Indian J. Genet., 80(2) 173-178 (2020)
DOI: 10.31742/IJGPB.80.2.7

Estimation of G x E interaction by AMMI model in some elite pigeonpea [*Cajanus cajan* (L.) Millspaugh] genotypes

Amit Kumar Gaur*, S. K. Verma, R. K. Panwar and R. K. Sharma[1]

Department of Genetics and Plant Breeding, GBPUA&T, Pantnagar, Uttarakhand 263 145; [1]Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

(Received: September 2019; Revised: April 2020; Accepted: April 2020)

Abstract

The G x E interaction was studied in pigeonpea genotypes using AMMI model. The results indicated that main effects as well as G x E interaction effects were significant for most of the traits. Major portion of the G x E was contributed by the genotypes. AMMI model having two principle components axis was found as the best predictive model in this study. AMMI biplots, ASV and YSV indicated PA 620 to be the most stable genotype for seed yield and number of secondary branches per plant during all the three years of testing.

Key words: AMMI, G x E interaction, pigeonpea, stability

Introduction

Pigeonpea [*Cajanus cajan* (L.) Millspaugh] commonly known as red gram, tur and arhar is the second most important pulse crop after chickpea and occupies an important place under rainfed agriculture (Saxena et al. 2010). Pigeonpea can be grown under diverse climatic conditions and can also be intercropped with other crops without any allelopathic effect (Baskaran and Muthaiah 2005). India contributes about 85% of world's pigeonpea production and consumption (Danekar et al. 2014). In India it is annually grown on 4.43 million hectare area with an annual production of 4.25 million tones (Mt) at a productivity level of 960 kg/ha during 2017-18 (Anonymous 2018). This crop is a boon for the resource poor farmers as it can be grown with minimum inputs and fetches high price in market. In order to make it popular among farming community, it is very important to increase its productivity by developing area-specific high yielding varieties and their suitable cultivation practices. The genotype x environment interaction is an important part of plant breeding (Freeman, 1985). A stable variety must have high mean yield with low genotype x environment interaction when grown under changing environmental conditions. For precise and reliable selection of genotypes both yield and stability must be considered simultaneously (Sara et al. 2019). Becker and Leon (1988) defined a stable genotype as "one possessing a constant performance irrespective of any changes in environmental conditions". An ideal genotype for rainfed conditions must combine reasonably high yield potential with stress-specific traits those buffer yield against severe moisture stress (Blum 1983).

The additive main effects and the multiplicative interaction analysis (AMMI) model are used extensively by researchers to study G x E interaction in different crops (Singh et al. 2000; Jha et al. 2013). AMMI model clearly discriminate main effects and interaction effects as it combines analysis of variance with principal component analysis and makes reliable yield estimations in multi-location trials (Gauch 1988, 1992 and 2006; Yan and Rajcan 2002). Stability *per se* should not be used as the only selection criteria to select desirable genotypes as most of stable genotypes would not necessary give the high yield performance (Mohammadi et al. 2007). There is an approach that incorporates both mean performance as well as stability in a single index called as Yield Stability Index (YSI), which can be used for simultaneous selection of high yield and stability (Eskridge 1990; Kang 1993; Bajpai and Prabhakaran 2000). Hence, considering the reliability and effectiveness of AMMI model along with YSI are

---

*Corresponding author's e-mail: gaur.amit.823@gmail.com

Published by the Indian Society of Genetics & Plant Breeding, A-Block, F2, First Floor, NASC Complex, IARI P.O., Pusa Campus, New Delhi 110 012; Online management by www.isgpb.org; indianjournals.com

important parameters to identify stable genotypes. Keeping these points in mind a study was conducted during three consecutive cropping seasons (*kharif* 2016-2018) to identify the stable breeding lines of pigeonpea for yield and important yield components under the varying environmental conditions of *tarai* region.

Materials and methods

The experimental site geographically falls in the humid sub-tropical climate zone situated at 29.5° North latitude, 79.3° East longitudes at an altitude of 243.84m above mean sea level. The climatic condition remains highly variable in this *tarai* region during different years (Supplementary Figs. 1, 2 and 3). The experimental material comprised of eleven genotypes namely, *viz*., Pusa 992, Paras, UPAS 120, Pant A 291, PA 620, PA 622, PA 623, PA 624, PA 625, PA 626 and PA 627 that included the released varieties and high yielding breeding lines. The experiment was laid down in a Randomized Block Design with three replications in same plot at the N. E. B. Crop Research Centre, GBPUA&T, Pantnagar for three consecutive years during *kharif*, 2016-17, 2017-18 and 2018-19 following the recommended package of practices to raise a normal and healthy crop. The observations were recorded on seed yield and yield contributing traits *viz*., plant height (cm), no. of primary branches per plant, no. of secondary branches per plant, no. of pods per plant, no. of seed per pod, 100-seed weight (g) and seed yield/plant (g). The AMMI model was used to analyse the G x E interactions (Gauch, 1992). The planting seasons during three consecutive years treated as environments [Environment I (2016-17), Environment II (2017-18) and Environment III (2018-19). An F-test devised by Gollob (1968) was used to test the significance of main effects as well as interaction effects. All the statistical analysis related to AMMI model as well as constructions of biplots were performed on GEA-R (2017) Version 4.1 software available at www.cimmyt. org. AMMI stability values (ASV) were also estimated to rank the genotypes according to their stability (Purchase et al. 2000). The Yield Stability Index incorporating both mean yield and stability in a single index was used to identify stable genotypes with high seed yield (Kang 1993; Bajpai and Prabhakaran 2000; Bose et al. 2014).

Results and discussion

Analysis of Variance (ANOVA) of AMMI Model

The ANOVA revealed that for all the traits under study, the G x E interaction was found to be significant except for no. of seeds per pod and 100-seed weight (Table 1). It clearly indicated that climatic conditions influence the seed yield to a large extent in pigeonpea. Significant main effects (environment and genotype) and G x E interaction effect indicated that traits were influenced by both main effects as well as their interactions. The number of seeds per pod and 100-seed weight was not analysed further as G x E was non-significant. In pigeonpea, the significance of main effects (environment and genotype) as well as G x E interaction effects for no. of primary branches and no. of pods per plant were also reported earlier by Singh et al. (2018) while for seed yield per plant by several researchers (Chauhan et al. 1998 1999; Wamatu and Thomas 2002; Muniswamy et al. 2018; Singh et al. 2018). In all studied traits, major portion of total sum of squares (TSS) was contributed by genotypic effects indicating that genotypes under study were diverse and the large differences between genotypic means resulted in variation in the traits. However, the effects by G x E component cannot be ignored as all the studied traits except no. of seeds per pod and 100-seed weight have significant G x E interaction effect. The effects by environment were small as compared to genotype and G x E effects for all the traits but still exhibited significance except for two traits, no. of seeds per pod and 100-seed weight where small and non-significant effects were reported. The significance of environment effect indicated that the environments under study were variable. The sum of squares due to G x E interaction were further partitioned into two principal component axis i.e. IPCA I and IPCA II accounting for 100 per cent of the G x E interaction sum of squares and uses entire degrees of freedom available in the interaction. Thus, in the present study AMMI having two principle components axis *i.e*., IPCA I and IPCA II is the best predictive model. The AMMI having two principle components axis is also considered as best predictive model earlier by Zobel et al. (1988). The detailed discussion of ANOVA for different yield and yield attributing traits is presented in Table 1.

In general, it is evident from the Table 1 that for all the traits studied, the major portion of TSS was contributed by genotype followed by G x E and least by environment. These results indicated that variation exhibited by these traits was largely due to the difference between genotypic mean, however the larger contribution of G x E interaction than the environment suggested the differential response of environments towards genotypes. In all the studied traits AMMI having two principal component axis (IPCA I and IPCA II) was found as best predictive model with IPCA I accounting for major portion of G x E sum of squares. As far as seed yield is concerned, a close perusal of the Table 1 also revealed that for seed yield per plant, 50.88% of TSS was attributable to genotypic effects, 41.71% to G x E effects and 7.41% to environment effect. The IPCA I accounted for 88.61% of the genotype x environment interaction while the IPCA II accounted for 11.39% of G x E interaction. The major contribution of genotypes towards the total sum of squares for yield per plant and other important components has also been reported earlier (Thangavel et al. 2011; Rashidi et al. 2013; Tolessa et al. 2013; Singh et al. 2018; Horn et al. 2018).

Stability analysis on basis of AMMI biplots and ASV values

AMMI biplots are used by researchers to diagnose the G x E interaction pattern in the forms of graph. These biplots provide a visual inspection and interpretation of the G x E interaction (Gabriel 1971). AMMI biplots are of two type *i.e.*, AMMI I and AMMI II. In case of AMMI I biplots, genotype and environment mean (main effects) are plotted on the X-axis against IPCA I score of both genotype and environment on the Y-axis (Vargas and Crossa 2000). In case of AMMI II biplot IPCA I score of both genotype and environment are plotted against IPCA II score of genotype and environment. In AMMI I biplot genotypes or environments having large IPCA 1 scores (either positive or negative) possess high interactions and hence considered as less stable; whereas IPCA 1 scores close to zero have small interactions and hence, considered more stable. In AMMI biplot II, the genotypes near the origin are non-sensitive to environmental interaction hence are more stable and those distant from origin are sensitive and have large interaction. If the IPCA I score of genotype and environment possess same sign, it produces positive interaction effects (high mean performance in that environment), whereas if they have opposite signs negative interactions (low mean in that environment) is produced. AMMI stability values (ASV) ranked the different genotypes on basis of their yield stability (Purchase et al. 2000). In ASV method, a genotype with least ASV value will be considered as most stable. Another technique known as Yield stability index was used to identify high yielding and stable genotypes. The genotype with lowest YSI is considered to be most stable with high grain yield (Bose et al. 2014).

In case of plant height on basis of low IPCA I score, near to origin position of genotypes on AMMI II biplot and least ASV value, genotype UPAS 120 (IPCA I, 0.12; ASV, 0.51) was ranked as best in terms of stability, while genotype PA 625 (IPCA I, 0.19; ASV, 0.59) ranked second for plant height (Table 2). UPAS 120 (219.33 cm) also marked as most desirable genotype as it had above average mean for plant height as compared to general mean (209.67 cm) along with top most ASV rank. Among the genotypes, PA 622 and PA 626 and in case of environments, the

Table 1. ANOVA of AMMI showing different variance component and their per cent contribution

Source of variation	*d.f.*	Plant height (cm)		No. of primary branches		No. of secondary branches		No. of pods/plant		No. of seeds/pod		100- Seed weight (g)		Seed yield/ plant (g)	
		MSS	Explained (%)	MSS	Explained (%)	MSS	Explained (%)	MSS	Explained (%)	MSS	Explained (%)	MSS	Explained (%)	MSS	Explained (%)
Environment	2	1991.81**	19.03	95.67**	27.56	23.8**	6.38	3406.37**	18.79	0.03	0.41	0.07	0.60	102.10**	7.41
Genotype	10	1104.31**	52.76	25.79**	37.14	39.51**	52.96	1750.76**	48.29	1.43**	84.11	2.35**	95.82	140.29**	50.88
G x E	20	295.14**	28.20	12.25**	35.29	15.16**	40.64	596.38**	32.90	0.13	15.47	0.04	3.57	57.51**	41.71
PC1	11	403.31**	75.16	18.80**	84.39	25.15**	91.23	677.54**	62.48	0.23**	97.64	0.07	89.77063	92.64**	88.61
PC2	9	162.92**	24.84	4.25**	15.60	2.95	8.76	497.18**	37.51	0.0069	2.35	0.01	10.22937	14.55	11.39
Error	66	50.70		1.82		2.85		43.59		0.08		0.09		19.17	

where, SS = Sum of Square; MSS = Mean Sum of Square, PC = Principle Component, **significant at 1%, *significant at 5% level environment III reported positive IPCA I scores along with high average mean for plant height (Table 2). Hence environment III can be considered as favourable environment for the genotypes PA 622 and PA 626. The genotype PA 620 and environment I reported negative IPCA I scores along with high average mean for plant height indicating that environment I was most suitable for the genotype PA 620.

For no. of primary branches, genotype PA 622 (IPCA I, -0.24; ASV, 1.36) ranked as most stable while PA 625 (IPCA I,-0.29; ASV, 1.59) ranked as second most stable genotype. The genotype PA 622 (11.89) was identified as most desirable as its mean for number of primary branches was higher than the general mean (10.65) along with top most ASV rank. Among the genotypes, PA 627 and in case of environments, environment III reported positive IPCA I scores along with high average mean for plant height (Table 2). Hence environment III can be considered as favourable environment for PA 627.

For no. of secondary branches per plant, genotype PA 620 (IPCA I,-0.13; ASV, 1.38) ranked first in terms of stability while genotype PA 625 (IPCA I,-0.13; ASV, 1.40) ranked second and Pant A 291 (IPCA I, 0.16; ASV, 1.70) ranked third (Table 2). The mean of PA 620 (10.11) and PA 625 (11.22) was less than the general mean (12.52) and hence, the genotypes Pant A 291 (14.33) was considered as most desirable genotypes as its mean was higher than the general mean (12.52) alongwith third ASV rank. Among the genotypes Pusa 992, Pant A 291 and PA 627 and in case of environments, environment III recorded positive IPCA I scores along with high average mean for plant height (Table 2). Hence environment III can be considered as favourable environment for Pusa 992, Pant A 291 and PA 627. Similarly, among all the genotypes, the genotypes *viz*., UPAS 120, PA 622 and PA 626 and in case of environments, environment I recorded positive IPCA I scores along with high average mean for number of secondary branches per plant and hence environment

Table 2. IPCA components of genotypes along with AMMI stability value for different morphological traits and Yield Stability Index (YSI) for seed yield per plant

Genotype	Plant height (cm)				No. of primary branches				No. of secondary branches				No. of pods/plant				Seed yield/plant (g)				YSI
	IPCA I	IPCA II	ASV	Rank	IPCA I	IPCA II	ASV	Rank	IPCA I	IPCA II	ASV	Rank	IPCA I	IPCA II	ASV	Rank	IPCA I	IPCA II	ASV	Rank	
Pusa 992	-0.80	0.12	2.42	10	-0.37	0.22	2.01	3	0.21	-0.03	2.22	5	-0.22	-0.10	0.37	4	-0.15	0.54	1.29	6	11
Paras	-0.32	0.30	1.01	7	0.85	-0.74	4.67	9	0.73	0.03	7.56	9	0.61	-0.18	1.02	8	-0.70	-0.12	5.44	9	19
UPAS 120	0.12	-0.35	0.51	1	-0.65	0.29	3.52	7	-0.44	0.26	4.62	8	0.03	0.12	0.13	1	-0.03	-0.05	0.24	3	7
Pant A 291	0.21	0.02	0.62	3	-0.50	-0.03	2.72	6	0.16	-0.47	1.70	3	-0.08	0.06	0.15	2	-0.03	0.03	0.22	1	7
PA 620	-0.01	-0.66	0.66	4	1.00	-0.02	5.40	11	-0.13	0.22	1.38	1	0.19	0.12	0.33	3	-0.03	0.07	0.23	2	4
PA 622	0.15	0.64	0.79	5	-0.24	0.47	1.36	1	-0.16	-0.59	1.79	4	0.54	-0.26	0.93	7	-0.11	0.12	0.89	5	6
PA 623	-0.22	-0.44	0.81	6	0.49	-0.09	2.66	5	0.74	0.27	7.66	10	0.08	-0.44	0.45	6	-0.53	-0.30	4.13	8	16
PA 624	-0.70	0.01	2.12	9	-0.40	-0.72	2.26	4	-1.00	0.08	10.41	11	-0.82	-0.14	1.37	11	1.00	-0.30	7.79	11	20
PA 625	0.19	0.08	0.59	2	-0.29	-0.08	1.59	2	-0.13	0.14	1.40	2	0.06	-0.44	0.44	5	-0.42	-0.45	3.33	7	14
PA 626	0.38	0.41	1.23	8	-0.83	-0.05	4.47	8	-0.26	0.03	2.66	6	0.34	1.00	1.14	9	0.09	0.55	0.87	4	7
PA 627	1.00	-0.13	3.03	11	0.94	0.75	5.12	10	0.29	0.04	3.07	7	-0.72	0.24	1.22	10	0.92	-0.09	7.14	10	21
Environments																					
EI (2016)	-1	-0.31	3.04	3	0.63	0.51	3.49	2	-0.07	-0.61	1.01	1	-0.55	-0.73	1.18	2	-0.03	-0.68	0.72	1	3
EII (2017)	0.13	0.81	0.92	1	-1	0.10	5.41	3	-0.92	0.34	9.61	2	-0.44	0.79	0.91	1	1	0.32	7.79	3	6
EIII (2018)	0.86	-0.49	2.65	2	0.36	-0.62	2.05	1	1	0.27	10.42	3	1	-0.05	1.67	3	-0.97	0.35	7.56	2	3

I is considered favourable environment for these genotypes.

With regard to no. of pods per plant, the genotypes UPAS 120 (IPCA I, 0.03; ASV, 0.13) ranked first in terms of stability while Pant A 291 (IPCA I, -0.08; ASV, 0.15) ranked as second most stable genotype (Table 2). UPAS 120 (166.33) was identified as most desirable genotypes as number of pods per plant in UPAS 120 was higher than the general mean (156.83) along with small IPCA I score. Among the genotypes, UPAS 120, PA 620, PA 622 and PA 626 and in case of environments, environment I reported positive IPCA I scores along with high average mean for pods per plant (Table 2). Hence, it can be concluded that environment I was the favourable environment for genotypes UPAS 120, PA 620, PA 622 and PA 626. Diverse environment play a great role in identifying a stable genotype in any crop. Bhartiya et al. (2018) reported from the GGE biplot analysis that the environments have direct correlation with the selection of genotypes showing maximum yiled of soybean in North West Himalayan Hills region.

For seed yield per plant, genotype Pant A 291 (IPCA I, -0.03; ASV, 0.22) was identified as most stable genotype (Table 2). Considering the mean values along with the IPCA I score, genotype Pant A 291(43.67 g) was marked as most desirable genotypes as its mean for seed yield per plant was higher than the general mean 42.55 g along with top most ASV rank. The genotypes *viz*., Pusa 992, UPAS 120, Pant A 291, PA 620 and PA 622 and the environment III had high mean for seed yield/plant along with negative IPCA I score (Table 2). Hence environment III is identified as favourable for the genotypes, Pusa 992, UPAS 120, Pant A 291, PA 620 and PA 622.

ASV only gives an idea about the stability of genotypes but it does not provide any idea about the high mean yield. The analysis of yield stability index (YSI) suggested that the genotype PA 620 has the lowest YSI score and hence this genotype had the high and stable seed yield across the studied environments (Table 2). Among the environment, EIII and EI were found as stable and high yielding environments for seed yield per plant.

On the basis of AMMI biplot I & II, ASV (AMMI Stability Value), and Yield Stability Index (YSI) scores, the genotype PA 620 was identified as most stable and high yielding genotype for seed yield per plant across three studied years, it was also found to be most stable for no. of secondary branches per plant. The genotype UPAS 120 was identified as most stable for plant height and no. of pods per plant while for seed yield per plant it is at third position. The genotype PA 622 was found to be most stable for no. of primary branches per plants while it holds fourth and fifth position in terms of stability for no. of secondary branches per plant and seed yield per plant, respectively.

Author's contribution

Conceptualization of research (SKV, RKP and RKS); Designing of the experiments (SKV, RKP and RKS); Contribution of experimental materials (SKV and RKP); execution of field/ lab experiments and data collection (AKG and SKV); Analysis of data and Interpretation (AKG, SKV and RKS); Preparation of manuscript (AKG, SKV, RKS and RKS).

Declaration

The authors declare no conflict of interest.

References

Anonymous. 2018. Pulses Revolution-From food to Nutritional security. Government of India. Ministry of Agriculture and farmer welfare, Krishi Bhawan, New Delhi. 122 p.

Bajpai P. K. and Prabhakaran V. T. 2000. A new procedure of simultaneous selection for high yielding and stable crop genotypes. Indian J. Genet., **60:** 141-146.

Becker H. C. and Leon J. 1988. Stability analysis in plant breeding. Plant Breed., **101**(1): 1-23.

Bhartiya Anuradha, Aditya J. P., Kumari Vedna, Kishore Naval , Purwar J. P., Agrawal Anjuli, Kant L. and Pattanayak A. 2018. Stability analysis of soybean [*Glycine max* (L.) Merrill] genotypes under multi-environments rainfed condition of North Western Himalayan hills. Indian J. Genet., **78**(3): 342-347. DOI: doi.org/10.31742/IJGPB.78.3.6.

Bhaskaran K. and Muthiah A. R. 2005. Screening and inheritance pattern of sterility mosaic disease resistance in pigeonpea. Indian J. Pulse Res., **18:** 124-126.

Blum A., Poyarkova H., Golan G. and Mayer J. 1983. Chemical dissection of wheat plants as a stimulator of post anthesis stress. I. Effects on translocation and kernel growth. Field Crops Res., **6:** 51-58.

Bose L. K., Jambhulkar N. N., Pande K. and Singh O. N. 2014. Use of AMMI and other stability statistics in the simultaneous selection of rice genotypes for yield and stability under direct-seeded conditions. Chil. J. Agr. Res., **74**(1): 1-9.

Chauhan Y. S., Atukorala W. D., Perera K. D. A., Joseph K. D. S. M., Saxena K. B. and Johansen K. B. 1999. Adaptation of Extra-Short-Duration Pigeonpea in the Short Rainy Season of a Tropical Bimodal Rainfall Environment. Expl. Agric., **35:** 87-100.

Chauhan Y. S., Wallace D. H., Johansen C. and Singh L. 1998. Genotype-by-environment interaction effect on yield and its physiological bases in short-duration pigeonpea. Field Crop Res., **59:** 141-150.

Danekar P., Tyagi A., Mahto A., Krishna K.G., Singh A., Raje R. S., Gaikward K. and Singh N. K. 2014. Genome wide characterization of *Hsp 100* family genes from pigeon pea. Indian J. Genet., **74**(3): 325-334.

Eskridge K. M. 1990. Selection of stable cultivars using a safety-first rule. Crop Sci., **30:** 369-374.

Freeman G. H. 1985. The analysis and interpretation of interaction. J. Applied Stat., **12:** 3-10.

Gabriel K. R. 1971. The biplot graphic display of matrices with application to principle component analysis. Biometrika, **58:** 453-467.

Gauch H. G. 1988. Model selection and validation of yield trials with interaction. Biometrics. **44:** 705-715.

Gauch H. G. 1992. Statistical analysis of regional trials: AMMI analysis of factorial design. 1st ed. Elsevier, Amsterdam. pp. 53-110.

Gauch H. G. 2006. Statistical analysis of yield trials by AMMI analysis and GGE. Crop Sci., **46:** 1488-1500.

GEA-R (2017) Version 4.1 software, www.cimmyt.org.

Gollob H. F. 1968. A statistical model which combines features of factor analysis and analysis of variance techniques. Psychometrika, **33:** 73-115.

Horn L., Shimelis H., Sarsu F., Mwadzingeni L. and Laing M. D. 2018. Genotype-by-environment interaction for grain yield among novel cowpea (*Vigna unguiculata* L.) selections derived by gamma irradiation. Crop J., **6:** 303-313.

Jha S. K., Singh N. K., Kumar A. R., Agrawal P. K., Bhatt J. C., Guleria S. K., Lone A. A., Sudan R. S., Singh K. P. and Mahajan V. 2013. Additive main effects and multiplicative interaction analysis for grain yield of short duration maize hybrids in North-Western Himalayas. Indian J. Genet., **73**(1): 29-35.

Kang M. S. 1993. Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. Agron. J., **85:** 754-757.

Mohammadi R. A., Abdulahi R., Haghparast. and Armion M. 2007. Interpreting genotype-environment interactions for durum wheat grain yields using non-parametric methods. Euphytica. **157:** 239- 251.

Muniswamy S., Bellad S. B., Girish G. and Talawar A. 2018. AMMI biplot analysis forstability of grain yield in pigeonpea (*Cajanus cajan* L.). Environ. Ecol., **36**(2): 531-534.

Purchase J. L., Hatting H. and Vandeventer C. S. 2000. Genotype x environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: Stability analysis of yield performance. S. Afr. J. Plant Soil., **17:** 101-107.

Rashidi M., Farshadfar E. and Jowkar M. M. 2013. AMMI analysis of phenotypic stability in chickpea genotypes over stress and non-stress environments. Intl. J. Agri. Crop Sci., **5**(3): 253-260.

Sara M., Abbas R., Reza A. and Alireza. 2019. Yield stability of rapeseed genotypes under drought stress conditions. Indian J. Genet., **79**(1): 40-47.

Saxena R. K., Saxena K, B., and Varshney R. K. 2010. Application of SSR markers for molecular characterization of hybrid parents and purity assessment of ICPH2438 hybrids of pigeonpea [*Cajanus cajan* (L.) Millsp.]. Mol. Breed., **26:** 371-380.

Singh J., Kumar A., Fiyaz A. R. and Singh M. K. 2018. Stability analysis of pigeonpea genotypes by deployment of AMMI model under *rainfed* environment. Legume Res., **41**(2): 182-188.

Singh P. K., Kumar S. and Singh J. 2000. Stability analysis for sugarcane genotypes grown under three different conditions. Indian J. Sugarcane Techno., **15:** 52-58.

Thangavel P., Anandan A., and Eswaran R. 2011. AMMI analysis to comprehend genotype-by-environment (G x E) interactions in rainfed grown mungbean (*Vigna radiata* L.). Aust. J. Crop Sci., **5**(13): 1767-1775.

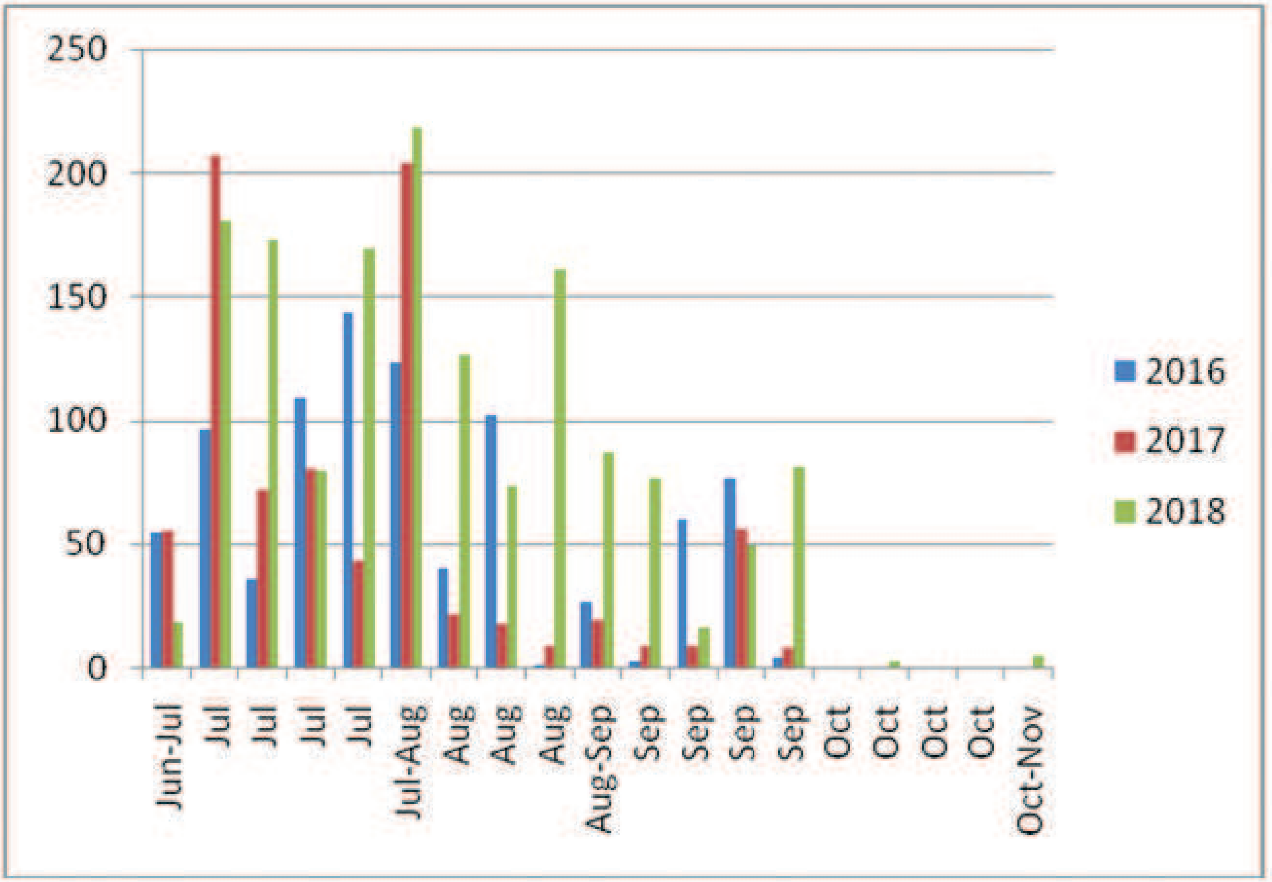
Tolessa T. T., Keneni G., Sefera T., Jarso, M. and Bekele Y. 2013. Genotype x Environment interaction and performance stability for grain yield in field pea (*Pisum sativum* L.) genotypes. Intl. J. Plant Breed., 7(2): 116-123.

Vargas M. and Crossa J. 2000. The AMMI analysis and graphing the biplot. Biometrics and Statistics Unit, CIMMYT.

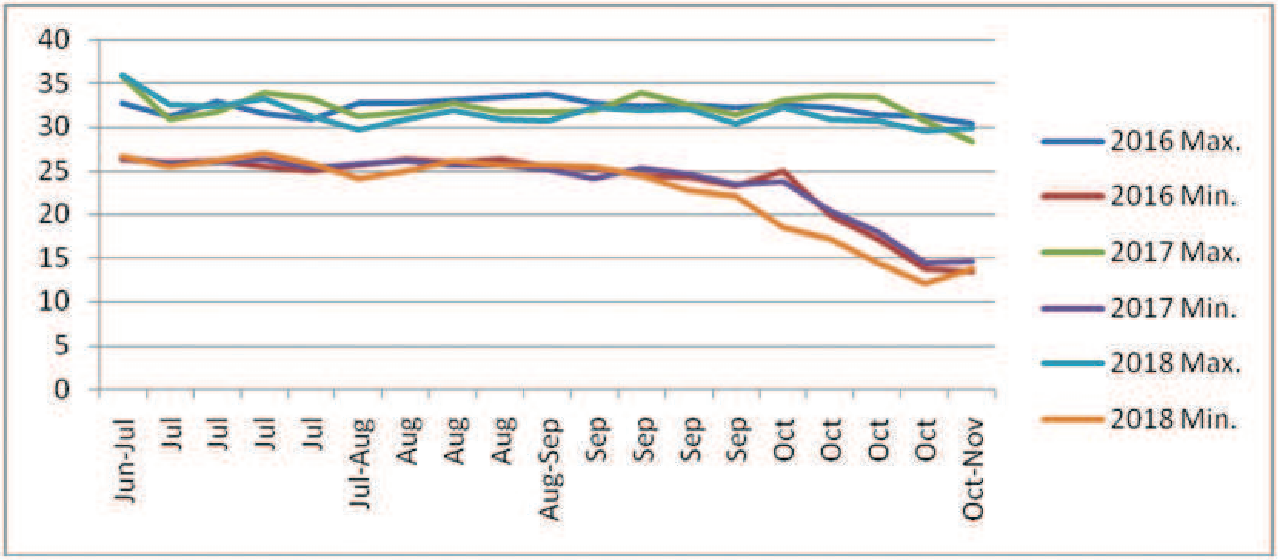
Wamatu J. N. and Thomas E. 2002. The Influence of Genotype-Environment Interaction on the Grain Yields of 10 Pigeonpea Cultivars Grown in Kenya. J. Agron. Crop Sci., **88:** 5-33.

Yan W. and Rajcan I. 2002. Biplot Analysis of test sites and Trait relations of Soybean in Ontario. Crop Sci., **42:** 11-20.

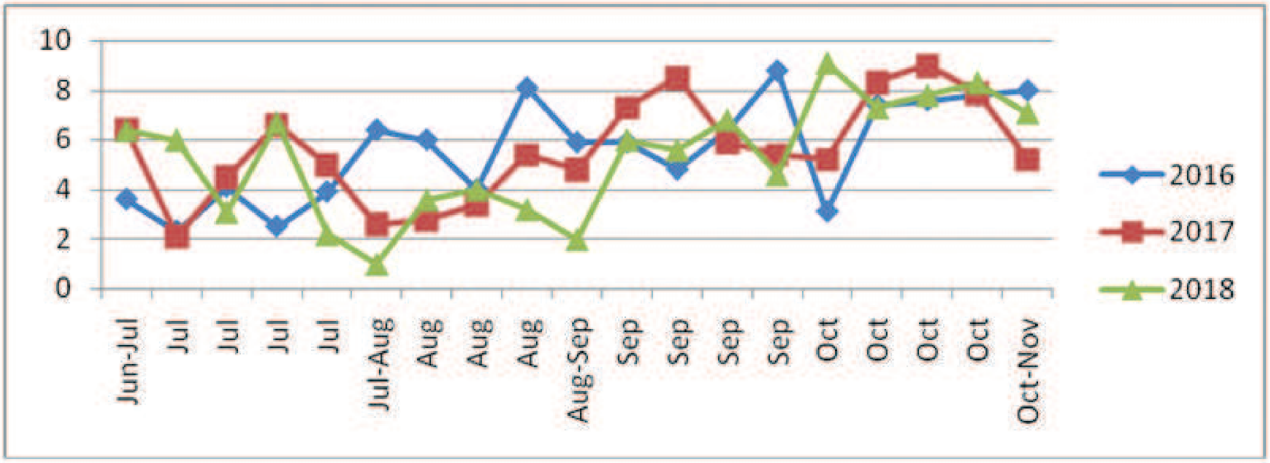
Zobel R.W., Madison J. W. and Gauch H.G. 1988. Statistical analysis of a yield trial. Agron. J., **80:** 388-393.



Supplementary Fig. 1. Rainfall during *Kharif* 2016-18 from the last week of June upto November first week



Supplementary Fig. 2. Maximum and minimum temperature (^{o}C) during *kharif* 2016-18 from the last week of June upto November first week



Supplementary Fig. 3. Sunshine hours during *kharif* 2016-18 from the last week of June 2016 upto first week of November, 2018