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Application of heterotic grouping, standard heterosis and *per se* performance in breeding high-yielding inbred and hybrid cultivars of pigeonpea

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Abstract

A set of 102 hybrid combinations, developed by crossing three A_4 CMS lines and 34 diverse testers, was evaluated to identify potential parental genotypes for breeding new high yielding cultivars. The hybrid combinations were assessed for their *per se* performance, standard heterosis and combining ability. Significant differences were recorded for parents versus hybrids for yield and its related traits, suggesting the presence of substantial heterotic responses. Highly significant GCA effects for yield were recorded within the female parents and testers. Relatively more number of hybrids involving ICPA 2092, as female parent, exhibited significant positive SCA values for yield, days to flower, plant height, primary branches, pods/plant, seed size and seeds/pod. A total of 45 hybrids recorded significant SCA effects for productivity. The yield superiority of hybrids over the inbred control cultivar ranged from 50.81 to 76.89%. Interestingly, 23 hybrids were also found superior to the first released pigeonpea hybrid ICPH 2671 by a margin of 5.48% to 64.31%. On the basis of their performance in hybrid combinations, the testers were classified into seven heterotic groups. The present study identified two CMS lines (ICPA 2092 and ICP 2043) and 13 testers including ICP 3525, ICPL 20196, BDN 2001-6 and BSMR 198 etc. as potential parental lines for use in breeding medium duration pigeonpea pure line and hybrid cultivars.

Key words: *Cajanus cajan*, combining ability, genetic diversity, heterotic group, parental lines.

Introduction

Globally, the cytoplasmic-nuclear male-sterility (CMS) systems have played a significant role in increasing the productivity in a number of economically important crops through its use in commercial exploitation of hybrid vigour. To reap the benefits of this technology, it is imperative that the hybrids, wherever they are grown, have full fertility restoration, high yield and broad adaptation. Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an often cross-pollinated pulse, but over the decades in this crop only pure line cultivars were bred without any significant gain in its productivity. Efforts to exploit its natural out-crossing to break the yield plateau through hybrid breeding began with the discovery of a stable CMS system by Saxena et al. (2005). This breakthrough was followed by the release of first commercial pigeonpea hybrid for cultivation in India (Saxena et al. 2013). The hybrid technology in pigeonpea has a potential to break the decades-old low yield plateau (Saxena et al. 2018), but it is still new and under the process of rooting. Therefore, to achieve a sustainable success in this endeavour in future, it is imperative that new high-yielding hybrids are produced at regular intervals; and therefore, new hybrid parental lines with high combining ability, disease resistance, high yield potential and wide adaptation are bred and made available to pigeonpea breeders. Hence as a backup strategy, it is important that a strong and vibrant hybrid parent breeding programme is established. In this context, the genetic characterization of advanced breeding inbred lines and diverse germplasm with respect to their per se performance, combining ability, and hybrid vigour is carried out. In the present study these parameters were estimated in 34 testers and three CMS lines;

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and based on the results some potential parents for use in breeding high yielding hybrid and inbred cultivars were identified.

Materials and methods

The experimental materials consisted of three stable pigeonpea CMS lines (ICPA 2043, ICPA 2047 and ICPA 2092) carrying A_4 (*Cajanus cajanifolius*) cytoplasm (Saxena et al. 2005). The testers comprised of 13 genotypes (ICP 3525, ICPL 20106, ICP 12749, ICP 13991, ICP 10934, HPL 24-63, ICP 10650, ICP 3963, ICP 3407, ICP 11376, ICP 3514, ICP 3475 and ICP 3374) from ICRISAT; 10 (BSMR 198, BSMR 846, BSMR 175, BSMR 2, BSMR 203, BWR 164, BWR 154, BDN 2001-6, BSMR 571 and BSMR 736) from Agricultural Research Station, Badnapur; five (Phule-T-00-5-7-4-1, Phule-T-04-3-1, Phule-T-00-4-11-6-2, Phule-T-00-1-25-1 and Vipula) from Agricultural University, Rahuri; and six (AKT-9913, AKT-222521, AKT 8811, AKT-00-12-6-4, TV 1, and AKT-9915) from Agricultural University, Akola. The hybrid combinations were made in a line x tester mating design through hand pollinations at the Agricultural University at Parbhani during 2008. In the following rainy season the resultant 102 F_1 hybrids along with their 37 parents and two controls (cv. BSMR 736 and hybrid ICPH 2671) were sown in single row plots of 4.2 m length using α-lattice design with two replications at ICRISAT Research Station, Patancheru. In this experiment the inter- and intra-row spacing were maintained at 75 cm and 30 cm, respectively. To provide uniform and competitive growing conditions, each test entry was flanked by one guard row of cv. ICPL 87119 on each of its sides. At full flowering stage five competitive plants from each plot were tagged randomly for recording observations on days to flower, plant height (cm), number of primary branches/plant, number of pods/plant, number of seeds/pod,100-seed weight (g) and grain yield/plant (g). The data were subjected to analysis of variance (Panse and Sukhatme, 1985) and the estimates of combining ability were calculated using Genstat 12 edition software. The testers were classified into different heterotic groups using their SCA effects as per the procedure followed by Saxena and Sawargaonkar (2014).

Results and discussion

Genetic variation

The analysis of variances (table not included here) indicated significant variation among the parents and hybrids for all the plant and grain characters studied. Mean sum of squares (MSS) due to hybrids were significant for days to flower and number of pods/plant. The MSS due to lines (females) was significant for all the traits except seeds/pod; while for testers (males) it was significant for days to flower, plant height, number of branches, number of pods/plant and grain yield. Variation due to parents x hybrids was significant for the all traits except that of days to flower; and this suggested the presence of substantial heterotic responses in these traits. High magnitude of variance due to lines and testers for most of the traits indicated the presence of considerable genetic variability. These observations were in agreement with the reports published earlier by Yamunara et al. (2016), Sameer Kumar et al. (2009), Jahagirdar (2003) and Hazarika et al. (1988). The ratios of general to specific combining ability variances were less than unity, suggesting relatively greater contribution of non-additive genes in the expression of these traits. Mhasal et al. (2015), Yamanura et al. (2014), Pandey et al. (2014), Chethana et al. (2013) and Meshram et al. (2013) also reported similar results for days to flower, plant height, number of branches, pods/plant, seeds/pod, 100-seed weight and seed yield

General combining ability

The estimates of general combining ability effects of the parents (Table 1) revealed that out of 37 genotypes evaluated, 12 exhibited significant negative GCA effects for days to flower. These include one female line and 11 testers. For seed yield CMS line ICPA 2092 exhibited highly significant and positive GCA effect. The other two females and eight testers recorded significant negative GCA effects for yield. Thirteen tester genotypes showed significant positive GCA effects for grain yield with ICP10934 (51.33**) and BDN 2001-6 (43.43**) recording very high values (Table 1). High GCA values for yield were also reported in pigeonpea by Phad et al. (2009) and Sameer Kumar et al. (2009) and Yadav et al. (2008). In general, high GCA effect in a specific parent is potent evidence of (i) relatively high concentration of additive genes in it and (ii) greater flow of such genes to its offspring. The preponderance of additive alleles often results in high heritability, relatively less complex genetic interactions, high breeding value, and greater response to selection.

Considering per se performances and GCA effects together, HPL 24-63, ICP 3514, ICP 3374 and ICPL 20106 were found promising with respect to grain yield and number of pods/plant. Hybridization of two parents each with high GCA effect for a desired trait

Table 1. Estimates of general combining ability effects of the parental lines for different traits

Parents	Days to flower	Plant height	Primary branches	No. of pods/ plant	Seeds/ pod	100-seed weight	Yield/ plant
Lines							
ICPA 2043	–3.123**	–9.697**	–1.454**	–24.325**	0.007	0.252	–6.271**
ICPA 2047	2.627**	9.710**	0.832**	–4.840**	0.007	0.025	–1.494**
ICPA 2092	0.495*	–0.013	0.622	29.165**	–0.014	–0.277	7.765**
SE (I) ±	±0.76	±0.49	±0.08	±0.99	±0.01	±0.02	±0.32
Testers							
BSMR198	1.284**	1.464	–1.657**	21.719**	0.008	–0.274**	4.959**
BSMR846	–1.382	–2.403	–0.907**	–64.581**	0.008	0.259**	–23.389**
BSMR164	1.451	5.280**	–0.640**	–30.398**	–0.009	0.593**	–6.793**
BDN2001-6	–1.049	9.130**	2.260**	81.919**	0.251**	0.043	43.432**
ICP3525	1.118	7.430**	–0.807**	–36.998**	–0.199**	–0.974**	–28.848**
BSMR175	1.118	–6.636**	–1.257**	–33.498**	0.201**	0.831**	–0.483
BSMR2	3.784**	–24.736**	0.726**	–20.031**	0.135**	0.154**	–2.924**
ICPL12749	2.118**	–15.086**	–1.990**	–9.915**	0.218**	0.776**	8.892**
BSMR203	3.951**	7.530**	1.693**	–31.831**	0.051	–0.041	–12.878**
BWR154	–0.216	10.997**	–0.607*	–19.581**	–0.132**	–0.341**	–16.248**
BSMR571	1.451	–7.220**	–0.290	–29.415**	–0.165**	–0.224**	–18.279**
ICP13991	2.618**	11.364**	–4.624**	–59.965**	–0.015	0.143*	–24.756**
ICP10934	–2.549**	–28.186**	0.060	135.835**	0.018	–0.174**	51.326**
HPL24-63	–1.549*	–13.353**	–1.524**	34.719**	0.048	–0.201**	13.526**
AKT 9915	2.451**	–9.820**	0.543	–15.815**	0.151**	0.131*	–1.433

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

Table 1. continued

Parents	Days to flower	Plant height	Primary branches	No. of pods	Seeds/ pod	100-seed weight	Yield/ plant
ICP10650	1.784*	–7.203**	–1.657**	1.152	0.051	0.026	2.207*
ICP 3407	–2.049**	–10.053**	–1.307**	19.719**	–0.165**	–0.052	2.504*
ICP3475	–6.716**	–6.136**	–2.390**	9.002**	0.175**	–0.036	8.411**
BSMR736	–2.549**	3.047	0.526	7.969*	0.001	–0.274**	0.056
TV 1	–4.216**	15.497**	3.410**	–23.515**	–0.032	0.521**	–4.993**
AKT8811	–3.382**	7.230**	–0.107	–46.981**	–0.199**	–0.807**	–30.256**
PHULE T-00-1-25-1	–0.549	26.364**	–1.524**	–46.315**	–0.142**	–0.369**	–26.589**
PHULE T-04-31	–1.382	–0.153	0.860**	–56.715**	–0.015	–0.124*	–24.781**
AKT9913	–1.216	19.347**	–1.157**	3.569	–0.075	0.659**	6.987**
AKT222521	0.951	1.264	1.643**	–70.281**	–0.165**	–0.507**	–37.683**
AKT00-12-6-4	–1.716*	–8.420**	–2.407**	–6.715*	–0.047	–0.236**	–7.479**
ICP3963	–0.716	–5.986**	–1.940**	–14.415**	–0.232**	0.393**	–10.579**
PHULE T-00-5-7-4-1	–0.216	7.147**	0.210	–75.181**	–0.054	–0.507**	–36.301**
VIPULA	–3.382**	0.897	0.710*	–8.315*	0.001	0.031	–3.574**
PHULE T-00-4-11-6-2	–3.882**	–3.353*	0.726*	6.185	–0.025	0.043	1.569
ICP11376	–1.382	0.547	0.843**	36.752**	–0.099*	–0.202**	7.689**
ICP3514	2.618**	3.847*	3.693**	91.302**	0.168**	–0.074	41.881**
ICP3374	6.118**	5.047**	2.526**	110.569**	0.301**	0.459**	64.406**
ICPL20106	7.284**	5.314**	6.360**	140.052**	–0.015	0.359**	60.424**
SE (I) ±	±0.76	±1.66	±0.28	±3.34	±0.04	±0.06	±1.09

*, ** = significant at 5 and 1 percent level of significance, respectively

is likely to produce a potential population due to enhanced frequency of favourable alleles. Besides this, it is also likely that such populations could also produce desirable transgressive (extreme) segregants in various generations. If desired, such high combining parental lines could also be used in recurrent selection programmes. In the present study it was observed that some high yielding cross combinations such as ICPA 2092 x BSMR 164 and ICPA 2092 x ICP 3525 one parent had high and another low GCA effect. This situation leads to believe that in these crosses additive x non-additive type of gene actions were involved, and therefore, such combinations could be considered for heterosis breeding (Baskaran and Muthiah 2007). On the other hand, Maida et al. (2017) and Yadav et al. (2008) observed that some hybrids exhibited high SCA effects, irrespective of the high GCA effects in their parents. They opined that this situation may arise due to the involvement of both dominance and epistatic genetic variances. The estimates of GCA suggested that parents with high per se performance such as HPL 24-63, ICP 3514, ICP 3374 and ICPL 20106 were good general combiners for seed yield and its related characters.

Specific combining ability

Specific combining ability is considered one of the best criteria for selecting promising cross combinations for breeding. In the present study, the significant SCA effects of hybrids for grain yield (Table 2) were associated with positive SCA effects for yield contributing traits such as seed size, number of primary branches, pods/plant and plant height. A perusal of results across the three CMS-derived hybrids revealed that for grain yield the highest number (16) of hybrids involving ICPA 2092 as female parent exhibited significant positive SCA effects. This was followed by ICPA 2043 (15) hybrids and ICPA 2047 (14) hybrids. Highest SCA effect for grain yield was recorded in cross ICPA 2092 x BSMR 164 (47.13) and followed by ICPA 2092 x ICP 3525 (23.72). Maida et al. (2017) reported that in pigeonpea the crosses with high SCA effects for yield also exhibited significant SCA effects for days to flower, plant height, branches/ plant, pods/plant, seeds/pod and seed size. In this study, the male parent BSMR 2 when crossed with ICPA 2043 and ICPA 2047 produced hybrids with significantly positive SCA effects for grain yield. Similarly, ICP 11376 when crossed with ICPA 2047 and ICPA 2092 produced hybrids with significant positive SCA effect for grain yield. Hybrid ICPA 2092 x ICP 11376 had significant positive SCA effects for days to flower, primary branches, pods/plant and seed yield.

Table 2. Estimates of specific combining ability effects of the hybrids developed by crossing 34 testers with three CMS lines

Genotypes	Grain yield/plant		
	ICPA 2043	ICPA 2047	ICPA 2092
BSMR198	–11.506**	3.922*	7.584**
BSMR846	–30.587	16.02**	14.567**
BSMR164	–21.779	–25.346	47.125**
BDN2001-6	13.891**	4.964**	–18.855
ICP3525	–15.394	–8.321	23.715**
BSMR175	–9.874	5.839**	4.035*
BSMR2	17.968**	14.75**	–32.718
ICPL12749	5.551**	7.724**	–13.275
BSMR203	–0.649	–13.316	13.965**
BWR154	0.686	0.774	–1.46
BSMR571	–15.092	7.42**	7.672**
ICP13991	–12.146	21.212**	–9.066
ICP10934	–8.097	–9.065	17.162**
HPL24-63	–45.867	86.82**	–40.953
AKT9915	7.681**	–10.731	3.05
ICP 3407	–4.234	–9.546	13.78**
ICP 10650	–10.681	19.982**	–9.301
ICP3475	34.373**	–5.78	–28.593
BSMR736	17.958**	1.11	–19.068
TV1	6.381**	–14.151	7.77**
AKT8811	26.454**	–25.228	–1.226
PHULE T-00-1-25-1	15.273**	–6.435	–8.838
PHULE T-04-1-3-1	5.124**	–13.518	8.394**
AKT9913	–0.384	–21.306	21.69**
AKT222521	11.251**	–4.081	–7.17
AKT00-12-6-4	–7.467	15.38**	–7.913
ICP3963	–6.717	–8.66	15.377**
PHULE T-00-5-7-4-1	3.099	11.907**	–15.006
VIPULA	–19.327	6.46**	12.867**
PHULET- 00-4-11-6-2	22.274**	–18.098	–4.176
ICP11376	–30.636	19.287**	11.349**
ICP3514	7.438**	–3.485	–3.953
ICP3374	37.808**	–21.4	–16.408
ICPL20106	17.229**	–25.103	7.874**
SE (I)	±1.89		

Four crosses, ICPA 2043 x BSMR 2, ICPA 2047 x BSMR 2, ICPA 2047 x ICP 11376, ICPA 2092 x ICP 11376, exhibited that the higher order SCA effect for seed yield involved the parents characterized by different (low, high, or both) types of GCA effects. It was also observed that high GCA female (ICPA 2092) and low GCA male (BSMR 164 or ICP 3525) parents produced hybrids with high SCA effect for yield. This indicated the involvement of additive x non-additive type of gene action and such crosses could be recommended for heterosis breeding (Baskaran and Muthiah 2007). Yadav et al. (2008) reported no relationship between GCA of the parents and performance of the hybrids, thereby suggesting the involvement of additive, dominance, and/or epistatic gene actions in the manifestation of hybrid yield. Sameer Kumar et al. (2009) revealed that in some cases the high SCA hybrids can be produced by crossing the two parents having high GCA effects. Some crosses with positive and highly significant SCA effects for yield also had significant and positive SCA effects for some other key yield components. This may be attributed to a direct and strong relationship of yield with that particular trait(s). The parents of hybrids such as ICPA 2092 x BSMR 164 and ICPA 2092 x ICP 3525 with high x low GCA effects could also be exploited through selection, followed by inter-mating of segregants in early generation. Considering their high SCA effects for grain yield, the promising crosses identified were ICPA 2043 x ICP 3374, ICPA 2043 x AKT 8811, ICPA 2047 x HPL 24-63, ICPA 2092 x BSMR 164 and ICPA 2092 x ICP 3525.

Heterosis for yield

Estimation of heterosis for yield (Table 3) in ICPA 2043-based hybrids over the control cv. BSMR 736 ranged from -50.81% to 76.89%; and from -54% to 62.13% over the released hybrid ICPH 2671. Similarly in ICPA 2047-based hybrids, the heterosis over standard checks BSMR 736 and ICPH 2671 respectively, ranged from -29.81% to 76.09% and -38.70% to 64.31%. Twenty three hybrids produced significantly greater yield over the controls BSMR 736 and ICPH 2671. It was also observed that hybrid ICPA 2047 x HPL 24-63 recorded the highest (79.07%) heterosis for yield, closely followed by hybrids ICPA 2043 x ICP 3374 (76.69%) and ICPA 2092 x ICP 10934 (60.62%) over the control BSMR 736.

Heterotic groups

Shull (1908) and Richey (1922) observed that the maize hybrids which were produced by crossing dissimilar parents produced plants with more vigour and grains. This ‘dissimilarity of parents’ was an indication of genetic diversity; meaning thereby that high yield was a consequence of diversity between the two parents. Subsequently to stream line this concept for hybrid breeding, Sprague and Tatum (1942) evolved the popular concept of ‘combining ability’ for discriminating the hybrid parents on the basis of their ability to produce promising hybrids. Later, various ideas and concepts in relation to tagging of parental lines for breeding hybrids were put together and gradually the concept of ‘heterotic groups’ evolved. This approach involved the clustering of hybrid parental lines either on the

Table 3. Hybrid combinations recording significant standard heterosis (SH) over popular inbred cultivar BSMR 736 and released hybrid ICPH 2671

Cross	Het. group of tester	SH (%) over BSMR 736	SH (%) over hybrid 2671
ICPA 2043 x ICP3374	V	76.69**	62.13**
ICPA 2043 x ICPL20106	VII	56.64**	43.73**
ICPA 2043 x BDN 2001-6	IV	40.04**	28.51**
ICPA 2043 x ICP3514	I	33.51**	22.51**
ICPA 2043 x ICP10934	III	28.54**	17.95**
ICPA 2047 x HPL 24-63	II	79.07**	64.31**
ICPA 2047 x BDN 2001-6	IV	36.66**	25.4**
ICPA 2047 x ICP3374	V	32.26**	21.36**
ICPA 2047 x ICP10934	III	31.65**	20.8**
ICPA 2047 x ICP3514	I	28.49**	17.91**
ICPA 2047 x ICPL20106	VII	25.98**	15.6**
ICPA 2047 x ICP11376	III	19.17**	9.35**
ICPA 2047 x ICP3407	I	15.51**	5.99**
ICPA 2092 x ICP10934	III	60.62**	47.38**
ICPA 2092 x ICPL20106	VII	60.46**	47.24**
ICPA 2092 x ICP3374	V	43.89**	32.03**
ICPA 2092 x BSMR164	III	37.63**	26.29**
ICPA 2092 x ICP3514	I	35.67**	24.49**
ICPA 2092 x AKT9913	VI	28.12**	17.56**
ICPA 2092 x BDN 2001-6	IV	24.77**	14.49**
ICPA 2092 x ICP11376	III	20.25**	10.34**
ICPA 2092 x BSMR198	VI	14.95**	5.48**
ICPA 2092 x ICP 10650	II	17.76**	8.06**

Het. = Heterosis

basis of their performance in F_1 generation, combining ability, origin, phenotypic and/or genetic diversity.

In the present study, the testers were divided into seven heterotic groups on the basis of their SCA effects for grain yield (Table 4). In heterotic group I, eight testers (ICP 3514, ICP 3475, BSMR 736, AKT 8811, PHULE T-00-1-25-1, AKT 222521, PHULE T-00-4-11-6-2 and AKT 9915) were included. Four testers including ICP 13991, HPL 24-63, ICP 10650 and AKT 00-12-6-4 were placed in heterotic group II; while ICP 10934, BSMR 164, ICP 3525, BSMR 203, ICP 3407 and ICP 11376 constituted the heterotic group III. Three testers were placed each in the heterotic group IV (BSMR 2, BDN 2001-6, ICPL 12749) and V (TV 1, ICP 3374, PHULE T-04-1-3-1). Seven genotypes (BSMR 198, BSMR 846, BSMR 175, BSMR 571, AKT 9913, ICP 3963, Vipula) were grouped in heterotic group VI; while ICPL 20106 was the lone member of heterotic group VII. These observations were indicative of the performance of the testers, as a group, in hybrid combinations and their genetic divergence.

Table 4. CMS line and testers identified for breeding medium maturing pigeonpea hybrid and inbred cultivars

Heterotic group	Description	Genotypes (No.)	Lines/testers selected
Lines			
-	#CMS lines	**3**	ICPA 2092 ICPA 2043
Testers			
I	ICPA 2043 crosses	8	ICP 3475, BSMR 736
II	ICPA 2047 crosses	4	HPL 24, AKT-12-6-4
III	ICPA 2092 crosses	6	ICP 3525, ICP 11376
IV	ICPA 2043, 2047 crosses	3	BSMR 2, BDN 2001-6
V	ICPA 2043, 2002 crosses	3	TV 1, ICP 3374
VI	ICPA 2047, 2092 crosses	7	BSMR 198, ICP 3963
VII	ICPA 2043, 2047,2092 crosses	1	ICPL 20106

Source: Mudaraddi and Saxena (2015)

Earlier, on the basis of molecular diversity, Mudaraddi and Saxena (2015) classified the same three CMS lines in to two heterotic groups. ICPA 2043 was in first heterotic group, while ICPA 2047 and ICPA 2092 found place in the second heterotic group.

According to the concept of heterotic grouping, the crosses made among the intra-group genotypes are not likely to produce highly heterotic hybrids; while the hybrids produced by crossing the genotypes representing two different (diverse) groups have greater probability of producing high yields. Further, high yielding inbred lines can also be bred by exploiting their additive genetic variation using the intra-group crosses. Hence, the approach of heterotic grouping can be of help to pigeonpea breeders in identifying parental lines for breeding high yielding pure lines and hybrid cultivars.

Selection of parents

Authors would like to clarify that the inferences drawn from this study were based on some specific parents (fixed effects) and, therefore, cannot be generalized or considered as rule while breeding pigeonpea. However, these can certainly provide useful guidelines for selecting potential parental materials for generating new breeding populations and hybrids with high probability of success. It is obvious that in any plant breeding programme, a large number of parental lines cannot be used to develop breeding materials due to the limitation of resources. Therefore in this study, keeping in view the importance of genetic diversity, combining ability, disease resistance, yield and some key market-preferred seed traits, 13 testers and two CMS lines were identified for use in breeding programmes aimed to develop medium duration pigeonpea hybrid and inbred cultivars.

Female parents

Of the three CMS lines used as female parents, ICPA 2092 and ICPA 2043 were selected (Table 5), but the former was considered better because it exhibited

Table 5. Key traits of A-lines and testers identified as potential parents for breeding medium duration hybrid and inbred cultivars

Het. Gr	Genotype	Origin	PH	SW	Wilt	SM	Bran	SP	Yield	GCA
CMS	ICPA 2092	Rec. parent ICP 96058	187	10.0	9.0	0.0	10	4.0	133.0	7.8**
	ICPA 2043	Rec. parent ICPL 20176	161	10.7	1.0	0.0	12	4.2	141.7	-6.3**
I	ICP 3475	Landrace, Bihar	165	10.7	0.0	0.0	11	3.4	103.2	8.4**
	BSMR 736	(ICP7217 x 148) x BDN1	182	10.9	0.0	0.0	11	3.3	90.6	0.1
II	HPL 24-63	ICPL 20205	162	10.5	7.0	21.0	13	3.7	150.8	13.5**
	AKT 12-6-4	Adv. line, Maharashtra.	195	11.6	0.0	0.0	11	3.3	95.3	-7.5**
III	ICP 3525	PI-395257	190	10.7	0.0	0.0	12	4.2	232.7	-28.8**
	ICP 11376	Nepal	165	10.7	0.0	0.0	15	3.9	52.0	7.7**
IV	BSMR 2	Maharashtra	210	11.0	0.0	0.0	12	3.9	113.7	-2.9**
	BDN 2001-6	Maharashtra	215	10.2	0.0	0.0	14	3.9	117.2	44.4**
V	TV 1	Maharashtra	190	11.5	0.0	0.0	11	3.7	153.6	-5.0**
	ICP 3374	Landrace, Bihar	189	11.8	0.0	0.0	14	3.9	101.4	64.4**
VI	BSMR 198	PantA-3 x ICP-7035	203	11.4	0.0	0.0	14	4.0	145.7	5.0**
	ICP 3963	Landrace,Uttar Pradesh	155	11.2	0.0	0.0	16	3.7	136.9	-10.6**
VII	ICPL 20106	IPH 487 -120	283	11.9	4.0	1.0	19	4.1	91.3	60.4**

Where: PH = Plant height (cm), SW = 100 seed wt. (g), SM = Sterility mosaic (%), Wilt (%), Bran. = Branches/plant (no.), SP = Seeds/pod (no), Yield (g/plant); GCA = General combining ability

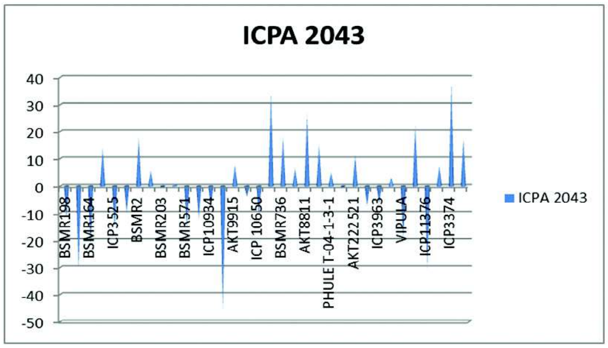

Fig. 1. Estimates of specific combining ability effects of the ICPA 2043 based hybrids developed by crossing 34 testers with three CMS lines

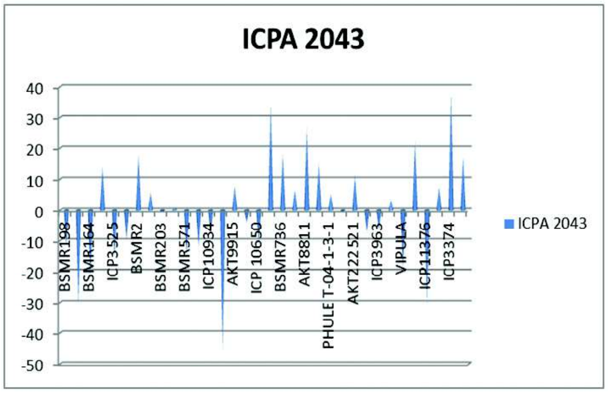

Fig. 2. Estimates of specific combining ability effects of the ICPA 2047 based hybrids developed by crossing 34 testers with three CMS lines

highest positive GCA effect for seed yield, pods/plant and flowering; and besides this, it also produced high yielding hybrids. Out of 34 hybrids involving ICPA 2092 assessed for yield, 16 exhibited highly significant and positive SCA effects. This female parent is of medium maturity (around 180 days) duration with good seed quality in terms of colour (white), shape (round) and size (medium bold). This male sterile line also possesses high levels of resistances to the two most common pigeonpea diseases *i.e.* fusarium wilt and sterility mosaic virus. These traits make ICPA 2092 an ideal female parental line for breeding pigeonpea hybrids.

Male parents

Based on various genetic parameters, a total 13 promising testers (Table 5) were identified for breeding. These included two genotypes each from heterotic groups I to VI and one from group VII. In the heterotic groups I, III and VI comparatively more genotypes were housed. The selection of testers within each heterotic group was done on the basis of their diversity

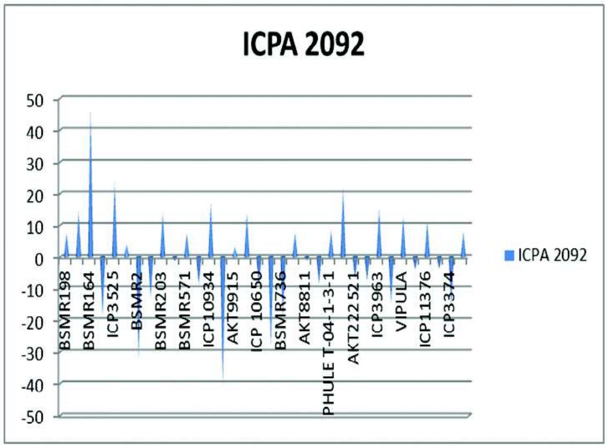

Fig. 3. Estimates of specific combining ability effects of the ICPA 2092 based hybrids developed by crossing 34 testers with three CMS lines

(as judged by their parentage and origin), combining ability and per se performance. Parents with high GCA values point towards the greater number of additive genes in them; besides this, it can also be seen as the potent evidence of greater flow of such (additive) alleles from the parent to its offspring. In a pure line breeding programme, the breeders' try to bring together various positive alleles with additive effects from diverse sources in a single breeding population or inbred line. This can best be achieved through intra heterotic group mating which may lead to reduced complex gene interactions and relatively high response to selection. This scheme, however, does not exclude specific inter-group crosses also to achieve the same goal.

As discussed earlier the intra-group crosses offer a unique opportunity to bring together the positive additive alleles and produce superior inbred lines. One such example is 'ICPL 20106'. It is a high yielding inbred line derived through pedigree selection from a hybrid that was selected from a set of diallel crosses at ICRISAT. This hybrid was high yielder and exhibited highly significant SCA effect. The parents of this cross were local landraces from central India; and both them had highly significant GCA effects (Saxena 1977). In the present study ICPL 20106, when crossed with CMS line ICPA 2092, produced the best hybrid and it was a lone occupant in heterotic group VII. The hybrid-derivative inbred lines, loaded with additive alleles, can also be used as parents for breeding improved inbred line.

Hence in the future hybrid breeding programmes, the two CMS lines ICPA 2043 and ICPA 2092 can be crossed with the selected 13 testers to develop new high yielding hybrids. It may also be important to mention here that since the commercial hybrid seed production is the backbone for the adoption of hybrids, the breeders at ICRISAT have already developed an economically viable seed technology for hybrids and the parents (Saxena 2006). Breeders can now venture in developing high yielding CMS-based commercial hybrids in pigeonpea. This development will help in extending the benefits of hybrid technology to farmers who are suffering for decades with the low productivity of the crop.

Authors' contribution

Conceptualization of research (KBS); Designing of the experiments (SLS); Contribution of experimental materials (SLS, KBS); Execution of field/lab experiments and data collection (SLS); Analysis of data and interpretation (SLS); Preparation of manuscript (KBS, SLS).

Declaration

The authors declare no conflict of interest.

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