprimary branches plant^{-1} and also fornumber of secondary branches plant^{-1}. Similar results were reported by Shoba and Balan (2010) in CMS/GMS based pigeonpea hybrids. Shrivastava *et al*. (1976) reported that 96% heterosis for secondary branches per plant. Mudaraddi and Saxena (2013) reported that the days to flower, number of secondary branches, pods per plant and seeds per pod in hybrids haddirect positive effects in determining yield.

For pods plant^{-1}seven hybrids,ICPA 2092 x ICPL 20108 (53.69%), ICPA 2047 x ICPL 20108 (40.05%), ICPA 2047 x ICPL 20126 (38.60%), ICPA 2048 x ICPL 87119 (37.93%), ICPA 2092 x ICPL 20186 (31.49%), ICPA 2092 x ICPL 20106 (29.37%) and ICPA 2047 x ICPL 20111(19.37%) showed significant positive heterosis over standard check Maruti. Only one hybrid, ICPA 2092 x ICPL 20108 (25.44%) showed significant positive heterosis over standard check Asha. The range of standard heterosis from -6.67% (ICPA 2047 x ICPL 20098) to 53.69% (ICPA 2092 x ICPL 20108) against Maruti while -23.82% (ICPA 2047 x ICPL 20098) to 25.44% (ICPA 2092 x ICPL 20108) against Asha, which is in agreement with reports of Singh (1971),Shrivastava *et al.* (1976), Patel and Patel (1992), Pandey and Singh (2002), and Phad *et al.* (2009). For seeds pod^{-1} twelve hybrids, ICPA 2078 x ICPL 87119 (26.49%), ICPA 2048 x ICPL 20108 (15.18%), ICPA 2043 x ICPL 87119 (14.29%), ICPA 2048 x ICPL 20093 (13.39%), ICPA 2047 x ICPL 20126 (13.10%), ICPA 2048 x ICPL 20106 (12.80%), ICPA 2047 x ICPL 20129 (11.90%), ICPA 2048 x ICPL 20096 (11.31%), ICPA 2048 x ICPL 20098 (10.71%), ICPA 2047 x ICPL 87119 (10.71%), ICPA 2047 x ICPL 20098 (10.42%) and ICPA 2092 x ICPL 20108 (9.23%) showed significant positive heterosis over standard check Asha. The range of standard heterosis was from 0.60% (ICPA 2092 x ICPL 87119) to 26.49% (ICPA 2078 x ICPL 87119) against Asha. Similarly, significant positive heterosis for seeds pod^{-1} was reported by Wankhade *et al*. (2005).

Among the 20 hybrids, fourteen of them exhibited significant positive standard heterosis over both checks (Maruti and Asha) for 100 seed weight. The range of standard heterosis for Maruti was from -14.63 (ICPA 2092 x ICPL 20186) to 25.81% (ICPA 2048 x ICPL 20093) and for Asha it was from -17.0 (ICPA 2092 x ICPL 20186) to 22.33% (ICPA 2048 x ICPL 20093). In pigeonpea positive standard heterosis for 100-seed weightwerealsoreported byReddy *et al*. (1979), Manivel *et al*. (1999), Deshmukh *et al*. (2001) and Wankhade *et al*. (2005). For grain yield plant^{-1},eight hybrids viz.,ICPA 2047 x ICPL 20126 (40.91%), ICPA 2047 x

Table-1: Analysis of variance for 13 characters in pigeonpea

Source	Replication (d.f.=1)	Treatment (d.f.=21)	Error (d.f.=21)
Days to 1st flower	0.09	53.09**	9.85
Days to 50% flower	20.45	55.66**	11.45
Days to maturity	3.27	25.41*	10.18
Plant height(cm)	17.82	221.37	197.96
No. of prim. branchesplant^{-1}	0.23	23.60*	9.18
No. of sec. branchesplant^{-1}	9.09	17.31*	8.21
Pods plant^{-1}	173.41	2615.99*	1133.93
Seeds pod^{-1}	0.03	0.08*	0.04
100-seed weight(gm)	0.06	1.81*	0.22
Yield plant^{-1}(gm)	0.15	336.93*	127.20
Yield plot^{-1}(gm)	10832.68	180953.14**	335.23
Yield(kg ha^{-1})	10412.04327	173926.51**	322.21
Pollen fertility %	10.33	171.773**	10.47

Where, *, ** = significant at 5% and 1% level, respectively

Table-2: Standard Heterosis (SH) in percentage for different characters in Pigeonpea

Genotype	Days to 1st flower		Days to 50% flower		Days to maturity		Plant height (cm)		No. of primary branchesplant^{-1}		No of secondary branchesplant^{-1}	
	SH1	SH2	SH1	SH2	SH1	SH2	SH1	SH2	SH1	SH2	SH1	SH2
ICPA 2078 x ICPL 87119	3.32	-8.02**	8.93**	-8.27**	6.98**	-0.54	5.84	5.3	9.42	30.17	11.26	-9.19
ICPA 2043 x ICPL 87119	-0.95	-11.81**	5.36**	-11.28**	7.27**	-0.27	7.11	6.57	13.77	35.34*	4.95	-14.34
ICPA 2047 x ICPL 87119	12.32**	0	11.61**	-6.02**	7.85**	0.27	1.27	0.76	-26.81	-12.93	13.2	-7.61
ICPA 2047 x ICPL 20098	14.69**	2.11	12.95**	-4.89**	9.01**	1.35	3.55	3.03	44.93**	72.41**	-6.67	-23.82**
ICPA 2047 x ICPL 20108	9.00**	-2.95	10.27**	-7.14**	7.56**	0	11.17*	10.61*	3.62	23.28	40.05**	14.3
ICPA 2047 x ICPL 20126	11.37**	-0.84	14.29**	-3.76*	8.14**	0.54	6.09	5.56	36.23*	62.07**	38.60**	13.13
ICPA 2092 x ICPL 87119	11.85**	-0.42	13.39**	-4.51**	6.98**	-0.54	2.03	1.52	10.14	31.03	11.26	-9.19
ICPA 2092 x ICPL 20108	14.22**	1.69	14.29**	-3.76*	8.43**	0.81	10.15*	9.60*	60.14**	90.52**	53.69**	25.44**
ICPA 2048 x ICPL 87119	12.80**	0.42	14.73**	-3.38*	8.14**	0.54	4.57	4.04	76.09**	109.48**	37.93**	12.57
ICPA 2048 x ICPL 20093	14.22**	1.69	17.86**	-0.75	11.05**	3.24**	-1.02	-1.52	21.01	43.97**	10	-10.22
ICPA 2047 x ICPL 20111	16.11**	3.38*	16.96**	-1.5	8.43**	0.81	8.63	8.08	26.81	50.86**	19.37*	-2.57
ICPA 2047 x ICPL 20129	14.69**	2.11	16.52**	-1.88	8.43**	0.81	9.90*	9.34*	5.8	25.86	-3.77	-21.46**
ICPA 2048 x ICPL 20106	16.59**	3.80*	19.64**	0.75	10.76**	2.97**	10.66*	10.10*	-3.62	14.66	3.6	-15.44
ICPA 2048 x ICPL 20096	15.17**	2.53	16.07**	-2.26	9.01**	1.35	11.42*	10.86*	21.74	44.83**	-3.47	-21.21*
ICPA 2048 x ICPL 20098	13.27**	0.84	15.63**	-2.63	8.43**	0.81	16.24**	15.66**	42.03**	68.97**	10.99	-9.41
ICPA 2048 x ICPL 20108	14.22**	1.69	17.41**	-1.13	7.56**	0	18.27**	17.68**	15.94	37.93*	9.05	-10.99
ICPA 2048 x ICPL 20111	12.32**	0	16.07**	-2.26	8.14**	0.54	14.72**	14.14**	-5.8	12.07	12.3	-8.35
ICPA 2092 x ICPL 20106	13.27**	0.84	16.07**	-2.26	9.01**	1.35	10.15*	9.60*	1.45	20.69	29.37**	5.59
ICPA 2092 x ICPL 20186	15.17**	2.53	18.75**	0	8.72**	1.08	6.85	6.31	44.93**	72.41**	31.49**	7.32
ICPA 209 x ICPL 20123	15.64**	2.95	17.86**	-0.75	9.30**	1.62	11.93*	11.36*	28.26	52.59**	5.09	-14.23

Table 2: Cont......

Genotype	Pods plant^{-1}		Seeds pod^{-1}		100-seed weight (gm)		Yield plant^{-1} (gm)		Yield plot^{-1} (gm)		Pollen fertility %	
	SH1	SH2	SH1	SH2	SH1	SH2	SH1	SH2	SH1	SH2	SH1	SH2
ICPA 2078 x ICPL 87119	26.11**	26.49**	41.62**	17.79*	21.04**	17.69**	54.79**	21.11*	39.91**	18.12**	-1.71	-1.54
ICPA 2043 x ICPL 87119	13.95**	14.29**	18.5	-1.44	12.70**	9.58**	58.08**	23.68*	32.82**	8.46**	-2.05	-1.88
ICPA 2047 x ICPL 87119	10.39**	10.71**	10.4	-8.17	8.94**	5.93*	32.37**	3.57	26.02**	-0.81	-2.33	-2.15
ICPA 2047 x ICPL 20098	10.09*	10.42*	14.45	-4.81	9.76**	6.72*	39.93**	9.48	33.29**	9.09**	-3.02	-2.84
ICPA 2047 x ICPL 20108	4.45	4.76	30.64**	8.65	10.57**	7.51*	67.99**	31.44**	44.74**	24.70**	-1.26	-1.08
ICPA 2047 x ICPL 20126	12.76**	13.10**	32.95**	10.58	13.92**	10.77**	80.10**	40.91**	47.56**	28.54**	-8.04**	-7.87**
ICPA 2092 x ICPL 87119	0.3	0.6	-10.4	-25.48**	2.64	-0.2	31.85**	3.17	27.77**	1.57**	-2.04	-1.87
ICPA 2092 x ICPL 20108	8.90*	9.23*	-15.61	-29.81**	3.56	0.69	66.45**	30.23**	43.94**	23.60**	-3.99	-3.82
ICPA 2048 x ICPL 87119	5.93	6.25	8.67	-9.62	21.54**	18.18**	48.05**	15.84	36.78**	13.85**	-7.16**	-6.99**
ICPA 2048 x ICPL 20093	13.06**	13.39**	4.62	-12.98	25.81**	22.33**	39.08**	8.82	33.08**	8.81**	-11.36**	-11.20**
ICPA 2047 x ICPL 20111	4.75	5.06	1.16	-15.87	-3.96	-6.62*	29.83*	1.58	28.13**	2.06	-11.59**	-11.43**
ICPA 2047 x ICPL 20129	11.57**	11.90**	23.12*	2.4	11.59**	8.50*	42.30**	11.34	33.85**	9.86**	-25.36**	-25.23**
ICPA 2048 x ICPL 20106	12.46**	12.80**	8.09	-10.1	23.37**	19.96**	65.59**	29.56**	29.80**	4.33**	-13.51**	-13.36**
ICPA 2048 x ICPL 20096	10.98**	11.31**	23.70*	2.88	12.30**	9.19**	37.44**	7.54	31.87**	7.16**	-40.64**	-40.53**
ICPA 2048 x ICPL 20098	10.39**	10.71**	12.72	-6.25	11.18**	8.10**	52.46**	19.29*	38.93**	16.78**	-6.02**	-5.85**
ICPA 2048 x ICPL 20108	14.84**	15.18**	9.83	-8.65	16.57**	13.34**	23.81*	-3.13	26.22**	-0.54	-6.02**	-5.85**
ICPA 2048 x ICPL 20111	3.86	4.17	-4.05	-20.19*	2.64	-0.2	20.23	-5.93	22.26**	-5.93**	-7.96**	-7.79**
ICPA 2092 x ICPL 20106	6.53	6.85	21.39*	0.96	11.99**	8.89**	28.71*	0.71	27.44**	1.13	-10.65**	-10.48**
ICPA 2092 x ICPL 20186	6.23	6.55	8.67	-9.62	-14.63**	-17.00**	62.98**	27.52**	42.77**	22.01**	-12.67**	-12.51**
ICPA 209 x ICPL 20123	5.93	6.25	-34.10**	-45.19**	-0.2	-2.96	11.11	-13.06	15.54**	-15.09**	-6.46**	-6.29**

Where, *, ** = significant at 5% and 1% level, respectively; SH1-Standard heterosis against Maruti variety, SH2- Standard heterosis against Asha variety

ICPL 20108 (31.44%), ICPA 2092 x ICPL 20108 (30.23%), ICPA 2048 x ICPL 20106 (29.56%), ICPA 2092 x ICPL 20186 (27.52%), ICPA 2043 x ICPL 87119 (23.68%), ICPA 2078 x ICPL 87119 (21.11%) and ICPA 2048 x ICPL 20098(19.29%) showed significant positive standard heterosis over Asha. The range of standard heterosis for Asha was from -13.06 (ICPA 2092 x ICPL 20123) to 40.91% (ICPA 2047 x ICPL 20126).The positive and high magnitude of heterosis for grain yield plant^{-1} may be attributed to one or more yield contributing characters. Yadav and Singh (2004), Sekhar*et al*. (2004), Wankhade*et al*. (2005) and Phade*t al.* (2009) recorded positive standard heterosis for seed yield plant^{-1} in pigeonpea.

For Seed yield plot^{-1}(g) all 20 hybrids showed significant positive standard heterosis over Maruti, whereas 16 hybrids showed positive standard heterosis over Asha. The range of standard heterosis over Maruti was from 15.54(ICPA 2092 x ICPL 20123) to 47.55% (ICPA 2047 x ICPL 20126) and for Asha it was from -15.09 (ICPA

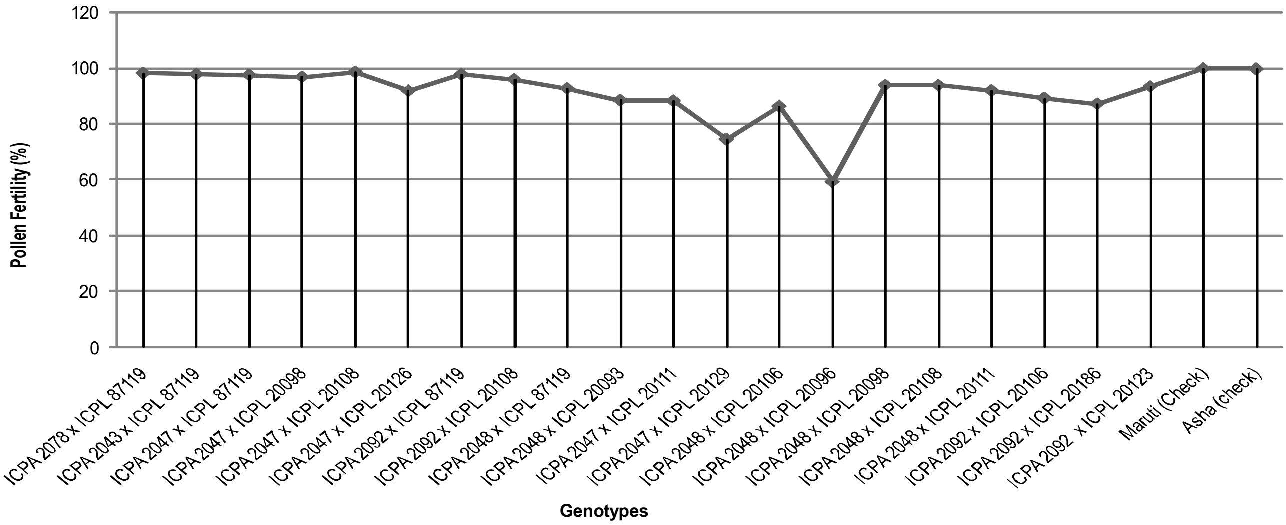

Fig.1: The graph showing pollen fertility status of different CMS-based hybrids and checks of pigeonpea

2092 x ICPL 20123) to 28.54% (ICPA 2047 x ICPL 20126). Pollen fertility (%) is an important character to evaluate the restoration of fertility and amount of viable pollens produced by particular hybrid which is a basic need for the successful production of high yielding CMS-based hybrids of pigeonpea. At Patancheru, the variability for pollen fertility ranged from 59.22 to 99.76% (Fig. 1). Among the hybrids, ICPA 2047 x ICPL 20108 recorded maximum pollen fertility (98.50%) followed byICPA 2078 x ICPL 87119 (98.05%) and ICPA 2092 x ICPL 87119 (97.72%), whereas the minimum pollen fertility was recorded in ICPA 2048 x ICPL 20096 (59.22%) followed by ICPA 2047 x ICPL 20129 (74.46%). Among the all genotypes (hybrids and checks), Asha recorded maximum pollen fertility (99.76%) followed by Maruti (99.58%). Heterosis for seed yield in hybrid pigeonpea were depends upon all yield contributing characters including pollen fertility%. So for fully exploitation of heterosis, hybrid with good pollen fertility is needed. Similar result reported by Wanjari *et al*. (2007).

The results obtained from present investigations may be concluded as,out of 11, nine male pollinator genotypes performed good fertility restoration while two male lines showed lower level of restoration. These 9 male lines may be used as fertility restorer. Significant variability for pollen fertility was present among the hybrids. Yield point of view, most of the hybrids showed positive standard heterosis for yield and it was up to 59.93%. So over all most of the hybrids and its component showed good impact in terms of production of hybrid seeds and yield potential of pigeonpea hybrid.

Acknowledgement

This study was financially supported by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The authors also express their sincere thanks to Dr. K.B. Saxena (Principal Scientist, Pigeonpea Breeding) for constructive suggestions during research work.

References

Deshmukh, R.B., Rodge. R.G., Patil, J.V. and Sahane, D.V.: Heterosis for yield and yield components in relation to cropping systems in pigeonpea. *Legume Res.*, **24**: 101-104 (2001).

FAO.: www.faostat.org (2010).

Manivel, P., Rangasamy, P. and Samdur, M.Y.: Heterosis studies involving genetic male sterile lines in pigeonpea. *Crop Res.*, **18**: 240-242 (1999).

Mudaraddi, B. and Saxena, K.B.: Character association between seed yield and component traits among CMS-based pigeonpea hybrids. *Electronic Journal of Plant Breeding,* **4**: 1086-1089 (2013).

Pandey, N. and Singh, N.B.: Hybrid vigour and combining ability in long duration pigeonpea [*Cajanus Cajan* (L.) Millsp.] hybrids involving male sterile lines. *Indian J. of Genetics & Plant Breeding*., **62**: 221-225 (2002).

Patel, J.A. and Patel, D.B.: Heterosis for yield and yield components in pigeonpea. *Indian J. of Pulses Res.*, **5**: 15-20 (1992).

Phad, D.S, Madrap, I.A. and Dalvi, V.A.: Heterosis in relation to combining ability effects and phenotypic stability in pigeonpea. *Journal of Food Legumes*, **22**: 59-61 (2009).

Reddy, R.P., Vidyasagar, K. and Rao. N.G.P.: Heterosis and combining ability in pigeonpea. *Indian J. of Genetics & Plant Breeding*. **39**: 240-246 (1979).

Sameer Kumar, C.V., Ch. Sreelakshmi and Shivani, D.: Gene effects, heterosis and inbreeding depression in Pigeonpea, *Cajanus cajan* L. *Electronic J. Plant Breeding,* **3**: 682-685 (2012).

Sarode, S.B., Singh, M.N. and Singh, U.P.: Heterosis in long duration pigeonpea [*Cajanus cajan*(L.) Millsp.]. *International Journal of Plant Sciences,* **4**: 106-108 (2009).

Saxena, K.B, Kumar, R.V. and Rao, P.V.: Pigeonpea nutrition and its improvement. In: quality improvement in crops. The Food Products Press. Crop Science, USA: 227-260 (2002).

Saxena, K.B. and Nadarajan, N.: Prospects of pigeonpea hybrids in Indian Agriculture. *Electronic J. Plant Breeding,* **1**: 1107-1117 (2010).

Saxena, K.B., Sultana, R., Saxena, R.K., Kumar, R.V., Sandhu, J.S., Rathore, A., Kishor, P. B.K. and Varshney, R.K.:Genetics of fertility restoration in A4-based, diverse maturing hybrids of pigeonpea [*Cajanus cajan* (L.) Millsp.]. *Crop Sci.,* **51**: 574-587 (2011).

Sekhar, M.R., Singh, S.P., Mehra, R.B. and Govil, J.N.: Combining ability and heterosis in early maturing pigeonpea [*Cajanus cajan*(L.) Millsp.] hybrids. *Indian J. of Genetics & Plant Breeding.* **64**: 212-216 (2004).

Sharma, H.K., Singh, L. and Sharma, D.: Combining ability in diallel crosses in pigeonpea. *Indian Journal of Agricultural Science,* **43**: 25-29 (1973).

Shoba, D. and Balan, A.: Heterosis in CMS/GMS based pigeonpea [*Cajanus cajan* (L.)Millsp.] hybrids. *Agriculture Sci. Digest*, **30**: 32-36 (2010).

Singh G.P., R.M. Singh and U.P. Singh.: Heterosis in pigeonpea. *Int. Pigeonpea News,* **10**: 6-8 (1989).

Solomon, S., Argikar, G.P., Salanki, M.S. and Morbad, I.R.: A study of heterosis in *Cajanus cajan*(L.) Millsp. *Indian J. of Genetics*. **17**: 90-95 (1957).

Srivastava, M.P., Singh, L. and Singh, R.P.: Heterosis in pigeonpea. *Indian Journal of Genetic*. **36**: 197-200 (1976).

Wanjari, K.B., Bhongle, S.A. and Sable, N.H.: Evaluation of heterosis in CMS based hybrids in pigeonpea. *Journal of Food Legumes*. **20**:107-108 (2007).

Wankhade, R.R., Wanjari, K.B., Kadam, G.M. and Jadhav, B.P.: Heterosis for yield and yield components in pigeonpea involving male sterile lines. *Indian Journal ofPulses Research*. **18**:141-143(2005).

Yadav, S.S. and Singh, D.P.: Heterosis in pigeonpea. *Indian Journal of Pulses Research.* **17**:179-180 (2004).