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Stability of French bean (*Phaseolus vulgaris*) genotypes under diverse environments

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ABSTRACT

The present investigation was undertaken to ascertain stable genotypes across six environments. Twenty five genotypes of French bean were evaluated for yield and quality traits in three different locations of Punjab during 2017–18. The stability of genotypes was worked out by using Eberhart and Russel (1966) and GGE biplot models. Highly significant mean squares for environments and genotype × environment interaction were recorded for all the traits except for protein content. The linear component of genotype × environment interaction was significant for all the characters under study. The highest green pod yield per plant was observed in genotype Arka Suvidha followed by Arka Anoop, Falguni, Arka Sharath and FB-3-16 which produced significantly more green pod yield than check Contender. Genotype FB VAR-5 was identified suitable for favorable environments and genotypes Arka Sharath, Arka Suvidha, Falguni, FB 2-16 and Swarna Priya were found promising for unfavorable environments. The genotype Arka Anoop was stable in all environments. In terms of environments KVK, Sangrur 2017 was more informative. The dry matter of genotype Contender was high while genotypes Arka Suvidha, Arka Anoop and Falguni produced highest protein content. All the environments were positively correlated for yield traits, which meant that same information about the genotypes could be obtained from fewer test environments, and hence depicting the potential to reduce testing cost by dropping one of them.

Key words: French bean, G × E interactions, GGE biplot, Stability analysis

French bean (*Phaseolus vulgaris* L.) (2n=2x=22) is an important legume vegetable crop, belongs to family Fabaceae. It is highly self-pollinated crop. Like other beans, it is an important source of protein. The 100 g edible pods constitute 1.7% protein (Gopalkrishanan 2007). The crop occupies over 200000 ha in the country with a total production of 2015000 mt with a productivity of 10.07 t/ha. The total area under Punjab is 1500 ha with annual production of 2000 mt and average productivity of 1.58 t/ha (Anonymous 2017).

In French bean breeding programmes, the search for genotypes with high yield, adapted in most varied environments is one of the most important objectives for breeders. Genotype × environment interactions are important source of variation in the crop breeding programme and the term stability is used to characterize a genotype which exhibits a relatively constant yield across the environment under test. A genotype with low genotype × environment (GEI) will have high stability and vice-versa. Therefore, while developing a high yielding cultivar, if care is not taken to select for both yield and stability of performance, one may end up with a high yielding genotype which is suitable only at particular environment.

Various approaches have been used to study G × E interactions (Finlay and Wilkinson 1963, Eberhart and Russel 1966 and Perkins and Jinks 1968). Eberhart and Russell's model has been commonly used to estimate stability parameters in various crop plants. Other method used to estimate stability is GGE biplot analysis. GGE stands for genotype main effect (G) plus genotype × environment interactions (GE). Mathematically, GGE is the genotype by environment data matrix after the environment means are subtracted. A biplot graphically displays the two-way data and allows visualization of the interrelationship among testers (environments), the interrelationship among the entries (genotypes) and the interactions between entries and testers and used to visually analyze the multi environmental trials data (Gabriel 1971,Yan *et al.* 2000 and Yan and Tinker 2006). Therefore, present study was carried out to study stability analysis of French bean genotypes across six different environments.

MATERIALS AND METHODS

The present investigation was conducted at Punjab Agricultural University, Ludhiana. Twenty five promising genotypes of French bean, viz. Arka Anoop, Arka Sharath,

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Aishwaraya, Arka Suvidha, Contender (C), Falguni, FB-1-14, FB-1-16, FB-2-14, FB-2-16, FB-3-14, FB-3-16, FB-4-14, FB-4-16, FB-5-16, FB-6-16, FBK-2, FB-VAR-2, FB-VAR 5, Rani Beans, RKS-1, Swarna Priya, S-9, Shakira and Shriya were used for the present study. These genotypes were sown at three different locations in Punjab during two spring seasons 2017–18. The different environments were E1 (PAU, Ludhiana 2017), E2 (USF, Usman 2017), E3 (KVK, Sangrur 2017), E4 (PAU, Ludhiana 2018), E5 (USF, Usman 2018) and E6 (KVK, Sangrur 2018).

The experiment at each location was conducted in randomized block design with three replications. The experimental area was prepared well by deep ploughing and cross harrowing followed by leveling and then dividing the area into plots for each genotype. The size of plot was 2.7 per m^2 (2 m length of plot having width of 1.35 m). To save irrigation water and crop from adverse effect of heavy rainfall the seeds were sown on beds of 67.5 cm width (top 37.5 cm and furrow 30 cm). Two rows were sown on 37.5 cm top of bed with plant to plant spacing of 15 cm.

The observations were recorded for yield and quality traits. The stability analyses were performed as per method suggested by Eberhart and Russell (1966) and GGE biplot analysis (Yan *et al.* 2000, Yan 2002 and Yan and Tinker 2006).

RESULTS AND DISCUSSION

Estimation of stability using Eberhart and Russell model: The pooled analysis of variance for 25 genotypes in the six environments indicated highly significant differences among the genotypes for all characters under study. This indicated enough genetic variability among the genotypes. The linear component of genotype × environment interaction was also significant for all traits. Mean squares due to pooled deviations were highly significant for all the characters under study which indicated that genotypes differed with respect to their stability. On partitioning it into linear and non-linear components, both the components were equally responsible for the expression of any trait. However the linear component was higher in magnitude than non-linear component for all traits, indicating that the variation in the performance of genotypes when grown over environments could be predicted. Similar results of significant G × E interactions were also been obtained by Pereira *et al.* (2009) and Thakare *et al.* (2016).

The mean values, regression coefficient (bi) and variation due to deviation (S^2di) for various yield and quality traits is presented in Table 1.

The green pod yield per plant ranged from 59.8g in genotype FB-3-14 to 123.7g in genotype Arka Suvidha. The genotypes that showed higher green pod yield per plant than the general mean (Xi =86.5) were Arka Suvidha, Arka Anoop, Falguni, Arka Sharath, FB-3-16, Contender, FBK-2, FB-2-16, FB VAR-5, FB-6-16, FB-4-16, Swarna Priya and FB-2-14. The genotype FB VAR-5 identified suitable for growing under favorable conditions while genotypes Arka Sharath, Arka Suvidha Falguni, FB-2-16 and Swarna Priya were found suitable for growing under unfavorable conditions. The genotype Arka Anoop was stable in all environments. Similar, results for yield and its attributing traits have earlier been reported by Jayanathamma (1984), Pal and Prasad (1996), Smitha (2005), Pan *et al.* (2006), Singh *et al.* (2007), Pan *et al.* (2009), Hosamani *et al.* (2010), Keerthi *et al.* (2014) and Thakare *et al.* (2016).

The dry matter content was measured by taking random sample of 100 g pods from each replication of each genotype were cut into small pieces and dried in an oven at 60 ± 2°C .The per cent dry matter content was obtained by dividing dry weight of final material to initial weight of fresh material. It ranged from 4.9 in genotype FB-2-14 to 10.6% in genotype Contender. The genotypes with higher dry matter than the general mean (Xi=7.2) were Contender, Arka Anoop, Swarna Priya, FB-3-16, Shakira, FB-VAR-5, S-9, FB-1-14, FB-2-16, FBK-2, FB VAR-2, RKS-1 and Falguni. The genotypes FB-1-14, FB VAR-5 and RKS-1 were identified suitable for growing under favorable conditions while genotypes Falguni and Swarna Priya were found promising for growing under unfavorable conditions.

The protein content was determined by the Lowry's Method, (Lowry *et al.* 1951). The protein content ranged from 4.5% in genotype Rani Beans to 7.5% in genotype Arka Suvidha. The genotypes with higher protein content than the general mean (Xi =5.6) were Arka Suvidha, Arka Anoop, Aishwaraya, Arka Sharath, Falgui ,FB VAR-5, FB VAR-2, FB-3-16,FB-5-16,FB-6-16, and FB-4-16. The genotypes Aishwaraya, FB-5-16 and FB-6-16 were suitable for growing under favorable conditions while genotypes Arka Anoop, Arka Sharath, Arka Suvidha, FB-3-16 and FB VAR-2 were found suitable for growing under unfavorable conditions.

Estimation of stability using GGE biplot analysis: GGE biplot defines an ideal genotype, based on both mean performance and stability across environments. Visualization of the "which-won-where' pattern of MET data is important for studying the possible existence of different mega-environments in the region (Yan *et al*. 2000). The performance of French beans genotypes for green pod yield per plant (g) across six environments (E1-E6) is presented in Table 2.

Environment evaluation based on GGE biplot for green pod yield per plant (g)

Relationships among test environment: All the environments were positively correlated (an acute angle). An acute angle between the vectors of environments suggested that these environments were similar in the manner that they discriminate among genotypes as reported by Kroonenberg (1995) and Yan (2002).The positive correlation between environments for yield and its related characters have been reported by Singh (2013).The distance between two environments measured their dissimilarity in discriminating the genotypes. These six environments fall into two apparent groups and environments E5: E2: E6:E3 formed one group while other environments E1:E4 formed second group.

Table 1 Stability parameters of 25 French beans genotypes for yield and quality traits

Genotype	Green pod yield per plant (g)			Dry matter content (%)			Protein content (%)		
	Mean	Bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
Arka Anoop	123.00	0.98	0.53	7.3	-0.02	0.4**	6.6	-2.90	0.01
Arka Sharath	111.22	0.24	2.17	6.8	-1.09	0.31**	6.0	0.30	0.06
Aishwaraya	70.33	0.19	1.72	7.1	0.74	0.4**	5.7	2.85	0.14
Arka Suvida	123.72	0.26	1.44	6.8	0.44	0.7**	7.5	-2.08	0.04
Contender (C)	99.17	2.25	66.67**	10.6	0.90	0.1	5.5	-1.0	0.2*
Falguni	111.56	0.18	17.18**	7.4	0.007	0.2	6.5	0.99	0.04
FB-1-14	64.56	0.46	26.8**	7.3	1.21	0.23	5.4	1.3	0.3*
FB-1-16	81.94	0.71	17.43**	5.9	1.11	0.4**	5.4	-0.7	0.1
FB-2-14	86.61	1.27	61.46**	4.9	1.28	0.2	5.6	0.23	0.3**
FB-2-16	95.17	0.57	1.71	7.6	0.89	0.2	5.5	-0.04	0.5**
FB-3-14	59.89	1.92	6.01**	5.2	0.76	0.3**	5.3	-2.60	0.03
FB-3-16	103.61	1.47	11.63**	8.9	1.14	0.1	5.7	-2.06	0.2
FB-4-14	78.17	0.38	3.64**	6.3	1.21	0.3	5.6	0.43	0.2*
FB-4-16	89.11	1.34	5.43**	6.4	1.24	0.3*	5.7	5.60	0.5**
FB-5-16	68.94	0.76	6.23**	5.4	1.27	0.3**	5.6	3.58	0.1
FB-6-16	91.06	1.77	7.11**	5.2	1.22	0.2	5.7	5.33	0.05
FBK-2	97.39	1.29	17.18**	8.2	0.79	1.1**	5.3	1.43	0.09
FB-VAR-2	69.33	1.21	14.52**	7.9	2.04	1.01**	5.9	-1.17	0.14
FB-VAR-5	94.17	2.16	1.78	7.7	1.44	0.2	5.9	2.82	0.9**
Rani Beans	73.83	1.15	16.10**	6.5	2.81	0.4**	4.5	0.72	0.02
RKS-1	74.83	1.45	12.75**	7.5	1.86	0.03	5.4	4.63	0.1
SwarnaPriya	88.83	0.3	0.42	10.2	0.81	0.2	5.4	1.21	0.1
S-9	83.33	1.07	2.94**	7.7	2.67	1.3**	5.4	-0.1	0.1
Shakira	61.06	0.62	2.06	8.7	1.03	0.217	5.3	0.23	1.3**
Shriya	62.67	1.33	13.69**	6.3	-0.84	0.06	5.2	6.0	0.01
Overall mean	86.54			7.1			5.6		
SE (Mean) Genotype	0.18			0.47			0.44		
SE (Mean) Environment	0.03			0.11			0.10		

*Significant at P=0.05, ** Significant at P=0.01

Discriminating ability and representativeness of test environment: The discriminating ability of the entire environment falls in equal range. The test environment E3 was both discriminating and representative so it was the good test environment for selecting generally adapted genotypes.

Ideal test environments for selecting generally adapted genotypes for green pod yield per plant (g): An ideal test environment was the center of the concentric circles and it was a point on the average environment axis (AEA) in the positive direction as environment E3 with a distance to the biplot origin equal to the longest vector of all environments.

Genotype evaluation based on GGE biplot for green pod yield per plant (g)

Mean performance and stability of the genotypes: Within a single mega environment, genotypes should be evaluated on both mean performance and stability across environments (Fig 1).

The single-arrowed line was the AEC abscissa (or AEA) and it points to higher mean yield across environments. Thus, genotype Arka Suvidha recorded highest green pod yield per plant followed by Arka Anoop, Falguni, Arka Sharath and FB-3-16 while the genotype FB-3-14 had the lowest mean green pod yield per plant.

The double-arrowed line was the AEC ordinate and

Table 2 Performance of French beans genotypes for green pod yield per plant (g) across six environments (E1-E6)

Genotype symbol used for GGE biplot	Genotype	E1 (PAU, Ludhiana 2017)	E2 (USF, Usman 2017)	E3 (KVK, Sangrur 2017)	E4 (PAU, Ludhiana 2018)	E5 (USF, Usman 2018)	E6 (KVK, Sangrur 2018)	Grand mean
1.	Arka Anoop	125.33	120.33	122.33	127.67	120.00	122.33	123.00
2.	Arka Sharath	112.67	108.33	109.33	113.00	111.67	112.33	111.22
3.	Aishwaraya	70.33	68.00	69.00	72.33	70.67	71.67	70.33
4.	Arka Suvidha	124.00	121.33	123.67	126.33	122.00	125.00	123.72
5.	Contender (C)	104.33	95.33	84.67	122.33	83.00	105.33	99.17
6.	Falguni	112.00	111.67	109.67	113.33	109.67	113.00	111.56
7.	FB-1-14	69.67	66.00	54.33	67.67	65.00	64.67	64.56
8.	FB-1-16	86.33	71.67	80.33	95.00	82.33	76.00	81.94
9.	FB-2-14	99.33	81.67	87.00	104.33	75.67	71.67	86.61
10.	FB-2-16	97.00	95.33	92.67	99.00	92.67	94.33	95.17
11.	FB-3-14	63.33	58.33	53.67	66.33	56.67	61.00	59.89
12.	FB-3-16	105.33	96.33	103.33	109.33	106.00	101.33	103.61
13.	FB-4-14	83.00	72.33	75.33	93.33	71.00	74.00	78.17
14.	FB-4-16	94.67	80.67	88.67	101.67	82.33	86.67	89.11
15.	FB-5-16	72.33	66.33	66.00	77.00	68.33	63.67	68.94
16.	FB-6-16	102.33	83.33	86.00	106.00	82.00	86.67	91.06
17.	FBK-2	104.33	92.67	95.67	108.33	85.33	98.00	97.39
18.	FB-VAR-2	76.67	66.00	61.67	80.67	68.00	63.00	69.33
19.	FB-VAR-5	102.33	82.67	89.00	115.33	86.00	89.67	94.17
20.	Rani Beans	75.00	65.00	68.00	86.67	75.00	73.33	73.83
21.	RKS-1	84.33	64.00	72.00	85.67	67.33	75.67	74.83
22.	Swarna Priya	90.33	86.67	88.00	91.33	87.33	89.33	88.83
23.	S-9	85.33	77.00	80.33	95.00	80.67	81.67	83.33
24.	Shakira	63.00	56.33	61.00	67.00	58.00	61.00	61.06
25.	Shriya	63.33	53.00	59.33	77.33	58.33	64.67	62.67
	Mean	90.66	81.61	83.24	96.07	82.60	85.04	86.54
	SE(m) Genotypes	2.05						
	SE(m) Environments	0.42						
	CD (P=0.05)	1.17						

it points to greater variability (poorer stability) in either direction. Thus genotype Contender was highly unstable because its yield varied among different environments.

Ideal genotypes for green pod yield per plant: Ideal genotypes should have the highest mean performance and be absolutely stable across environments (Yan and Kang 2003). An ideal genotypes to be a point on the AEA (absolutely stable) on the positive side. Genotypes located closer to the ideal genotypes were more desirable than others. Thus, the genotypes Arka Suvidha followed by Arka Anoop, Falguni, Arka Sharath and FB-3-16 was an ideal and desirable genotype. The genotype FB-3-14 was of course, the poorest genotype because it was consistently the poorest across environments. The term high stability was used only when it has high mean performance. The genotype Arka Suvidha followed by Arka Anoop, Falguni, Arka Sharath and FB-3-16 was stable. This implied that stable genotypes were desirable only when they had high mean performances. The relative contributions of stability and high mean green pod yield per plant has been reported by several workers in GGE biplot studies (Samonte *et al.* 2005 and Fan *et al.* 2007).

Which-won-where pattern for green pod yield per plant (g): One of the most attractive features of a GGE biplot

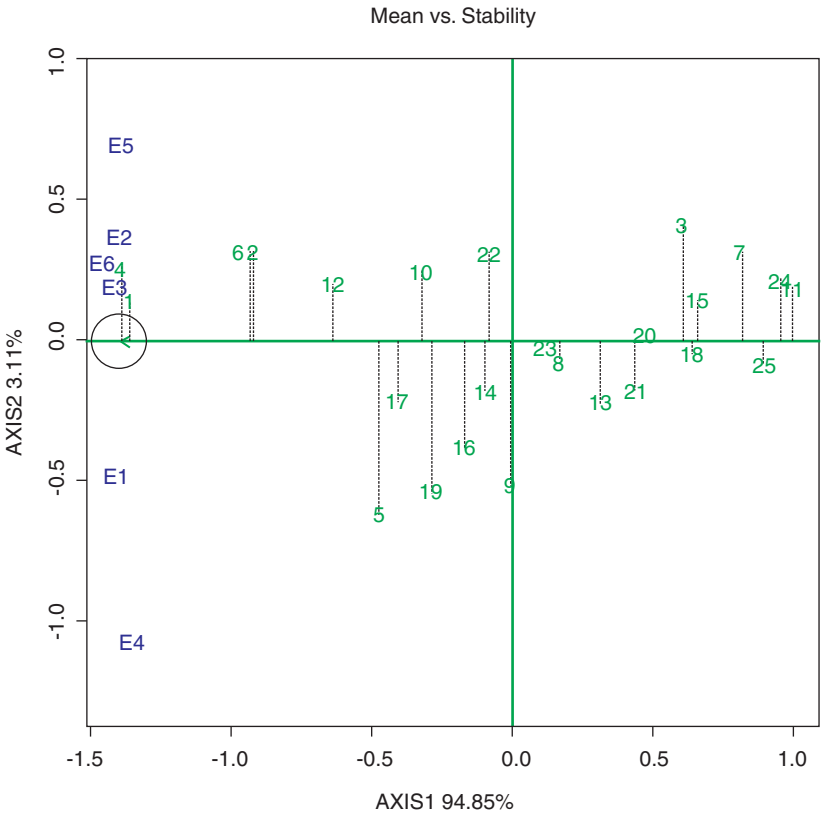

Fig 1 The average-environment coordination (AEC) view to show the mean performance and stability of the genotypes for green pod yield per plant.

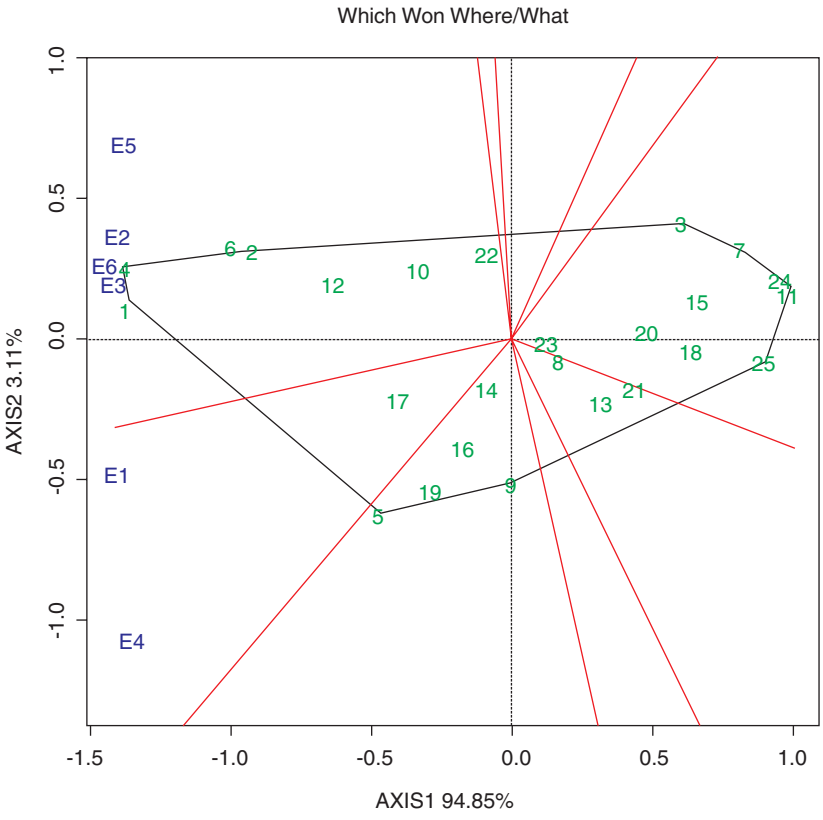

Fig 2 The which-won-where view of the GGE biplot to show which genotypes performed best in which environments for green pod yield per plant.

was its ability to show the which-won-where pattern of genotypes by environment dataset (Yan and Tinker 2006) (Fig 2). The polygon view of a biplot is the best way to visualize the interaction patterns between genotypes and environments and to effectively interpret a biplot (Yan and Kang 2003). The genotypes located on the vertices of the polygon as Arka Suvidha, Arka Anoop, Falguni and Arka Sharath performed best and genotypes like FB-3-14 and Shriya performed poorest in one or more environments (Yan and Hunt 2002). The equality line between genotypes Arka Suvidha and Arka Anoop indicated that genotype Arka Suvidha was better in environment E6 and E2, whereas genotype Arka Anoop was better in environment E3.The equality lines divided the biplot into sectors, and the winning genotype for each sector was the one located on the respective vertex. In this case, the six environments fell into one sector. The genotypes Arka Anoop and Arka Suvidha were winner in environment E6 and E2.

The conclusion can be drawn from this investigation is that genotypes Arka Suvidha followed by Arka Anoop, Falguni, Arka Sharath, FB-3-16 produced significantly more green pod yield than check Contender. These genotypes will be further utilized for development of stable varieties under Punjab conditions. All the environments were positively correlated for yield traits.

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