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Stability of Garden Pea Genotypes based on GGE Biplot and Regression Model

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ABSTRACT

Background: In garden pea, the availability of produce early in the season provides a premium price to the growers. Keeping this in view, efforts were made to develop varieties with stable performance across environments for early maturity and high pod yield.

Methods: 48 lines were evaluated in *Alpha Lattice* design over 7 diverse environments ranged from sub-tropical to dry temperate conditions of north-western Himalaya during 2016-17 and 2017-18.

Result: Genotypes SP-22, SP-18, SP-2, SP-17, SP-12, SP-6, and SP-3 showed earliness for days to flowering and first picking, significantly better than check Pb-89 and were also stable (S^2_{di}=0 and bi=1) except SP-6 and can be adapted to suboptimal environmental situations. The environment (E6-Kukumseri) was the most ideal for the first flowering node while E1-Bajaura for days to flowering and first picking. Mean vs stability biplot and "which-won-where" depicted SP-6, SP-22, SP-17 and SP-18 as the most stable and winning genotypes for early flowering and picking. SP-6 and SP-22 are the most promising genotypes with stable performance across environments for early maturity and high pod yield based on GGE biplot and AMMI, respectively. They could be a better alternative to the popular growing variety Pb-89 in the north-western Himalayas.

Key words: AMMI, Correlation, Earliness, Garden pea, Genotype × environment interaction, GGE, Stability analysis.

INTRODUCTION

Garden pea is an important cool-season vegetable crop grown throughout the world for its tender green pods, seeds, and foliage. It is nutritionally rich in phytonutrients, vitamins, minerals and antioxidants (Sharma *et al*., 2020). It is commercially grown as an off-season crop in the north-western Himalayan region of Himachal Pradesh, Jammu and Kashmir and Uttarakhand (Sharma *et al*., 2013) throughout the year *i.e*., during the winter season in low and mid-hills and during the summer season in high hills. The reproductive stage of the crop coincides with heavy rainfall during early spring in winter-sown crop. Similarly, autumn crop overlap with low temperature during November onwards. This ultimately affects the expected yield potential of a variety. Therefore, it is essential to develop varieties of garden pea which mature before the manifestation of adverse conditions so that farmers get optimum produce and price by selling quality green peas.

Earliness is a highly desirable attribute in pea breeding in the sense that the prevailing prices in the market are invariably higher early in the season. Earliness is a quantitative trait and genotype × environment interaction (GEI) and the interplay of genetic and non-genetic effects influence this character to a large extent. The uncontrollable factors of the environment which can change with season and location can manipulate the performance of the genotype and therefore, it is important to quantify their effects on various variables of the crop. The pre-requisite of the breeding programme is to screen and identify phenotypically stable genotype(s) with uniform performance under diverse agro-climatic conditions. Some genotypes frequently show fluctuations in flowering behaviour in different environments as a result of GEI. Genotypes that interact less with the environments are selected which aid the breeders to a greater extent in developing stable early genotypes. Thus, G × E interactions are of foremost significance to the breeders in the process of evaluation of improved genotypes at multi-locations for their economic performance.

To analyse the GE interaction graphically, GGE biplot analysis (genotype main effect plus genotype × environment interaction) has been proposed for effectively identifying mega-environments (Rana *et al.*, 2021). GGE could explain the source of variation of G (genotype) and GE (genotype ×

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environment) in more detail (Yan *et al.,* 2007) and provides an easy and comprehensive solution to genotype by environment data analysis. In this perspective, four diverse parents were selected based on different days to maturity and quality pods were involved in three inter-varietal crosses to isolate transgressive segregants that have resulted in 44 progenies with different days to maturity. The research programme primarily focused to develop cultivars with the early harvest and high yield potential over a broad spectrum of environments to identify stable and early maturing lines of a garden pea.

Materials and Methods

Experimental material and layout

Forty-four advanced breeding lines developed from three inter-varietal crosses along with four standard checks namely: Palam Priya, Palam Sumool, Azad-P1, and Punjab 89 were evaluated in *Alpha Lattice* design (Parsad *et al.,* 2007) across seven environments with three replications, in eight blocks with six entries in each block. Each entry was raised in two rows of 3 m length over the replications at spacing of 45 cm in rows and 7.5cm from plant to plant.

The recommended farmyard manure @ 20 tonnes/ha was mixed in the soil at the time of field preparation. The recommended dose of synthetic fertilizers @ 50:60:60 kg of N, P_2O_5 and K_2O ha^{-1} were applied at the time of sowing in rows beneath the seed. Seeds were also treated with 'Carbendazim' @ 3 g kg^{-1} of seed. Irrigation was provided before sowing and as per requirement thereafter at 15-20 days intervals. Hand weeding and hoeing were done thrice to keep the field weed- free. Natural Farming practices followed with basic criteria of using natural products includes application of *Ghanjeevamrit* (prepared from Indian cow dung, cow urine, gram flour, soil and Jaggery in 10:5:1:1:1) @ 250 kg/ha in rows at the time of sowing and thereafter at the flower initiation stage. In addition, 10% *Jeevaamrit* solution (*Ghanjeevamrit* 1 part dissolved in 10 parts of water) was sprayed at three weeks intervals till the last harvest.

Experimental sites

The current study was carried out at CSK Himachal Pradesh Krishi Vishvavidyalaya in seven diverse environments across the state of Himachal Pradesh (India) *viz.,* Bajaura (E1)- temperate, Dhaulakuan (E2) and Una (E3)- subtropical, Palampur- temperate moist (E4) during winter 2016-17, Kukumseri (E6)-dry temperate during summer 2017 and Palampur (E7) during winter 2017-18. These experimental sites (369 m to 2672 m above mean sea level) are comprised of five diverse agro-climatic conditions ranging from sub-tropical to dry temperate regions. The environment E5 constituted of Natural Farming practices at Palampur where the evaluation was undertaken during winter 2016-17.

Data recording and statistical analysis

The observations were recorded from ten plants of each genotype selected at random in all the replications for first flowering node, days to 50% flowering and days to first harvest. Data were statistically analyzed as per the procedure given by Panse and Sukhatme (1984). The performance of the genotypes tested was analyzed using two stability models namely: Eberhart and Russell (1966) and GGE biplot. The stability analysis as per Eberhart and Russell (1966) was done using HAU-OPSTAT software and BMM1 software (PAU, Ludhiana). The analysis of the GGE biplot was performed using GGE Biplot software R-Package "GGE" version 1.4 and PB Tools software. The GGE and AMMI biplots were constructed using the basic model.

Results and Discussion

Breeding for earliness is an essential and complex process in pea breeding. The inheritance of this trait is controlled by many genes and is highly influenced by internal and external environmental factors. Evaluation of genotypes for different traits under multilocation trials is an important step in the varietal release process (Bishaw and Van Gastel 2009). For releasing varieties that will show consistent performance over different locations, stable performing pea genotypes need to be identified. The GEI is a matter of concern in the breeding, genetics, and production of crops as it manipulates the performance of a plant. Thus, to overcome the consequences of GEI, the evaluation of genotypes is carried out in multi-environment trials (MET) (Alwala *et al*. 2010). Garden pea is one of the highest paying crops in north-western Himalayas due to its off-season cultivation throughout the year in one or the other zones. Farmers have specific demand for varieties that mature early to fetch high prices in the market. However, the lack of early varieties with stable performance to varied agroclimatic conditions has forced farmers to purchase seeds at higher rates from private enterprises. Therefore, there is a dire need to recommend stable early maturing varieties of a garden pea to meet the farmers' demand.

The evaluation of genetic material in MET becomes very challenging due to the presence of G × E interactions. This can be overcome by using statistical models such as Eberhart and Russell's model and GGE biplot. These models help plant breeders to understand the performance of genotypes in different environmental conditions and allow the selection of the most ideal genotypes for a particular environment or group of environments (Gauch and Zobel, 1996). The selected genotypes can be released as varieties for commercial cultivation in their respective best-performing locations.

Joint regression analysis

The perusal of the analysis showed that the mean sum of squares due to genotypes and environments were highly significant for all the characters (Table 1). The means sum of squares due to genotype × environment interactions were significant indicating the suitability of applying stability parameters. The combined variance of environment and genotype × environment interaction [E + (G × E] was also significant for all the traits indicating that the environments and their interaction with genotypes played an important

role in determining the performance of genotypes. The variation in different characters may be due to differences in climate or soil factors among environments (Alake and Ariyo 2012). Further, partitioning of [E + (G × E] revealed the significance of linear components for first picking, suggesting to proceed for stability analysis (Eberhart and Russel 1966). The significant non-linear component of combined environment and genotype × environment variance indicated that the genotypes differed considerably concerning their stability for all the traits. The significant non-linear component of GEI was also observed by Pan *et al*. (2001) and Hassan *et al*. (2013).

Stability based on Eberhart and Russell's model

To find out the suitable recommendation of a variety, the phenotypic stability of a particular genotype should be judged by consideration of mean performance vis-à-vis both linear (bi) and nonlinear (S^{-2}_{di}) components of GEI as it was suggested by Eberhart and Russell (1966) that their responses are independent of each other. The variation in the regression coefficient (b_i) for all the traits indicates differences in responses to environmental changes. The genotypes with non-significant deviation (S^2_{di}=0) were categorized as predictable and stable suggesting the preponderance of linear component G × E interaction. The genotypes SP-22, SP-12, SP-10 and SP-24 for the first flowering node and SP-22, SP-18, SP-2, SP-17, SP-12 and SP-3 for early flowering and first picking were stable in all the environments (Table 2). Similarly, the genotypes with consistent performance for early flowering and early first picking based on mean performance, significantly better than check Pb-89 revealed deviation for only one line SP-6 while rest of the six lines had S^2_{di}=0 and bi=1. El-Dakkak *et al*. (2015) also identified early genotypes in pea using Eberhart and Russel model under different conditions.

Genotype response to specific adaptation

The most interesting feature of the GGE biplot is its potential to depict the 'which-won-where' pattern of a genotype by environment data set. The genotypes falling on the vertices

Table 1: Combined regression analysis of variance for different characters over the environment.

Source	DF	First flowering node	Days to 50% flowering	Days to the first harvest	Harvest duration (days)
Genotypes	47	1.10 **	39.80 **	67.11 **	11.06 **
Environments	6	14.42 **	11903.53 **	19108.21 **	2150.06 **
G × E	282	1.05 **	20.44 **	27.15 **	8.30 **
Environments+G × E	288	0.64 **	254.81 **	406.95 **	47.50 **
Environments (Linear)	1	86.54 **	71421.15 **	114649.27 **	12900.39 **
G × E (Linear)	47	0.22 n.s.	4.69 n.s.	13.84 **	5.50 **
Pooled Deviation (Non-Linear)	240	0.37 **	7.27 **	7.92 **	2.18 **
Pooled error	658	0.32	5.54	5.33	1.62

**Significant at P≤0.01; n.s.= Not significant at P≤0.05, DF= Degrees of freedom.

Table 2: Individual regression analysis and estimates of stability parameters with respect to top ranked genotypes for first flowering node, days to 50% flowering and days to the first harvest.

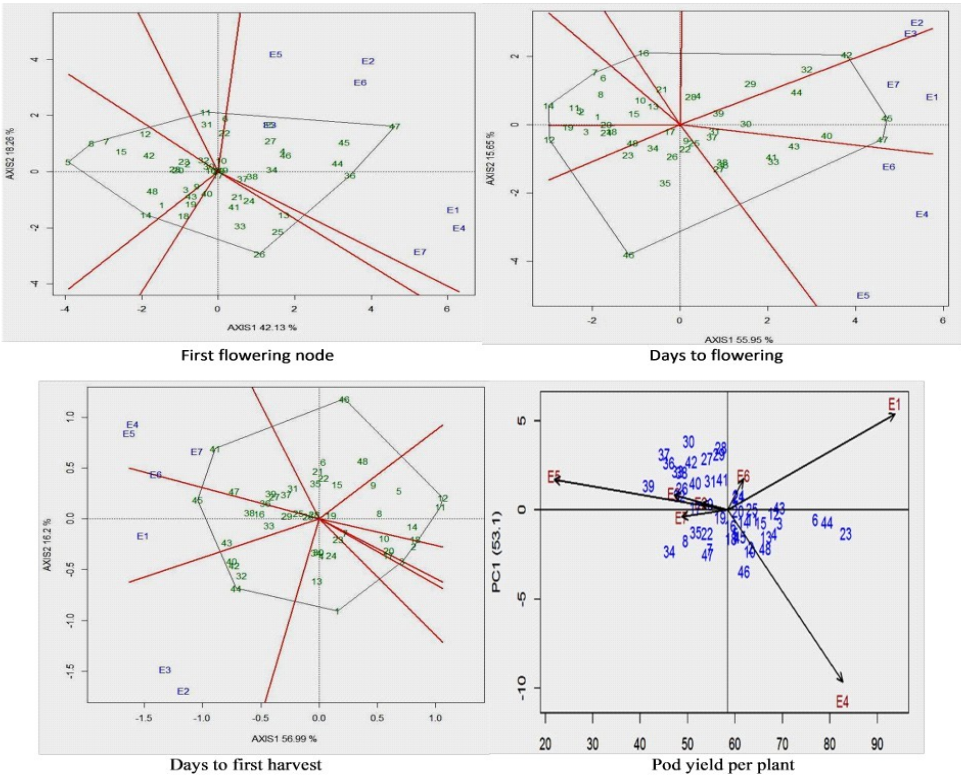
Genotypes	First flower node			Days to 50% flowering			Days to first picking		
	Mean	bi	S^{-2}_{di}	Mean	bi	S^{-2}_{di}	Mean	bi	S^{-2}_{di}
SP-2	12.06	0.63±0.34	0.09	75.48	0.93±0.06	2.96	107.67	0.93±0.05	5.30
SP-3	12.11	1.37±0.71	0.79*	76.24	0.97±0.04	0.98	108.14	0.95±0.07	9.85
SP-5	12.64	0.45±0.30	0.05	78.24	1.02±0.09	8.91	111.71	0.93±0.08	13.28*
SP-6	11.39	0.51±0.77	0.97*	75.81	0.93±0.04	0.07	108.24	1.03±0.07	10.24*
SP-10	11.63	0.48±0.33	0.09	75.71	0.89±0.10	10.52	110.86	0.97±0.04	2.25
SP-12	11.55	0.66±0.49	0.31	76.05	0.93±0.09	7.46	109.05	0.95±0.07	9.93
SP-17	12.38	1.27±0.51	0.36	75.57	1.00±0.07	3.85	106.38	0.97±0.05	5.33
SP-18	11.96	0.93±0.46	0.26	75.29	0.96±0.03	-0.52	106.19	0.95±0.06	7.35
SP-22	11.53	0.76±0.55	0.43	75.10	0.96±0.05	2.49	107.86	0.96±0.04	2.34
SP-24	11.64	1.37±0.42	0.21	77.00	0.94±0.05	2.25	111.71	1.10±0.04*	2.63
Azad P-1	12.61	0.95±0.38	0.15	78.67	1.14±0.16	36.15*	111.52	1.18±0.09*	17.04*
Pb-89	11.73	0.79±0.23	-0.01	77.86	1.02±0.04	-0.33	110.52	1.06±0.05	3.58
Grand mean	12.17	1	-	78.56	1.00	-	112.34	1.00	-
S.E (m) ±	0.25	0.45	-	1.10	0.07	-	1.15	0.06	-
CD	0.35	-	-	1.41	-	-	1.51	-	-

* Significant deviation, bi- Regression coefficient, S^{-2}_{di} - Stability parameter.

of the polygons in the GGE biplots indicate their level of performance in a particular environment (Yan and Tinker 2006). 'Which-won-where' polygon view of GGE biplot model (Fig 1) for first flowering node showed that SP-6 (G5) was placed at the vertex with a flower at the lower node, suggesting it to be the most desirable and top winning genotype followed by SP-12 (G8), SP-10 (G7) and SP-24 (G15). SP-22 (G14) along with SP-12 (G8) were also placed on the vertices within the same environment sector as SP-6. Palam Sumool (G47) was the most responsive and the winning genotypes of the corresponding environment sector for the first flower at the highest node, depicting thereby as late maturing. The similar inference was also obtained based upon the joint regression analysis and mean vs. stability biplot except for SP-6 which was unstable as per regression analysis. The genotypes SP-22 and SP-18 were the earliest to days to flowering and were also the winning genotypes within the same sector placed on the vertices. Genotypes SN-6-1 (G19), SP-17 (G11), SP-6 (G5), SP-2 (G2) and SP-3 (G3) were also highly stable and desirable genotypes, making them the candidate of selection for early flowering. For days to first harvest, SP-18 and SP-17 were the earliest, placed close to the vertices along with SP-22 (G14) and SP-6 (G5). They were the winning genotypes simultaneously based on GGE biplot and joint regression analysis. SN-5-1 (G18), SP-2 (G2) and SP-3 (G3) also lie on the equality line between two winning genotypes among different sectors and depict sequential suitability. Earlier researchers have also made predictions based on stability analysis in chickpea (Yadav *et al*., 2014) and cluster bean (Teja *et al*., 2022).

Correlation with yield

The genotypes SP-6 and SP-22 with early flowering and first harvest also showed significantly superior performance for pod yield/plant in comparison to check Pb-89 while the other genotypes namely, SP-18, SP-17, and SP-2 were at par with the check (Fig 2). PC1 vs. mean yield AMMI biplot revealed that the genotypes SP-6, SP-22 and SP-17 were closer to the center point indicating stability across the environments (Fig 1). The correlation studies revealed that



The letters "E" represent the environment. E1- Bajaura, E2- Dhaulakuan, E3- Una, E4- Palampur 2016-17, E5- Natural Farming, E6- Kukumseri and E7- Palampur 2017-18.

48 genotypes are specified as digits. 1:SP-1, 2:SP-2, 3:SP-3, 4:SP-5, 5:SP-6, 6:SP-7, 7:SP-10, 8:SP-12, 9:SP-14, 10:SP-15, 11:SP-17, 12:SP-18, 13:SP-19, 14:SP-22, 15:SP-24, 16:SN-1, 17:SN-4, 18:SN-5-1, 19:SN-6-1, 20:SN-7-1, 21:SN-11-1, 22:SN-15, 23:SN-2, 24:SN-5-2, 25:SN-6-2, 26:SN-7-2, 27:SN-8, 28:SN-10, 29:SN-11-2, 30:SN-13, 31:SN-19, 32:SN-21, 33:SN-22, 34:SA-1, 35:SA-4, 36:PSPP-8, 37:SP-12-1, 38:SP-12-2, 39:SP-15-1, 40:SP-23-1, 41:SP-28-1, 42:SN-8-2, 43:SN-3-1, 44:SN-9-2, 45:Palam Priya, 46:Azad-P1, 47:Palam Sumool, 48:Pb-89.

Fig 1: "Which Won Where" G+GE biplots for first flowering node, days to flowering and days to first harvest and AMMI biplot for pod yield per plant.

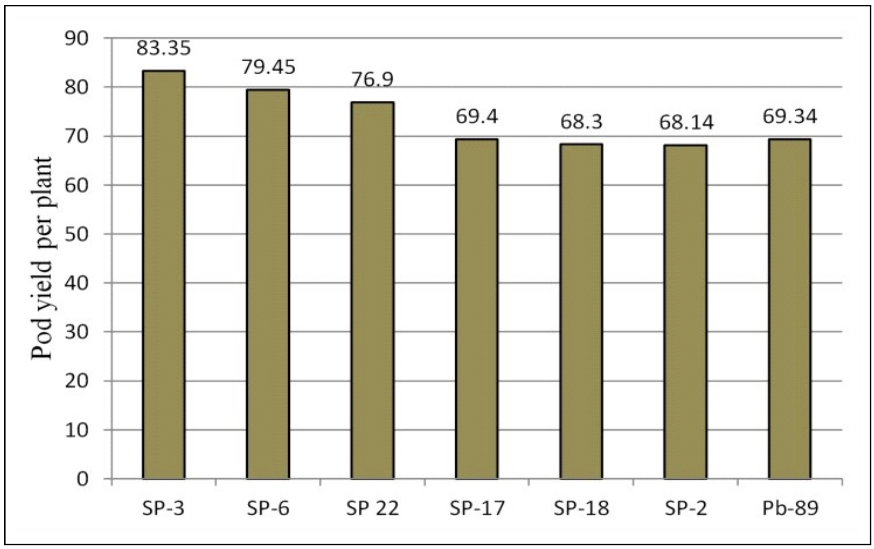


Fig 2: Pod yield per plant performance of early and stable genotypes along with check Pb-89.

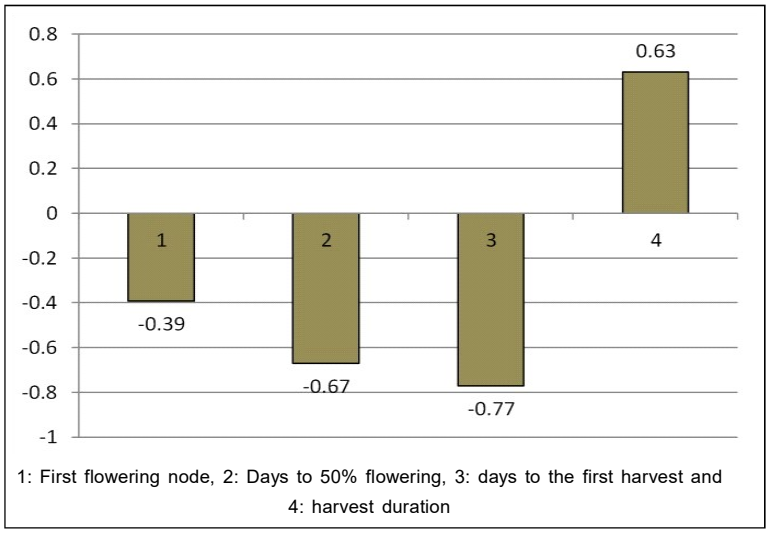


Fig 3: Correlation of earliness related traits with pod yield per plant.

the first flower node, days to flowering and days to first picking had a negative association with pod yield, while harvest duration was positively correlated with the yield (Fig 3). The first flower node, days to flowering and harvest duration revealed a moderate association with pod yield (r=0.30-0.70) whereas days to first picking had a strong effect on pod yield (r>0.70). This indicated that genotypes with early flowering and early first harvest resulted in high yield with the maximum influence of days to first picking. Early harvesting resulted in increased pod yield due to prolonged harvest duration. Therefore, the genotypes significantly early in first picking and have stable performance throughout the environments should be focused on while selecting for earliness rather than the first flower node with less effect on yield.

CONCLUSION

The genotypes *viz.*, SP-6, SP-22, SP-18 and SP-17 were identified as early and stable by joint regression and GGE/ AMMI biplot which indicate the accurateness and usefulness of these methods in understanding the G × E interactions for days to flowering and first harvest. 'Which-won-where' polygon view of GGE biplot model showed that the high yielding genotypes SP-6 and SP-22 were the winners for earliness also based on their performance for all three phenological traits and also pod yield based on AMMI. Based on these aspects, it can be concluded that the genotypes SP-6 and SP-22 with significant and stable performance across environments than check Pb-89 for pod yield, early flowering, and first harvest and may be promoted for release in the North-Western Himalayas.

Conflict of interest

The authors decline that the research was coducted in the absence of any commercial or financial relationships.

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