Indian Journal of Agricultural Sciences **92** (8): 931–935, August 2022/Article
https://doi.org/10.56093/ijas.v92i8.86669

Simultaneous selection for yield and stability of Chickpea (*Cicer arietinum*) germplasm through AMMI based parameters

T LAKSHMI PATHY[1]*, A TRIVIKRAMA REDDY[2], JAYARAME GOWDA[3], V JAYALAKSHMI[4] and A VIJAYABHARATHI[5]

University of Agricultural Sciences, Bengaluru, Karnataka 560 065, India

Received: 01 February 2019; Accepted: 31 March 2022

ABSTRACT

Identifying a stable variety is essential before recommending it for cultivation at a particular location. In the present study, 23 chickpea (*Cicer arietinum* L.) genotypes were evaluated for pod yield per plot in randomized complete block design at Hebbal, Gouribidanur, and Nandyal during 2015–17. Among the three environments, Nandyal had the highest environmental index with a high mean yield. Pooled analysis of variance indicated significant differences due to environment, genotypes, and their interaction, necessitating the selection of genotypes with general and specific adaptation. AMMI (Additive main effects and multiplicative interaction) analysis extracted two significant principal components which explained all the variation. Univariate parametric measures like Francis' coefficient of variation, Wricke's ecovalence, Lin and Binns' superiority index, Eberhart and Russel's regression coefficient (b_i), and deviation from linearity (S^2d_i) were estimated along with AMMI based parameters, which include either one or both significant principal components. Most of these measures had similar rankings for genotypes. Rank sums were calculated for genotypes over these stability parameters, where DCP-92-3, BG-212, and KAK-2 had the best ranks. Simultaneous selection indices were constructed assigning equal weightage to yield and stability for each of the AMMI-based parameters, and the genotypes DCP-92-3, BG-212, and KAK-2 had the highest index values. All the analyses were performed in R studio. Based on the above measures, it can be concluded that these three genotypes are stable and can be cultivated to obtain stable yields across environments.

Keywords: Additive main effects, Chickpea, Environmental index, Multiplicative interaction, Simultaneous selection indices

Assessing the stability of a particular genotype is a prerequisite before releasing it for commercial cultivation. Varieties differ in their ranks across environments, indicating their differential performance and adaptation to a specific environment. This type of interaction is cross-over interaction and is the most prevalent. This poses a challenge of selecting varieties that are stable across environments, and those suitable for particular environments. Hence, multi-environmental trials help breeder identify the variety suited to a particular environment.

Additive main effects and multiplicative interaction (AMMI) model uses ordinary ANOVA to analyze main effects, and the principal component to analyze the non-additive residual leftover by the ANOVA model (Zobel *et al*. 1988, Gauch 1992). This model can effectively dissect the additive and multiplicative effects and depict them in the form of a biplot, where the PC1 is plotted against PC2. AMMI stability value (ASV) is one of the measures developed out of the first two PCs, which effectively estimates the distance of a particular entity from the origin. But when there are more PCs that are significant and when the first two PCs explain less variation, then a simple biplot is not effective to conclude. Hence, various measures have been derived from AMMI IPC scores, which estimate the position of a particular genotype considering all the significant PCs.

The practical interest of combining high levels of mean yield and yield stability has led to the development of the yield reliability concept (Eskridge 1990, Kang and Pham 1991), where a reliable genotype is characterized by having consistently high yield across environments (Annicchiarico 2002). Therefore, an optimum combination of yield and stability is required for a variety to sustain in cultivation. Many researchers have developed simultaneous selection indices that combine both yield and stability and therefore identify a superior genotype for both attributes. Rao and Prabakaran (2005) used ASTAB to develop a simultaneous

[1]ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu; [2]Andhra Pradesh State Seed Certification Authority, Guntur, Andhra Pradesh; [3]University of Agricultural Sciences, Bengaluru, Karnataka; [4]Acharya N G Ranga Agricultural University, Hyderabad, Telangana; [5]Ravi Hybrid Seeds Pvt Ltd, Hyderabad, Telangana. *Corresponding author email: pathy4u76@gmail.com

selection index, which can deploy differential weights for yield and stability and selects the genotypes upon. In the present study, 23 chickpea (*Cicer arietinum* L.) genotypes were evaluated for pod yield per plot to identify a stable variety.

MATERIALS AND METHODS

Twenty three genotypes, including three checks, viz. JG-11 JAKI-9218 and KAK-2 were selected based on their seed yield per plant in rainy (*kharif*) season 2015 and winter (*rabi*) season 2016 for germplasm evaluation and also to study their reaction to dry root rot disease based on field screening.

The seeds of 23 chickpea genotypes were sown in randomized complete block design (RCBD) with two replications at three locations, viz. GKVK-Bengaluru, Regional Agricultural Research Station (RARS)-Nandyal, Farmers' field at Viduraswatha village, Gouribidanur during winter (*rabi*) season 2016–17. Each genotype was sown in four rows of 4 m length with a row-to-row spacing of 30 cm maintaining an inter-plant distance of 10 cm. All the recommended management practices were followed during the crop growth period to raise a healthy crop. Data were recorded in both replications on pod yield per plot (g) where the weight of the yield was recorded from each plot.

A few univariate parametric measures, such as coefficient of variation (CV) (Francis and Kannenberg 1978), Shukla's stability variance (ri^2) (1972), Wricke's Ecovalence (Wi) (1962), superiority measure (P_i) (Lin and Binns 1988), and Eberhart and Russel's regression coefficient (b_i) and deviation from linearity (S^2d_i) were calculated from the data. The genotypes whose regression coefficients did not significantly differ from unity were determined using the P value. However, the above measures did not account for the multiplicative effects of the interaction. Hence, the Additive effects and multiplicative interaction (AMMI) model was deployed and the number of principal components that explained most of the variation was determined. A large number of parameters were determined based on the AMMI statistics, which include one, two, and all of the significant principal components. The loading scores of IPCs were used to estimate these parameters. These parameters determine the stability of genotypes by estimating their distance from the origin in the plot, irrespective of several dimensions. This method is most useful when the number of locations or years or both are high, which essentially produces more

Table 1 Univariate stability statistics for 23 chickpea genotypes

		Standard deviation	Coefficient of variation	Regression coefficient				Stability variance	Ecovalence	Superiority measure
Genotype	Mean	Sd	CV(%)	b_i	S^2d_i	t value*	P value	ri^2	Wi	Pi
ICCV-07305	1070.50	492.44	46.00	0.74	1218.38	-3.26	<0.01	30899.96	66421.17	1142223.21
ICCV-10110	1540.67	1084.84	70.41	1.62	57044.99	7.72	<0.01	211627.39	396445.17	618555.42
ICC-19830	1975.83	679.78	34.40	0.79	378556.63	-2.68	0.01	226963.10	424449.50	232177.71
ICC-19336	1166.67	366.17	31.39	0.54	11327.91	-5.80	<0.01	107163.31	205684.67	1017892.08
RVSSG-10	1647.33	556.58	33.79	0.49	399998.26	-6.32	<0.01	339216.79	629434.50	545015.25
KBG-36	1749.83	947.51	54.15	1.39	86450.03	4.93	<0.01	119607.31	228408.50	387404.21
GNG-1958	2289.67	703.15	30.71	0.91	259656.47	-1.14	0.27	143716.06	272433.17	73080.17
PBC-1103	2227.67	834.05	37.44	1.14	248025.79	1.75	0.09	142744.03	270658.17	127313.42
DCP-92-3	1704.00	583.40	34.24	0.88	-3792.52	-1.49	0.15	2326.02	14242.67	383462.25
KAK-2	1514.33	693.28	45.78	1.04	16456.17	0.45	0.66	7171.81	23091.50	578575.08
BG-2094	1588.50	480.70	30.26	0.70	27370.99	-3.75	<0.01	55684.10	111679.17	508528.04
GNG-1969	1723.67	434.13	25.19	0.53	127690.02	-5.91	<0.01	174546.46	328732.17	399945.42
JG-62	1670.33	962.23	57.61	1.45	873.14	5.65	<0.01	95825.31	184980.50	461462.08
IPC-02-248	1884.83	749.26	39.75	1.11	34707.26	1.40	0.18	22550.60	51174.50	260906.71
L-550	1414.67	497.05	35.14	0.75	1295.20	-3.18	<0.01	29222.06	63357.17	681831.75
JG-11	2046.00	861.58	42.11	1.29	13340.47	3.67	<0.01	46225.63	94407.17	172567.75
GNG-1499	1205.83	263.91	21.89	0.40	-3524.56	-7.55	<0.01	170625.14	321571.50	983512.13
JAKI-9218	1963.00	1137.37	57.94	1.72	-5462.82	8.98	<0.01	242313.77	452481.17	288402.17
RKG-155	2034.50	597.11	29.35	0.74	231553.59	-3.29	<0.01	157473.07	297554.67	206540.38
PG-06102	1922.50	920.59	47.88	1.39	7590.92	4.82	<0.01	73078.40	143442.67	256206.38
BG-212	1562.83	566.52	36.25	0.86	-4841.77	-1.81	0.08	4894.81	18933.50	517501.21
Phule G 0215-2	1883.50	881.55	46.80	1.28	107763.88	3.53	<0.01	94892.53	183277.17	292439.21
GCP-105	2014.00	897.15	44.55	1.26	208954.44	3.28	<0.01	144949.84	274686.17	202722.42

**t*-value under H_0:b_i=1

number of significant PCs. A simple biplot, which is the output of conventional AMMI analysis explains the loadings of the first two PCs, ignoring other significant PCs. These AMMI-based parameters include ASI, AVAMGE, DA, DZ, EV, FA, ASV, SIPC and Za (Ajay *et al*. 2018). Simultaneous selection indices (SSI) were calculated using each of the above AMMI parameters, where Rao and Prabakaran (2005) equation was extrapolated to all the measures. Hence, there are as many SSIs as the number of AMMI measures. While estimating SSIs, equal weightage was assigned to yield and stability and the genotypes having the highest value of the index were ranked first. All the analyses were performed using R studio through various packages.

RESULTS AND DISCUSSION

Twenty chickpea genotypes along with three standards were analyzed for their yield stability by the AMMI model and other related parameters. Analysis of variance (ANOVA) indicated that genotypes, environments and genotype-environment interaction were significant indicating that differences existed among entries, locations, and their interaction, respectively. Out of the above-mentioned significant components, locations explained nearly 62% of the variation, while genotypes and their interaction component contributed to 21% and 15%, respectively, of the total variation in the data. These findings are in agreement with the findings reported by Rao (2011), Rao and Rao (2014), Yadav *et al*. (2014) and Tilahun *et al*. (2015). As the entries were tested in three locations, two principal components were extracted and both were significant according to Gollob's F-test explaining all the variation accounted by the G × E component. Environmental means were highest for Nandyal, followed by Gouribidanur and MRS, Hebbal, which also indicated a significant difference in ANOVA. The pooled mean yield of the entries over locations ranged from 2289.7 to 1070.5, with GNG-1958 being the highest followed by PBC-1103. The rank difference of the genotypes among the locations indicated the presence of a cross-over interaction.

CV was least for GNG-1499 followed by GNG-1969 and RKG-155, where Shukla's stability variance and Wricke's ecovalence gave similar ranks to genotypes in which DCP-92-3 had the least rank followed by BG-212 and KAK-2. Superiority index measure gave completely different result from the above, the genotypes with the highest yield, viz. GNG-1958, PBC-1103, and JG-11 were the best having the lowest value. Eberhart and Russell's parameters like regression coefficient, deviation from linearity indicated genotypes GNG-1958, PBC-1103, DCP-92-3, KAK-2, IPC-02-248 and BG-212 as stable. These genotypes had regression coefficients near to unity, and the P values greater than 0.05 suggested that these don't differ significantly from one. S^2d_i values of these entries were also low, indicating their minimum deviance from linearity (Table 1).

All the AMMI-based stability parameters estimated from two principal components, suggested the genotypes DCP-92-3, KAK-2 and BG-212 as the most stable by virtue of them being present in the top three of all the parameters. However, their relative rankings varied among the estimates. ASI ranked DCP-92-3 as first followed by KAK-2 and BG-212, while in a majority of parameters, viz. ASTAB, AVAMGE, DA, DZ, EV and FA, DCP-92-3 ranked first followed by BG-212 and KAK-2, wherein the rest, viz. SIPC and Za, KAK-2, topped followed by DCP-92-3 and BG-212. The genotype DCP-92-3 consistently ranked as the most stable in eight of ten parameters. The genotypes RVSSG-10 and JAKI-9218 were the least stable in the present study, as these had the largest ranks in all the estimates.

Rank sums (RS) of the genotypes over the AMMI measures give an indication of genotype rank across the parameters. RS was calculated by estimating ranks of sums over all the measures where DCP-92-3 had the lowest RS followed by BG-212 and KAK-2. DCP-92-3 ranked best and KAK-2 ranked next best in most of the measures. However, these three genotypes had a moderate yield (below the general mean yield of 1730.5). The highest yielders like GNG-1958 and PBC-1103 had RS values of 15 and 13.5, respectively, indicating their moderate stability.

To make a compromise between yield and stability, simultaneous stability indices (SSI) were constructed and estimated according to Rao and Prabakaran (2005). These indices were calculated for each parameter separately unlike Rao and Prabakaran (2005), where ASTAB alone was used in SSI. While constructing SSIs, equal weightage was given to yield and stability, because the main emphasis here was to obtain genotypes having high yield with stability as well. In nine out of ten SSIs estimated (except for SSI_Za), DCP-92-3 ranked first indicating its stable performance for yield and stability as a whole whereas, BG-212 and KAK-2 were the next best entries. This is also evident from the Rank sums (RS) calculated across all the SSIs. DCP-92-3 despite having moderate yield is highly stable hence can be recommended for cultivation in marginal or low input environments for sustainable agriculture and returns to the farmers. The genotypes GNG-1499, RVSSG-10 and ICC-19936 had the highest RS, deferring their suitability for cultivation. RVSSG-10 although having a moderate yield, is least stable across locations indicating its prolific dependency on the environment and its fluctuations (Table 2).

The environmental index for the three locations was also calculated, in which the Nandyal center had a high positive value where the other two displayed negative values, suggesting favorable conditions at the former. The high mean values of most of the genotypes are attributed to their high yield at this location. PBC-1103 is the only genotype that ranked among the top three among the three test centers. Hence, this genotype along with GNG-1958 can be recommended for high input conditions like Nandyal. The most stable genotype DCP-92-3 had a yield on par with that of the mean yield of all the locations individually, justifying its plasticity. RVSSG-10 and GNG-1499, had lower yields in Nandyal, suggesting their inability to make

Table 2 AMMI based measures and their corresponding simultaneous selection indices for 23 genotypes of chickpea

Genotype	Mean	ASI	SSI	ASTAB	SSI	AVAMGE	SSI	DA	SSI	DZ	SSI	EV	SSI	FA	SSI	MASV	SSI	SIPC	SSI	Za	SSI
ICCV-07305	1070.50	3.31	1.88	41.27	1.82	388.33	1.93	257.72	1.91	0.16	1.92	0.01	1.83	66421.17	1.80	7.32	1.88	8.99	1.81	0.11	1.78
ICCV-10110	1540.67	8.44	1.38	238.53	1.10	970.33	1.42	629.64	1.42	0.38	1.44	0.07	1.11	396445.17	1.09	18.65	1.38	17.15	1.51	0.23	1.47
ICC-19830	1975.83	7.57	1.69	280.58	1.32	1022.00	1.64	651.50	1.65	0.43	1.63	0.09	1.31	424449.50	1.33	16.75	1.69	17.02	1.77	0.20	1.81
ICC-19336	1166.67	5.85	1.39	127.39	1.06	692.67	1.41	453.52	1.41	0.28	1.42	0.04	1.07	205684.67	1.06	12.93	1.39	15.71	1.35	0.20	1.34
RVSSG-10	1647.33	10.17	1.36	391.57	1.08	1273.00	1.35	793.37	1.37	0.49	1.37	0.12	1.08	629434.50	1.08	22.48	1.36	27.76	1.34	0.35	1.33
KBG-36	1749.83	6.30	1.67	139.25	1.37	709.00	1.73	477.92	1.71	0.29	1.73	0.04	1.38	228408.50	1.36	13.92	1.67	15.51	1.70	0.20	1.67
GNG-1958	2289.67	6.08	2.01	179.81	1.60	774.33	1.98	521.95	1.96	0.34	1.93	0.06	1.59	272433.17	1.61	13.46	2.01	14.99	2.03	0.18	2.07
PBC-1103	2227.67	6.05	1.98	178.89	1.56	800.67	1.92	520.25	1.93	0.34	1.90	0.06	1.55	270658.17	1.58	13.38	1.98	13.90	2.05	0.16	2.10
DCP-92-3	1704.00	1.53	3.71	8.87	6.56	177.33	3.86	119.34	3.77	0.07	3.79	0.01	6.61	14242.67	6.51	3.37	3.71	4.19	3.53	0.05	3.49
KAK-2	1514.33	1.77	3.23	15.26	4.12	231.00	3.08	151.96	3.06	0.10	2.96	0.01	3.97	23091.50	4.28	3.91	3.23	4.18	3.43	0.05	3.58
BG-2094	1588.50	4.45	1.85	67.61	1.65	478.33	1.98	334.18	1.91	0.20	1.95	0.02	1.68	111679.17	1.62	9.82	1.86	10.23	1.96	0.13	1.91
GNG-1969	1723.67	7.00	1.59	211.30	1.23	898.33	1.56	573.35	1.57	0.37	1.56	0.07	1.23	328732.17	1.24	15.47	1.59	20.05	1.53	0.25	1.53
JG-62	1670.33	5.62	1.71	113.56	1.40	679.00	1.72	430.09	1.74	0.26	1.76	0.03	1.41	184980.50	1.39	12.41	1.71	14.48	1.70	0.19	1.68
IPC-02-248	1884.83	2.64	2.66	33.73	2.56	367.00	2.48	226.22	2.56	0.15	2.49	0.01	2.49	51174.50	2.63	5.85	2.66	6.73	2.67	0.08	2.75
L-550	1414.67	3.23	2.11	39.40	2.07	377.67	2.17	251.71	2.14	0.16	2.15	0.01	2.09	63357.17	2.06	7.14	2.11	8.80	2.03	0.11	2.01
JG-11	2046.00	3.87	2.26	59.43	2.02	437.33	2.35	307.26	2.26	0.19	2.26	0.02	2.01	94407.17	2.02	8.56	2.26	10.90	2.16	0.14	2.15
GNG-1499	1205.83	7.57	1.25	194.14	0.95	926.00	1.25	567.07	1.28	0.34	1.31	0.06	0.96	321571.50	0.94	16.73	1.25	16.72	1.34	0.22	1.30
JAKI-9218	1963.00	8.93	1.60	274.41	1.31	1094.67	1.60	672.67	1.63	0.41	1.65	0.08	1.32	452481.17	1.31	19.73	1.60	20.96	1.64	0.27	1.62
RKG-155	2034.50	6.83	1.79	188.14	1.44	890.67	1.75	545.49	1.78	0.35	1.78	0.06	1.44	297554.67	1.44	15.10	1.79	19.38	1.73	0.24	1.72
PG-06102	1922.50	4.88	1.96	88.98	1.67	574.67	2.00	378.74	1.99	0.24	2.00	0.03	1.67	143442.67	1.66	10.78	1.97	13.17	1.92	0.17	1.91
BG-212	1562.83	1.80	3.22	11.63	5.16	217.00	3.25	137.60	3.32	0.08	3.37	0.01	5.26	18933.50	5.06	3.97	3.22	4.64	3.20	0.06	3.14
Phule G 0215-2	1883.50	5.08	1.91	119.72	1.50	697.33	1.82	428.11	1.86	0.28	1.84	0.04	1.49	183277.17	1.52	11.24	1.91	14.06	1.85	0.17	1.87
GCP-105	2014.00	6.58	1.80	173.35	1.45	855.33	1.76	524.11	1.80	0.33	1.80	0.05	1.45	274686.17	1.45	14.55	1.80	18.61	1.74	0.23	1.73

use of favorable conditions and hence not recommended for cultivation in such areas.

Analyzing yield stability of 23 chickpea genotypes over three locations through the AMMI model and its related parameters indicated that the locations played a major role in explaining most of the variation in the data. The interaction between genotypes and environment was also significant, thereby providing scope for selecting genotypes with general and specific adaptation. The genotype DCP-92-3 was found stable in almost all the parameters and indices constructed thereof, however further trials need to be conducted at a large number of environments over years to ascertain and confirm the stability of the variety before recommending it for cultivation.

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