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Stability analysis of yield and related traits in pigeonpea hybrids

S.L. SAWARGAONKAR[1,2], K.B. SAXENA[1], I.A. MADRAP[2] and A. RATHORE[1]

[1]International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 502 324, Andhra Pradesh, India;
[2]Marathwada Krishi Vidyapeeth, Parbhani, 431 401, Maharashtra, India; E-mail: sawargaonkar_sl@rediffmail.com

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ABSTRACT

Studies were carried out during 2009-10 under four environments to evaluate phenotypic stability of 102 CMS-based pigeonpea hybrids and their parents for the yield and yield contributing traits. At each location, experiments were conducted in á-lattice design with two replications. Significant genotypic differences were observed for all the characters except seeds/pod and 100-seed weight, suggesting differential responses of genotypes to the environmental changes. The results showed that parents 'HPL24-63', 'ICP 3963', 'ICPA 2043', 'PHULE T-00-4-11-6-2' and 'ICP 10934' exhibited general stability for grain yield. The stability analysis further revealed that the hybrids 'ICPA 2043 × ICPL 20106' and 'ICPA 2047 × ICPL 20106' were stable for days to flower, days to maturity, pods/plant, pod weight/plant and yield/plant; while hybrids 'ICPA 2092 × AKT 9913' and 'ICPA 2092 × BSMR 203' exhibited stability for grain yield/plant, plant height, pods/plant and pod weight/plant. Grain yield in the hybrids was positively associated with pods/plant, pod weight/plant and seeds/pod in all the four locations.

***Key words*:** Biplot, *Cajanus cajan* (L.) Millsp., Correlation, GGE, Hybrid pigeonpea, Stability

In pigeonpea (*Cajanus cajan* (L.) Millsp.), the development of stable cytoplasmic nuclear male-sterility (CMS) system (Saxena *et al*. 2005, 2010), identification of fertility restorers (Saxena *et al*. 2011), occurrence of a reasonable level of natural out-crossing (Saxena *et al*. 1990) and existence of significant standard heterosis (Saxena and Nadarajan 2010) have opened a new research avenue for enhancing yield through hybrid breeding. The CMS-derived pigeonpea hybrids are new introduction in the states of Maharashtra, Karnataka, Andhra Pradesh, and Madhya Pradesh though information on their stability and adaptation is lacking. To determine linear relationship between genotypic performance and environment, a number of models for stability analyses has been proposed time to time. Eberhart and Russell (1966) proposed a methodology in which the environmental index is estimated as the mean performance of all the entries in an environment. The performance of each genotype is regressed on the environment to obtain its mean performance over all environments. A desirable genotype is one with high mean value, with unit regression coefficient and non-significant deviation from regression. Such a genotype will perform better as the environment improves. The present study was therefore aimed to evaluate new hybrids for their stability for yield and yield components across different environments of Maharashtra and Andhra Pradesh.

MATERIALS AND METHODS

The experimental materials consisted of 102 CMS-based pigeonpea hybrids derived from crosses involving three diverse CMS-lines and 34 testers made in a line × tester mating scheme during 2008 at Marathwada Krishi Vidyapeeth (MKV), Parbhani, Maharashtra. The F_1's and their parents were grown with two checks 'BSMR 736' and 'ICPH 2671' in a á-lattice design with two replications at Patancheru (17°53'N, 78°27'E, 545.0 m), Parbhani (19°16'N, 67°47'E, 409.0 m), Latur (18°24'N, 76°36'E, 633.8 m), and Badnapur (19°50'N, 47°53'E, 519.6 m) during 2009-10. 14 plants in each entry, sown in 4.2 m long single rows, were maintained after thinning. The inter- and intra-row spacing was kept at 75 cm and 30 cm, respectively. The recommended package of cultural practices (Ramkrishna *et al*. 2005) was followed to raise a good crop. In each plot, five competitive plants were identified randomly for recording data on days to flower and maturity, plant height (cm), number of primary branches/plant, number of secondary branches/plant, number of pods/plant, pod weight/plant (g), seeds/pod, 100-seed weight (g) and grain yield/plant (g). The data recorded at all the locations were subjected to stability analysis according to the model proposed by Eberhart and Russel (1966) and three stability parameters mean (m), regression coefficient (bi) and the deviation from linearity (S^2di) were estimated. To examine the relationships among the stability parameters of yield with their related traits, the parents and hybrids were compared. The stable genotypes were further studied to estimate the main and genotype-environment interaction effect for seed yield, using GGE biplot approach proposed by Yan (1999) and Yan *et al*. (2000). To achieve this, the total G + GE effects were separated from the observed mean and partitioned into multiplicative terms by using singular values decompositions (SVD) for the first principal component (PC 1) and second principal component (PC 2). The Pearson's correlation coefficients among the characters were also estimated.

RESULTS AND DISCUSSION

The genotypic differences were found to be highly significant for all the traits in each environment (ANOVA not presented). The mean genotypic values from different locations were subjected to pooled analysis. The mean sum of squares (MSS) due to genotypes (G) were significant for all the traits except seeds/pod and 100-seed weight; and that due to environments (E) were significant for all the characters when tested against MSS due to G × E. The results were in close conformity to the findings of Phad *et al.* (2005). The MSS due to G × E when tested against pooled error, were found highly significant for all the characters except seeds/pod and 100-seed weight. Thus stability analysis was carried out for all the traits except seeds/pod and 100-seed weight. The variances due to G × E were partitioned into G × E (linear) and due to

Table 1. Mean performance of lines, testers and control cultivar over locations for yield and yield contributing characters during 2009 rainy season

Genotypes	Days to		Plant height (cm)	Primary branches/ plant (no.)	Secondary branches/ plant (no.)	Pods/ plant (no.)	Seeds/ pod (no.)	Pod weight/ plant (g)	100-Seed weight (g)	Grain yield/ plant (g)
	flowering (no.)	maturity (no.)								
Lines										
ICPA 2043	116	166	161	11	26	217	4.1	163.2	10.7	102.0
ICPA 2047	119	167	179	10	28	111	4.5	81.3	11.0	58.5
ICPA 2092	128	174	187	11	30	207	4.0	127.8	10.0	94.2
Testers										
BSMR198	122	170	168	10	25	283	3.9	159.9	11.0	106.1
BSMR846	126	176	169	10	17	117	3.7	68.0	9.9	46.2
BSMR164	122	173	183	10	16	112	4.0	69.8	10.1	40.1
BDN 2001-6	129	174	185	10	27	199	3.8	109.5	9.7	83.0
ICP3525	128	176	190	12	33	432	4.1	232.7	10.7	183.6
BSMR175	124	177	191	9	27	151	4.0	107.5	10.6	72.1
BSMR2	127	169	185	11	24	190	3.9	111.2	11.0	79.4
ICPL12749	128	173	172	12	25	178	3.9	102.0	10.3	66.9
BSMR203	125	173	172	10	24	182	4.0	112.7	11.5	72.7
BWR154	124	172	175	9	25	203	3.7	105.1	10.9	75.5
BSMR571	121	171	180	9	23	206	3.9	132.3	10.6	86.2
ICP13991	125	167	166	11	27	254	3.8	152.8	10.9	108.0
ICP10934	123	166	181	13	23	274	3.8	131.0	12.0	97.4
HPL 24-63	122	168	177	11	30	312	3.7	174.3	11.1	118.1
AKT 9915	118	171	177	13	28	214	3.8	123.3	11.3	75.7
ICP 10650	118	168	175	13	26	192	3.6	113.4	10.3	65.3
ICP 3407	125	175	181	10	18	141	3.4	81.0	11.2	45.1
ICP3475	123	175	165	11	29	207	3.3	118.9	10.7	74.7
BSMR736	119	174	170	10	21	185	3.3	112.3	11.4	63.1
TV 1	117	173	180	11	22	342	3.6	167.5	10.7	118.5
AKT8811	118	173	175	12	30	248	3.7	127.1	10.8	87.0
PHULE T-00-1-25-1	117	175	172	10	24	240	3.8	136.7	11.0	90.8
PHULET-04-3-1	120	172	178	11	23	140	3.5	115.1	12.2	48.7
AKT9913	120	171	171	12	23	110	3.7	71.2	10.9	46.9
AKT222521	127	172	167	11	23	214	3.8	119.0	11.5	76.9
AKT 00-12-6-4	122	173	173	12	22	217	3.2	127.3	11.4	68.5
ICP 3963	125	180	184	11	24	264	3.6	150.0	10.8	103.1
PHULE T-00-5-7-4-1	121	174	174	12	25	110	3.6	80.9	11.2	46.9
VIPULA	117	170	174	12	26	209	3.2	127.3	11.3	67.2
PHULE T-00-4-11-6-2	120	171	174	8	23	252	3.8	136.4	11.2	100.5
ICP11376	122	168	165	12	30	110	3.8	67.7	10.7	32.9
ICP3514	120	175	188	11	23	110	3.6	114.7	11.7	81.5
ICP3374	128	173	189	11	23	183	3.8	125.3	11.8	71.5
ICPL20106	121	172	176	12	26	156	4.0	91.1	11.0	59.8
BSMR 736 (Check 1)	121	173	172	10	24	220	4.0	130.4	10.3	92.8
ICPH 2671 (Check 2)	121	174	176	11	28	232	4.1	138.9	10.5	99.8
SEm (±)	0.63	0.50	2.58	0.27	1.07	4.82	0.08	3.89	0.10	8.02
CV (%)	0.70	0.40	1.40	3.90	4.40	3.30	2.10	3.10	1.40	18.30
CD (P= 0.05)	1.77	1.39	5.09	0.77	2.12	13.46	0.16	7.67	0.29	22.43

pooled deviation (non-linear). These variances were highly significant when tested against pooled error (Table 5). These observations indicated that some reliable predictions about G × E interactions as well as its unpredictable components can be made for these traits. Hence, both these components contributed significantly in determining the stability of genotypes. Venkateshwaralu (1998) also reported similar findings in pigeonpea.

Mean performance of parents and hybrids: The mean performances of genotypes (parents and hybrids) for each of the characters over pooled environments are given in Table 1-4. The parents 'ICPA 2043', 'TV 1', 'PHULE T-00-1-25-1' and 'VIPULA' and the hybrids 'ICPA 2043 × HPL 24-63', 'ICPA 2043 × ICP-3475', 'ICPA 2043 × BSMR 736' were significantly superior to checks for early flowering. The parents 'ICPA 2043', 'ICP 10934', 'ICP 13991' and hybrids 'ICPA 2043 × BSMR 2', 'ICPA 2043 × ICP 10934', and 'ICPA 2043 × PHULE T-00-4-11-6-2' were significantly superior to controls for days to maturity. For grain yield/plant, the parents 'ICP 3525', 'TV 1', 'HPL 24-63', 'ICP 13991', 'BSMR 198', 'ICP 3963', 'PHULE T-00-4-11-6-2' and 'ICP 11376' were *at par* with the controls; whereas hybrids 'ICPA 2043 × ICP 3374', 'ICPA 2047 × HPL 24-63', 'ICPA 2092 × ICPL 20106', 'ICPA 2092 × ICP 10934' and 'ICPA 2043 × ICPL 20106' were superior to the controls.

Correlation among the traits: The correlation coefficients were estimated among all the pairs of variables at Patnacheru, Parbhani, Latur and Badnapur (Table 8). It was observed that the secondary branches/plant had significant and positive correlation with primary branches/plant at Patancheru, Parbhani and Latur. The seeds/pod was significantly and positively associated with pod weight/plant, while pod weight/plant was positively correlated with pods/plant across the

Table 2. Mean performance of 'ICPA 2043'-derived hybrids

Hybrids	Days to flowering (no.)	Days to maturity (no.)	Plant height (cm)	Primary branches/ plant (no.)	Secondary branches/ plant (no.)	Pods/ plant (no.)	Seeds /pod (no.)	Pod weight/ plant (g)	100-Seed weight (g)	Grain yield/ plant (g)
ICPA2043 × BSMR198	119	168	171	9	19	177	4.0	119.9	11.0	74.7
ICPA2043 × BSMR846	119	173	178	9	22	99	3.3	68.3	11.6	35.7
ICPA2043 × BSMR164	123	174	172	9	24	114	4.1	86.1	11.2	54.1
ICPA2043 × BDN 2001-6	125	171	176	11	27	293	4.1	172.5	11.2	127.9
ICPA2043 × ICP3525	122	175	186	10	25	150	3.2	85.6	11.7	47.0
ICPA2043 × BSMR175	121	172	171	10	28	162	4.0	109.2	11.5	70.5
ICPA2043 × BSMR2	118	166	172	10	20	227	3.9	132.8	12.1	93.3
ICPA2043 × ICPL12749	121	174	169	10	23	154	4.5	133.1	11.2	83.8
ICPA2043 × BSMR203	119	171	182	9	21	156	3.7	89.6	11.8	66.5
ICPA2043 × BWR154	117	172	186	8	24	173	3.6	106.3	11.1	66.3
ICPA2043 × BSMR571	118	170	179	10	22	148	3.4	85.9	11.8	53.7
ICPA2043 × ICP13991	118	171	179	10	26	110	3.6	80.4	10.9	48.3
ICPA2043 × ICP10934	119	167	169	10	26	253	4.0	151.5	11.6	115.2
ICPA2043 × HPL24-63	115	168	170	10	23	134	3.9	83.1	12.0	54.8
ICPA 2043 × AKT9915	120	171	161	11	26	176	4.2	115.3	11.7	84.8
ICPA2043 × ICP3407	118	172	170	9	21	182	3.9	110.7	11.1	75.7
ICPA2043 × ICP10650	118	170	174	8	22	193	3.6	127.2	11.8	72.4
ICPA2043 × ICP3475	115	171	180	10	24	273	4.1	165.0	10.4	115.7
ICPA2043 ×BSMR736	115	170	179	11	22	243	3.9	151.2	10.5	95.9
ICPA2043 × TV1	117	170	193	13	26	175	3.7	109.8	9.8	76.9
ICPA2043 × AKT8811	118	168	186	11	23	187	3.8	110.7	11.7	74.8
ICPA2043 × PHULE-T-00-1-25-1	117	171	201	9	24	177	3.9	106.1	10.2	68.0
ICPA2043 × PHULE-T-04-1-31	119	170	192	10	17	131	3.9	92.9	10.0	58.1
ICPA2043 × AKT9913	122	173	192	12	27	174	3.9	112.9	11.2	80.3
ICPA2043 × AKT222521	119	172	185	8	22	119	4.1	78.4	11.2	51.6
ICPA2043 × AKT-00-12-6-4	119	170	181	7	23	146	4.0	99.5	11.1	62.3
ICPA2043 × ICP3963	122	170	181	8	23	146	3.9	85.1	10.8	62.9
ICPA2043 × PHULET-00-5-7-4-1	122	173	180	9	25	135	3.8	84.6	10.7	54.2
ICPA2043 × VIPULA	120	172	180	10	29	129	3.8	89.0	11.2	56.2
ICPA2043 × PHULET-00-4-11-6-2	119	167	180	9	26	263	3.9	151.6	11.7	103.9
ICPA2043 × ICP11376	122	170	179	7	24	147	3.7	88.8	12.3	58.7
ICPA2043 × ICP3514	123	172	179	9	30	281	3.8	147.7	10.7	123.3
ICPA2043 × ICP3374	125	171	177	12	30	357	4.0	220.2	10.7	164.9
ICPA2043 × ICPL20106	123	171	189	9	30	288	4.0	193.7	10.8	144.5

locations. The traits that were positively correlated with grain yield across the four locations were number of pods/plant, pod weight/plant and seeds/pod. It indicated that these characters may be used in selection for high yield. Similar associations were also reported by Sarma *et al*. (1994) in pigeonpea.

Stability analysis of parent genotypes: Based on stability parameters, 12 hybrid parental genotypes were classified as stable for grain yield/plant. The parents 'HPL 24-63', 'ICP 3963', and 'ICPA2043' were among the top entries which had their mean yield greater than the average of all the parents with unit regression coefficient (bi = 1) and non-significant deviation from regression ($S^2di = 0$). This indicated their high stability over all the environments. Patel *et al.* (2005) reported above average stability of pigeonpea lines for seed yield. The parents 'BSMR 2', 'ICP 3514', and 'BDN 2001-6' had bi = 1 and $S^2di = 0$, but their mean was low, indicating their adaptation to stress environments (Table 6).

The stability analysis revealed that 11 parents were stable for pods/plant, 9 for pod weight/plant, 7 for secondary branches/plant, 5 for plant height, and one each for both number of primary branches/plant and days to maturity (Table 6). The parent 'PHULE T-00-1-25-1' was stable for plant height, secondary branches/plant, pods/plant, and pod weight/plant, while 'HPL 24-63' was stable for primary branches/plant, pods/plant and pod weight/plant. Similarly, the parents 'ICP 3963', 'PHULE T-00-4-11-6-2', 'ICP 10934' and 'ICP3514' were stable for secondary branches/plant, pods/plant, and pod weight/plant. The results suggested that these traits might have stability for seed yield. It was also observed that the parents, which showed above average stability for grain yield, also exhibited non-significant regression coefficient for all the

Table 3. Mean performance of 'ICPA 2047'-derived hybrids

Hybrids	Days to flowering (no.)	Days to maturity (no.)	Plant height (cm)	Primary branches/ plant (no.)	Secondary branches/ plant (no.)	Pods/ plant (no.)	Seeds /pod (no.)	Pod weight/ plant (g)	100-Seed weight (g)	Grain yield/ plant (g)
ICPA2047 × BSMR198	124	173	194	8	20	239	3.8	140.3	11.2	94.1
ICPA2047 × BSMR846	127	174	178	10	20	134	4.0	98.2	11.5	69.8
ICPA2047 × BSMR164	126	178	184	9	21	132	3.8	85.1	11.3	54.4
ICPA2047 × BDN 2001-6	129	177	184	11	21	304	3.9	176.8	10.3	126.3
ICPA2047 × ICP3525	128	177	188	9	21	144	4.0	89.3	11.3	56.1
ICPA2047 × BSMR175	126	175	195	8	18	165	3.9	127.7	11.2	86.5
ICPA2047 × BSMR2	129	177	171	9	24	167	4.2	116.1	10.9	88.4
ICPA2047 × ICPL12749	128	176	187	9	21	195	3.8	129.3	10.5	95.7
ICPA2047 × BSMR203	125	177	195	10	26	150	4.2	98.5	10.4	64.7
ICPA2047 × BWR154	128	177	192	10	23	152	4.1	102.3	10.2	68.1
ICPA2047 × BSMR571	126	175	185	8	17	192	3.7	114.7	10.8	75.5
ICPA2047 × ICP13991	129	175	197	8	28	202	4.0	110.9	10.7	81.9
ICPA2047 × ICP10934	128	174	182	8	26	323	3.7	176.4	11.5	125.3
ICPA2047 × HPL24-63	125	174	199	9	23	384	4.1	234.0	10.5	164.4
ICPA2047 × AKT9915	126	177	186	11	20	171	4.0	106.5	10.2	72.5
ICPA2047 × ICP3407	127	179	174	9	21	182	4.1	114.0	10.5	77.5
ICPA2047 × ICP10650	124	178	185	8	24	255	3.9	146.4	11.0	106.2
ICPA2047 × ICP3475	122	174	178	7	25	196	4.1	129.4	10.0	85.1
ICPA2047 × BSMR736	123	174	193	9	22	206	4.0	123.4	10.7	85.0
ICPA2047 × TV1	123	175	204	10	21	168	3.9	99.7	10.3	68.2
ICPA2047 × AKT8811	123	172	194	8	24	136	3.3	74.5	10.2	43.8
ICPA2047 × PHULE-T-00-1-25-1	123	173	196	7	21	146	3.9	84.8	10.3	56.0
ICPA2047 × PHULE-T-04-1-3-1	124	176	186	8	22	133	3.7	88.2	11.0	51.0
ICPA2047 × AKT9913	125	176	203	9	26	187	3.5	109.0	10.8	73.2
ICPA2047 × AKT222521	120	174	190	10	25	134	3.6	80.7	10.1	49.0
ICPA2047 × AKT-00-12-6-4	125	175	191	11	24	236	3.8	142.6	10.3	95.5
ICPA2047 × ICP3963	123	174	196	7	20	146	4.0	100.4	10.3	64.8
ICPA2047 ×PHULET00-5-7-4-1	126	176	201	7	22	147	3.9	93.1	10.0	62.2
ICPA2047 × VIPULA-27	125	174	181	11	21	219	4.1	124.4	10.2	88.6
ICPA2047 × PHULET-00-4-11-6-2	122	172	176	10	26	160	4.0	99.6	10.5	68.6
ICPA2047 × ICP11376	125	172	182	9	24	235	4.0	155.5	10.9	108.3
ICPA2047 × ICP3514	128	175	184	8	22	317	4.0	178.2	10.2	120.8
ICPA2047 × ICP3374	131	173	185	9	30	237	4.4	156.5	10.1	119.4
ICPA2047 × ICPL20106	133	176	189	13	27	297	3.9	174.2	10.7	120.5

characters except days to flower, secondary branches/plant, and pod weight/plant. For pod weight/plant, the parent 'BSMR 571' recorded high mean yield; but high regression coefficient and significant deviation from regression indicated its instability in different environments. Phenotypic stability of various component traits associated with the stability for yield was also reported by Muthiah and Kalaimagal (2003) for branches/plant and Patel *et al.* (2003) for days to maturity, branches/plant and pods/plant.

Stability analysis of hybrids: Among the 102 hybrids evaluated, 29 were found stable for grain yield/plant, 25 for pods/plant, 22 for pod weight/plant, 6 each for days to flower and primary branches/plant, 5 each for days to maturity and plant height, and one hybrid for secondary branches/plant (Table 7). It was further observed that the hybrids derived from 'ICPA2092' exhibited greater stability followed by 'ICPA 2047' and 'ICPA2043' hybrids. The most stable hybrid derived from 'ICPA2043' was 'ICPA2043' × 'ICP 3514' which had a high mean yield, unit regression coefficient and no deviation from regression. The other most stable hybrids derived from 'ICPA2047' was 'ICPA2047' × 'ICPL20106' and from 'ICPA 2092', it was 'ICPA2092' × 'BSMR 164'. Similar results were reported by Kyu *et al.* (2011). They reported that CMS-derived hybrid had high stability across the three different environments of Myanmar and produced 1846 to 1967 kg/ha yield with 30.4 to 41.7% standard heterosis.

Considering the three stability parameters, hybrid 'ICPA 2043' × 'PHULE T-00-4-11-6-2' was found to be highly stable

Table 4. Mean performance of 'ICPA2092'-derived hybrids

Hybrids	Days to flowering (no.)	Days to maturity (no.)	Plant height (cm)	Primary branches/ plant (no.)	Secondary branches/ plant (no.)	Pods/ plant (no.)	Seeds /pod (no.)	Pod weight/ plant (g)	100-Seed weight (g)	Grain yield/ plant (g)
ICPA2092 × BSMR198	127	178	185	11	27	272	3.9	159.1	10.3	108.1
ICPA2092 × BSMR846	125	179	180	8	24	206	4.3	119.8	10.5	85.9
ICPA2092 × BSMR164	126	180	183	9	25	294	3.8	178.1	11.0	128.8
ICPA2092 × BDN 2001-6	122	175	192	12	23	247	4.4	158.2	10.9	114.4
ICPA2092 × ICP3525	126	177	191	13	25	238	3.9	139.5	10.9	91.6
ICPA2092 × BSMR175	124	179	194	9	23	207	4.2	131.8	11.7	94.7
ICPA2092 × BSMR2	131	179	188	13	22	162	3.9	98.7	10.8	62.3
ICPA2092 × ICPL12749	127	176	177	10	25	238	3.9	129.5	11.2	91.6
ICPA2092 × BSMR203	126	174	188	11	26	233	3.9	137.3	10.8	93.9
ICPA2092 × BWR154	127	175	186	12	22	233	3.7	123.5	11.0	81.4
ICPA2092 × BSMR571	125	173	182	12	28	195	4.0	121.2	10.6	82.8
ICPA2092 × ICP13991	124	172	171	11	20	138	4.0	83.7	10.2	59.8
ICPA2092 × ICP10934	123	177	181	12	24	403	3.9	221.8	11.4	148.7
ICPA2092 × HPL24-63	123	171	178	11	26	164	3.9	102.7	10.5	66.7
ICPA2092 × AKT9915	126	174	185	9	21	231	3.9	140.7	10.4	94.4
ICPA2092 × ICP10650	129	175	183	10	20	259	3.9	160.6	10.6	109.3
ICPA2092 × ICP3407	126	175	194	9	31	227	3.7	153.6	10.6	88.8
ICPA2092 × ICP3475	122	178	188	10	27	167	4.2	108.7	10.6	73.1
ICPA2092 × BSMR736	122	177	185	7	22	192	3.8	128.8	12.4	76.6
ICPA2092 × TV1	124	178	193	10	28	208	3.9	140.7	10.2	93.7
ICPA2092 × AKT8811	120	177	186	10	23	171	3.9	104.0	10.1	65.7
ICPA2092 ×PHULET-00-1-25-1	123	176	194	9	25	157	3.3	99.2	10.2	61.3
ICPA2092 × PHULE-T-04-1-3-1	122	179	187	12	27	185	3.9	114.5	11.6	77.6
ICPA2092 × AKT9913	122	176	199	9	25	267	3.9	170.5	11.0	119.8
ICPA2092 × AKT222521	123	174	190	11	22	168	3.5	97.6	10.8	56.9
ICPA2092 × AKT-00-12-6-4	120	178	168	8	20	217	3.8	143.0	11.2	82.3
ICPA2092 × ICP3963	127	179	177	8	20	284	3.3	148.3	9.9	102.3
ICPA2092 × PHULET00-5-7-4-1	122	178	183	12	23	128	3.8	73.9	10.2	47.6
ICPA2092 × VIPULA	123	179	172	11	27	243	3.9	153.1	11.4	102.3
ICPA2092 × PHULET0-4-11-6-2	146	175	171	9	26	210	3.6	124.5	11.6	90.2
ICPA2092 × ICP11376	123	175	175	11	27	337	3.7	156.1	10.8	115.2
ICPA2092 × ICP3514	127	178	184	13	28	275	4.3	187.3	10.2	125.4
ICPA2092 × ICP3374	127	175	185	10	25	332	4.0	195.3	10.9	135.8
ICPA2092 × ICPL20106	126	178	180	9	22	419	3.9	218.3	10.0	153.3
BSMR 736 (Check 1)	121	173	172	10	24	220	4.0	130.4	10.3	92.8
ICPH 2671 (Check 2)	121	174	176	11	28	232	4.1	138.9	10.5	99.8

for yield/plant, primary branches/plant, secondary branches/ plant, pods/ plant and pod weight/plant (Table 7). Hybrids 'ICPA 2043' × 'ICPL 20106' and 'ICPA 2047' × 'ICPL 20106' exhibited stability for days to flower, days to maturity, pods/ plant, pod weight/plant and yield/plant. Hybrid 'ICPA 2092' × 'AKT 9913' showed stability for grain yield/plant, plant height, pods/plant and pod weight/plant, while 'ICPA 2092' × 'BSMR 203' registered stability for plant height, primary branches/ plant and pods/plant. In general, it was observed that the hybrids which showed stability for grain yield also exhibited stability for pods/plant, pod weight/plant, days to maturity and number of primary branches/plant. In contrast, three hybrids 'ICPA 2043' × 'ICP 3514', 'ICPA 2047' × 'AKT-00-12-6-4' and 'ICPA 2092' × 'VIPULA' showed stability for grain yield but had significant values for both bi and S^2di for secondary branches/plant indicating instability of hybrids under both favourable and stress environmental condition. Similarly, hybrids 'ICPA 2092' × 'VIPULA' and 'ICPA 2092' × 'ICP 3963' for days to maturity, 'ICPA 2092' × 'BDN 2001-6' for days to flower, 'ICPA 2092' × 'ICP 3525' for plant height and 'ICPA 2043' × 'ICP 3514' for pod weight/plant showed instability in the four environments. It is evident that no generalization can be made with regard to stability of genotypes for yield and its component traits. Among the three stability parameters, greater genotypic mean was found to be the most important, since the other two parameters do not have practical utility if the genotype is low yielding. The hybrid having high *per se* performance had above average stability.

The hybrid parents 'ICP 3475', 'BSMR 736' and 'BSMR 2', when crossed with the male-sterile lines 'ICPA 2043' and 'ICPA 2047' produced hybrids with greater adaptability across the environments. Similarly, crossing of 'ICP 3514' and 'PHULE T-00-11-6-2' with 'ICPA2043' and 'ICPA2092'; and 'ICP 11376', 'ICP 10650', 'ICP 12749', 'BSMR 198' and 'VIPULA' with 'ICPA 2047' and 'ICPA 2092' produced hybrids with greater stability in diverse environments. From this study, it is concluded that the hybrids derived by crossing of 'ICPA 2047' and 'ICPA 2092' with 'ICP 3514', 'PHULE T-00-11-6-2', 'ICP 11376', 'ICP 10650', 'ICP 12749', 'BSMR 198' and 'VIPULA' may be stable under variable environmental conditions.

It was observed that the stable hybrids derived from 'ICPA 2043' involved parents with above average stability and high *per se* performance. This indicated a positive

Table 5. Analysis of variance for yield and yield contributing characters

Source	df	Days to flowering (no.)	Days to maturity (no.)	Plant height (cm)	Primary branches /plant (no.)	Secondary branches /plant (no.)	Pods/ plant (no.)	Pod weight/ plant (g)	Grain yield/ plant (g)
Genotypes (G)	140	133.476**	48.35**	638.24**	13.21**	19.13**	493.52**	405.39**	387.59**
Environments (E)	3	5755.972**	5703.47**	413470.8**	2417.6**	4487.97**	19915.23**	9742.35**	16453.56**
G × E	420	84.651**	32.47**	470.06**	14.42**	21.22**	7.64**	7.95**	6.98**
E + (G × E)	423	62.437**	64.559	1699.572	19.935	109.685	5480.723	951.6851	1001.328
E (Linear)	1	8633.958**	15197.34	620206.2	4595.001	27916.09	2200237	361305.4	399807.1
G × E (linear)	140	40.388**	25.117**	266.028**	7.042**	74.372**	332.738**	123.4192**	89.856**
Pooled deviation (non-linear)	282	42.988**	30.479**	217.974**	10.112**	28.612**	253.934**	85.031**	39.627**
Pooled error	560	1.373	0.888	13.241	0.634	2.073	36.827	12.362	8.1

*,**: Significant at P = 0.05 and 0.01, respectively

Table 6. Two way table showing stable and unstable parents for yield verses component characters

Genotype no.	Stable parent for seed yield	Days to flowering (bi/S^2di)	Days to maturity	Plant height (bi/S^2di)	Primary branches plant (bi/S^2di)	Secondary branches /plant (bi/S^2di)	Number of Pods/ plant (bi/S^2di)	Pod weight/ plant (bi/S^2di)
118	HPL 24-63	S/*	S/*	S/*	S/S	S/*	S/S	S/S
131	ICP 3963	S/*	S/*	S/*	S/*	S/S	S/S	S/S
139	ICPA 2043	S/*	S/S	S/S	S/*	*/S	S/S	S/S
134	PHULE T-00-4-11-6-2	S/*	S/*	S/*	S/*	S/S	S/S	S/S
117	ICP10934	S/*	S/*	S/*	S/*	S/S	S/S	S/S
141	ICPA 2092	S/*	S/*	S/*	S/*	S/*	S/*	S/S
126	PHULE T-00-1-25-1	S/*	S/*	S/S	S/*	S/S	S/S	S/S
125	AKT8811	S/*	S/*	S/S	S/*	S/*	S/S	S/*
115	BSMR571	S/*	S/*	S/*	S/*	S/S	S/S	*/*
108	BDN 2001-6	S/*	S/*	S/S	S/*	*/S	S/S	S/S
136	ICP3514	S/*	S/*	S/*	S/*	S/S	S/S	S/S
111	BSMR2	S/*	S/*	S/S	S/*	S/S	S/S	S/*

Stability parameter of yield components (spanning columns 3–9)

S: stable parent, S/S: stable hybrid, S/*, */S and */*: unstable hybrid, bi: regression coefficient, S^2di: deviation from regression line, *: bi #1, S^2di #0 association between *per se* performance and stability. The 'ICPA 2043' based stable hybrids were 'ICPA 2043' × 'ICP 3514', 'ICPA2043' × 'ICP 10934', 'ICPA2043' × 'PHULE T-00-4-11-6-2' and 'ICPA2043' × 'BSMR 2'. Similarly, 'ICPA2092' based stable hybrids were 'ICPA 2092' × 'PHULE T-00-4-11-6-2', 'ICPA2092' × 'ICP 3963', and 'ICPA 2092' × 'BDN 2001-6'. It was also observed that the greater stability in 'ICPA 2047' derived hybrids was independent of stability of their parents. The hybrids made on 'ICPA 2047' involved both stable and unstable parents. The 'ICPA 2047'-based stable hybrids were 'ICPA 2047' × 'ICPL 20106', 'ICPA 2047' × 'ICP 12749' and 'ICPA 2047' × 'VIPULA'. These observations support the conclusions of Phad *et al.* (2005) and Muthiah and Kalaimagal (2005). They also reported stability of hybrids under stress environments and found that a few hybrids performed better only under favorable environments. Vanniarajan (2007) found that the genotypes which showed high stability for yield showed unstable performance for yield components.

Biplot analysis of parents and hybrids: Yield data from multi-environment trials are usually large, and their graphical presentation helps understand the pattern involved in particular data set. The GGE biplot allows visual examination of the GE interaction pattern of multi environment trials data. The biplot analysis, as viewed the environment-vector of parents and hybrids, has been shown in Figure 1. The results

Table 7. Two way table showing stable and unstable hybrids for yield versus component characters

Hybrid No.	Hybrids	Stability of parents		Mean		Stability parameter of yield components						
						Days to		Plant height	Primary branches	Secondary branches/	Number of pods/	Pod weight/
		P1	P2	P1	P2	flowering (bi/ S^2di)	maturity (bi/ S^2di)	(bi/ S^2di)	/plant (bi/S^2di)	plant (bi/S^2di)	plant (bi/S^2di)	plant (bi/S^2di)
34	ICPA2043 × ICP3514	S	S	102	81.5	S/*	S/S	S/*	S/*	*/*	S/S	*/*
20	ICPA2043 × ICP3475	S	S	102	74.7	S/S	S/*	S/S	S/S	S/*	S/*	S/S
15	ICPA2043 × ICP10934	S	S	102	97.4	S/S	S/*	S/*	S/*	S/*	S/S	S/*
32	ICPA2043 × PHULET-00-4-11-6-2	S	S	102	100.5	S/*	S/*	S/*	S/S	S/S	S/S	S/S
21	ICPA2043 × BSMR736	S	S	102	63.1	S/*	S/*	S/*	S/*	S/*	S/S	S/S
9	ICPA2043 × BSMR 2	S	S	102	79.4	S/*	S/*	*/S	S/S	S/*	S/S	S/S
70	ICPA2047 × ICPL20106	UNS	S	58.5	59.8	S/S	S/S	S/*	S/*	S/*	S/S	S/S
69	ICPA2047 × ICP3374	UNS	S	58.5	71.5	S/*	S/*	S/S	S/*	S/*	S/*	S/*
67	ICPA2047 × ICP11376	UNS	UNS	58.5	32.9	S/S	S/*	S/*	S/*	S/*	S/S	S/S
53	ICPA2047 × ICP10650	UNS	UNS	58.5	65.3	S/*	S/*	S/*	S/*	S/*	S/S	S/S
44	ICPA2047 × ICP12749	UNS	UNS	58.5	66.39	S/*	S/*	S/S	S/*	S/*	S/S	S/S
62	ICPA2047 × AKT-00-12-6-4	UNS	S	58.5	103.1	S/S	S/S	S/*	S/*	*/*	S/S	S/*
37	ICPA2047 × BSMR198	UNS	UNS	58.5	106.1	S/*	S/S	S/*	S/*	S/*	S/S	S/S
65	ICPA2047 × VIPULA	UNS	S	58.5	67.2	S/*	S/S	S/*	S/*	S/*	S/S	S/*
43	ICPA2047 × BSMR2	UNS	S	58.5	79.4	S/*	S/*	S/*	S/*	S/*	S/S	S/S
54	ICPA2047 × ICP3475	UNS	S	58.5	74.7	S/*	S/*	S/S	S/*	S/*	S/S	S/S
55	ICPA2047 × BSMR736	UNS	S	58.5	63.1	S/*	S/*	S/*	S/S	S/S	S/S	S/S
73	ICPA2092 × BSMR164	S	UNS	94.2	40.1	S/*	S/*	S/*	S/*	*/S	S/S	S/S
102	ICPA2092 × ICP3514	S	S	94.2	81.5	S/*	S/*	S/*	S/*	*/S	S/S	S/S
94	ICPA2092 × AKT9913	S	S	94.2	46.9	S/*	S/*	S/S	S/*	S/*	S/S	S/S
101	ICPA2092 × ICP11376	S	UNS	94.2	32.9	S/*	S/*	S/S	S/*	S/S	S/*	S/S
74	ICPA2092 × BDN 2001-6	S	S	94.2	83	*/*	S/*	S/*	S/*	S/*	S/S	S/S
86	ICPA2092 × ICP10650	S	UNS	94.2	65.3	S/*	S/*	S/*	S/*	S/*	S/S	S/S
71	ICPA2092 × BSMR198	S	UNS	94.2	106.1	S/*	S/*	S/*	S/S	S/*	S/S	S/S
97	ICPA2092 × ICP3963	S	S	94.2	103.1	S/*	*/*	S/*	S/*	S/*	S/*	S/S
99	ICPA2092 × VIPULA	S	S	94.2	67.2	S/*	*/*	S/*	S/*	*/*	S/S	S/S
76	ICPA2092 × BSMR175	S	S	94.2	72.1	S/S	S/*	S/*	S/*	S/*	S/S	S/*
79	ICPA2092 × BSMR203	S	S	94.2	72.7	S/*	S/*	S/S	S/S	S/*	S/S	S/*
90	ICPA2092 × TV1	S	UNS	94.2	118.5	S/*	S/*	S/*	S/S	S/*	S/S	S/*
75	ICPA2092 × ICP3525	S	UNS	94.2	183.6	S/*	S/*	*/*	S/*	S/*	S/S	S/S
78	ICPA2092 × ICP12749	S	S	94.2	66.9	S/*	S/*	S/*	S/*	S/*	S/S	S/S
100	ICPA2092 × PHULET-00-4-11-6-2	S	S	94.2	100.5	S/*	S/*	S/*	S/*	*/S	S/*	S/S
87	ICPA2092 × ICP3407	S	UNS	94.2	45.1	S/*	S/*	S/*	S/*	S/*	S/S	S/S
72	ICPA2092 × BSMR846	S	S	94.2	46.2	S/*	S/*	S/*	S/*	S/*	S/S	S/S

S: stable parent, UNS: unstable parent, S/S: stable hybrid, S/*, */S and */*: unstable hybrid, bi: regression coefficient, S^2di: deviation from regression line, *: bi # 1 or S^2di # 0

DF: days to flower, DM: days to maturity, PH: plant height (cm), PB: primary branches/plant, SB: secondary branches/plant, PP: pods/plant, PW: pods weight/plant (g), SP: seeds/pod, SW:100-seed weight (g)

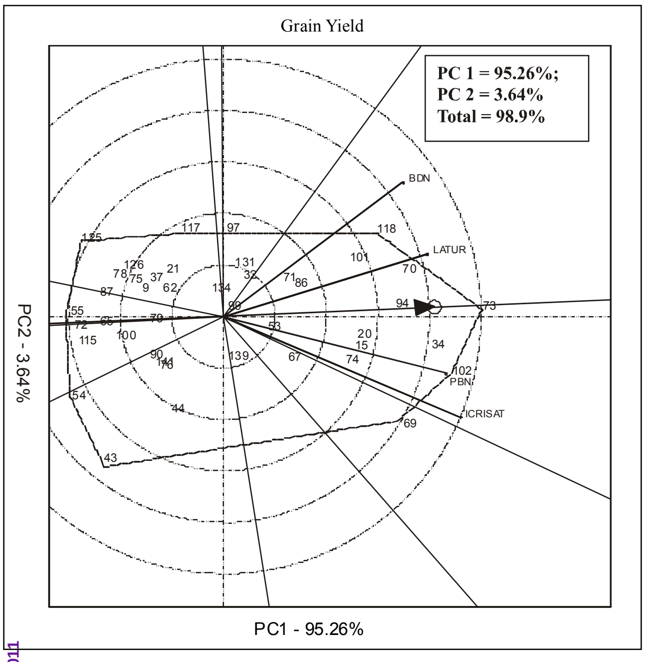
BDN: Badnapur location, PBN: Parbhani location, ICRISAT: Patancheru location, Latur: Latur location of PCA of GEI (genotype × environment interaction) showed that the first two principal components in the biplot explained 98.9% of the total variation in GEI (Cooper and De-lacy 1994). The environment vectors covered a small Euclidean space, indicating that the four environments used in this study represented positive association among the environmental conditions (Fig. 1). To construct a meaningful biplot, PC1 and PC2 eighnvectors were plotted after partitioning of singular values into the genotype and environment eighnvectors. Theoretically, the partitioning factors can take any value between 0 and 1. However, for this analysis a value of 0.5 was used to give equal importance to both the genotypes as well as environments.

Environment evaluation based on GGE biplots: The pattern

Table 8. Pearson correlation between different yield and yield contributing traits at four locations

Variable	Environment	DF	DM	PH	PB	SB	PP	PW	SP	SW	GY
DF	Patancheru	1	0.41**	0.25**	0.12	0.06	0.12	0.13	0.15	-0.07	0.17**
	Parbhani	1	0.66**	0.46**	0.08	0.04	0.29**	0.3**	0.27**	-0.08	0.32**
	Latur	1	0.32	0.08**	-0.02*	-0.18*	0.04	0.04*	-0.01	-0.07*	0.06
	Badnapur	1	0.11	-0.05	-0.17**	0.11	0.15**	0.16**	0.02	-0.01	0.15
DM	Patancheru		1	0.36**	0.04	-0.15	0.04	0.05	0.12	-0.27*	0.11
	Parbhani		1	0.47	-0.15	0.05	0.03	0.08	0.15	-0.18*	0.08
	Latur		1	0.06	-0.16	-0.18*	0.16	0.13	-0.07	-0.05*	0.12
	Badnapur		1	0.08	-0.14	0.03	0.12	0.13	-0.16**	0.03	0.09
PH	Patancheru			1	0.13	-0.02	-0.01	0.01	0.08	-0.13	0.03
	Parbhani			1	-0.05	-0.01	0	0.03	0	-0.21	-0.01
	Latur			1	0.3**	0.04	-0.02	0	0.16*	-0.17*	0.03
	Badnapur			1	0.13	0	0.11	0.06	-0.11	0.02	0.09
PB	Patancheru				1	0.34**	0.29**	0.28**	0.06	0.25	0.26**
	Parbhani				1	0.27**	0.05	0.01	0.02	0.02	-0.01
	Latur				1	0.32*	-0.13	-0.1	0.19*	-0.05	-0.08
	Badnapur				1	0.09	-0.06	-0.08	-0.3**	-0.08	-0.11
SB	Patancheru					1	0.37**	0.35**	0.08**	0.16	0.35**
	Parbhani					1	-0.03	0.02	0.17**	-0.14	0.06
	Latur					1	-0.13	-0.09	-0.04	0.06	-0.08
	Badnapur					1	0.15	0.18*	-0.08	-0.08	0.16
PP	Patancheru						1	0.94**	0.1	0.07	0.92**
	Parbhani						1	0.92**	0.14	0.08*	0.93**
	Latur						1	0.93**	0.11	0.07	0.96**
	Badnapur						1	0.92**	0.09	0.05	0.97**
PW	Patancheru							1	0.24*	0.02	0.95**
	Parbhani							1	0.27**	0.02	0.95**
	Latur							1	0.27**	0.06	0.97**
	Badnapur							1	0.12	0.04	0.91**
SP	Patancheru								1	-0.13	0.36**
	Parbhani								1	0.04	0.34**
	Latur								1	-0.01	0.27**
	Badnapur								1	-0.04	0.25**
SW	Patancheru									1	0.02*
	Parbhani									1	0.05*
	Latur									1	0.05
	Badnapur									1	0.05
GY	Patancheru										1
	Parbhani										1
	Latur										1
	Badnapur										1

DF: days to flowering (no.), DM: days to maturity (no.), PH: plant height (cm), PB: primary branches/plant (no.), SB: secondary branches/plant (no.), PP: pods/plant (no.), PW: pods weight/plant (g), SP: seeds/pod (no.), SW:100-seed weight (g)



BDN: Badnapur location, PBN: Parbhani location, ICRISAT: Patancheru location, Latur: Latur location

Fig 1. The environment-vector view of the GGE biplot to show similarities among test environments in discriminating the genotypes

of environment in the biplots (Fig. 1) suggests that all the environments were clustered in one group. In present study, as the angle between any two environments was less than 90^0, it suggested that GE was moderately small and these environments tend to discriminate among genotypes in a similar manner. The Latur and Badnapur environment vectors positioned above the Average Environment Axis (AEA) with smaller angle (<45°) between them indicated presence of positive correlation between them. Similarly, the Patancheru and Parbhani environment vectors were found below the AEA and were positively correlated. This indicated that stability could be assessed by testing either Latur or Badnapur and Patancheru or Parbhani. Patancheru had the longest environment vector which demonstrated more discriminating ability than other environments. The environments of Parbhani and Latur were most discriminating among with smaller angle with the AEA and the genotypes nearer to these two environment vectors exhibited stability for grain yield; whereas Patancheru and Badnapur had larger angle with AEA and these were classified as discriminating. The non-representative test environments and genotypes evaluated in these environments had specific adaptation.

Evaluation of genotypes based on GGE biplots: The position and perpendicular projection of genotypic points onto an environmental vector can be used to identify a genotype or genotypes having specific adaptation in that environment (Yan *et al*. 2000). The genotypes that are farther along the positive direction of the vector tend to give higher yields, and are better adapted to those environments. Among the parents, 'HPL 24-63' was away from AEA and near to Badnapur and Latur indicating their specific adaptability to both the environment (Fig. 1). On the contrary, 'ICPA 2043', 'PHULET-00-4-11-6-2' and 'ICP 3963' had a mean yield similar to the mean of the parents with less angle with AEA exhibiting general adaptability. The parents 'ICP 10934' and 'AKT 8811' recorded grain yield below mean and had longest distance from the AEA indicating their specific adaptability under stress environments of Badnapur and Latur, whereas 'BSMR 571' had low mean and near to AEA indicating their general adaptability. The hybrid 'ICPA 2092' × 'BSMR 164' had the highest mean yield and it was placed on AEA indicating their general stability followed by 'ICPA 2043' × 'ICP 3514', 'ICPA 2043' × 'ICP 3475' and 'ICPA 2043' × 'ICP 10934'. The hybrid 'ICPA 2047' × 'ICPL 20106' had above average mean, and it was away from AEA and situated exactly on Latur vector indicating their specific adaptability. Similarly, hybrid 'ICPA 2043' × 'ICP 3514' had specific adaptability to Parbhani while 'ICPA 2047' × 'ICP 3374' to Patancheru. The hybrid 'ICPA 2092' × 'PHULE T-00-4-11-6-2' had low mean and it was was near to AEA indicating its general adaptability under stress environmental conditions.

Seed yield is complex character and the analysis of individual yield component can lead to simplification in explaining the stability for seed yield. The stable genotypes identified could be used as parents in the future breeding programmes for developing suitable genotypes with wider adaptability. Analysis of stability of component characters revealed that yield stability in the parents 'PHULE T-00-1-25-1', 'PHULE T-00-4-11-6-2', 'ICP 3963', 'ICP 10934' and 'ICP 3514' might be due to the high mean performance and non-significant values of bi and S^2di. The study of yield stability of 'ICPA 2043' derived hybrids with component characters revealed that the parents with high *per se* performance and general adaptability produced stable hybrids which can be grown across the four environments. In contrast 'ICPA 2047' and 'ICPA 2092' derived hybrids were stable for yield. The stable hybrids derived from 'ICPA 2047' and 'ICPA 2092' had parents with high × low *per se* performance and general and specific adaptability.

The critical examination of stability of parents and cross combinations reveals interesting information on the role of component characters in imparting yield stability. Three crosses 'ICPA 2043' × 'ICPL 20106', 'ICPA 2047' × 'ICPL 20106' and 'ICPA 2092' × 'BSMR 203' exhibited high plasticity (predictable G × E interaction) for yield component traits. The cultivars lacking stability for yield were characterized by unpredictable G × E interaction. Bradshaw (1965) suggested that minimum fitness could be obtained by adjustment in the plastic component traits. In a homeostastically buffered population, expression of component traits can shift in the compensating manner in changing environment in order to perform for the final traits.

From the present investigation, it is concluded that superior performing parents 'HPL 24-63', 'ICP 3963', 'ICPA 2043', 'PHULE T-00-4-11-6-2' and 'ICP 10934' were stable over four locations for yield and its important components and could be used for developing stable hybrids. Even though as many stable hybrids were identified among the hybrids, the most high yielding potential stable hybrids were 'ICPA 2043' × 'ICPL 20106', 'ICPA 2047' × 'ICPL 20106', 'ICPA 2092' × 'AKT 9913' and 'ICPA 2092' × 'BSMR 203' across the four different environmental conditions since they possessed favorable combination of all stability parameters or ideal stability values with significant desired mean performance levels over both promising checks 'BSMR 736' and 'CPH 2671' for yield and its important components.

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