Journal of Food Legumes 28(2): 105-110, 2015

Combining ability studies of pigeonpea CGMS lines with an obcordate leaf marker

S.B. PATIL, A.J. HINGANE, C.V. SAMEER KUMAR, MULA MYER, R. VIJAYA KUMAR and K.B. SAXENA

Grain Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 502 324, Andhra Pradesh, India; Email: c.sameerkumar@cgiar.org

(Received: March 24, 2014; Accepted: June 16, 2105)

ABSTRACT

Hybrid pigeonpea [*Cajanus cajan* (L.) Millsp.] breeding technology based on CGMS was recently developed. A program was initiated to track the purity of female parental lines by incorporating an obcordate leaf shape marker in established male sterile A-lines. Seven obcordate A-lines developed by backcrossing and selection were crossed with four known fertility restorers in line x tester mating design to study their general and specific combining ability. Higher magnitude of SCA effect showed that, hybrid yield was under the control of non-additive genes. Among A-lines, ICPA 2204 was the best general combiner. Among testers, ICPL 20116 was the best general combiner. Among hybrids, ICPA 2208 x ICPL 20108 a cross between high GCA parents was the best with positive significant SCA effect and higher mean performance for grain yield, 100-seed mass, number of seeds/pod and resistance to fusarium wilt disease. The success of this technology will help addressing the issue of seed quality to some extent.

***Key words*:** Combing ability, Line × tester, GCA, SCA, Obcordate leaf shape, Pigeonpea

In order to achieve a breakthrough in the productivity of pigeonpea, hybrid breeding technology based on cytoplasmic genetic male sterility was developed at ICRISAT (Saxena 2008). Significant yield gains with improved disease and drought resistance in the hybrids over traditional cultivars are likely to help in enhancing production and productivity of pigeonpea (Saxena *et al.*, 2013). To achieve this mission, it is important to establish a stable and robust hybrid seed production technology that will fulfil the ever increasing demand for quality hybrid seed. The genetically uniform parental lines and commercial hybrids are necessary in production and marketing of quality hybrid crops. Quality control of hybrid seeds is traditionally done by Grow out Test (GoT) in most of the crops. In pigeonpea this process is more resource intensive in terms of time and labour due to its long generation time. Considering this constraint, efforts were made to incorporate an easily identifiable morphological marker [naked eye polymorphism (NEP)] in female parents to track the purity of the female parent and hybrids. Although morphological markers are limited in nature but their assays neither require sophisticated equipment nor complicated procedures (Singh, 1992). The obcordate leaf shape used as NEP is a highly heritable trait with single recessive genetic control. To develop hybrid technology based on NEP, the obcordate leaf marker was transferred to A-lines through backcrossing (Saxena *et al.*, 2011). The objective of this study was to identify obcordate male sterile lines with good general and specific combining ability for use in hybrid breeding program.

MATERIALS AND METHODS

Seven CGMS lines with obcordate leaf marker and their corresponding B-lines were developed by backcrossing two established male sterile lines ICPA 2047 and ICPA 2048 with obcordate leaf donor ICP 5529. These A-lines designated as ICPA 2200, ICPA 2201, ICPA 2202, ICPA 2203, ICPA 2204, ICPA 2206 and ICPA 2208 were crossed with four known male fertility restorers (ICPL 20116, ICPL 87119, ICPL 20108 and ICPL 20093) in a line x tester mating design. A field experiment was conducted with 28 F_1 hybrids and three standard checks ICPL 87119 (Asha), ICPH 2671, and ICPH 2740 in a randomized complete block design with two replications. The experiment was conducted at Patancheru in 2012 rainy season. Each plot consisted of two rows of 4 m length with inter and intra row spacing of 75 cm and 30 cm, respectively. To avoid border effect one border row was planted at each side of the plot. All the hybrids and their parents were also grown in single row plots in disease sick nursery for assessing their reaction to fusarium wilt and sterility mosaic diseases. Fusarium wilt incidence was recorded based on the number of plants wilted out of total plants available in a plot, and expressed in percentage. The incidence of sterility mosaic was studied using leaf stapling method. In this technique 10-15 day old seedlings were stapled with leaves infected with eriophyid mite (*Aceria cajani*) that carries sterility mosaic virus. Sterility mosaic incidence was recorded based on the number of plants infected out of total plants available in a plot, and expressed in percentage. The agronomic practices included basal application @ 100 kg/ha of di-ammonium phosphate. Pre-emergence herbicide application using pendimenthalin and paraquat dichloride @ 2 and 4 l/ha was done to control weeds. Two hand weedings, two irrigations, and three sprays of pesticides (acephate and spinosoid @ 1 kg/ha and 0.2 L/ha, respectively) were done to control pod borer complex. Data were recorded on days to 50 % flowering, days to 75 % maturity, plant height, plant stand, number of seeds/pod, 100-seed mass and seed yield (kg/ha). The statistical analysis was performed using AGROBASE GEN-II software.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) along with estimates of GCA (general combining ability) and SCA (specific combining ability) variances for six characters is presented in Table 1. The analysis revealed significant differences among testers and crosses for days to 50 % flowering, days to 75 % maturity, and grain yield. Variance due to lines x testers was also significant for grain yield indicated the importance of specific combining ability. These results are in agreement with those of Kumar *et al.* (2003) and Phad*et al.* (2007). The mean squares due to testers were of larger magnitude than those of lines and line x tester for all the characters except number of seeds/pod indicating greater diversity among the testers than the lines and this is expected becausethe seven lines were derived using two females and one donor parent.

General and specific combining ability

The magnitude of SCA variance for grain yield was much greater than that of GCA, suggesting the preponderance of non-additive gene action. This observation is in agreement with the results of Baskaran and Muthiah (2007), Waghela *et al.* (2009) and Acharya *et al.* (2009). The rest of the characters showed greater magnitude of GCA than SCA and it indicated that these traits were under the control of additive gene action. Similar results were also reported by Khorgade *et al.* (2000), Thiruvengadam and Muthiah (2012) for days to 50 % flowering and seeds/pod.

The estimates of GCA effects (Table 2) revealed that male sterile lines ICPA 2204, ICPA 2208, ICPA 2200 and ICPA 2203 had positive GCA effects for grain yield. For days to 50 % flowering, ICPA 2200 and ICPA 2201 showed highly significant negative GCA effects. Among the testers ICPL 20116 and ICPL 20108 were superior parents considering their GCA effects for yield and maturity. ICPA 2206 exhibited highly significant positive GCA effect for the character 100-seed mass. Lines ICPA 2204, ICPA 2208, ICPA 2203 and testers ICPL 20116 and ICPL 20108 were selected based on their higher GCA effects for yield and yield contributing characters.

SCA effect is generally considered the best criteria for selection of superior hybrid combination. In the present investigation no cross combination was found good for all the characters studied (Table 3). However hybrids ICPA 2204 x ICPL 20093, ICPA 2208 x ICPL 20108 and ICPA 2203 x ICPL 20116 showed significant positive SCA effects for grain yield. For earliness, hybrid ICPA 2202 x ICPL 20093

Table 1. Combining ability analysis for different traits

		Mean sum of squares					
Source	df	Days to 50 % flowering	Days to 75 % maturity	Plant height (cm)	Seeds/pod	100-seed mass (g)	Grain yield (kg/ha)
Replication	1	5.79	28.57	429.02	0.00	0.12	4350.53
Crosses	27	26.38*	30.02*	76.90	0.04	0.88	198365.24*
Lines	6	14.35	41.37	88.24	0.06	1.78	166296.15
Testers	3	114.40**	71.43**	220.69	0.01	2.15	292601.67*
Line x Tester	18	15.72	19.35	49.16	0.04	0.38	193348.05*
Error	27	11.16	12.83	61.43	0.03	0.74	89625.19
Variance of GCA		4.42	3.37	9.57	0.00	0.14	3281.71
Variance of SCA		2.28	3.26	-6.13	0.01	-0.18	51861.43
GCA/SCA		1.94	1.03	-1.56	0.00	-0.80	0.06

*, ** Significant at p= 0.05 and p=0.01 %, respectively

Table 2. Estimates of general combining ability effects for different characters

Parents	Days to 50 % flowering	Days to 75 % maturity	Plant height (cm)	Number of seeds/pod	100-seed mass (g)	Grain yield (kg/ha)
Lines						
ICPA 2200	-1.018	-3.30**	-2.68	0.06	-0.18	77.51
ICPA 2201	-0.768	-2.68*	1.07	-0.14*	-0.41	-266.04*
ICPA 2202	-1.518	-0.80	6.70*	0.11	-0.26	-62.72
ICPA 2203	-0.518	1.70	-1.43	-0.07	-0.27	21.31
ICPA 2204	1.607	1.70	-3.30	-0.01	0.33	188.71
ICPA 2206	1.982	2.32	-0.18	-0.02	0.93**	-38.92
ICPA 2208	0.232	1.07	-0.18	0.06	-0.16	80.14
Testers						
ICPL 20116	-3.11**	-2.14*	-2.77	0.03	0.56	154.73
ICPL 87119	-0.32	0.71	0.45	0.00	-0.22	-59.14
ICPL 20108	-0.39	-1.43	5.45*	0.01	-0.08	76.08
ICPL 20093	3.82**	2.86**	-3.13	-0.04	-0.26	-171.68*
SE (Lines)	1.093	1.172	2.565	0.054	0.282	97.994
SE (Testers)	0.773	0.829	1.814	0.038	0.199	69.292

*, ** Significant at p= 0.05 and p=0.01 %, respectively

Table 3. Estimates of specific combining ability effects in 28 hybrids for different characters

Hybrids	Days to 50 % flowering	Days to 75 % maturity	Plant height (cm)	Number of seeds per pod	100 seed mass (g)	Grain yield (kg/ha)
ICPA 2200 X ICPL 20116	-0.27	-0.98	-1.61	-0.03	-0.16	96.19
ICPA 2200 X ICPL 87119	3.95	3.66	-2.32	-0.05	-0.32	106.31
ICPA 2200 X ICPL 20108	-3.98*	-4.20*	5.18	-0.06	-0.06	-140.36
ICPA 2200 X ICPL 20093	0.30	1.52	-1.25	0.14	0.54	-62.15
ICPA 2201 X ICPL 20116	-0.52	-4.11	2.14	0.22*	0.06	-158.31
ICPA 2201 X ICPL 87119	0.70	0.54	-8.57	0.05	-0.25	67.01
ICPA 2201 X ICPL 20108	1.77	2.68	1.43	0.04	0.12	53.69
ICPA 2201 X ICPL 20093	-1.95	0.89	5.00	-0.31	0.06	37.60
ICPA 2202 X ICPL 20116	2.73	4.02	6.52	-0.08	-0.34	-182.57
ICPA 2202 X ICPL 87119	2.45	1.16	0.80	0.00	0.46	57.00
ICPA 2202 X ICPL 20108	0.02	0.80	-6.70	-0.06	-0.03	252.23
ICPA 2202 X ICPL 20093	-5.20*	-5.98**	-0.63	0.14	-0.09	-126.66
ICPA 2203 X ICPL 20116	-0.27	-0.98	-2.86	0.01	0.33	381.94*
ICPA 2203 X ICPL 87119	-1.05	1.16	3.93	-0.11	0.07	-425.14*
ICPA 2203 X ICPL 20108	-0.48	-1.70	3.93	-0.12	0.08	174.84
ICPA 2203 X ICPL 20093	1.80	1.52	-5.00	0.22*	-0.48	-131.65
ICPA 2204 X ICPL 20116	0.61	1.52	-3.48	-0.10	0.23	66.94
ICPA 2204 X ICPL 87119	-1.68	-1.34	3.30	0.08	-0.18	209.36
ICPA 2204 X ICPL 20108	-1.61	0.80	-1.70	-0.03	-0.37	-758.21**
ICPA 2204 X ICPL 20093	2.68	-0.98	1.88	0.06	0.33	481.90**
ICPA 2206 X ICPL 20116	-2.27	-1.61	3.39	0.01	0.73	78.38
ICPA 2206 X ICPL 87119	-3.55	-4.46*	-2.32	0.04	0.02	56.05
ICPA 2206 X ICPL 20108	2.02	2.68	-4.82	0.08	-0.37	-30.62
ICPA 2206 X ICPL 20093	3.80	3.39	3.75	-0.13	-0.38	-103.81
ICPA 2208 X ICPL 20116	-0.02	2.14	-4.11	-0.03	-0.84	-282.58
ICPA 2208 X ICPL 87119	-0.80	-0.71	5.18	0.00	0.21	-70.61
ICPA 2208 X ICPL 20108	2.27	-1.07	2.68	0.14	0.62	448.42*
ICPA 2208 X ICPL 20093	-1.45	-0.36	-3.75	-0.11	0.01	-95.23

*, ** Significant at p= 0.05 and p=0.01 % respectively

showed highly significant negative SCA effect, whereas ICPA 2206 x ICPL 87119 and ICPA 2200 x ICPL 20108 showed significant negative SCA effects suggesting their importance in developing short duration hybrids. The SCA effects for plant height and 100-seed mass were non-significant indicating little or no variation among the parental lines for these traits. This was further confirmed with the results obtained in analysis of variance (Table 1). Hybrids ICPA 2201 x ICPL 20116 and ICPA 2203 x ICPL 20093 exhibited significant positive SCA effects for seeds/pod. Considering SCA effects for yield and yield contributing traits, hybrids ICPA 2204 x ICPL 20093, ICPA 2208 x ICPL 20108, ICPA 2203 x ICPL 20116 were found promising for improving grain yield.

Vanniarajan *et al.* (1999) reported that some of the cross combinations having parents with high x low and low x high gca effects for grain yield also produced significant sca effects. It was observed for the crosses, ICPA 2204 x ICPL 20093 and ICPA 2203 x ICPL 20116 for grain yield kg/ha. This high sca effect of high x low combinations indicated the operation of additive x non-additive gene effects and hence these crosses can be utilized in heterosis breeding. The cross ICPA 2208 x ICPL 20108 showed significant sca effects when both the parents also had average general combining ability. It revealed the operation of non-additive gene effects. Similar results were also reported by Devi *et al.* (2011) for grain yield and its component characters.

Heterosis and per se performance

Standard heterosis was estimated over control ICPL 87119 (Asha) which is the best ruling variety in the country. Hybrid ICPA 2200 x ICPL 20108 expressed significant negative heterosis for maturity (Table 4) which is a desirable characteristic. Plant height recorded significant increase in only one cross ICPA 2202 x ICPL 20116. Number of seeds/pod showed significant heterosis (11.1 %) in crosses ICPA 2202 x ICPL 20093 and ICPA 2208 x ICPL 20093 over the standard check. Considering per se performance, high positive heterosis was revealed for crosses ICPA 2208 x ICPL 20108 (60.4 %), ICPA 2203 x ICPL 20116 (55.8 %) and ICPA 2204 x ICPL 20116 (50.1 %) with seed yield of 1649 kg/ha, 1604 kg/ha and 1544 kg/ha respectively.Hybrid ICPA 2203 x ICPL 20116 showed high level of resistance to fusarium wilt and sterility mosaic disease (Table 4). It is clear from the yield data, that obcordate leaf shape of A-lines has no effect on the per se performance of hybrid combinations.

In the present investigation, the long term process of converting already established male sterile lines in to obcordate leaf marker seems to be working with the recovery of some competitive hybrids such as ICPA 2208 x ICPL

Table 4. **Estimates of standard heterosis (superiority over cultivar Asha) and per se performance for yield and yield contributing traits and disease reaction of crosses**

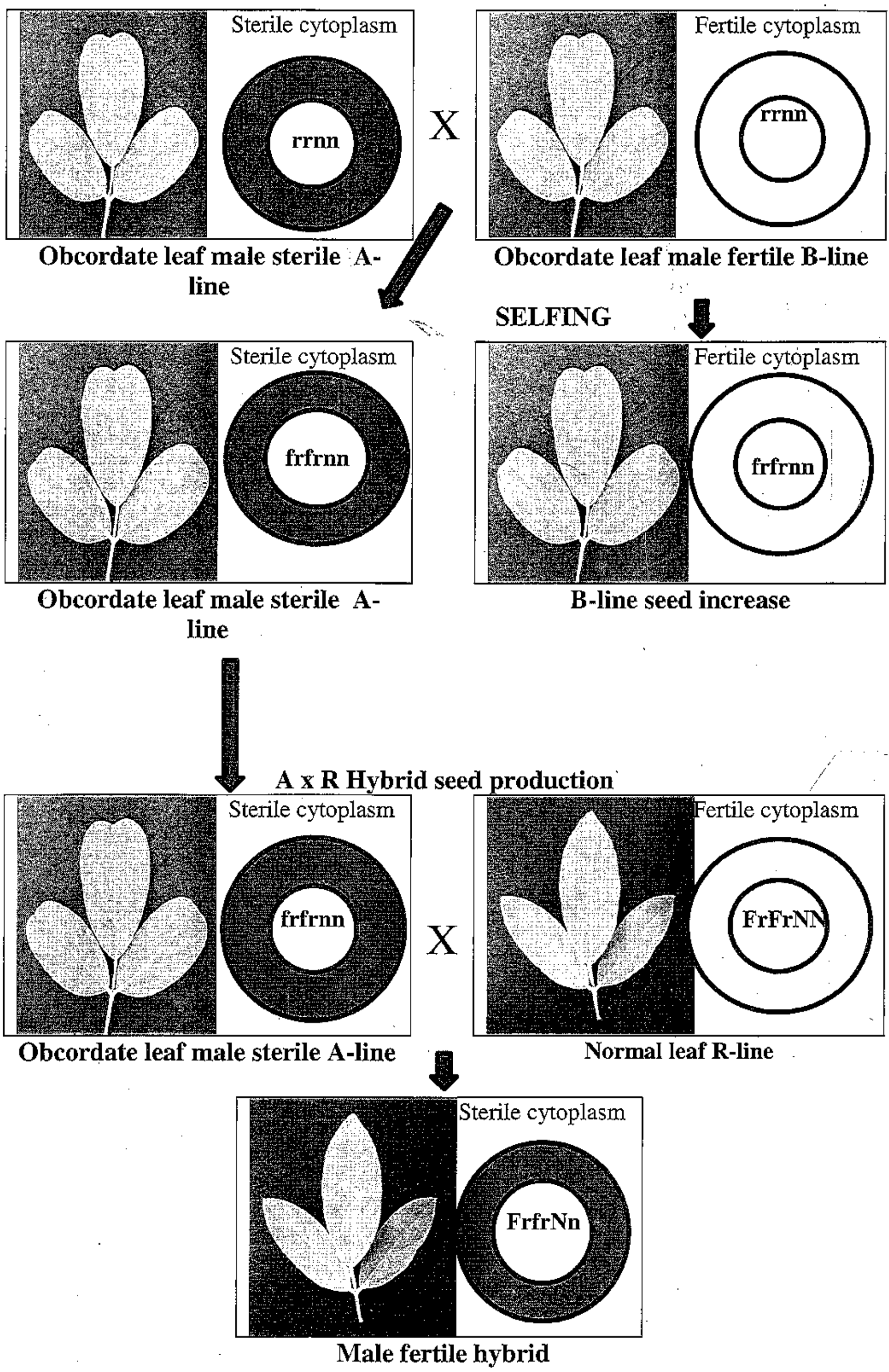
Hybrids	Days to 50 % flowering		Days to 75 % maturity		Plant height (cm)		Number of seeds per pod		100-seed mass (g)		Grain yield (kg/ha)		Disease reaction (%)	
	Mean	Heterosis (%)	Mean	Heterosis (%)	Mean	Heterosis (%)	Mean	Heterosis (%)	Mean	Heterosis (%)	Mean	Heterosis (%)	Sterility mosaic	Fusarium wilt
ICPA 2200 X ICPL 20116	116	-4.9	160	-4.9	227.5	0.0	3.9	6.9	10.6	-6.6	1373.3	33.5	0.0	12.5
ICPA 2200 X ICPL 87119	123	0.8	168	0.8	230.0	1.1	3.8	5.6	9.7	-15.0	1170.6	13.7	0.0	12.5
ICPA 2200 X ICPL 20108	115	-5.7 *	158	-5.7*	242.5	6.6	3.8	5.6	10.1	-11.4	1058.1	2.9	0.0	0.0
ICPA 2200 X ICPL 20093	124	1.2	168	1.2	227.5	0.0	4.0	9.7*	10.5	-7.9	888.6	-13.6	0.0	33.3
ICPA 2201 X ICPL 20116	116	-4.9	158	-4.9	235.0	3.3	3.9	8.3	10.6	-6.6	775.3	-24.6	0.0	0.0
ICPA 2201 X ICPL 87119	120	-1.6	165	-1.6	227.5	0.0	3.7	2.8	9.5	-16.3*	786.7	-23.5	0.0	0.0
ICPA 2201 X ICPL 20108	121	-0.8	165	-0.8	242.5	6.6	3.7	2.8	10.0	-11.8	908.6	-11.7	0.0	33.3
ICPA 2201 X ICPL 20093	122	-0.4	168	-0.4	237.5	4.4	3.3	-8.3	9.8	-14.1	644.8	-37.3	0.0	0.0
ICPA 2202 X ICPL 20116	119	-2.9	168	-2.9	245.0	7.7*	3.9	6.9	10.4	-8.8	954.3	-7.2	0.0	0.0
ICPA 2202 X ICPL 87119	121	-0.8	168	-0.8	242.5	6.6	3.9	8.3	10.4	-8.8	980.0	-4.7	0.0	50.0
ICPA 2202 X ICPL 20108	119	-2.9	165	-2.9	240.0	5.5	3.9	6.9	10.0	-12.0	1311.5	27.4	0.0	0.0
ICPA 2202 X ICPL 20093	118	-3.7	163	-3.7	237.5	4.4	4.0	11.1*	9.8	-14.1	683.8	-33.5	0.0	0.0
ICPA 2203 X ICPL 20116	117	-4.5	165	-4.5	227.5	0.0	3.8	4.2	11.0	-3.1	1603.9	55.8	0.0	0.0
ICPA 2203 X ICPL 87119	119	-2.8	170	-2.9	237.5	4.4	3.6	0.0	10.0	-12.3	581.9	-43.4	0.0	0.0
ICPA 2203 X ICPL 20108	119	-2.5	165	-2.5	242.5	6.6	3.6	0.0	10.1	-11.0	1317.1	28.1	0.0	0.0
ICPA 2203 X ICPL 20093	126	2.8	173	2.9	225.0	-1.1	3.9	8.3	9.4	-17.6*	762.9	-25.8	0.0	33.3
ICPA 2204 X ICPL 20116	120	-2.0	168	-2.1	225.0	-1.1	3.7	2.8	11.5	1.3	1455.3	41.5	15.4	7.7
ICPA 2204 X ICPL 87119	120	-1.6	168	-1.6	235.0	3.3	3.9	6.9	10.3	-9.2	1384.8	34.5	10.0	10.0
ICPA 2204 X ICPL 20108	120	-1.6	168	-1.6	235.0	3.3	3.8	4.2	10.3	-9.7	551.5	-46.4	0.0	0.0
ICPA 2204 X ICPL 20093	129	5.3	170	5.3	230.0	1.1	3.8	5.5	10.8	-5.3	1543.8	50.1	0.0	0.0
ICPA 2206 X ICPL 20116	117	-4.1	165	-4.1	235.0	3.3	3.8	5.6	12.6	11.0	1239.1	20.5	0.0	0.0
ICPA 2206 X ICPL 87119	119	-2.9	165	-2.9	232.5	2.2	3.8	5.6	11.1	-2.2	1002.9	-2.5	0.0	23.1
ICPA 2206 X ICPL 20108	124	1.6	170	1.6	235.0	3.3	3.9	6.9	10.9	-4.4	1051.4	2.2	0.0	0.0
ICPA 2206 X ICPL 20093	130	6.6*	175	6.5*	235.0	3.3	3.6	0.0	10.7	-6.5	730.5	-29.0	0.0	0.0
ICPA 2208 X ICPL 20116	118	-3.7	168	-3.7	227.5	0.0	3.9	6.9	10.0	-12.3	997.2	-3.1	45.5	0.0
ICPA 2208 X ICPL 87119	120	-2.1	168	-2.0	240.0	5.5	3.9	6.9	10.2	-10.1	995.3	-3.2	33.3	8.3
ICPA 2208 X ICPL 20108	123	0.4	165	0.4	242.5	6.6	4.0	11.1*	10.8	-5.3	1649.5	60.4	25.0	0.0
ICPA 2208 X ICPL 20093	123	0.8	170	0.8	227.5	0.0	3.7	2.8	10.0	-12.3	858.1	-16.6	0.0	0.0
SE+/-	2.37	-	2.55	-	5.63	-	0.11	-	0.60	-	28.69	-	-	-
CV (%)	2.79	-	2.17	-	3.41	-	4.22	-	8.17	-	213.58	-	-	-

*, ** Significant at p= 0.05 and p=0.01 %, respectively

20108 (1649.4 kg/ha), ICPA 2203 x ICPL 20116 (1603.9 kg/ha) and ICPA 2204 x ICPL 20093 (1543.8 kg/ha). This is the first report to use obcordate leaf shape in pigeonpea to track the purity of hybrids and their parental lines. These hybrids will be tested in large scale plots to test their commercial application. The obcordate leaf shape used as NEP is working well and cab be used as a marker both in the maintenance of A-lines and production of F_1 hybrids. The seed production scheme using obcordate leaf marker is presented in Fig. 1. When the obcordate leaf male sterile A-line is crossed with the corresponding obcordate leaf male fertile B-line, the resultant progeny will be obcordate leaf male sterile due to the sterile cytoplasm from A-line and presence of obcordate leaf trait in homozygous recessive form. The same seed will be used for A x R hybrid seed production and selfed seed from B-lines will be used for A x B maintenance. The hybrid between obcordate leaf A-line and normal leaf restorer lines will be normal leaf fertile due to complete dominance of normal leaf over obcordate leaf shape and hybrid is fertile due to the interaction of cytoplasmic and nuclear genes.

When farmers buy a seed from any institute or company, they expect to receive a good quality seed. To remove impurities like other crops seeds, weed seeds and any inert matter is possible through seed graders and cleaners. The most important factor that deteriorates the actual performance of any hybrid or variety is genetic impurity. In case of hybrids, it is very important to produce and manage the supply of adequate quantities of pure hybrid seeds (Saxena *et al.* 2010). It is not possible to remove all these admixtures completely with the use of cleaning machines and some seeds always remain present and there is necessary to take purity test or analysis, to determine how much % of the admixture is present in the seed lot. It is traditionally done with grow out test but not practically and economically possible due to long growing season of pigeonpea crop. The main idea with this technology is, when a commercial seed lot comes for seed purity assessment from different production sources, we can use a representative sample from each lot to undertake grow out test to check the purity of hybrid seed. It takes around 4-6 weeks after sowing to express the obcordate leaf shape which is very less period as compared to regular grow out test in which we have to wait six months or more. Since normal leaf shape is completely dominant over obcordate leaf shape, the pure hybrid will have a normal leaf seedling. The off types in the A-line maintenance can be identified with any normal leaf seedlingand if hybrids showed obcordate leaf shape seedlings, we can easily discard such material for further seed distribution.

Figure 1. Schematic representation of hybrid seed production activity with obcordate leaf marker
A x B maintenance



REFERENCES

Acharya SJ, Patel B, Tank CJ and Yadav AS. 2009. Heterosis and combining ability studies in Indo-African crosses of pigeonpea. Journal of Food Legumes **22:** 91-95.

Baskaran K and Muthiah AR. 2007. Studies on combining ability in pigeonpea (*Cajanus cajan* L. Millsp.) Legume Research **30:** 67-69.

Devi RS, Prasanthi L, Reddy KH and Reddy BVB. 2011. Gene action for yield and yield contributing characters in pigeonpea (*Cajanus* *cajan* (L.) Millsp.) Current Biotica **5:** 137-143.

Khorgade PW, Wankhade RR and Wanjari KB. 2000. Combining ability analysis in pigeonpea using male sterile lines. Indian Journal of Agricultural Research **34:** 112-116.

Phad DS, Madrap IA and Dalavi VA. 2007. Study of combining ability analysis in pigeonpea under different environments for yield contributing characters. Legume Research **30:** 123-127.

Saxena KB. 2008. Genetic improvement of pigeonpea – a review. Tropical Plant Biology **1:** 159-178.

Saxena KB, Vales MI, Kumar RV, Sultana R and Srivastava RK. 2011. Ensuring genetic purity of pigeonpea hybrids by incorporating a naked-eye polymorphic marker in A and B lines. Crop Science **51:** 1564-1570.

Saxena KB, Kumar RV, Tikle AN, Saxena MK, Gautam VS, Rao SK, Khare KD, Chauhan YS, Saxena RK, Varshney RK, Reddy BVS, Sharma D, Reddy LJ, Green JM, Faris DG, Nene YL, Mula MG, Sultana R, Srivastava RK, Gowda CLL and Sawargaonkar SL. 2013. ICPH 2671- The world's first commercial food legume hybrid. Plant Breeding. Doi:10.111/pbr.10245

Saxena RK, Saxena KB and Varshney RK. 2010. Application of SSR markers for molecular characterization of hybrid parents and purity assessment of ICPH 2438 hybrid of pigeonpea [*Cajanus cajan* (L.) Millspaugh]. Molecular Breeding **26:** 371-380.

Singh DP and Singh BB. 1992. Inheritance of morphological characters in chickpea (*Cicer arietinum* L.). Indian Journal of Genetics and Plant Breeding **52:** 55-57.

Kumar S, Lohithaswa HC and Dharmaraj PS. 2003. Combining ability analysis for grain yield, protein content and other quantitative traits in pigeonpea. Journal of Maharashtra Agricultural Universities **28:** 141-144.

Thiruvengadam V and Muthiah AR. 2012. Combining ability analysis for yield and its components in pigeonpea using genetic male sterile lines. Journal of Food Legumes **25:** 171-174.

VanniarajanV, Rangasamy P, Nadarajan N and Ramalingam J. 1999. Assessment of stability performance in pigeonpea. The Madras Agricultural Journal **86:** 438-440.

Waghela KO, Desai RT, Nizam JR, Patel JD and Sharma V. 2009. Combining ability analysis in pigeonpea [*Cajanus cajan* (L.) Millsp.]. Legume Research **32:** 274-277.