

Full Length Research Paper

Combining ability studies of pigeonpea cytoplasmic male sterile (CMS) lines with an obcordate leaf marker

S. B. Patil, A. J. Hingane, C. V. Sameerkumar*, M. G. Mula, R. V. Kumar and K. B. Saxena

Grain Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 502 324, Andhra Pradesh, India.

Received 24 March, 2014; Accepted 26 June, 2014

Hybrid pigeonpea [*Cajanus cajan* (L.) Millsp.] breeding technology based on cytoplasmic-genetic male sterility (CMS) was recently developed ICRISAT, Patancheru in India. 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 specific combining ability (SCA) effect showed that, hybrid yield was under the control of non-additive genes. Among A-lines, ICPL 2204 was the best general combiner. Among testers, ICPL 20116 was the best general combiner. Among hybrids, ICPL 2208 x ICPL 20108 a cross between high general combining ability (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 to address the issue of seed purity to some extent.

Key words: Combining ability, line x tester, general combining ability (GCA) and specific combining ability (SCA), obcordate leaf shape, pigeonpea.

INTRODUCTION

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. 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

*Corresponding author. Email: c.sameerkumar@cgiar.org

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](http://creativecommons.org/licenses/by/4.0/)

Table 1. Combining ability analysis for different traits.

Source	df	Mean sum of squares					
		Days to 50% flowering	Days to 75% maturity	Plant height (cm)	Number of 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 5 and 1% level of probability, respectively.

equipment nor complicated procedures (Singh and 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 cytoplasmic male sterile (CMS) 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 F₁ 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 and 30 cm, respectively. To avoid border effect, one border row was planted at each side of the plot and first and last plant from each row was excluded from the plot yield and yield kg/ha was calculated considering net plot area 5.4 m². 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 to 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 at 100 kg/ha of di-ammonium phosphate. Pre-emergence herbicide application using pendimethalin and paraquat dichloride at 2 and 4 l/ha was done to control weeds. Two hand weedings, two irrigations

at flower initiation and pod development, and three sprays of pesticides (acephate and spinosoid at 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 at the time of harvesting, 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 general combining ability (GCA) and specific combining ability (SCA) 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 because the 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 except number of seeds per pod 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) and Thiruvengadam and Muthiah

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 5 and 1 % level of probability, respectively.

(2012) for days to 50% flowering and number of 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, ICPL 20108 and ICPL 20093 were superior parents considering their GCA effects for yield and early 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 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 number of 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) a high-yielding pigeonpea variety, resistant to fusarium wilt and sterility mosaic diseases, identified for release in the central and south zones of India in 1992. The variety has medium maturity duration (180 days) with average seed size of 10.7 g and has been recommended for release in sterility mosaic endemic areas in deep block soils. 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

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/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 5 and 1 % level of probability, respectively.

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 20108 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 20093 (50.1%) with seed yield of 1649, 1604 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 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 time 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 can be use

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/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 5 and 1 % level of probability, respectively.

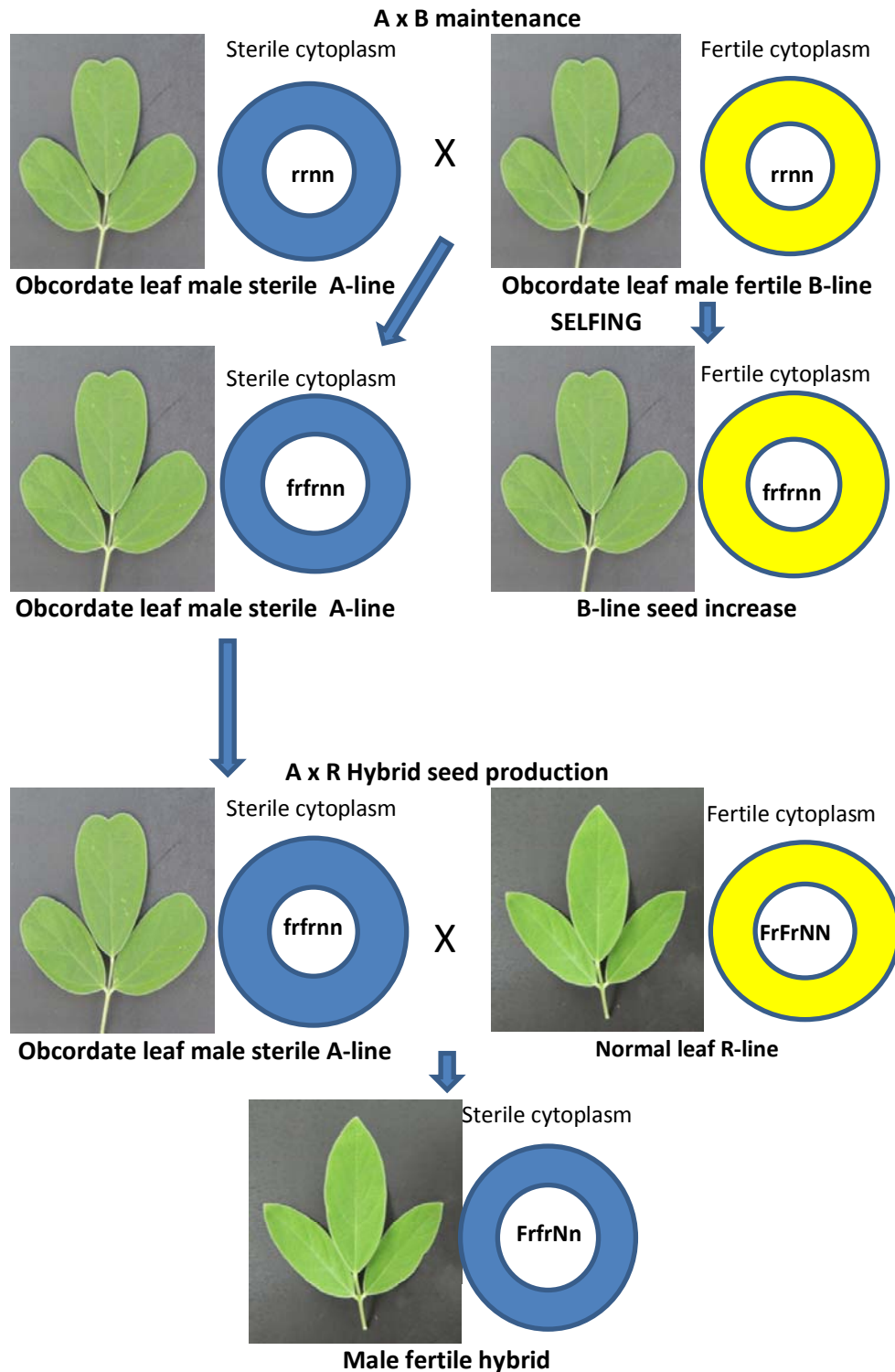


Figure 1. Schematic representation of hybrid seed production activity with obcordate leaf marker.

as a marker both in the maintenance of A-lines and production of F₁ hybrids. The seed production scheme using obcordate leaf marker is presented in Figure 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. Removing physical 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 which are not true to the type always remain present and it is necessary to conduct purity test or analysis, to determine percent admixture present in the seed lot. However, it is traditionally done with grow out test but not practically and economically feasible due to long growing season of pigeonpea crop. The main idea with this technology is, when a commercial seed lot is received 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 to 6 weeks after sowing to express the obcordate leaf shape which is a very short period as compared to regular grow out test in which we have to wait for 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 seedling and if hybrids showed obcordate leaf shape seedlings, they can be easily discarded for further seed distribution.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors acknowledge Dr. K. B. Saxena, Principal scientist, pigeonpea breeding for the encouragement and guidance for writing this manuscript and all field staff for making crosses and recording observations.

REFERENCES

- Acharya SJ, Patel B, Tank CJ, Yadav AS (2009). Heterosis and combining ability studies in Indo-African crosses of pigeonpea. *J. Food Legum.* 22(2): 91-95.
- Baskaran K, Muthiah AR (2007). Studies on combining ability in pigeonpea (*Cajanus cajan* L. Millsp.). *Legume Res.* 30(1): 67-69.
- Devi RS, Prasanthi L, Reddy KH, Reddy BVB (2011). Gene action for yield and yield contributing characters in pigeonpea (*Cajanus cajan* (L.) Millsp.). *Curr. Biotica* 5(2): 137-143.
- Khorgade PW, Wankhade RR, Wanjari KB (2000). Combining ability analysis in pigeonpea using male sterile lines. *Indian J. Agric. Res.* 34(2): 112-116.
- Kumar S, Lohithaswa HC, Dharmaraj PS (2003). Combining ability analysis for grain yield, protein content and other quantitative traits in pigeonpea. *J. Maharashtra Agric. Univ.* 28(2): 141-144.
- Phad DS, Madrap IA, Dalavi VA (2007) Study of combining ability analysis in pigeonpea under different environments for yield contributing characters. *Legume Res.* 30(2): 123-127.
- Saxena KB (2008). Genetic improvement of pigeonpea – A review. *Trop. Plant Biol.* 1: 159-178.
<http://dx.doi.org/10.1007/s12042-008-9014-1>
- Saxena KB, Vales MI, Kumar RV, Sultana R, Srivastava RK (2011). Ensuring genetic purity of pigeonpea hybrids by incorporating a naked-eye polymorphic marker in A and B lines. *Crop Sci.* 51: 1564-1570. <http://dx.doi.org/10.2135/cropsci2010.11.0655>
- Saxena RK, Saxena KB, 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]. *Mol. Breed.* 26: 371-380.
<http://dx.doi.org/10.1007/s11032-010-9459-4>
- Singh DP, Singh BB (1992). Inheritance of morphological characters in chickpea (*Cicer arietinum* L.). *Indian J. Genet. Plant Breed.* 52(1):55-57.
- Thiruvengadam V, Muthiah AR (2012). Combining ability analysis for yield and its components in pigeonpea using genetic male sterile lines. *J. Food Legum.* 25(3): 171-174.
- Vanniarajan V, Rangasamy P, Nadarajan N, Ramalingam J (1999). Assessment of stability performance in pigeonpea. *Madras Agric. J.* 86: 438-440.
- Waghela KO, Desai RT, Nizam JR, Patel JD, Sharma V (2009). Combining ability analysis in pigeonpea [*Cajanus cajan* (L.) Millsp.]. *Legume Res.* 32(4): 274-277.