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Genetic diversity and path coefficient analysis for yield and yield related traits in French bean

A Panchbhaiya and Dhirendra Kumar Singh

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Abstract

Seventy four genotypes of French bean have been evaluated for various economic traits at GBPUAT, Pantnagar. Among the genotypes FB-202, FB-209, FB-206, Arka Suvidha and FB-205 were found superior with respect to yield and quality characters. The overall values of PCV were higher than those of GCV. The highest estimate of GCV was observed for plant height (42.45) followed by seed yield per plant (39.72), while highest heritability was recorded for seed length (99.04%). High heritability along with high genetic advance as per cent of mean was estimated for plant height. Pod yield had significant positive correlation with days to 50% flowering, seed yield per plant, plant height, number of pods per plant, number of pod clusters per plant, number of pods per cluster, number of seeds per pod, pod length and weight of single pod. Path coefficient analysis revealed that single pod weight and number of pods per plant had the highest positive contribution towards the total yield respectively. Principal component analysis showed that the first principal component had maximum of 30.85% variation of total variation, while the first seven principal component axes together with explained 83.41% variation, suggesting first seven principal axes are adequate to explain the variation in reduced dimension. Clustering through D^2 analysis revealed maximum inter-cluster distance of clusters V and IX (1405.141) followed by cluster III and IX (1297.298).

Keywords: Genetic variability, heritability, correlation, path coefficient analysis, principal component analysis, D^2 analysis, French bean.

Introduction

French bean (*Phaseolus vulgaris* L.), 2n = 22 is the most popular leguminous vegetable crop in many part of the world. It was brought to India from Europe during the 17th century. It is adapted to variety of climatic conditions, being grown from 52^0 north latitude to 32^{0}south latitude in the humid tropics, semi arid tropics and even cold climate regions Schoonhoven and Voysest (1991). French bean had evolved from a wild growing vine *viz., Phaseolus aborigineus* distributed in the highlands of middle America and Andes Brucher (1988). India has about 137.54 thousand ha area under bean cultivation and the production is 1370.21 thousand MT with an annual productivity 9.96 MT/ha green pod NHB (2015). The knowledge of genetic diversity is an important pre-requisite to any breeding programme aimed to exploit hybrid vigour. Moreover, the information related to the nature and extent of association among various yield attributes, direct and indirect influence of each of the component traits on yield could prove helpful in formulating effective breeding strategy.

Materials and Methods

The present investigation was conducted at Vegetable Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar (Uttarakhand), India during Jan-May, 2014. The experimental material comprised of 74 genotypes. The experiment was laid out in randomized block design with three replications. Each genotype was sown in three meter row length following plant spacing at 30 x 20 cm apart.

Observations were recorded on five randomly selected competitive plants per replication for each entry on twenty two quantitative traits. The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated as per Burton and De Vane (1953). Heritability (broad sense) and genetic advance as per cent of mean were computed by following the methods of Johnson *et al.* (1955) and Allard (1960), respectively. Correlation and path coefficient analysis were calculated by Searle's (1961) and Dewey and Lu (1959), respectively. PCA and D^2 analysis were calculated as per Hotelling (1933) and P.C. Mahalanobis (1936), respectively.

Department of Vegetable Science, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, India

Results and Discussion

The variation in the characters of any crop species is the raw material for a plant breeder and extent of variability present in the population with respect to various characters is the factor for the success of plant breeder in improvement of crop plant. Larger variability ensures better chances of producing desired crop variety. The mean estimates of genotypes for various characters revealed that the wide range was recorded in seed yield per plant, plant height, 100 seed weight, number of pods per plant, number of seeds per pod, pod length, seed length, pod yield per plant and pod yield per hectare, while moderate range was recorded in days to 1st flowering, days to 50 % flowering, days to 50% pod setting, days to 1st picking, days to 2nd picking, days to 50 % maturity, number of pods per cluster, number of pod clusters per plant, pod diameter, seed width, leaf length, leaf width and single pod weight. Similar findings were also reported by Amini *et al*. (2002), Kapila *et al*. (2002) and Prakash and Ram (2014).

In the present investigation, phenotypic coefficient of variation was higher than that of genotypic coefficient of variation for all the characters under study. It may be because of the reason that the variability at phenotypic level includes both genotypic and environmental variability. For most of the characters, the differences in estimates of PCV and GCV were less, indicating that these characters were less affected by environment and therefore they were stable. Highest genotypic as well as phenotypic coefficient of variations were exhibited by plant height, followed by seed yield per plant, pod yield per plant, pod yield per hectare and number of pods per cluster, while lowest in days to 2nd picking, followed by days to 1st picking, days to 50% maturity, days to 50% pod setting and days to 50% flowering. Similar results also reported by Kamaluddin and Ahmed (2011), Pandey *et al*. (2013) and Prakash and Ram

Table 1: Analysis of variance for twenty two quantitative characters in French bean

S. N.	Characters	df	Mean sum of squares		
			Replication	Genotype	Error
			2	73	146
1	Days to 1st flowering		1.27	31.58**	1.93
2	Days to 50% flowering		0.22	37.81**	1.64
3	Days to 50% pod setting		1.23	40.21**	2.36
4	Days to 50% maturity		0.29	42.41**	0.54
5	Days to 1st picking		1.15	34.71**	0.51
6	Days to 2nd picking		0.66	29.67**	0.53
7	Number of pods/ cluster		0.01	0.88**	0.07
8	Number of pod clusters/ plant		0.07	1.67**	0.13
9	Number of pods/ plant		1.35	12.89**	0.76
10	Pod diameter (mm)		0.05	10.46**	0.27
11	Pod length (cm)		0.86	11.33**	0.40
12	Leaf length (cm)		0.43	10.21**	0.38
13	Leaf width (cm)		0.91	3.44**	0.27
14	Single pod weight (g)		0.00	2.69**	0.07
15	Plant height (cm)		6.83	1016.23**	13.56
16	Number of seeds/ pod		0.50	1.20**	0.41
17	Seed length (mm)		0.07	9.92**	0.03
18	Seed width (mm)		0.05	1.93**	0.01
19	100 seed weight (g)		0.55	169.58**	1.53
20	Seed yield/plant (g)		0.46	74.72**	3.24
21	Pod yield/ plant (g)		12.01	370.28**	39.18
22	Pod yield/ ha (q)		48.03	1481.14**	156.72

Table 2: Range, Coefficient of variation, heritability, genetic advance, genetic advance as per cent of mean and genetic parameters for different quantitative characters of French bean

S.N.	Characters	Range	GM	Sem	Variability		Heritability (h^2%)	Genetic advance	Genetic advance as per cent of mean
					PCV (%)	GCV (%)			
1	Days to 1st flowering	40.33 - 57.67	44.71	0.8016	7.69	7.03	83.68	5.92	13.25
2	Days to 50% flowering	44.00 - 60.00	48.18	0.7385	7.68	7.21	88.05	6.71	13.93
3	Days to 50% pod setting	47.00 - 63.67	52.09	0.8873	7.43	6.82	84.23	6.72	12.89
4	Days to 50% maturity	59.00 - 74.33	63.98	0.4258	5.95	5.84	96.25	7.55	11.80
5	Days to 1st picking	57.00 - 71.33	61.86	0.412	5.58	5.46	95.72	6.81	11.00
6	Days to 2nd picking	61.00 - 76.00	66.65	0.4202	4.80	4.68	94.83	6.25	9.38
7	Number of pods/ cluster	01.13 - 03.50	2.08	0.1549	28.14	25.01	78.96	0.95	45.78
8	Number of pod clusters/ plant	02.20 - 05.53	4.05	0.2109	19.86	17.69	79.39	1.32	32.47
9	Number of pods/ plant	03.80 - 13.43	8.19	0.503	26.76	24.56	84.20	3.80	46.42
10	Pod diameter (mm)	07.37 - 14.24	10.31	0.2988	18.56	17.87	92.69	3.66	35.45
11	Pod length (cm)	06.69 - 15.60	10.83	0.3647	18.57	17.63	90.13	3.73	34.48
12	Leaf length (cm)	05.23 - 12.53	9.08	0.3563	21.07	19.94	89.58	3.53	38.88
13	Leaf width (cm)	04.20 - 09.80	6.74	0.3002	17.09	15.25	79.60	1.89	28.03
14	Single pod weight (g)	02.53 - 06.67	4.85	0.1513	20.01	19.27	92.70	1.85	38.21
15	Plant height (cm)	25.23 - 119.6	43.07	2.1258	43.30	42.45	96.34	36.92	85.73
16	Number of seeds/ pod	02.17 - 06.10	4.53	0.3703	21.43	16.08	56.27	1.12	24.85
17	Seed length (mm)	08.24 - 16.74	13.82	0.1032	13.20	13.13	99.04	3.72	26.92
18	Seed width (mm)	04.81 - 08.55	6.79	0.069	11.91	11.78	97.82	1.63	24.01
19	100 seed weight (g)	12.47 - 46.47	33.04	0.7144	22.96	22.65	97.34	15.21	46.04
20	Seed yield/plant (g)	03.44 - 27.84	12.29	1.0394	42.34	39.72	88.03	9.43	76.77
21	Pod yield/ plant (g)	13.48 - 62.59	38.08	3.6139	32.12	27.59	73.80	18.59	48.83
22	Pod yield/ ha (q)	26.95 - 125.19	76.15	7.2277	32.12	27.59	73.80	37.18	48.83

(2014).

The study of genotypic coefficient of variation helps to measure the range of genotypic variation existing at specified environmental site for a particular character and to compare the variability existing in various characters. However, it cannot measure the heritable variation; the genotypic coefficient of variation together with heritability estimates would give reliable indication of the expected improvement through selection as reported by Burton and Devane (1953).

High heritability coupled with high or moderate high genetic advance was recorded in plant height, seed yield per plant, 100 seed weight, number of pods per plant, pod diameter, pod length, leaf length, single pod weight and seed yield per plant indicated that most likely the heritability is due to additive gene effects and selection may be effective. Similar finding were also reported by Singh and Singh (2013), Ahmed and Kamaluddin (2013) and Verma *et al*. (2014). High heritability coupled with low genetic advance was found in seed length, days to first flowering, days to 50 per cent flowering, days to 50 per cent pod setting, days to 50 per cent maturity, days to 1st picking and days to 2nd picking, revealed non-additive gene action, hence selection for such traits may not be rewarding.

The efficiency of selection can be improved by estimating the relative degree of association between different pair of characters. An increase in production per unit area per unit time is an ultimate aim of most of the breeding programmes. The expression of a complex character like yield is a sum total of the contribution of many simply inherited characters and therefore, direct selection for it may not be their action but are interlinked and in this interlinked complex genetic system, selection practiced for an individual character might subsequently bring about a simultaneous change in other, thus an understanding of the association between the component characters and their relative contribution to yield is essential to bring a rational improvement in their desirable traits.

Seed yield per plant showed positive and highly significant correlation with days to 50% maturity, 100 seed weight, number of pods per plant, number of seeds per pod, seed length, pod yield per plant and pod yield per hectare. Similar findings were also reported by Karasu and Oz (2010), Kamaluddin and Ahmed (2011), Ahmed and Kamaluddin (2013) and Negahi *et al*. (2014).

Number of pods per plant showed positive and highly significant correlation with days to 50% flowering, seed yield per plant, number of pods per cluster, number of pod clusters per plant, number of seeds per pod, pod yield per plant and pod yield per hectare. Similar results were also reported by Berrocal *et al*. (2002), Bhushan *et al*. (2007) and Saha *et al*. (1990).

Pod yield per hectare shows highly significant correlation with pod yield per plant, number of pods per plant, seed yield per plant, weight of single pod, days to 1st flowering, days to 50% flowering, days to 50% pod setting, days to 1st picking, days to 2nd picking, days to 50% maturity, number of pod clusters per plant, number of seeds per pod, plant height, pod length and pod width was observed, so these characters will helpful in breeding programme for selecting high yielding variety. Similar findings were also reported by Yuvraj and Naidu (2009), Rai *et al*. (2010) and Singh and Singh (2013).

Path coefficient analysis gives an idea about contribution of each independent character on dependent character i.e., pod yield per plant. Since the mutual relationship of component characters might vary both in magnitude and direction it may tend to vitiate the association of pod yield with attributes, it is necessary to partition the genotypic and phenotypic correlation into direct and indirect effects of each other. Correlation is useful for making rational improvement in yield and its components but these does not provide an exact picture of the relative importance of direct and indirect influences of each of these component characters. In such situation it becomes necessary to study path coefficient analysis which takes into account the causal relationship in addition to degree of relationship.

In present investigation, path coefficient analysis revealed that single pod weight had highest direct effect on pod yield per plant followed by number of pods per plant, number of pods per cluster, days to 1st picking, number of pod clusters per plant, seed yield per plant, days to 50% pod setting, seed length, pod diameter, days to 1st flowering, leaf width, leaf length and number of seeds per pod, seed width, days to 50% flowering, plant height, pod length, days to 50% maturity, 100 seed weight and days to 2nd picking. Similar findings were also reported by Ahmed and Kamaluddin (2013), Rai *et al*. (2010) and Pandey *et al*. (2013).

The principal component analysis of 74 French bean genotypes based on correlation matrix of yield and yield contributing traits yielded seven eigen roots or eigen values. The percent variation explained by each eigen roots are presented in Table 5. The principal component score based on the correlation of 22 quantitative characters of 74 genotypes of French bean is presented in Table 6. The Eigen root of first principal component was accounted approximately 30.857% of total variation followed by second to seven components which

Table 3: Estimates of phenotypic and genotypic correlation among different traits in French bean

Character		Days to 1st flowering	Days to 50% flowering	Days to 50% pod setting	Days to 50% maturity	Days to 1st picking	Days to 2nd picking	Number of pods/ cluster	Number of pod clusters/ plant	Number of pods/ plant	Pod diameter (mm)	Pod length (cm)	Leaf length (cm)	Leaf width (cm)	Single pod weight (g)	Plant height (cm)	Number of seeds/ pod	Seed length (mm)	Seed width (mm)	100 seed weight (g)	Seed yield /plant (g)	Pod yield/ plant (g)	Pod yield/ ha (q)
Days to 1st flowering	P	1.000																					
	G	1.000																					
Days to 50% flowering	P	0.821**	1.000																				
	G	0.935**	1.000																				
Days to 50% pod setting	P	0.740**	0.926**	1.000																			
	G	0.869**	0.979**	1.000																			
Days to 50% maturity	P	0.690**	0.899**	0.887**	1.000																		
	G	0.773**	0.970**	0.978**	1.000																		
Days to 1st picking	P	0.685**	0.834**	0.799**	0.863**	1.000																	
	G	0.758**	0.908**	0.892**	0.899**	1.000																	
Days to 2nd picking	P	0.672**	0.873**	0.857**	0.946**	0.884**	1.000																
	G	0.743**	0.949**	0.963**	0.984**	0.928**	1.000																
Number of pods/ cluster	P	0.083	0.131	0.147	0.146	0.224	0.167	1.000															
	G	0.082	0.153	0.172	0.184	0.270*	0.184	1.000															
Number of pod clusters/ plant	P	0.312**	0.332**	0.309**	0.297*	0.301**	0.291*	-0.373**	1.000														
	G	0.414**	0.391**	0.381**	0.334**	0.326**	0.329**	-0.380**	1.000														
Number of pods/ plant	P	0.321**	0.376**	0.376**	0.374**	0.454**	0.381**	0.665**	0.374**	1.000													
	G	0.389**	0.447**	0.457**	0.424**	0.507**	0.423**	0.668**	0.424**	1.000													
Pod diameter (mm)	P	0.085	0.041	0.036	-0.020	-0.115	-0.049	-0.108	0.030	-0.052	1.000												
	G	0.096	0.035	0.040	-0.022	-0.124	-0.047	-0.151	0.049	-0.067	1.000												
Pod length(cm)	P	0.261*	0.232*	0.246*	0.219	0.078	0.158	-0.051	0.176	0.102	0.191	1.000											
	G	0.322**	0.286*	0.299*	0.242*	0.086	0.160	-0.089	0.229**	0.098	0.198	1.000											
Leaf length (cm)	P	-0.023	0.008	0.031	0.044	0.005	0.026	-0.039	-0.076	-0.113	-0.296*	-0.064	1.000										
	G	-0.030	0.001	0.040	0.044	0.006	0.017	-0.041	-0.091	-0.117	-0.336**	-0.061	1.000										
Leaf width (cm)	P	0.040	0.043	0.070	0.104	0.034	0.042	-0.009	0.009	-0.029	-0.406**	0.114	0.649**	1.000									
	G	0.036	0.068	0.100	0.106	0.032	0.036	-0.023	0.008	-0.046	-0.475**	0.102	0.765**	1.000									
Single pod weight (g)	P	0.298*	0.334**	0.297*	0.333**	0.238*	0.318**	-0.149	0.292*	0.012	0.145	0.403**	-0.018	0.159	1.000								
	G	0.328**	0.360**	0.326**	0.349**	0.252*	0.335**	-0.169	0.344**	0.024	0.152	0.437**	-0.028	0.191	1.000								
Plant height (cm)	P	0.049	0.074	0.082	0.116	0.081	0.091	0.156	-0.062	0.093	0.086	0.252*	-0.324**	-0.191	0.256*	1.000							
	G	0.058	0.095	0.099	0.124	0.085	0.092	0.178	-0.066	0.106	0.092	0.272*	-0.348**	-0.227	0.275*	1.000							
Number of seeds/ pod	P	0.244*	0.246*	0.265*	0.262*	0.303**	0.295*	0.362**	0.070	0.376**	-0.259*	0.038	0.136	0.145	0.034	-0.073	1.000						
	G	0.331**	0.348**	0.373**	0.387**	0.409**	0.394**	0.464**	0.075	0.464**	-0.364**	0.047	0.216	0.189	0.025	-0.093	1.000						
Seed length (mm)	P	0.016	0.061	0.074	0.106	0.041	0.089	-0.119	-0.032	-0.141	0.273*	0.068	0.027	0.031	0.435**	0.175	-0.037	1.000					
	G	0.009	0.065	0.077	0.108	0.041	0.090	-0.128	-0.039	-0.151	0.289*	0.072	0.027	0.038	0.450**	0.183	-0.063	1.000					
Seed width (mm)	P	0.027	0.046	0.071	0.073	0.001	0.072	-0.197**	-0.056	-0.246*	0.419**	-0.135	-0.033	-0.076	0.219	-0.021	-0.104	0.680**	1.000				
	G	0.026	0.042	0.078	0.075	0.002	0.077	-0.223	-0.079	-0.270*	0.443**	-0.144	-0.034	-0.091	0.234*	-0.021	-0.149	0.689**	1.000				
100 seed weight (g)	P	-0.109	-0.074	-0.062	-0.034	-0.021	-0.004	-0.056	-0.145	-0.184	0.239*	-0.234*	-0.008	-0.047	0.262*	0.022	-0.005	0.812**	0.698**	1.000			
	G	-0.118	-0.084	-0.070	-0.035	-0.023	-0.009	-0.059	-0.165	-0.197	0.247*	-0.251*	0.000	-0.064	0.266*	0.025	-0.009	0.826**	0.719**	1.000			
Seed yield/plant (g)	P	0.273*	0.318**	0.326**	0.344**	0.416**	0.377**	0.532**	0.176	0.665**	0.028	-0.031	-0.042	-0.009	0.177	0.050	0.638**	0.353**	0.223	0.450**	1.000		
	G	0.310**	0.365**	0.383**	0.388**	0.453**	0.408**	0.563**	0.190	0.679**	0.030	-0.041	-0.035	-0.019	0.195	0.059	0.660**	0.374**	0.237*	0.480**	1.000		
Pod yield/ plant (g)	P	0.436**	0.484**	0.466**	0.466**	0.484**	0.459**	0.421**	0.449**	0.751**	0.058	0.306**	-0.072	0.094	0.604**	0.207	0.328**	0.163	-0.043	0.023	0.619**	1.000	
	G	0.539**	0.591**	0.581**	0.554**	0.571**	0.541**	0.405**	0.538**	0.777**	0.053	0.342**	-0.096	0.087	0.655**	0.247**	0.410**	0.187**	-0.053	0.023	0.668**	1.000	
Pod yield/ha (q)	P	0.436**	0.484**	0.466**	0.466**	0.484**	0.459**	0.421**	0.449**	0.751**	0.058	0.306**	-0.072	0.094	0.604**	0.207	0.328**	0.163	-0.043	0.023	0.619**	1.000	1.000
	G	0.539**	0.591**	0.581**	0.554**	0.571**	0.541**	0.405**	0.538**	0.777**	0.053	0.342**	-0.096	0.087	0.655**	0.247**	0.410**	0.187**	-0.053	0.023	0.668**	1.000	1.000

Table 4. Estimates of direct and indirect effect of different characters on marketable yield at phenotypic and genotypic level in French bean

Character		Days to 1st flowering	Days to 50% flowering	Days to 50% pod setting	Days to 50% maturity	Days to 1st picking	Days to 2nd picking	Number of pods/ cluster	Number of pod clusters/ plant	Number of pods/ plant	Pod dia(mm)	Pod length(cm)	Leaf length (cm)	Leaf width (cm)	Single pod weight (g)	Plant height (cm)	Number of seeds/ pod	Seed length (mm)	Seed width (mm)	100 seed weight (g)	Seed yield /plant (g)
Days to 1st flowering	P	0.0248	0.0204	0.0184	0.0171	0.0170	0.0167	0.0021	0.0077	0.0080	0.0021	0.0065	-0.0006	0.0010	0.0074	0.0012	0.0060	0.0004	0.0007	-0.0027	0.0068
	G	0.2096	0.1959	0.1820	0.1620	0.1588	0.1558	0.0173	0.0868	0.0815	0.0201	0.0675	-0.0063	0.0075	0.0687	0.0122	0.0694	0.0020	0.0055	-0.0247	0.0649
Days to 50% flowering	P	-0.0048	-0.0058	-0.0054	-0.0052	-0.0048	-0.0051	-0.0008	-0.0019	-0.0022	-0.0002	-0.0013	0.0000	-0.0002	-0.0019	-0.0005	-0.0014	-0.0004	-0.0003	0.0004	-0.0018
	G	-0.3648	-0.3902	-0.3821	-0.3787	-0.3544	-0.3702	-0.0596	-0.1527	-0.1745	-0.0136	-0.1115	-0.0005	-0.0267	-0.1406	-0.0356	-0.1357	-0.0252	-0.0166	0.0327	-0.1424
Days to 50% pod setting	P	0.0454	0.0568	0.0613	0.0544	0.0490	0.0526	0.0090	0.0190	0.0231	0.0022	0.0151	0.0019	0.0043	0.0182	0.0049	0.0163	0.0045	0.0043	-0.0038	0.0200
	G	0.0420	0.0474	0.0484	0.0473	0.0431	0.0466	0.0083	0.0184	0.0221	0.0019	0.0145	0.0019	0.0048	0.0158	0.0048	0.0180	0.0037	0.0038	-0.0034	0.0185
Days to 50% maturity	P	-0.0328	-0.0428	-0.0422	-0.0476	-0.0411	-0.0450	-0.0070	-0.0141	-0.0178	0.0010	-0.0104	-0.0021	-0.0049	-0.0158	-0.0056	-0.0124	-0.0050	-0.0035	0.0016	-0.0164
	G	-0.1209	-0.1517	-0.1530	-0.1564	-0.1406	-0.1538	-0.0287	-0.0523	-0.0663	0.0035	-0.0379	-0.0069	-0.0166	-0.0546	-0.0193	-0.0605	-0.0169	-0.0117	0.0055	-0.0606
Days to 1st picking	P	0.0505	0.0615	0.0590	0.0637	0.0738	0.0652	0.0165	0.0222	0.0335	-0.0085	0.0057	0.0004	0.0025	0.0176	0.0058	0.0224	0.0030	0.0001	-0.0015	0.0307
	G	0.1015	0.1217	0.1195	0.1204	0.1340	0.1244	0.0362	0.0437	0.0679	-0.0166	0.0114	0.0008	0.0043	0.0338	0.0116	0.0548	0.0056	0.0002	-0.0031	0.0607
Days to 2nd picking	P	-0.0707	-0.0918	-0.0901	-0.0995	-0.0929	-0.1052	-0.0176	-0.0306	-0.0401	0.0052	-0.0166	-0.0028	-0.0044	-0.0335	-0.0097	-0.0310	-0.0093	-0.0076	0.0004	-0.0396
	G	0.1709	0.2181	0.2214	0.2262	0.2135	0.2299	0.0424	0.0756	0.0973	-0.0107	0.0367	0.0038	0.0083	0.0770	0.0209	0.0907	0.0208	0.0178	-0.0021	0.0939
Number of pods/ cluster	P	0.0090	0.0142	0.0160	0.0159	0.0244	0.0182	0.1087	-0.0406	0.0722	-0.0117	-0.0056	-0.0042	-0.0009	-0.0162	0.0174	0.0393	-0.0129	-0.0214	-0.0061	0.0578
	G	0.1034	0.1917	0.2157	0.2305	0.3388	0.2315	1.2549	-0.4773	0.8387	-0.1894	-0.1121	-0.0518	-0.0293	-0.2117	0.2199	0.5817	-0.1607	-0.2797	-0.0737	0.7067
Number of pod clusters/ plant	P	0.0225	0.0239	0.0222	0.0214	0.0217	0.0209	-0.0268	0.0719	0.0269	0.0022	0.0126	-0.0054	0.0006	0.0210	-0.0051	0.0051	-0.0023	-0.0040	-0.0104	0.0127
	G	0.4331	0.4095	0.3989	0.3499	0.3413	0.3439	-0.3979	1.0462	0.4431	0.0508	0.2399	-0.0953	0.0084	0.3595	-0.0635	0.0786	-0.0411	-0.0825	-0.1727	0.1992
Number of pods/ plant	P	0.1901	0.2225	0.2229	0.2215	0.2692	0.2260	0.3940	0.2213	0.5926	-0.0310	0.0602	-0.0671	-0.0171	0.0070	0.0572	0.2230	-0.0835	-0.1457	-0.1091	0.3941
	G	-0.2123	-0.2442	-0.2496	-0.2314	-0.2766	-0.2310	-0.3650	-0.2313	-0.5461	0.0367	-0.0533	0.0638	0.0250	-0.0132	-0.0565	-0.2533	0.0826	0.1473	0.1074	-0.3706
Pod diameter (mm)	P	0.0029	0.0014	0.0012	-0.0007	-0.0039	-0.0017	-0.0036	0.0010	-0.0018	0.0336	0.0064	-0.0100	-0.0136	0.0049	0.0030	-0.0087	0.0092	0.0141	0.0080	0.0009
	G	0.0092	0.0033	0.0038	-0.0021	-0.0119	-0.0045	-0.0146	0.0047	-0.0065	0.0964	0.0191	-0.0324	-0.0458	0.0147	0.0087	-0.0351	0.0279	0.0427	0.0238	0.0029
Pod length(cm)	P	-0.0066	-0.0059	-0.0062	-0.0056	-0.0020	-0.0040	0.0013	-0.0045	-0.0026	-0.0049	-0.0254	0.0016	-0.0029	-0.0102	-0.0063	-0.0009	-0.0017	0.0034	0.0059	0.0008
	G	0.0067	0.0059	0.0062	0.0050	0.0018	0.0033	-0.0019	0.0048	0.0020	0.0041	0.0207	-0.0013	0.0021	0.0091	0.0057	0.0010	0.0015	-0.0030	-0.0052	-0.0009
Leaf length (cm)	P	-0.0002	0.0001	0.0003	0.0004	0.0000	0.0003	-0.0004	-0.0007	-0.0011	-0.0028	-0.0006	0.0095	0.0062	-0.0002	-0.0031	0.0013	0.0003	-0.0003	-0.0001	-0.0004
	G	-0.0002	0.0000	0.0002	0.0003	0.0000	0.0001	-0.0002	-0.0005	-0.0007	-0.0020	-0.0004	0.0059	0.0045	-0.0002	-0.0021	0.0013	0.0002	-0.0002	0.0000	-0.0002
Leaf width (cm)	P	0.0008	0.0009	0.0014	0.0021	0.0007	0.0009	-0.0002	0.0002	-0.0006	-0.0083	0.0023	0.0133	0.0205	0.0033	-0.0040	0.0030	0.0006	-0.0016	-0.0010	-0.0002
	G	0.0015	0.0028	0.0041	0.0043	0.0013	0.0015	-0.0010	0.0003	-0.0019	-0.0194	0.0041	0.0313	0.0409	0.0078	-0.0092	0.0077	0.0016	-0.0037	-0.0026	-0.0008
Single pod weight (g)	P	0.1774	0.1984	0.1769	0.1981	0.1417	0.1894	-0.0886	0.1740	0.0070	0.0864	0.2398	-0.0105	0.0948	0.5949	0.1508	0.0202	0.2586	0.1304	0.1560	0.1051
	G	0.1419	0.1560	0.1411	0.1511	0.1092	0.1451	-0.0730	0.1488	0.0105	0.0658	0.1892	-0.0119	0.0826	0.4330	0.1198	0.0109	0.1949	0.1014	0.1153	0.0842
Plant height (cm)	P	-0.0007	-0.0011	-0.0011	-0.0016	-0.0011	-0.0013	-0.0022	0.0010	-0.0013	-0.0012	-0.0035	0.0045	0.0027	-0.0035	-0.0139	0.0010	-0.0024	0.0003	-0.0003	-0.0007
	G	-0.0006	-0.0010	-0.0011	-0.0013	-0.0009	-0.0010	-0.0019	0.0007	-0.0011	-0.0010	-0.0030	0.0038	0.0024	-0.0030	-0.0108	0.0011	-0.0020	0.0002	-0.0003	-0.0006
Number of seeds/ pod	P	0.0007	0.0007	0.0007	0.0007	0.0008	0.0008	0.0010	0.0002	0.0010	-0.0007	0.0001	0.0004	0.0004	0.0001	-0.0002	0.0028	-0.0001	-0.0003	0.0000	0.0018
	G	-0.0109	-0.0114	-0.0122	-0.0127	-0.0134	-0.0129	-0.0152	-0.0025	-0.0152	0.0119	-0.0015	-0.0071	-0.0062	-0.0008	0.0032	-0.0328	0.0021	0.0049	0.0003	-0.0216
Seed length (mm)	P	0.0008	0.0029	0.0035	0.0050	0.0019	0.0042	-0.0057	-0.0015	-0.0067	0.0131	0.0032	0.0013	0.0015	0.0208	0.0084	-0.0018	0.0478	0.0325	0.0388	0.0169
	G	0.0021	0.0147	0.0176	0.0246	0.0094	0.0206	-0.0292	-0.0090	-0.0345	0.0660	0.0163	0.0062	0.0087	0.1026	0.0416	-0.0144	0.2279	0.1570	0.1882	0.0852
Seed width (mm)	P	-0.0001	-0.0001	-0.0002	-0.0002	0.0000	-0.0002	0.0004	0.0001	0.0005	-0.0009	0.0003	0.0001	0.0002	-0.0005	0.0001	0.0002	-0.0015	-0.0022	-0.0015	-0.0005
	G	0.0009	0.0014	0.0026	0.0025	0.0001	0.0026	0.0075	0.0027	0.0091	0.0149	0.0048	0.0011	0.0031	0.0079	0.0007	0.0050	0.0232	0.0337	0.0242	0.0080
100 seed weight (g)	P	0.0089	0.0061	0.0051	0.0028	0.0017	0.0001	0.0046	0.0119	0.0151	-0.0196	0.0192	0.0007	0.0039	-0.0215	-0.0019	0.0004	-0.0667	-0.0573	-0.0821	-0.0369
	G	0.0181	0.0128	0.0107	0.0053	0.0035	0.0014	0.0090	0.0253	0.0301	-0.0379	0.0385	0.0000	0.0098	-0.0408	-0.0038	0.0014	-0.1265	-0.1102	-0.1532	-0.0735
Seed yield/plant (g)	P	0.0185	0.0216	0.0221	0.0234	0.0282	0.0256	0.0361	0.0120	0.0451	0.0019	-0.0021	-0.0028	-0.0006	0.0120	0.0036	0.0433	0.0240	0.0151	0.0305	0.0679
	G	0.0096	0.0113	0.0118	0.0120	0.0140	0.0126	0.0174	0.0059	0.0210	0.0009	-0.0013	-0.0011	-0.0006	0.0060	0.0018	0.0204	0.0116	0.0073	0.0148	0.0309
Pod yield/ plant (g)	P	0.4364	0.4839	0.4659	0.4662	0.4844	0.4586	0.4209	0.4487	0.7510	0.0577	0.3060	-0.0720	0.0938	0.6038	0.2023	0.3277	0.1626	-0.0432	0.0233	0.6189
	G	0.5389	0.5911	0.5809	0.5538	0.5708	0.5405	0.4048	0.5381	0.7766	0.0527	0.3420	-0.0959	0.0873	0.6551	0.2501	0.4102	0.1866	-0.0531	0.0227	0.6678
Partilal R^2	P	0.0108	-0.0028	0.0286	-0.0222	0.0357	-0.0482	0.0457	0.0323	0.4450	0.0019	-0.0078	-0.0007	0.0019	0.3592	-0.0028	0.0009	0.0078	0.0001	-0.0019	0.0420
	G	0.1129	-0.2307	0.0281	-0.0866	0.0765	0.1243	0.5080	0.5630	-0.4241	0.0051	0.0071	-0.0006	0.0036	0.2837	-0.0027	-0.0134	0.0425	0.0018	-0.0035	0.0206

Table 5: Latent roots (Eigen values) and variability of Principal Components

Principal component	Eigene Value (Root)	% Var. Exp.	Cum. Var. Exp.
PC-1	6.789	30.857	30.857
PC-2	3.360	15.272	46.129
PC-3	2.834	12.884	59.012
PC-4	1.806	8.209	67.222
PC-5	1.440	6.545	73.767
PC-6	1.207	5.488	79.255
PC-7	0.914	4.155	83.410

accounted 15.272, 12.884, 8.209, 6.545, 5.488 and 4.155% of total variation presented among the genotypes, respectively. The first seven PC axes explained 83.41% of the variation, suggesting considerable diversity among the genotypes for all the characters, the rest of the components not considered. These were interpreted as relative weight of the variables in each component. The important variables are those which have high positive or negative relative weight values. Similar studies were reported by Vasic *et al.*

Table. 6: Principal component analysis for twenty two traits of French bean genotypes

S.N.	Traits	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
1.	Days to 1st flowering	0.305	0.142	0.034	0.044	0.134	0.088	0.013
2.	Days to 50% flowering	0.355	0.141	-0.048	0.008	0.069	0.109	0.028
3.	Days to 50% pod setting	0.285	0.091	-0.083	-0.008	0.088	0.156	-0.009
4.	Days to 50% maturity	0.353	0.118	-0.076	-0.044	0.035	0.136	0.060
5.	Days to 1st picking	0.334	0.134	-0.143	-0.022	-0.040	-0.026	0.022
6.	Days to 2nd picking	0.347	0.111	-0.126	-0.007	-0.003	0.114	0.041
7.	Number of pods/ cluster	0.052	0.056	-0.338	-0.101	-0.415	-0.279	0.033
8.	Number of pod clusters/ plant	0.000	-0.058	0.503	-0.013	0.090	-0.286	-0.198
9.	Number of pods/ plant	0.129	0.180	0.102	0.222	0.424	-0.452	-0.188
10.	Pod diameter (mm)	0.034	-0.151	0.163	0.523	0.183	0.139	-0.038
11.	Pod length (cm)	0.172	0.047	0.369	-0.232	-0.035	0.196	-0.059
12.	Leaf length (cm)	-0.099	-0.005	-0.250	-0.441	0.373	0.100	-0.115
13.	Leaf width (cm)	-0.211	0.047	-0.040	-0.453	0.281	-0.092	-0.031
14.	Single pod weight (g)	0.124	-0.073	0.388	-0.234	-0.028	0.109	0.049
15.	Plant height (cm)	0.123	-0.099	0.309	-0.163	-0.504	0.026	0.013
16.	Number of seeds/ pod	-0.209	0.316	0.066	-0.039	0.122	0.383	0.207
17.	Seed length (mm)	0.080	-0.466	0.002	-0.113	0.090	0.070	0.057
18.	Seed width (mm)	0.066	-0.407	-0.133	0.202	0.140	0.218	0.221
19.	100 seed weight (g)	0.007	-0.500	-0.130	-0.028	0.043	-0.020	0.097
20.	Seed yield/plant (g)	0.271	-0.155	-0.176	-0.076	-0.048	-0.342	-0.231
21.	Pod yield/ plant (g)	-0.277	0.254	-0.103	0.248	-0.197	0.014	0.039
22.	Pod yield/ ha (q)	0.060	0.067	0.127	-0.064	0.120	-0.392	0.858

Table 7: Distributing pattern of seventy four genotypes of French bean into nine clusters

Cluster number	Numberof genotypes	Genotype included
I	18	FB-211, FB-213, Pant Anupama, FB-243, FB-240, FB-242, FB-241, FB-247, FB-245, VL Bean-2, Pant Bean-3, FB-246, FB-222, Arka Komal, Pant Bean-2, FB-239, FB-225, Arka Anoop
II	24	FB-254, FB-256, FB-237, FB-215, FB-259, FB-252, FB-260, FB-250, IIHR-909, Chitra, FB-257, FB-249, FB-208, FB-228, FB-217, FB-230, FB-206, FB-216, FB-218, FB-235, Contender, FB-220, FB-203,FB-224
III	1	VLFB-510
IV	8	FB-212, FB-233, FB-234, FB-204, FB-244, FB-210, FB-236, FB-209
V	17	Arka Suvidha, VLFB-130, VLFB-628, FB-229, FB-251, FB-219, FB-253, FB-231, VLFB-629, FB-255, FB-226, FB-227, FB-201, FB-223, FB-202, FB-248, FB-238
VI	1	FB-221
VII	1	FB-207
VIII	3	FB-205, FB-214, FB-258
IX	1	FB-232

Table. 8: Inter and intra-cluster distances

Cluster	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
I	**(143.385)**								
II	416.010	**(185.279)**							
III	205.233	482.642	**(0.000)**						
IV	305.500	475.676	493.731	**(233.564)**					
V	339.879	414.385	319.626	614.217	**(314.619)**				
VI	409.254	338.490	583.866	357.602	648.004	**(0.000)**			
VII	673.280	283.195	596.048	733.913	486.652	692.887	**(0.000)**		
VIII	726.867	373.414	849.178	777.408	537.846	820.646	304.711	**(301.516)**	
IX	1049.301	715.481	1297.298	628.848	1405.141	315.828	986.414	1244.472	**(0.000)**

Table 9: Cluster mean for different economic traits in French bean

S. No.	Characters	Cluster mean								
		I	II	III	IV	V	VI	VII	VIII	IX
1	Days to 1st flowering	44.204	43.389	42.667	47.083	45.941	43.333	43.333	47.000	43.667
2	Days to 50% flowering	47.981	46.583	44.667	50.917	49.275	44.333	46.000	53.000	45.000
3	Days to 50% pod setting	51.815	50.542	48.667	55.083	53.118	48.667	49.333	56.889	48.333
4	Days to 50% maturity	64.167	62.097	59.000	66.583	65.098	60.333	62.667	69.667	59.000
5	Days to 1st picking	62.333	60.444	57.000	64.042	62.216	58.667	59.333	67.222	58.333
6	Days to 2nd picking	66.870	65.278	62.333	68.458	67.490	63.333	64.667	71.111	63.000
7	Number of pods/ cluster	2.007	2.126	2.033	2.321	1.980	2.000	1.767	2.256	1.833
8	Number of pod clusters/ plant	4.193	3.786	4.867	4.692	3.951	3.167	3.833	4.278	4.067
9	Number of pods/ plant	8.270	7.735	9.800	10.558	7.551	6.400	6.800	9.522	7.133
10	Pod diameter (mm)	9.546	10.493	13.687	9.083	11.204	11.960	10.140	9.790	11.080
11	Pod length (cm)	10.825	10.187	13.840	12.054	10.769	9.600	14.100	11.084	11.500
12	Leaf length (cm)	9.146	9.246	8.433	9.737	8.461	5.233	9.200	11.322	6.633
13	Leaf width (cm)	7.124	6.725	6.133	7.100	6.369	4.300	7.167	7.333	4.200
14	Single pod weight (g)	4.904	4.617	5.233	4.650	5.229	2.800	6.100	5.256	3.667
15	Plant height (cm)	38.606	39.325	45.867	39.150	51.865	41.733	85.400	45.431	43.933
16	Number of seeds/ pod	4.513	4.572	4.767	5.025	4.263	3.067	3.800	5.256	3.833
17	Seed length (mm)	13.319	13.780	15.080	11.643	15.450	10.140	15.680	15.853	8.240
18	Seed width (mm)	6.613	6.838	6.560	5.624	7.459	6.780	6.920	7.427	4.813
19	100 seed weight (g)	31.833	34.312	32.600	21.413	39.406	22.367	32.400	35.800	12.467
20	Seed yield/plant (g)	11.957	12.428	15.187	11.433	13.145	4.397	8.427	16.493	3.440
21	Pod yield/ plant (g)	37.926	34.719	48.433	46.562	38.550	17.890	39.407	47.329	26.223
22	Pod yield/ ha (q)	75.853	69.439	96.867	93.123	77.099	35.780	78.813	94.658	52.447

Table 10: Relative contribution of different characters to the total divergence in French bean

S.N.	Source	Contribution %
1	Days to 1st flowering	0
2	Days to 50% flowering	0
3	Days to 50% pod setting	0
4	Days to 50% maturity	1.3
5	Days to 1st picking	3.26
6	Days to 2nd picking	0.48
7	Number of pods/ cluster	0.07
8	Number of pod clusters/ plant	0.04
9	Number of pods/ plant	0
10	Pod diameter (mm)	1.44
11	Pod length (cm)	1.52
12	Leaf length (cm)	0.89
13	Leaf width (cm)	0.04
14	Single pod weight (g)	1.11
15	Plant height (cm)	5.26
16	Number of seeds/ pod	0
17	Seed length (mm)	25.84
18	Seed width (mm)	8.22
19	100 seed weight (g)	2.59
20	Seed yield/plant (g)	0.63
21	Pod yield/ plant (g)	0.11
22	Pod yield/ ha (q)	47.2

(2008), Sofi *et al*. (2014) and Stoilova *et al*. (2012).

Cluster analysis for yield and yield contributing traits classified all seventy four genotypes into 9 clusters. The analysis revealed the maximum inter-cluster distance was found between clusters V and IX having 17 genotypes and 1 genotype, respectively in the cluster. Arka Suvidha, VLFB-130, VLFB-628, FB-229, FB-251, FB-219, FB-253, FB-231, VLFB-629, FB-255, FB-226, FB-227, FB-201, FB-223, FB-202, FB-248, FB-238 were found in cluster V and FB-232 was placed in cluster IX. The genotypes containing high mean value for weight of single pod, pod length and plant height was included in cluster VII, while high mean value for pod yield per hectare was observed in cluster III. Genotypes with highest mean value for number of pods per plant were clubbed in cluster IV. Genotypes with highest mean value for number of seeds per pod and seed length were observed in cluster VIII, while genotypes with highest mean value for seed width and 100 seed weight were included in cluster V. The results presented here are in conformity with the findings of Gangadhara *et al*. (2014), Walling (2014), Boros *et al*. (2014), Javadian *et al*. (2014), Rai *et al*. (2010) and Verma *et al*. (2012) in French bean.

Pod yield per hectare contributed maximum towards genetic diversity, followed by seed length, seed width, plant height and days to first picking, hence these characters were considered to be important traits contributing toward genetic divergence. Similarly divergence studies were carried out by Dalsaniya *et al*. (2009), Walling *et al*. (2014), Govanakoppa *et al*. (2002), Gangadhara *et al*. (2014) and Chaubey *et al*. (2003).

सारांश

फराशबीन की 74 प्रभेदों का मूल्यांकन अनेकों आर्थिक गुणों के लिए गोविन्द बल्लभ पन्त कृषि एवं प्रौद्योगिकी विश्वविद्यालय, पंतनगर (उत्तराखण्ड) के लिए किया गया। प्रभेदों में एफ.बी.–202, एफ.बी. –209, एफ.बी.–206, अर्का सुविधा तथा एफ.बी.–2056, उपज तथा उपज घटकों के लिए उत्तम पाये गये। बाहय स्वरूप विभिन्नता गुणाक, अनुवांशिक विभिन्नता गुणांक से ज्यादा था। आनुवांशिक

विविधता गुणांक का अधिकतम आंकलन पौध ऊँचाई (42.45) पाया गया और इसके बाद बीज उपज/पौध (39.72) रहा। जबकि अधिकतम वंशागतित्व बीज की लंबई (99.04 प्रतिशत) के लिए अंकित किया गया। अधिकतम वंशागतित्व के साथ उच्च आनुवांशिक उन्नयन प्रतिशत माध्यम आंकलन पौध ऊँचाई के लिए अधिक था। फली उपज/पौध, पौध ऊँचाई, फलियों की संख्या/पौध, फल गुच्छा/पौध, प्रति गुच्छा फलियों की संख्या, बीजों की संख्या/फली, फली लम्बाई व प्रत्येक फली के वजन से है। मार्ग गुणाक विश्लेषण से स्पष्ट होता है कि एकल फली भार व फलियों की संख्या/पौध अधिक सार्थक योगदान उपज के प्रति क्रमशः पायी गयी। प्रिंसीपल घटक विश्लेषण से स्पष्ट होता है कि प्रथम प्रिंसिपल घटक में अधिकतम 30.85 प्रतिशत कुल विविधता विद्यमान है जबकि पहला, सातवां प्रिंसिपल घटक एक दूसरे के प्रति 83.41 प्रतिशत विविधता दर्शाते है जो प्रथम सातवां प्रिंसीपल एक दूसरे के प्रति पूर्णता से विविधता आयाम की व्याख्या करते है डी^{2} के द्वारा समूहकरण विश्लेषण स्पष्ट करता है अधिकतम अन्तः समूहक दूरी समूह V व IX (1405.141) में पाया गया तथा इसके बाद व IX (1297.298) में पाया गया।

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