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Assessment of *per se* performance, combining ability, hybrid vigour and reaction to major diseases in pigeonpea [*Cajanus cajan* (L.) Millsp.]

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Abstract: An experiment was carried out using seven cytoplasmic-genetic male sterile (CGMS) lines as females and seven diversified testers as males in a line × tester design. The analysis of variance for parents, females x males, hybrids and parents vs hybrids showed significant differences for almost all characters studied indicating the presence of sufficient variability among parents. Analysis of variance for combining ability revealed that mean squares due to females and line x tester interaction were significant for most of the characters. Thereby it is suggested that the variation in hybrids in respect of seed yield may be strongly influenced by the female lines. Analysis of variance revealed that the ratio of variance due to *GCA* to SCA was less than unity for all the characters indicating that these traits may be under the influence of non additive gene action and these characters are more likely to be improved through heterosis breeding. The *gca* effects of parents revealed that ICPA-2043, ICPA-2047, ICPA-2078, AKT-9913, BDN-2 and GRG-811 were good general combiners for seed yield and it's direct components. The top three crosses exhibiting high specific combing ability effects along with their *Per se* performance, standard heterosis and gca status of the parents indicated that the cross combinations ICPA-2092 x GRG-811, ICPA-2043 x ICP-7035 and ICPA-2047 x RVKP-261 were good specific combiners for seed yield. These parental combinations are being used for exploitation of hybrid vigour. The good general combiners (ICPA-2043, ICPA-2047, ICPA-2078, AKT-9913, BDN-2 and GRG-811) and promising crosses *viz.* ICPA-2047 x GRG-811 and ICPA-2047 x BDN-2 were resistant for SMD and *Fusarium* wilt diseases, having high mean performance, positive *sca* effects for seed yield were identified from the present investigation and these may be useful in future breeding program.

Keywords: *Cajanus cajan*, Combining ability, Hybrid vigour, *Per se*, Line X Testers

INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a perennial shrub belong to economically important tribe Phaseoleae and the subtribe *Cajanine*. It is an important grain legume mostly being cultivated in Africa, Asia and Americas. The global pigeonpea area, production and yield (in 2013) was ~6.22 mha, ~4.74 MT and 762.4 kg ha-1respectively (FAOSTAT 2015). During 2013, ~83.09% of global pigeonpea production and ~85.50% of area was in Asia, 14.34% and 12.19% in Africa, 2.57% and 2.31% in Americas (FAOSTAT 2015). The major pigeonpea producing countries include India (63.74% of global production), Myanmar (18.98%), Malawi (6.07%), Tanzania (4.42%) and Uganda 1.98%). In India pigeonpea was cultivated on 4.65 mha with a total production of 3.02 MT and yield of 650.0 kg ha-1during 2013(Laxmipathi *et al.,* 2015).

It is grown as sole crop or intercrop with urdbean, mungbean, castor, sorghum, soybean, cotton, maize and groundnut in different states like Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Gujarat, Jharkhand, Rajasthan Odisha, Punjab and Haryana. Pigeonpea is mostly consumed as dry split dhal besides several other uses of various parts of pigeonpea plant. It is an excellent source of protein (20 -22%), supplementing energy rich cereal diets in a mainly vegetarian population. Pigeonpea is a multipurpose crop that fits very well in the context of sustainable agriculture. In addition to food, it can be used as fodder, feed, fuel, functional utility (for making baskets, huts, fences, etc.), fertilizer (fixes atmospheric nitrogen and releases phosphorus), forest use (re-forestation, lac production), and even for pharmaceutical purposes. However, the current production of pigeonpea in India cannot meet the domestic demand leading to a decrease in per capita availability of pigeonpea from 70 gm to 35 gm. Despite the fact that a large number of high yielding varieties and have been released, productivity in the crop remains stagnant around 700 kg ha-1as compared to its potential yield (2500-3000 kg ha-1). This gap may be attributed to several biotic and abiotic factors. Since it is mainly a rainfed crop, unfavorable rainfall (delayed, erratic, improper distribution) leads to

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Table 1a. Categorization of genotypes for SMD and wilt reaction.

Percent disease incidence	Reaction scale
0-10% of plant infected	Resistant
10.1 – 30% plants infected	Moderately resistant
30.1 – 100% plants infected	Susceptible

terminal drought or heavy down pour. Non adoption of improved management practices and lack of proper research and commercial perspective for the crop influence the low productivity to a greater extent (Laxmipathi *et al.,* 2015).

Most of the economic characters like seed yield, number of pods per plant, days to 50 per cent flowering are mostly governed by polygenes and their inheritance is of complex nature. Therefore, before making attempts for improvement of these characters it is essential to know the nature of gene action controlling these quantitative characters. This information will be helpful to breeders in devising appropriate methods of breeding for crop improvement. A review of literature on quantitative genetics of pigeonpea showed that the presence of significant levels of non additive genetic variation for seed yield which could be profitably exploited through heterosis breeding to increase grain yield (Saxena and Sharma, 1990).

Exploitation of heterosis depends much on general and specific combining ability effects. Combining ability studies are useful in evaluation of the parental lines and their cross combinations, usually this information aids in selection of parents in terms of performance of hybrids and elucidate the nature and magnitude of various types of gene action involved in the expression of quantitative traits (Sony, 2010). Therefore, present study was undertaken to assess *per se* performance combining ability, hybrid vigour and reaction to major diseases in pigeonpea using seven cytoplasmic genic male sterile lines derived from A_2 and A_4 cytoplasm and 7 diverse testers crossed in line x tester design in pigeonpea.

MATERIALS AND METHODS

The parental material comprised of seven CGMS lines (ICPA-2043, ICPA-2078, ICPA-2047, GT-288A, ICPA-2048-4 ICPA-2092 and GT-307A) used as a females were crossed with seven genotypes *viz.* GRG-811, RVKP-260, RVKP-261, AKT-9913, ICP-7035, RAJA and BDN-2 used as a males in line x tester mating design during *Kharif* 2012 and sufficient numbers of hand pollinated seeds were produced. The evaluation experiment was carried out at Agriculture Research Station, Kalaburagi. A total of 49 experimental hybrids, seven females and seven males along with one check (Maruti) were grown in an 8 X 8 square lattice design with two replications. Each genotype was sown in two rows of 4.0 meter length with the spacing of 90 x 30 cm between rows and plants respectively.

Observations on five randomly selected competitive plants were recorded for days to 50% flowering, days

Table 1b. Mean sum of squares for parents and hybrids in respect of 11 characters in pigeonpea (*Cajanus cajan* (L.) Millsp.).

Source of variation	Degree of freedom	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Secondary branches	Pod bearing length (cm)	No. of pods/ plant	No. of seeds/plant	100-Seed weight (g)	Seed yield/ plant
Replication	1	42.29**	132.07**	54.70	3.69	11.81	246.36	1945.66**	0.02	0.35	383.08**
Parents	13	133.67**	406.51**	640.89**	23.45**	10.51**	450.23**	1684.97**	0.83**	13.61**	217.64**
Lines	6	254.61**	537.97**	520.21*	34.36**	10.02*	246.36**	1032.54**	0.21**	18.37**	1204.63**
Testers	6	25.95**	337.45**	1963.83**	16.01**	12.55**	450.23**	2050.07**	1.28**	5.39**	531.52**
Lines v/s Testers	36	54.32**	32.14**	0.41	2.70	1.19	151.59**	3408.93**	1.84**	10.86**	1404.81**
Crosses	48	50.44**	182.81**	448.55**	23.28**	13.26**	197.47**	5144.05**	0.13**	4.69**	341.74**
Parents v/s Hybrids	1	0.12**	5.66**	9433.31**	568.14**	231.80**	686.47**	64568.86**	0.36**	2.93**	3088.315**
Error	62	3.44	9.15	65.64	4.64	3.38	32.24	210.47	0.06	0.32	31.49

*, ** – Significant at 5% and 1% levels, respectively

Table 2. ANOVA for combining ability in respect of 11 characters in pigeonpea (*Cajanus cajan* (L.) Millsp.).

Source of variation	Degree of freedom	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Secondary branches	Pod bearing length (cm)	No. of pods/ plant	No. of seeds/ plant	100-Seed weight (g)	Seed yield/ plant
Females	6	280.16**	673.46**	520.21*	43.02*	15.07	403.11**	18740.98**	0.20	18.37**	1204.63**
Males	6	27.00	254.72*	1963.83**	51.12**	6.38	755.75**	7417.76*	0.13	5.39*	531.52**
Females x Males	36	16.07**	89.04**	184.06**	15.35**	14.10**	70.14*	2498.94**	0.12**	2.30**	166.28**
Error	48	3.43	9.65	68.86	5.15	3.81	37.21	244.58	0.04	0.35	28.49

*, ** – Significant at 5% and 1% levels, respectively

Table 3. Variance due to GCA, SCA and their proportion for 11 different characters.

S. N.	Characters	Variance due to GCA	Variance due to SCA	GCA / SCA proportion
1.	Days to 50 per cent flowering	0.82	6.32	1:7.72
2.	Days to maturity	2.23	39.69	1:17.78
3.	Plant height (cm)	6.29	57.59	1:9.14
4.	Primary branches	0.18	5.09	1:27.12
5.	Secondary branches	-0.02	5.14	1:-257.20
6.	Pod bearing length (cm)	3.03	16.46	1:5.43
7.	No. of pods/plant	62.97	1127.18	1:17.90
8.	No. of seeds /pods	0.0003	0.04	1:128.66
9.	100 seed weight (g)	0.05	0.97	1:17.15
10.	Seed yield/ plant (g)	4.17	68.90	1:16.49

to maturity, plant height (cm), number of primary and secondary branches/plant, pod bearing length (cm), number of pods/plant, No. of seeds /pods, 100 seed weight, and seed yield/plant (g). The data was subjected to analysis of variance and combining ability using statistic package WINDOSTAT 8.5 developed by Indostat services, Hyderabad (India). Experimental layout for screening *Fusarium* wilt was laid out on national wilt sick plot maintained at Agricultural Research Station, Gulbarga during *kharif* 2013 along with wilt susceptible check (ICP-2376) and resistant check (MARUTI) varieties. A row length of 4 meters each was maintained with spacing of 75 cm and 30 cm between the rows and plants respectively. The observations on per cent wilt was recorded at flowering (90 days after sowing) and at physiological maturity (150 days after sowing) stage by counting number of dead plants (due to *Fusarium* wilt) among the total number of plants present per genotype and per cent disease was estimated.

Experimental layout for screening sterility mosaic disease (SMD) was laid out at Agricultural Research Station, Bidar. Sterility Mosaic disease pressure was created by maintaining four rows of susceptible check (ICP-8863) all around the plot *i.e* “Infector hedge row technique”. Test entries were sown in two rows each and susceptible check was sown after every 10^{th} row. “Leaf Stapling Technique” (Nene and Reddy, 1977) was followed to build the disease incidence. Plants were scored for incidence of SMD at 15 days interval up to maturity stage by counting the healthy plants (no mosaic symptoms) and diseased plants (with mosaic symptoms). Categorization of genotypes for SMD and *Fusarium* wilt reaction was carried out following the standard scale given in table-1a (Singh *et al.,* 2003).

Percent disease incidence (PDI) was estimated using formulae.

$$\text{Per cent disease incidence} = \frac{\text{Number of plants infected in row}}{\text{Total number of plants in a row}} \times 100$$

RESULTS AND DISCUSSION

The analysis of variance for the mean sum of squares for parents showed significant differences for almost all characters studied indicating the presence of sufficient variability among parents. The interaction between females x males was significant for days to maturity, pod bearing length, number of pods per plant, number of seeds per pods, 100 seed weight, seed yield per plant and seed yield per hectare. The hybrids showed highly significant differences for all the quantitative traits. Parents Vs hybrids also showed significant difference for all the characters (Table 1b).

Analysis of variance for combining ability revealed that mean squares due to females were significant for all most all the characters except secondary branches and total number of seeds per pods, while mean squares due to males were significant for all the traits except days to 50% flowering, secondary branches, number of seeds per pods and seed yield per plant. The mean squares due to line x tester interaction were significant for all the traits. Thereby it is suggested that the variation in hybrids with respect of seed yield may be strongly influenced by the lines. The mean squares due to lines were larger in magnitude for most of the important yield attributes than those for testers indicating greater diversity amongst the lines as compared to testers (Table-2).

Analysis of variance revealed that the ratio of variance due to *GCA* to *SCA* was less than unity for all the characters (Table 3) indicating that these traits may be under the influence of non additive gene action and these characters are more likely to be improved through heterosis breeding. The above findings are in agreement with the earlier reports of Beekham and Umaharan (2010), Shobha and Balan (2010), Sony (2010), Chethana *et al.* (2013), Yamanura *et al.* (2014) and Meshram *et al.* (2013) also revealed the same results for most of the important characters including seed yield except plant height indicating these traits are under the influence of non additive gene action.

The analysis of variance for combining ability indicated that the mean squares due to general and specific combining ability effects were of both additive and nonadditive gene action. The mean sum of squares due to lines × testers and their interactions were highly significant for seed yield and it’s component characters indicating the importance of *sca* variance, and consequently the non-additive genetic variation in the inheritance of these characters. The trend recorded was in agreement with the findings of Khorgade *et al.* (2000), Sunil Kumar *et al.* (2003) and Sekhar *et al.* (2004). Vaghela *et al.* (2009), Sameer Kumar *et al.* (2009) and Bharate *et al.* (2011) for seed yield/plant and other

Table 4. General combining ability effects for parents in respect of 11 characters in pigeonpea (*Cajanus cajan* (L.) Millsp.).

S. N.	Entries	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Secondary branches	Pod bearing length (cm)	No. of pods/ plant	No. of seeds/ plant	100-Seed weight (g)	Seed yield/ plant
	LINES										
1.	ICPA-2043	-2.18 **	-8.37 **	-6.25 **	0.24	0.39	1.21	-14.40 **	-0.15 **	0.02	-2.83
2.	ICPA2078	-2.83 **	1.2	-4.04	-2.50 **	1.47 **	5.51**	28.38 **	-0.13 *	2.43 **	11.94 **
3.	ICPA-2047	3.74 **	-1.87 *	5.86 *	2.44 **	0.42	-1.56	-27.16 **	0.02	-0.63 **	-5.68 **
4.	GT-288A	-7.61 **	-7.72 **	-7.11 **	-1.38 *	-0.11	8.05 **	67.72 **	0.21 **	-0.27	14.88 **
5.	ICPA-2048-4	4.89 **	11.78 **	8.31 **	0.71	-1.06 *	-1.57	-5.89	0.06	-0.41 *	-6.18 **
6.	ICPA-2092	3.32 **	1.28	3.67	1.60 *	0.49	-7.15 **	-8.86 *	-0.01	-1.16 **	-6.52 **
7.	GT-307A	0.67	3.70 **	-0.43	-1.11	-1.61 **	-4.49 **	-39.78 **	-0.01	0.02	-5.61 **
	TESTERS										
1.	GRG-811	0.6	-3.51 **	9.82 **	0.81	-0.32	1.89	-23.85 **	-0.03	0.33 *	-5.01 **
2.	RVKP-260	-0.9	-0.51	2.2	0.93	-0.18	-0.44	-16.89 **	-0.1	-0.46 **	-6.58 **
3.	RVKP-261	-1.61 **	0.63	6.88 **	1.46 *	-0.32	2.81	3.74	0.04	1.17 **	0.67
4.	AKT-9913	1.10 *	1.13	9.08 **	0.94	0.63	8.73 **	33.92 **	0.04	-0.38 *	10.61 **
5.	ICP-7035	0.67	1.06	-12.02 **	-2.49 **	0.84	-8.92 **	-1.35	0.16 **	0.24	-1.36
6.	RAJA	1.82 **	7.42 **	-21.00 **	-3.04 **	-1.10 *	-10.64 **	-21.75 **	-0.13 *	-0.31	-3.81 *
7.	BDN-2	-1.68 **	-6.22 **	5.03 *	1.39 *	0.44	6.57 **	26.18 **	0.02	-0.58 **	5.47 **
	CV	1.81	1.94	4.37	16.40	23.70	14.32	10.44	6.29	4.73	15.81
	CD @ 5%	3.67	5.99	16.04	4.26	3.64	11.24	28.72	0.49	1.12	11.11
	CD @ 1%	4.87	7.96	21.30	5.66	4.83	14.93	38.15	0.66	1.49	14.75

*, ** – Significant at 5% and 1% levels, respectively

important yield attributes *viz.,* pod bearing length, number of pods per plant and 100 seed weight. Preponderance of non-additive genetic variance has been suggested. On contrary, predominance of additive gene action was obtained by Achamma *et al*. (1996) and Singh and Srivastava (2001). However, importance of both additive as well as non-additive gene action was recorded by Acharya *et al*. (2009).

The nature and magnitude of combining ability effects help in identifying superior parents and their utilization in breeding programme. Character-wise estimation of *gca* effects of lines and testers is presented in Table- 4. The *gca* effects of parents revealed that ICPA-2043, ICPA-2047, ICPA-2078, AKT-9913, BDN-2 and GRG-811 were good general combiners for seed yield and it's direct components. The lines GT -288A, ICPA-2043 and ICPA-2078 and testers BDN-2, GRG-811 and RVK-261 were good general combiners for days to 50 % flowering and days to maturity, lines ICPA-2047 and ICPA-2048-4 and testers GRG-811 and AKT-9913 for plant height, lines ICPA-2047, ICPA-2078 and ICPA-2092 and testers RVK-261, ICP-7035 and BDN-2 for number of branches/ plant, lines ICPA-2078 and GT-288A and testers AKT-9913 and BDN-2 for pod bearing length and number of pods/plant, line ICPA-2078 and tester RVK -261 for 100 seed weight (Table 4).

The top three crosses exhibiting high specific combing ability effects along with their *Per se* performance, standard heterosis and gca status of the parents indicated that the cross combinations ICPA-2092 x GRG-811, ICPA-2043 x ICP-7035 and ICPA-2047 x RVKP-261 were good specific combiners for seed yield per hectare. These parental combinations are being used for exploitation of hybrid vigour. The cross combination ICPA-2092 x RVKP-261, ICPA-2047x RAJA and ICPA-2078 x GRG-811 were good specific combiners for days to 50% flowering and maturity as they were showing highly significant negative *sca* effect and it is very much suitable to rainfed condition because it has advantage of escaping terminal moisture stress. The crosses GT-288A x ICP-7035, ICPA-2043 x ICP-7035 and ICPA-2043 x RAJA for plant height, ICPA-2078 x ICP-7035 and ICPA-2043 x RAJA for number of primary branches, ICPA-2078 x AKT-9913, GT-307A x BDN-2 and ICPA-2092 x GRG-811 for number of secondary branches, ICPA-2078 x GRG-811, ICPA-2043 x BDN-2 and GT-288A x AKT-9913 for pod bearing length, GT-288A x AKT-9913, ICPA-2043 x BDN-2 and ICPA-2043 x RAJA for number of pods per plant, GT-288A x ICP-7035, ICPA-2043 x RAJA and ICPA-2078 x RAJA for 100 seed weight, ICPA-2078 x AKT-9913, GT-288A x ICP-7035 and ICPA-2078 x AKT-9913 for seed yield per plant were found to be useful. The estimates of *sca* effects revealed that nine experimental hybrids had significant, desirable and positive *sca* effects for seed yield/plant. Among these, three best crosses were selected on the basis of

Table 5. Comparison of top three best crosses on the basis of specific combining ability effects for different characters.

Characters	Crosses	SCA effects	GCA effects of Parents and Status			Standard heterosis	*per se*	Significant SCA effects for other traits
			P1	P2	Status			
Days to 50 per cent flowering	ICPA-2092 x ICP-7035	-5.32	3.32	0.67	H X L	-10.22	101.00	DM
	ICPA-2047 x RAJA	-4.89	3.74	1.82	H X H	-8.44	103.00	DM, PHT, NPPP, YPP
	GT-307A x GRG-811	-4.10	0.67	0.60	L X L	-11.56	100.00	DM, SB, 100SW
Days to maturity	ICPA-2092 x RVKP-261	-9.20	1.28	0.63	L X L	-8.31	149.00	DFF, NPPP
	ICPA-2047x RAJA	-8.55	-1.87	7.42	L X H	-5.85	153.00	DFF, NPPP, YPP
	ICPA-2078 x GRG-811	-7.99	1.20	-3.51	L X L	-10.15	146.00	PBL, NPPP
Plant height (cm)	GT-288A x ICP-7035	24.20	-7.11	-12.02	L X L	10.40	195.21	SB, NPPP, NSPP, 100SW, YPP
	ICPA-2043 x ICP-7035	16.63	-6.25	-12.02	L X L	6.61	188.50	PHT, NSP, ,
	ICPA-2043 x RAJA	15.77	-6.25	-21.00	L X L	1.04	178.67	PB, NPPP, 100SW,
Primary branches	ICPA-2078 x ICP-7035	7.43	-2.50	-2.49	L X L	51.45	16.66	DFF, PB, 100SW
	ICPA-2043 x RAJA	3.39	0.24	-3.04	L X L	34.77	14.82	PHT, NPPP, 100SW,
	ICPA-2078 x AKT-9913	4.41	1.47	0.63	H X L	126.07	15.00	DFF, YPP
Secondary branches	GT-307A x BDN-2	3.52	-1.61	0.44	L X L	63.23	10.83	YPP
	ICPA-2092 x GRG-811	2.95	0.49	0.44	L X L	74.91	11.61	DFF, DM
	ICPA-2078 x GRG-811	12.19	5.51	1.89	H X L	-5.47	60.50	NPPP
Pod bearing length (cm)	ICPA-2043 x BDN-2	11.23	1.21	6.57	L X H	-6.38	59.92	NPPP, YPP
	GT-288A x AKT-9913	10.15	8.05	8.73	H X H	5.99	67.83	NPPP, YPP
	GT-288A x AKT-9913	95.17	67.72	33.92	H X H	125.75	348.43	PBL, YPP
No. of pods/plant	ICPA-2043 x BDN-2	54.20	-14.40	26.18	L X H	40.59	217.00	PBL, YPP
	ICPA-2043 x RAJA	51.13	-14.40	10.44	L X H	7.53	166.00	PHT, PB, 100SW, YPP
	GT-288A x ICP-7035	2.62	-0.27	0.24	L X L	51.66	14.61	PHT, SB, NSPP, 100SW, YPP
100 seed weight (g)	ICPA-2043 x RAJA	1.47	0.02	-0.58	L X L	37.02	13.20	PHT, PB, NPPP, YPP
	ICPA-2078 x RAJA	1.14	2.43	-0.58	H X L	58.62	15.28	PHT
	ICPA-2078 x AKT-9913	15.05	11.94	10.61	H X H	61.17	75.75	SB
Seed yield/ plant (g)	GT-288A x ICP-7035	14.76	14.88	-1.36	H X L	41.33	66.42	PHT, SB, NPPP, NSPP, 100SW
	ICPA-2078 x AKT-9913	12.42	11.94	-6.58	H X L	18.98	55.92	DFF, SB

DFF= Days to 50 % flowering; DM= Days to maturity; PHT= Plant height (cm); PB = No. of Primary branches; SB= No. of Secondary branches; PBL = Pod bearing length (cm); NPPP= No. of pods/ plant; 100SW= 100 seed weight (g); SYPP= Seed yield/ plant.

Table 6. Top three crosses based on *per se* for eleven yield and yield attributing characters in pigeonpea.

S. N.	Characters	Crosses	Per se performance	Sca effects	Gca status of parents	% heterosis over commercial parent	Wilt (PDI)	SMD (PDI)
		GT-288A x BDN-2	90.00	-3.03	H x H	-20.00	M(18.18)	S(53.33)
1.	Days to 50% flowering	GT-288A x RVKP-261	93.00	-0.10	H x H	-17.33	S(42.86)	S(41.18)
		GT-288A x RVKP-260	94.00	-0.32	H x L	-16.89	M(14.29)	S(50.00)
		GT-288A x BDN-2	136.00	-6.35	H x H	-16.31	M(18.18)	S(53.33)
2.	Days to maturity	GT-288A x GRG-811	142.00	-3.06	H x H	-12.62	R(0.00)	S(50.00)
		ICPA-2043 x BDN-2	143.00	0.80	H x H	-12.31	M(30.00)	S(50.00)
		ICPA-2048-4 x AKT-9913	221.17	13.64	H x H	25.08	S(40.00)	M(18.18)
3.	Plant height (cm)	ICPA-2047 x AKT-9913	212.26	7.18	H x H	20.04	S(54.76)	S(82.61)
		ICPA-2047 x BDN-2	210.16	9.14	H x H	18.86	R(9.38)	R(6.25)
		ICPA-2047 x RVKP-261	21.10	2.99	H x H	91.86	S(48.65)	R(8.33)
4.	No. of Primary branches	ICPA-2047x AKT-9913	20.77	3.16	H x L	88.82	S(54.76)	S(82.61)
		ICPA-2092 x RVKP-261	19.76	2.49	H x H	79.68	S(31.58)	S(36.36)
		GT-288A x ICP-7035	12.00	2.79	L x L	80.86	S(37.50)	M(26.32)
5.	No. of Secondary branches	ICPA-2092 x GRG-811	11.61	2.95	L x L	74.91	M(24.14)	M(16.67)
		ICPA-2078 x RVKP-260	11.50	1.72	H x L	73.32	M(14.29)	S(76.00)
		GT-288A x AKT-9913	67.83	10.15	H x H	5.99	S(40.00)	S(57.89)
6.	Pod bearing length (cm)	ICPA-2078 x GRG-811	60.50	12.19	H x L	-5.47	R(0.00)	M(21.05)
		ICPA-2043 x BDN-2	59.92	11.23	L x H	-6.38	M(30.00)	S(50.00)
		GT-288A x AKT-9913	348.43	95.77	H x H	125.75	S(40.00)	S(57.89)
7.	Number of pods per plant	GT-288A x ICP-7035	258.78	41.38	H x L	67.66	S(37.50)	M(26.32)
		ICPA-2078 x AKT-9913	225.62	12.28	H x H	46.18	M(16.67)	S(90.91)
8.	Number of seeds per pod	GT-288A x ICP-7035	5.00	0.70	L x H	28.37	S(37.50)	M(26.32)
		ICPA-2078 x RVKP-261	16.16	0.55	H x H	67.86	M(20.00)	M(26.32)
9.	100 seed weight (g)	ICPA-2078 x ICP-7035	15.66	0.98	H x L	62.62	S(60.00)	M(30.00)
		ICPA-2078 x RAJA	15.28	1.14	H x L	58.62	M(18.75)	S(75.00)
		ICPA-2078 x AKT-9913	75.75	15.05	H x H	61.17	M(16.67)	S(90.91)
10.	Seed yield per plant (g)	GT-288A x AKT-9913	71.25	7.61	H x H	51.60	S(40.00)	S(57.89)
		GT-288A x ICP-7035	66.42	14.76	H x L	41.33	S(37.50)	M(26.32)

Table 7. Top two parents for GCA effects and their mean performance for 10 characters.

Characters	Lines	GCA effects	Mean	Testers	GCA effects	Mean
Days to 50% flowering	GT-288A	-7.61	81.00	BDN-2	-1.68	100.00
	ICPA-2078	-2.83	92.00	RVKP-261	-1.61	107.50
Days to maturity	ICPA-2043	-8.37	152.00	BDN-2	-6.22	142.50
	GT-288A	-7.72	129.00	GRG-811	-3.51	156.50
Plant height (cm)	ICPA-2048-4	8.31	182.76	GRG-811	9.80	172.61
	ICPA-2047	5.86	197.50	AKT-9913	9.08	172.77
No. of primary branches	ICPA-2047	2.44	11.26	RVKP-261	1.46	9.77
	ICPA-2092	1.60	12.68	BDN-2	1.39	6.82
No. of secondary branches	ICPA-2078	1.47	2.62	ICP-7035	0.84	2.33
Pod bearing length (cm)	GT-288A	8.05	46.67	AKT-9913	8.73	30.16
	ICPA-2078	5.51	11.92	BDN-2	6.57	61.33
Number of pods per plant	GT-288A	67.72	73.00	AKT-9913	33.92	130.01
	ICPA-2078	28.38	56.33	BDN-2	26.18	136.50
100 seed weight (g)	ICPA-2078	2.43	13.30	RVKP-261	2.43	9.61
Seed yield per plant (g)	GT-288A	14.88	16.00	AKT-9913	10.61	28.42
	ICPA-2078	11.94	12.25	BDN-2	5.47	39.08

Table 8. Reaction of hybrids and parents to wilt and SMD during *Kharif* 2013.

S. N.	Cross name	*Fusarium* Wilt		Sterility mosaic disease	
		PDI	Reaction	PDI	Reaction
1.	ICPA-2043 x GRG-811	15.79	MR	20.00	MR
2.	ICPA-2043 x RVKP-260	23.53	MR	18.18	MR
3.	ICPA-2043 x RVKP-261	59.38	S	75.00	S
4.	ICPA-2043 x AKT-9913	33.33	S	22.22	MR
5.	ICPA-2043 x ICP-7035	35.71	S	4.55	R
6.	ICPA-2043 x RAJA	25.93	MR	5.56	R
7.	ICPA-2043 x BDN-2	30.00	MR	50.00	S
8.	ICPA-2078 x GRG-811	0.00	R	21.05	MR
9.	ICPA-2078 x RVKP-260	14.29	MR	76.00	S
10.	ICPA-2078 x RVKP-261	20.00	MR	26.32	MR
11.	ICPA-2078 x AKT-9913	16.67	MR	90.91	S
12.	ICPA-2078 x ICP-7035	60.00	S	30.00	MR
13.	ICPA-2078 x RAJA	18.75	MR	75.00	S
14.	ICPA-2078 x BDN-2	25.00	MR	33.33	S
15.	ICPA-2047 x GRG-811	8.06	R	5.88	R
16.	ICPA-2047 x RVKP-260	36.59	S	73.68	S
17.	ICPA-2047 x RVKP-261	48.65	S	8.33	R
18.	ICPA-2047 x AKT-9913	54.76	S	82.61	S
19.	ICPA-2047 x ICP-7035	63.16	S	10.00	R
20.	ICPA-2047 x RAJA	45.45	S	15.38	MR
21.	ICPA-2047 x BDN-2	9.38	R	6.25	R
22.	GT-288A x GRG-811	0.00	R	50.00	S
23.	GT-288A x RVKP-260	14.29	MR	50.00	S
24.	GT-288A x RVKP-261	42.86	S	41.18	S
25.	GT-288A x AKT-9913	40.00	S	57.89	S
26.	GT-288A x ICP-7035	37.50	S	26.32	MR
27.	GT-288A x RAJA	60.00	S	27.78	MR
28.	GT-288A x BDN-2	18.18	MR	53.33	S
29.	ICPA-2048-4 x GRG-811	27.03	MR	28.57	MR
30.	ICPA-2048-4 x RVKP-260	43.59	S	33.33	S
31.	ICPA-2048-4 x RVKP-261	44.44	S	26.32	MR
32.	ICPA-2048-4 x AKT-9913	40.00	S	18.18	MR
33.	ICPA-2048-4 x ICP-7035	47.37	S	27.78	MR
34.	ICPA-2048-4 x RAJA	16.00	MR	23.53	MR
35.	ICPA-2048-4 x BDN-2	35.90	S	20.00	MR
36.	ICPA-2092 x GRG-811	24.14	MR	16.67	MR
37.	ICPA-2092 x RVKP-260	39.29	S	31.25	S
38.	ICPA-2092 x RVKP-261	31.58	S	36.36	S
39.	ICPA-2092 x AKT-9913	28.57	MR	42.11	S
40.	ICPA-2092 x ICP-7035	27.78	MR	27.78	MR
41.	ICPA-2092 x RAJA	56.25	S	27.27	MR
42.	ICPA-2092 x BDN-2	30.00	MR	69.57	S
43.	GT-307A x GRG-811	40.91	S	28.00	MR
44.	GT-307A x RVKP-260	26.92	MR	28.57	MR
45.	GT-307A x RVKP-261	29.41	MR	21.74	MR
46.	GT-307A x AKT-9913	25.00	MR	52.94	S
47.	GT-307A x ICP-7035	33.33	S	15.79	MR
48.	GT-307A x RAJA	36.84	S	28.57	MR
49.	GT-307A x BDN-2	11.76	MR	23.08	MR
50.	GRG-811	9.80	R	20.00	MR
51.	RVKP-260	27.78	MR	32.00	S
52.	RVKP-261	44.74	S	50.00	S
53.	AKT-9913	33.33	S	66.67	S
54.	ICP-7035	88.89	S	4.55	R
55.	RAJA	85.71	S	4.17	R
56.	BDN-2	4.35	R	57.14	S
57.	ICPA-2043	20.45	MR	27.78	MR
58.	ICPA2078	9.68	R	28.57	MR
59.	ICPA-2047	9.80	R	0.00	R
60.	GT-288A	39.29	S	33.33	S
61.	ICPA-2048-4	22.50	MR	25.00	MR
62.	ICPA-2092	6.45	R	33.33	S
63.	GT-307A	20.51	MR	14.29	MR
64.	MARUTI (WRC and SSC)	6.51	R	100	S
65.	ICP-2376(WSC)	92.5	S	78.5	S

WSC: Wilt susceptible check; R: Resistant; WRC: Wilt resistant check; M: Moderately resistant; SSC: SMD susceptible check; S: Susceptible.

per se performance for ascertaining their association with *sca* effects of seed yield per plant and its attributes (Table 5).

Out of three crosses showing high mean and significant positive *sca* effects for seed yield along with their *per se* performance as well as *gca* effects of parents and their significant response to other characters are presented in Table 6. Out of three crosses showing high mean and significant positive *sca* effects for grain yield, two crosses ICPA-2043 x ICP-7035 and ICPA-2047 x RVKP-260 involved high × low *gca* parents and the remaining cross ICPA-2092 x GRG-811with low x low *gca* effects of parents. These results were also in conformity with those of Baskaran and Muthiah (2007), Meshram *et al.* (2013), Chethana *et al.* (2013) and Yamanura *et al.* (2014). Better performance of hybrids involving high x low or low x low general combiners indicated dominance x dominance (epitasis) type of gene action. The crosses showing high *sca* effects involving one good general combiner indicated additive x dominance type gene interaction which exhibit the high heterotic performance for yield and yield related traits.

The hybrid derivatives of crosses such as ICPA-2047 x GRG-811 and ICPA-2047 x BDN-2 were resistant for both the diseases with per cent disease incidence value of 8.06 & 9.38 for *Fusarium* wilt and 5.88 & 6.25 for SMD respectively (Table 8); these findings were in agreement with Sharma *et al.* (2013) and resistant sources identified in the field were confirmed in the greenhouse using a root dip screening technique for FW and a leaf stapling technique for SMD. Six accessions were found resistant to FW (<10%PDI). High level of resistance to SMD was found in 24 accessions <10% PDI).

Conclusion

The results suggested that hybrid derivatives of crosses ICPA-2047 x GRG-811 and ICPA-2047 x BDN-2 were resistant for both the diseases, having high mean performance, positive *sca* effects for seed yield. Their significant response to other related traits had necessarily involved both or at least one parent as good combiner which could be commercially exploited for heterosis by taking advantage of natural out crossing in pigeon pea.

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