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Morphological, Phenological and Agronomical Characterization of Variability in French Bean (*Phaseolus vulgaris* L.) Genotypes

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ABSTRACT

Background: Genotypes and changing environmental conditions significantly influence French bean productivity. Variability, heritability and genetic advance of genotypes are critical factors in selecting germplasm for wider adoption and cultivation.

Methods: The experimental material consisted of 25 germplasm lines, sown in a randomized block design (RBD) with three replicationsat Research block of the School of Agriculture, Graphic Era Hill University Dehradun, Uttarakhand. Recommended package of practices for French bean was followed to ensure a healthy crop stand. Observations were recorded on days to 50% flowering, days to first harvest, days to last harvest and ten other quantitative traits. Key parameters included green pod yield per plant, 100-seed weight (g), number of seeds per pod, number of pods per plant, pod length (cm), pod width (cm) and seed yield per plant (g). Data were analysed using OPSTAT software and Microsoft Excel.

Result: Among the 25 germplasm lines, three genotypes (GFB 21, GFB 23 and GFB 24) were viny types, while the remaining 22 were bush types. Genotypic coefficients of variation (GCV) for all traits were lower than phenotypic coefficients of variation (PCV), indicating environmental influence on trait expression. The mean seed yield per plant across genotypes was 156.83 g, while the mean green pod yield per plant was 562.30 g. High GCV was observed for seed yield per plant (48.96%) and green pod yield per plant (36.69%). Corresponding PCV values were 50.97% and 38.46%, respectively. Heritability estimates were highest for days to 50% flowering (97.92%), green pod yield per plant (97.42%) and number of seeds per pod (77.37%). Genetic advance was maximum for green pod yield per plant (194.24), highlighting its potential for genetic improvement.

Key words: French bean, Genetic advance, Genetic variability, Heritability, Yield.

INTRODUCTION

French bean (*Phaseolus vulgaris* L., 2n=2x=22) is a leguminous vegetable, known as common bean, kidney bean, green bean or snap bean.

Green or French beans are known to have originated from Central and South America where they are grown as an indigenous crop for the past 5,000 years. French bean evolved from a wild growing vine *viz*., *Phaseolus aborigineus* and distributed in the highlands of middle America and Andes is one of the oldest cultivated pulse crops. Green beans are available as “bush” types, which grow as short, erect bushes, or “pole” types, which are climbing vines that need support.

It can be grown throughout the world and contribute nearly 30% of the total production of food legumes. India occupied an area of 137.54 (000’ha) with annual production of 1370.21 (000’Mt) and an average productivity of 9.96 Mt/ha of French bean. The major Green or French bean growing states are West Bengal andhra Pradesh, Jharkhand, Jammu and Kashmir and Himachal Pradesh in India (Kumar *et al.,* 2022). In India, French bean is extensively grown as green pod vegetable for fresh pods which are known as Fras bean. The green immature pods are cooked and eaten as a vegetable. Immature pods are marketed fresh, frozen or canned, whole, cut or French cut. French bean also known as ‘meat of the poor’, ‘grain of hope’ and ‘Super food’ is one of the highly relished pulses, quite nutritious and potential source of protein, carbohydrates and minerals. French bean is one of the important leguminous crops which achieve its foremost importance in cultivation in the agricultural field due to its higher nutritional index of protein in fresh pods (1.7%) as well as in dried seeds (21.1%) that serve as a cheap source of higher protein (Alice *et al.,* 2018).

Green beans are a nutritional powerhouse, packed with vitamins, minerals and antioxidants. They help prevent blood clots, colon cancer and diabetes. This crop is gaining importance in country for its dual uses both for green pods and dried grain. It is now spreading to north eastern hilly (NEH) states of India like Nagaland (Kumar *et al.,* 2020).

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Importance of studying genetic variability provides a basis for selection and getting valuable information regarding selection of diverse parents for use in hybridization programme (Bijalwan and Madhvi, 2016). The breeder has to identify the sources of favourable genes, incorporate them in breeding populations and aim for isolation of productive genotypes and cultivars. Thus, improvement in any crop is based on the extent of genetic variation and the degree of improvement depends upon the magnitude of available beneficial genetic variability (Begna *et al.,* 2023). By examining the genetic parameters particularly, the phenotypic and genotypic coefficients of variation, heritability in the broad sense and genetic advance as a percentage of mean, an attempt was made to estimate the extent of existing variability for yield contributing character in green or french bean genotype. This indicates that they will assist to develop the appropriate selection criteria of french bean crop improvement.

MATERIALS AND METHODS

The field trial was conducted in an open field condition during the summer season of 2022-23 at Research Block of the School of Agriculture,Graphic Era Hill University Dehradun, Uttarakhand. The experimental site geographically situated at an altitude of 640 m above sea level with latitude of 30-34°N and longitude of 70.02°E. The experimental material comprised of 25 germplasm, sown in a randomized block design (RBD) with three replications. Package of practices for french bean has been followed to maintain healthy crop stand.

Observation

Data were recorded randomly on 5 plants of each genotype in all the replications for 10 quantitative traits *viz.,* days to 50% flowering, days to first harvesting, days to last harvesting, number of pods/plant, pod length (cm). Pod width (cm), number of seeds/pods, green pod yield/plant, 100 seed weight (g) and seed yield/plant (g).

Statistical analysis

Data analysis was carried out using OPSTAT software and Microsoft excel.The genotypic and phenotypic variances were estimated according to the formula suggested by Johnson *et al.* (1983). Genotypic and Phenotypic Coefficient of Variation estimated according to formula suggested by Burton (1952).

Heritability in broad sense (h^2_b) was calculated as per formula given by Burton and De Vane (1953) and Allard (1960). The heritability percentage will be categorized as low (0-50%), moderate (50-80%) and high (80% and above). Estimation of genetic advance (GA) and GA (% ofmean). The extent of genetic advance to be expected by selecting 5% of the superior progeny and will calculate by using the following formula given by Robinson *et al.* (1949). The GA (%) was categorized as low (0-15%), moderate (15-30%) and high (30% and above).

Table 1: Analysis of variance with respect to various characters of French bean.

Source	*df*	Days to 50% flowering	Days to first harvesting	Days to final harvesting	Number of pods/ plants	Pod length (cm)	Pod width (cm)	No. of seed/ pods	Green pod yield/plant	100 seed wt.(g)	Seed yield/ plant (g)
Replication	2	0.093	2.588	50.659	17.56	1.141	0.112	15.217	891.37	28.939	4853.177
Treatment	24	5.611**	3.661**	326.373**	50.222**	3.043**	1.014**	167.291**	35,590.264**	45.272**	21469.56**
Error	48	0.079	0.814	5.032	3.949	1.104	0.094	30.565	624.471	10.988	581.872

** → Significant at p<0.01.

RESULTS AND DISCUSSION

Analysis of variance revealed highly significant ($p<0.01$) genotypic differences for all thirteen quantitative traits studied (Table 1), confirming substantial genetic variability within the evaluated germplasm (Bhatt *et al.,* 2021). Days to 50% flowering, a key phenological marker, varied from 47.00 to 52.00 days (Table 2). Genotypes GFB-11 and GFB-14 were among the earliest to flower, reaching 50% flowering in just 47 days. This range in flowering time is a critical adaptive trait and the observed variability provides a valuable resource for breeding programs targeting specific maturity groups, a finding consistent with other studies on *Phaseolus vulgaris* diversity (Rana *et al*., 2015).

Significant divergence was also observed for yield-attributing traits. Days to first harvest ranged from 59.33 to 78.00 days (Table 5), indicating variability in the duration of the reproductive phase. More critically, the number of pods per plant, a primary determinant of yield, exhibited extreme variation, with GFB-3 recording the highest count (94.60) - a value significantly greater than most other genotypes and GFB-10 the lowest (20.47) (Table 2). This underscores the presence of strong genetic factors controlling pod set, as also reported Assefa *et al*. (2019) in common bean. Further more, significant differences were found for the number of seeds per pod, where GFB-17, GFB-19 and GFB-23 possessed the maximum (6.00), compared to the minimum of 3.27 for GFB-24. In contrast, pod length (11.83-15.93 cm) and pod width (0.91-2.31 cm) did not show statistically significant genotypic differences at the 5% level, though numerical variation existed. The identification of genotypes excelling in specific yield components (*e.g*., GFB-3 for pod number; GFB-17 for seeds per pod) provides direct candidates for use as parents in hybridization programs designed to pyramid these complementary traits.

A striking level of variation was recorded for the primary economic traits. Green pod yield per plant varied significantly, with GFB-25 producing the highest yield (845.28 g), significantly outperforming many other genotypes, while GFB-10 yielded the least (250.89 g) (Table 3). The mean green pod yield across the collection was 562.30 g. This substantial range highlights the potential for direct selection for fresh pod production, supporting

Table 2: Variation in phenology and growth characteristics of genotypes.

Genotypes	Days to 50% flowering	Days to first harvesting	Days to final harvesting	Number of pods/ plants	Pod length (cm)	Pod width (cm)	Number of seeds/ pods
GFB-1	48.00^{d}	64.00^{bc}	89.13^{abc}	32.13^{b}	12.54^{a}	1.24^{a}	4.00^{de}
GFB-2	48.00^{d}	64.00^{bc}	86.33^{bc}	31.53^{b}	13.01^{a}	2.01^{a}	5.00^{abcd}
GFB-3	48.00^{d}	63.00^{c}	87.33^{abc}	94.60^{a}	12.75^{a}	1.54^{a}	5.00^{abcd}
GFB-4	48.00^{d}	63.00^{c}	87.00^{bc}	23.20^{bc}	15.93^{a}	1.50^{a}	4.20^{cde}
GFB-5	49.00^{c}	67.67^{bc}	91.00^{abc}	23.20^{bc}	13.17^{a}	1.83^{a}	5.40^{abc}
GFB-6	48.00^{d}	67.67^{bc}	89.33^{abc}	29.73^{b}	12.39^{a}	1.55^{a}	5.40^{abc}
GFB-7	48.00^{d}	70.00^{abc}	92.00^{ab}	26.53^{b}	13.70^{a}	1.77^{a}	5.00^{abcd}
GFB-8	48.00^{d}	63.00^{c}	88.67^{abc}	35.47^{b}	11.99^{a}	1.15^{a}	5.00^{abcd}
GFB-9	48.30^{cd}	59.33^{d}	90.33^{abc}	36.33^{b}	12.07^{a}	1.05^{a}	4.00^{de}
GFB-10	48.00^{d}	63.00^{c}	85.33^{bc}	20.47^{c}	14.77^{a}	0.91^{a}	5.00^{abcd}
GFB-11	47.00^{e}	70.33^{abc}	89.33^{abc}	34.20^{b}	13.61^{a}	2.03^{a}	5.00^{abcd}
GFB-12	50.00^{b}	70.00^{abc}	88.33^{abc}	30.47^{b}	12.47^{a}	1.20^{a}	4.20^{cde}
GFB-13	50.00^{b}	70.00^{abc}	92.00^{ab}	35.87^{b}	13.24^{a}	2.24^{a}	5.47^{ab}
GFB-14	47.00^{e}	64.00^{bc}	87.67^{abc}	21.93^{bc}	14.77^{a}	1.31^{a}	5.00^{abcd}
GFB-15	48.00^{d}	78.00^{a}	94.33^{a}	31.13^{b}	13.81^{a}	1.19^{a}	5.27^{abc}
GFB-16	48.00^{d}	64.00^{bc}	86.67^{bc}	33.47^{b}	12.63^{a}	1.29^{a}	4.00^{de}
GFB-17	48.00^{d}	64.00^{bc}	88.67^{abc}	35.13^{b}	11.91^{a}	1.14^{a}	6.00^{a}
GFB-18	47.00^{e}	64.00^{bc}	89.33^{abc}	36.47^{b}	12.78^{a}	0.96^{a}	5.00^{abcd}
GFB-19	47.00^{e}	64.00^{bc}	84.00^{c}	29.93^{b}	14.44^{a}	1.75^{a}	6.00^{a}
GFB-20	48.00^{d}	64.00^{bc}	86.33^{bc}	36.93^{b}	12.73^{a}	1.67^{a}	4.40^{bcde}
GFB-21	49.00^{c}	64.00^{bc}	86.33^{bc}	36.13^{b}	13.41^{a}	0.98^{a}	5.00^{abcd}
GFB-22	52.00^{e}	69.67^{abc}	88.33^{abc}	32.73^{b}	11.83^{a}	2.31^{a}	4.60^{bcd}
GFB-23	50.00^{b}	70.67^{abc}	90.67^{abc}	39.20^{bc}	13.97^{a}	2.09^{a}	6.00^{a}
GFB-24	52.00^{a}	71.00^{abc}	87.33^{abc}	31.13^{b}	11.97^{a}	1.23^{a}	3.27^{e}
GFB-25	48.00^{d}	73.33^{ab}	92.00^{ab}	36.20^{b}	13.63^{a}	2.31^{a}	5.07^{abcd}
Mean	48.50	65.00	88.70	32.66	13.18	1.53	4.89
SE (M)±	0.133	1.81	1.28	4.055	0.855	0.429	0.227
LSD	0.70	9.95	7.05	22.24	4.68	2.34	1.22

similar findings on the high genetic variability for this trait (Gupta *et al*., 2021). Seed yield per plant also varied considerably, from 87.77 g (GFB-24) to 269.59 g (GFB-16), with a mean of 156.83 g. Notably, GFB-25 was also a top performer for seed yield (210.29 g). Conversely, 100-seed weight, an indicator of seed size, showed no statistically significant differences among genotypes, with values ranging from 33.38 g to 51.26 g and a mean of 43.18 g.

Table 3: Variation in yield characters of genotype.

Genotypes	Green pod yield/ plant (g)	100 seed weight (g)	Seed yield/ plant (g)
GFB-1	631.04^{abc}	33.38^{a}	256.2^{a}
GFB-2	565.07^{abc}	41.52^{a}	92.87^{a}
GFB-3	599.8^{abc}	42.03^{a}	251.93^{a}
GFB-4	472.27^{abc}	42.87^{a}	180.93^{a}
GFB-5	570.67^{abc}	37.97^{a}	176.40^{a}
GFB-6	592.56^{abc}	42.31^{a}	128.20^{a}
GFB-7	554.17^{abc}	45.19^{a}	127.97^{a}
GFB-8	484.86^{abc}	38.43^{a}	146.67^{a}
GFB-9	510.76^{abc}	47.36^{a}	197.54^{a}
GFB-10	250.89^{c}	48.73^{a}	94.20^{a}
GFB-11	415.27^{abc}	51.26^{a}	121.87^{a}
GFB-12	599.07^{abc}	35.77^{a}	128.53^{a}
GFB-13	552.48^{abc}	39.61^{a}	143.45^{a}
GFB-14	365.37^{bc}	37.81^{a}	113.80^{a}
GFB-15	726.76^{ab}	49.47^{a}	125.31^{a}
GFB-16	610.88^{abc}	44.98^{a}	269.59^{a}
GFB-17	587.27^{abc}	49.44^{a}	142.22^{a}
GFB-18	614.07^{abc}	39.48^{a}	117.05^{a}
GFB-19	547.75^{abc}	46.44^{a}	140.16^{a}
GFB-20	706.39^{ab}	42.65^{a}	155.25^{a}
GFB-21	798.75^{ab}	44.97^{a}	145.38^{a}
GFB-22	498.8^{abc}	49.37^{a}	206.75^{a}
GFB-23	364.17^{bc}	50.29^{a}	160.33^{a}
GFB-24	593.04^{abc}	44.51^{a}	87.77^{a}
GFB-25	845.28^{a}	33.65^{a}	210.29^{a}
Mean	562.30	43.18	156.83
Sem	80.45	5.60	38.06
LSD (0.05%)	24.78	22.58	42.03

The lack of significance for seed weight, despite numerical 2 differences, may suggest a stronger environmental influence on this trait within the context of this study, or a more uniform genetic base for seed size in this germplasm set compared to other yield components. The significant positive correlation observed between green pod yield and seed yield (r = 0.461*) suggests that selection for one may concurrently improve the other, a valuable insight for dual-purpose bean breeding.

Correlation analysis elucidated key interrelationships among yield components (Table 4). Green pod yield per plant showed significant positive correlations with both the number of pods per plant (r = 0.398*) and seed yield per plant (r = 0.461*). This indicates that increasing the number of pods per plant is a reliable strategy for enhancing both fresh and dry seed yields, a projection supported by earlier work (Pandey *et al*., 2013) and consistent with findings of Panchbhaiya and Singh, 2015 highlights pod number as a primary component of yield architecture in common bean. In contrast, pod length, pod width, number of seeds per pod and 100-seed weight did not exhibit significant correlations with seed yield in this study, suggesting these traits may have a less direct influence on final yield within this specific germplasm. However, they remain important for other quality parameters, such as market preference for pod dimensions or nutritional content linked to seed size. The strong, positive association between green pod yield and seed yield is particularly valuable for dual-purpose bean breeding, implying that selection for high fresh pod yield may concurrently improve seed yield, thereby maximizing crop utility.

The estimates of key genetic parameters are presented in Table 5, providing critical insights for selection strategies. For all traits, the phenotypic coefficient of variation (PCV) was greater than the genotypic coefficient of variation (GCV), confirming that environmental factors influence phenotypic expression, as previously noted in crop genetic studies (Ghosh *et al*., 2010). This disparity was most pronounced for pod width (difference = 5.18) and number of seeds per pod (difference = 4.21), indicating these traits are highly sensitive to environmental conditions.

High GCV, reflecting substantial genetic variability, was observed for seed yield per plant (48.96%), green pod yield

Table 4: Pearson correlation of observed traits.

	No. of pod per plant	Pod length	Pod width	No. of seeds per pod	Green pod yield/ plant	100 seed weight	Seed yield/ plant
No. of pod per plant	1						
Pod length	-0.376	1					
Pod width	0.055	0.099	1				
No. of seeds per pod	-0.050	0.251	0.307	1			
Green pod yield/plant	0.398*	-0.326	0.010	-0.116	1		
100 seed weight (g)	-0.135	0.080	0.003	0.224	-0.351	1	
Seed yield/plant	0.461*	-0.194	0.133	-0.232	0.268	-0.209	1

Table 5: Estimates of variability, heritability and genetic advance as per cent of mean for grain yield and yield components in French bean.

Characters	Range	GM	SE (m)±	Heritability (h^2_b %)	Genetic advance	Genetic advance as (%) of mean	Coefficient of variation (%)		
							GCV (%)	PCV (%)	ECV (%)
Days to 50 % flowering	47-52	48.50	0.133	97.92	179.74	89.56	2.80	2.86	0.06
Days to first harvest	59.33- 78.00	65.00	1.81	73.37	110.43	41.25	7.22	9.84	2.62
Days to last harvest	84.00-94.33	88.70	1.28	31.15	99.21	95.34	1.00	3.20	2.20
Number of pods/plants	20.47- 94.60	32.66	4.055	73.37	167.27	52.35	7.22	9.84	2.62
Pod length (cm)	11.83-15.93	13.18	0.855	60.77	88.34	150.23	6.10	10.04	3.94
Pod width (cm)	0.91-2.31	1.53	0.429	87.49	114.77	32.21	36.19	41.37	5.18
Number of seeds/pods	3.27-6.00	4.89	0.227	77.37	190.70	177.18	14.38	18.58	4.21
Green pod yield/plant	250.89-845.28	562.30	80.45	97.42	194.24	197.85	36.69	38.46	1.77
100 seed weight (gm)	33.38- 51.26	43.18	5.6	71.40	109.37	77.21	5.02	7.03	2.01
Seed yield/plant (gm)	187.77-269.59	156.83	38.06	96.07	192.34	82.34	48.96	50.97	2.00

per plant (36.69%) and pod width (36.19%). Traits with high GCV are considered to have greater potential for improvement through selection (Choudhary *et al*., 2016). In contrast, traits like number of pods per plant (7.22%), 100-seed weight (5.02%), days to 50% flowering (2.08%) and days to last harvest (1.00%) exhibited lower GCV, suggesting more limited genetic diversity for these characteristics within the evaluated germplasm. Similarly, high PCV values were recorded for seed yield per plant (50.97%), pod width (41.37%) and green pod yield per plant (38.46%), indicating both genetic and environmental contributions to their total variation. This pattern of variability, where yield traits show higher coefficients of variation than maturity traits, is consistent with genetic studies in French bean.

Heritability estimates in the broad sense (h^2b) for the studied traits ranged from 31.15% to 97.92% (Table 5). High heritability was observed for days to 50% flowering (97.92%), seed yield per plant (96.07%), green pod yield per plant (97.42%) and number of seeds per pod (77.37%). However, high heritability alone does not guarantee a strong selection response; it must be coupled with substantial genetic advance. The combination of high heritability and high genetic advance as a percentage of the mean was most notable for green pod yield per plant (h^2b = 97.42%, GA% = 197.85) and seed yield per plant (h^2b = 96.07%, GA% = 82.34). This indicates that these traits are predominantly controlled by additive gene action and are highly amenable to improvement through direct phenotypic selection (Upadhyay and Mehta, 2019). Such a genetic architecture is advantageous for plant breeders, as it allows for predictable gains from selection, a principle also emphasized in modern pulse breeding programs (Singh *et al*., 2021). In contrast, days to last harvest showed low heritability (31.15%) and moderate genetic advance, suggesting a greater influence of non-additive gene effects or genotype × environment interaction, which may complicate selection for this trait.

The 100-seed weight, a measure of seed size, varied from 33.38 g to 51.26 g, with a mean of 43.18 g. Seed yield per plant ranged from 87.77 g to 269.59 g, with a mean of 156.83 g. These findings align with earlier reports of significant variability for yield and yield components in French bean germplasm (Raffi and Nath, 2004), reinforcing the potential for genetic improvement through targeted selection.

CONCLUSION

The findings indicated that these french bean genotypes exhibited a broad range of genetic variation, including variations in PCV and GCV, high heritability and high genetic advancement as a percentage of the mean for nearly all the traits. GFB-25 has the highest green pod yield (845.28) and seed yield (210.29) among all the genotypes. GFB-17, GFB-19 and GFB-23 have the highest number of seeds per pod (6^a). As a result, selection can be carried out to improve these traits. It implies that these traits might be incorporated into the selection criteria for french bean crop improvement in terms of yield and other traits.

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Disclaimers

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Conflict of interest

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