Genotype x environment interaction and stability analysis for yield and component traits in French bean (*Phaseolus vulgaris* L.)

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ABSTRACT
Selection of stable and high yielding genotypes is important not only for increasing the agricultural production but also for use in regular breeding programmes. Twenty-seven French bean genotypes were evaluated in three different agroecological zones of Himachal Pradesh comprising four environments to study their stability in performance by following the model of Eberhart and Russell (1966) during summer 2008 and 2009. Analysis of variance, means, regression co-efficient (bi) and deviation from regression (s^2di) of the individual genotypes were estimated to evaluate the stable performance of the genotypes. The mean squares due to genotypes, environments and genotype-environment interaction were significant for most of the characters studied, which suggests variability among the genotypes for various characters over the environments. Genotype × environment interaction was also found significant for a majority of the traits. The stability analysis showed significance of linear component of variation for important traits including fresh pod and seed yield. On the basis of regression coefficient and mean values, the genotypes 'Arka Suvidha', 'DWDFB-1', 'DPDFB-1(M)', 'DPDFB-2(M)', 'IVRFV-1', 'IVFB-1', 'MFB-2' and 'MFB-3' showed stability below average (bi>1) for fresh pod yield, which indicated their specific adoption to favourable environments. Genotypes 'DWDFB-53', 'MFB-4' and 'Aparna' were found to be desirable and stable for high fresh pod yield under unfavourable environments stability above (bi<1) average. Genotype 'MFB-2' was observed to be the most stable for seed yield per plant and days to seed maturity over the environments

Keywords
Phaseolus vulgaris L., genotypes, environment, stability, yield and traits.

INTRODUCTION
French bean (*Phaseolus vulgaris* L.) is an important leguminous vegetable; it is grown for fresh pod consumption and for processing as a frozen vegetable in many countries (Biswas et al. 2010). Its average yield is low despite continuous breeding efforts due to unsuitable cultivars, biotic and abiotic stresses, genetic drift in the cultivars, and development of new pathogen races. Further, in dealing with instability and uncertainty of yield, genotype-environment interaction is a challenging issue for plant breeders (Raffi et al. 2004) and plays a major role in developing improved varieties (Akhtar et al. 2010). Generally, genotypes with consistent yield over environments are preferred over those with high yield in selected environments. It is essential to select cultivars that are adapted to inconsistent environmental conditions by evaluating them over locations and years. This allows the estimation of genotype × environment (G×E) interaction and selection of desirable germplasm, and helps to increase and stabilise agricultural production with utilization in regular breeding

programmes (Ali and Sarwar 2008). The identification of stable and high yielding lines is urgent for commercial exploitation in farmers' fields for boosting production and productivity of this crop. Keeping this in view, our studies were conducted to understand genotype-environment interaction and to identify stable and high yielding, dual-purpose (fresh and seed) lines of French bean genotypes under changing environments. The results may be useful for breeders and farmers to select suitable genotypes for sustainable French bean production.

MATERIAL AND METHODS

Twenty-seven genotypes of French bean from different public and private institutes were used in this study. These genotypes were raised in a Randomized Complete Block Design with three replications in three locations constituting four environments namely, Palampur (1, 290.8 masl; 32^0 6′ N and 76^0 3′ E) during 2008 and 2009, Bajaura (1,090 masl; 31^0 08′ N and 77^0 E) during 2008 and Kukumseri (2,672 masl; 31^o 44′ N and 76^o 41′ E) during 2008. The plot size consisted of two rows of 2.7 m length each and plants were spaced 0.45 m between rows and 0.15 m within rows. To investigate the stability, data were recorded on yield and yield related traits *viz.,* days to 50% flowering, pod length (cm), pods/plant, plant height (cm), seeds per pod, pod yield/plant (g) and seed yield per plant (g). Combined analysis of variance was used to detect G×E interactions and their magnitude. Stability components were determined by using the procedure given by Eberhart and Russell (1966) in which stability of varieties was defined by high mean yield and regression coefficient (bi = 1.0) and deviations from regression as small as possible (s^2 di = 0) as described below:

Regression	Stability	Mean yield	Remarks
bi=1	Average	High	Well adapted to all environments
bi=1	Average	Low	Poorly adapted to all environments
bi>1	Below average	High	Specifically adapted to favourable environments
bi<1	Above average	High	Specifically adapted to unfavourable environments

The significance of regression coefficient (bi) and deviations from regression (S^2di) were tested using t-test and F-test respectively.

RESULTS AND DISCUSSION

The mean sum of squares due to genotypes and environments were found significant for days to flowering, green pod length and seed yield per plant (Table 1) which validates considerable variation among genotypes as well as environments. However traits *viz*., pods per plant, plant height and fresh yield per plant were found significant only for the environments. The genotype x environment interaction tested against pooled error was found to be significant for all the traits under study. Hence, these varieties showed inconsistency in performance across the environments and satisfied the requirement of stability analysis. The partitioning of G×E interaction into linear and non-linear components showed that both components played an important role in total G×E interaction for different characters. G×E (linear) mean squares were found significant for days to flowering, pods per plant, plant height, fresh pod yield and seed yield per plant, which indicated the presence of predictable components, whereas the variation due to pooled deviation was found highly significant for all the traits. This suggests that performance of different varieties fluctuated from their respective linear path of response to environment, and thereby indicate difficulty in predicting the

performance of these varieties over environments for these traits. Patel et al. (2009) also found similar observations for some of these traits with their genetic material.

In interpreting the results of the present investigation, S^2_{di} was considered as the measure of stability (Breese 1969). Once the genotype was found to be stable based on nonsignificant deviation from regression ($S^2_{di}=0$), then the type of stability (measure of response or sensitivity to environmental changes) was based on regression coefficient and mean values. Regression coefficient (b_i) values above 1.0 define genotypes with higher sensitivity to environmental alteration. Regression coefficients below 1.0 ensure a greater resistance to environmental variation, and hence, increasing specificity of adaptability to low yielding environments (Kilic et al 2010).

In French bean, early maturing genotypes are ideal both from fresh and seed yield point of view to capture early market share and to fit into different cropping sequences. From average of all the environments, genotypes 'Arka Suvidha', 'DPDFB-1(M)', 'KPV-2' and 'MFB-4' were found early for day to 50% flowering (Table 2). They had values lower than population mean, $b_i>1$ and nonsignificant regression value (S^2_{di}), which showed its high stability and response to favourable environmental condition. Pod length of genotypes ranged between the highest 16.06 cm in genotype 'DWDFB-1' and lowest 12.55 cm in 'Falguni' across the environments. For pod length, four genotypes namely, 'DWDFB-53', 'HAFB-1', 'HAFB-3', and 'VLB-8' produced stable and desirable pod length below average performance of the genotypes, whereas 'Arka Suvidha', 'DPDFB-2 (M)', 'HAFB-2', 'IVRFB-1' and 'MFB-3' indicated better performance under favourable environments. For seeds per pod, 'Arka Anoop', 'DPDFB-1(M)', 'DPDFB-2(M)', 'DWDFB-57', 'HAFB-4', 'Aparna', 'Arka Komal' had shown above average mean value, average regression value (bi<1) and least deviation from regression (S^2di=0) and thus showed resistance to varied environmental conditions.

Number of pods per plant has a direct bearing on total productivity. In this regard, 'DWDFB-1', 'IVFB-2' and 'Aparna' showed their stability ($b_i \leq 1$) as potential genotypes with above average performance for number of pods per plant (Table 3). In addition, 'DPDFB-1(M)', 'DPDFB-2(M)', 'HAFB-1', 'HAFB-3', 'IVFB-1' 'MFB-2', 'MFB-3', 'VLB-8' and 'VLFB-130' may show stable performance under favourable environmental conditions (bi>1). Plant height in bush bean is desirable to the extent that it does not add to the cost of staking. Accordingly, genotypes 'Arka Suvidha', 'DWDFB-1', 'DPDFB-1(M)', 'DPDFB-2(M)', 'DWDFB-53', 'IVRFV-1', 'IVFB-1', 'IVFB-2' 'MFB-2' and 'MFB-3' and 'MFB-4' had more plant height over the standard checks, which might have resulted in significantly higher fresh pod yield per plant. However, based upon the stability parameters, genotypes 'IVRFB-1', 'IVFB-3', 'VLB-8', 'VLFB-2003' and 'Arka komal' were found more stable across the environments for this trait (Table 3).

For fresh pod yield per plant, however, all the genotypes were found with significant regression (S^2_{di}) except 'IVFB-3' (Table 3). On the basis of regression coefficient and mean values, the genotypes 'Arka Suvidha', 'DWDFB-1', 'DPDFB-1(M)', 'DPDFB-2(M)', 'IVRFB-1', 'IVFB-1', 'MFB-2' and 'MFB-3' showed stability above average ($b_i>1$) for high fresh pod yield, indicating that these genotypes are specifically adapted to favourable environments. Similarly, genotypes 'DWDFB-53', 'MFB-4' and 'Aparna' showed stability below (bi<1) average for high fresh pod yield, indicating their adaptation to unfavourable environments. Among the environments 'MFB-2' was observed to have the highest seed yield per plant with

bi<1 and non-significant S^2di value, indicating its stability under unfavourable environments with predictable performances.

Hence, it can be concluded that stability analysis helps to identify and select the most stable, high performing genotypes/varieties that are best suited under a given set of environmental conditions. Based upon the stability parameters, genotypes namely 'Arka Suvidha', 'DWDFB-1', 'DPDFB-1(M)', 'DPDFB-2(M)', 'DWDFB-53', 'IVRFB-1', 'IVFB-1', 'MFB-2' and 'MFB-3' were found stable across all environments. The wider adaptability of these genotypes can be attributed mainly to their wider adaptability for component traits like pods per plant, pod length, plant height, fresh and seed yield per plant. These genotypes are recommended for hybridization programmes to develop high yielding varieties with stability in performance.

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Table 1: Stability analysis of variance for yield and component characters in French bean

Source	df	Days to flowering	Pod length (cm)	Seeds per pod	Pods per plant	Plant height (cm)	Fresh pod yield per plant (g)	Seed yield per plant (g)
Environments (E)	3	761.81*	10.45*	0.39	1451.41*	1719.40*	40815.92*	3733.62*
Genotypes (G)	26	35.28*	8.56	1.07*	82.68	117.13	2728.70	711.27*
G × E	78	11.36*	2.52*	0.45	94.51*	75.00*	2686.83*	305.09*
E.+(G × E)	81	31.86*	1.20	0.16	84.09*	87.75*	2374.13*	236.02*
E (linear)	1	2285.43+	31.35+	1.16+	4354.23+	5158.15+	122448.1+	11200.89+
G × E (linear)	26	7.25+	0.79	0.17	48.84+	25.63+	1007.92+	184.72+
Pooled deviation	54	1.98*	0.83*	0.14*	21.96*	23.77*	808.33*	57.93*
Pooled error	208	0.75	0.31	0.04	0.84	1.32	7.43	3.95

Where, * Significant at P = 0.05; + Significant against pooled deviation at P=0.05

Table 2: Mean values and stability parameters for days to flowering, pod length and seeds/pod in French bean

Genotypes	Days to flowering			Pod length (cm)			Seeds per pod		
	Mean	b_i^2	S^2_{di}	Mean	b_i^2	S^2_{di}	Mean	b_i^2	S^2_{di}
Arka Suvidha	43.50	1.19	0.54	14.21	1.14	0.04	5.16	3.87	0.02
Arka Anoop	46.83	1.11	1.17	15.30	1.64	1.42*	5.57	2.43	0.02
DWDFB-1	46.25	0.93	0.36	16.06	0.49	0.74	5.81	-0.50	0.05
DPDFB-1(M)	44.08	1.28	0.62	14.96	1.98	0.20	5.56	3.50	0.10
DPDFB-2(M)	43.92	0.90	1.51	14.25	2.02	0.43	5.46	2.17	0.03
DWDFB-53	47.00	1.11	2.52*	13.55	0.82	0.65	5.05	1.50	0.26*
DWDFB-57	47.92	0.85*	0.27	15.21	0.37	0.39	5.01	2.29	0.21*
HAFB-1	45.67	0.99	2.39*	14.05	0.97	0.52	5.55	0.77	0.13*
HAFB-2	45.58	1.43	0.14	13.46	1.57	0.62	5.33	0.06	0.03
HAFB-3	46.17	1.01	0.77	13.70	0.53	0.65	5.43	-0.23	0.06
HAFB-4	46.25	1.10	0.56	14.03	-0.38	1.11*	5.73	1.25	0.02
IVRFB-1	48.42	1.37	12.05*	13.88	1.96	1.10*	5.65	-0.49	0.07
IVFB-1	44.25	0.86	0.70	15.07	1.56	0.17	5.50	0.45	0.05
IVFB-2	45.50	0.98	1.62	15.68	1.00	0.08	5.38	1.64	0.01
IVFB-3	45.08	1.11	4.50	15.15	1.36	0.49	5.57	0.20	0.09
KPV-2	43.08	1.10	0.85	13.56	0.22*	0.15	5.28	-2.77*	0.02
MFB-2	46.83	1.28	3.28*	14.89	1.10	3.17*	5.54	2.18	0.17*
MFB-3	43.58	0.98	0.38	14.13	1.11	0.10	5.81	-0.27	0.20*
MFB-4	44.25	1.10	0.67	15.10	2.00	2.93*	5.81	-0.54	0.59*
MFB-5	43.25	0.59*	1.79	15.47	0.85	0.18	5.84	0.39	0.26*
VLB-8	43.17	0.28*	5.49*	13.69	0.71	1.13*	5.60	3.42	0.40*
VLB-2003	42.67	0.70*	1.14	14.07	0.52*	0.04	5.03	0.94	0.04
VLFB-130	43.42	0.91	0.34	14.92	0.85	1.74*	5.08	1.20	0.52*
Aparna	45.92	1.69	3.90*	13.14	-0.47	2.37*	5.58	1.29	0.02
Falguni	46.67	1.09	1.68	12.55	-1.10*	0.54	6.21	-2.63*	0.09
Arka.Komal	42.83	0.64*	0.16	14.20	1.95	0.91	5.68	4.89	0.10
Contender	42.50	0.54*	3.87*	14.06	2.24	0.55	5.05	0.11	0.17*
Population mean	44.98	-	-	14.38	-	-	5.49		
CV (%)	3.84	-	-	7.69	-	-	6.31		

*Significant at P=0.05

Table 3: Mean values and stability parameters for pods per plant, plant height and yield (pod and seed) in French bean

Genotypes	Pods per plant			Plant height (cm)			Fresh yield per plant (g)			Seed yield per plant (g)		
	Mean	b_i^2	S^2_{di}	Mean	b_i^2	S^2_{di}	Mean	b_i^2	S^2_{di}	Mean	b_i^2	S^2_{di}
Arka Suvidha	14.82	0.70	21.32*	34.35	0.93	45.81*	104.72	1.21	591.17*	28.03	0.75	65.77*
Arka.Anoop	12.64	0.69	6.52*	33.69	1.19	9.66*	78.10	0.70	356.03*	17.57	0.34*	19.52*
DWDFB-1	16.96	0.82	5.42	34.90	0.57*	6.02*	113.74	1.14	76.99*	32.94	0.69	70.91*
DPDFB-1(M)	19.83	1.64	20.69*	35.62	1.01	4.69*	116.88	1.68	241.61*	44.27	2.36	284.22*
DPDFB-2(M)	18.56	1.87	40.02*	32.50	1.49	16.47*	105.06	1.71	643.82*	40.36	2.41	149.34*
DWDFB-53	17.63	0.57	60.16*	35.42	0.66	7.29*	104.47	0.38	2112.45*	28.16	0.56	132.73*
DWDFB-57	10.98	-0.19*	12.46*	32.15	1.18	13.19*	78.19	0.02	1503.90*	15.34	-0.28*	10.12
HAFB-1	18.57	1.21	55.73*	30.09	0.85	15.48*	109.01	1.00	1961.32*	31.69	1.10	83.71*
HAFB-2	15.94	1.22	22.81*	32.23	0.15*	12.43*	92.53	1.25	1622.09*	22.48	0.84	53.70*
HAFB-3	16.57	1.28	8.98*	32.28	1.20	6.03*	93.42	1.26	274.10*	21.56	0.93	39.71*
HAFB-4	13.73	0.87	1.09	36.38	1.32	9.80*	77.37	0.65	193.73*	21.05	1.10	11.12
IVRFB-1	14.84	1.19	14.80*	33.93	0.81*	0.80	104.21	1.37	934.08*	23.34	1.00	5.18
IVFB-1	18.13	1.38	13.64*	41.91	0.10	298.40*	106.41	1.32	823.58*	31.72	1.13	55.46*
IVFB-2	18.24	0.73	34.78*	36.46	0.82	9.57*	104.92	0.77	424.57*	28.51	0.72	61.66*
IVFB-3	15.99	0.61*	1.83	35.32	1.10	0.45	85.89	0.44*	2.70	24.72	0.54*	14.49*
KPV-2	14.74	1.40	28.89*	30.06	1.09	6.51*	69.73	1.04	1103.40*	21.19	0.98	27.07*
MFB-2	21.60	1.89	21.93*	35.08	1.46	19.25*	113.35	1.42	1126.30*	36.07	0.20*	9.42
MFB-3	22.31	1.80	2.31	34.39	0.66*	4.07*	128.69	1.91	129.74*	43.17	1.95	62.94*
MFB-4	14.87	0.61*	5.70*	34.73	1.08	19.35*	99.11	0.78	1305.56*	30.26	0.92	83.40*
MFB-5	15.38	1.24	12.02*	30.98	1.05	10.70*	91.62	1.02	373.82*	28.93	1.16	94.77*
VLB-8	16.39	1.25	2.91*	30.01	0.73	4.06	88.22	0.93	681.26*	28.20	1.14	26.69*
VLB-2003	11.91	0.37*	11.85*	29.00	1.21	1.09	70.28	0.47*	256.48*	22.33	0.05*	4.45
VLFB-130	16.65	1.52	7.92*	34.55	1.43	40.30*	82.33	1.39	626.27*	22.07	1.18	7.90
Aparna	17.52	0.78	100.53*	32.45	1.34	5.29*	96.87	0.91	2324.28*	23.68	0.46	143.47*
Falguni	16.89	-0.25*	11.59*	29.43	0.97	37.85*	78.45	0.04*	1090.37*	14.15	0.06*	0.72
Arka.Komal	15.84	0.63	54.30*	30.12	1.16	0.11	94.03	0.94	1014.02*	21.22	0.70	14.53*
Contender	14.49	1.11	12.86*	26.27	0.96	37.11*	85.81	1.22	643.29*	25.58	1.13	31.13*
Population mean	16.37	-	-	33.12	-	-	95.31	-	-	26.98	-	-
Coefficient of variation (%)	11.19	-	-	6.94	-	-	5.72	-	-	14.75	-	-

*Significant at P=0.05