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# DUS Characterization and Evaluation of Untapped French Bean (*Phaseolus vulgaris* L.) Genotypes

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

French bean is being considered as an important legume for human diet having rich source of dietary proteins, minerals and vitamins. Germplasm characterization and evaluation is having great contribution in breeding and crop improvement. Substantial phenotypic and genetic characterization of untapped French bean germplasm are still needed to unlock its breeding potential. Purposefully, 27 diverse French bean genotypes comprising primitive, cultivars, commercial cultivars, farmers grown varieties were collected from different parts of India, characterized as per Distinct, Uniformity and Stability (DUS) and evaluated for associated morpho-phenological traits in randomized complete

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block design. The screened panel revealed highly significant differences among French bean genotypes for all the traits under study which witnessed the existence of sufficient variability in the French bean genotypes in which first two Principal Component Analysis (PCA) explained 20.03% and 13.32% of the total morphological variability. The genotypes were well scattered in PCA axis forming groups with various traits as per contribution towards the variability. The genotype IC 632961 having desirable traits which could be an elite germplasm for future crop improvement.

*Keywords: DUS; keel; primitive; PCA; standard petals.*

## 1. INTRODUCTION

The French bean is also known as common bean, snap bean, salad bean, kidney bean, haricot bean and string bean (Purseglove [1]; Gepts and Debouck [2] and Wortmann [3]). French bean is a member of the *Fabaceae* family with a chromosome number of 2n = 2x = 22. The crop is an annual species that primarily self-pollinating species. It prefers an optimum temperature for growth and development and commercially cultivated during rabi season in plains and during spring and summer in hills of India. It is cultivated for its tender, green pods which are either consumed fresh or processed into canned, frozen, or freeze-dried goods. As a food source, the crop offers essential vitamins like folic acid and thiamine [4] and proteins, fibers, vitamins and minerals (Broughton et al. [5]; Mora- Avilés et al. [6]) and additionally, the stems are useful for livestock feed, particularly during the dry period that follows the primary cropping season [7]. It has natural anti-diabetic effects and is efficient in healing bladder burns and heart disorders. It helps in curing diarrhoea and constipation with both carminative and reparative properties [8]. It is a protective and nourishing vegetable that provides 1.7% protein, 4.5% fat, 1.8% fibre, 0.5% mineral constituents and 0.1% carbohydrates [9], flavonoids, antioxidants, and beneficial phytochemicals [10]. Being a legume crop, it improves soil fertility by fixing nitrogen from the atmosphere. In world scenario, India is leading country in producing dry French bean seed followed by Brazil and Myanmar. However, China leads the world in green beans production preceded by Indonesia and Turkey [11].

French bean is native to Central America and South America [12]. Its genesis is from wild species i.e., *Phaseolus aborigineus* L. which is regarded as progenitor [13]. Cultivated *P. vulgaris* are grouped into two types i.e., Bush types, determinate in growth habit and pole types, indeterminate in growth habit. Basically, the plant has tap root and lateral root system that are confined to top 15 cm of the soil surface. Conspicuous hair is present in plant and the density of the hairs and length on the stems vary depending on the cultivar. The hairs play an important role in resistance to disease and insects, particularly prevent the formation of fungal spores and lower the degree of secondary inoculum. The plant has trifoliate leaves which are arranged alternately on stem. Leaflet shapes vary among genotypes however leaflet with broad bases and acute tips are common leaf characteristics are observed. Depending on the cultivar, inflorescence is born as axillary or terminal racemes bears flowers of different colours i.e., white, purple, violet liliac, or pink. The flower is bisexual have a "keel" which has one to two turns and terminates in a coil. Depending on the cultivar, the pods vary in size, shape, and pigmentation in addition to having sparse hair. A diverse characteristic of seeds (colours, shapes, and sizes) are observed in French bean with an average weight test weight of 150-900 g which varies from one cultivar to another (Brink and Belay, [14] and Wortmann, [3]).

An extensive crop improvement programme has been conducted in French bean witnessing development of a number of varieties which comprise diverse range of agronomic and morpho-physiological characteristics including diversity in growth habit, seeds size and colour (Purseglove, [1] and Singh et al. [15]). Determinate growth, which is typically characterized by decreased branching, shorter and less number internodes, less twining, photo-insensitive, and, most importantly, an increased allocation of biomass to reproductive growth, is one of the traits that is most frequently chosen (Singh and Schwartz [16] and Kwak et al. [17]).

The DUS (Distinctness, Uniformity, and Stability) assessment mandated under the Plant Varieties and Farmers Right Act (PPV&FRA) [18], is crucial for a valid varietal registration. A useful method for identifying and preventing duplication is DUS characterization of crop genotypes (Das and Kumar, 2012). The morphological characterization of genotypes facilitates in the development of a database that can be helpful for identification and assessment of the genetic variation present in the genotypes. In order to improve crops, germplasm evaluation is crucial. A significant source of genetic diversity is the farming community's production of French bean accessions in India and Odisha. A global initiative to preserve plant biodiversity involves collecting germplasm. Invaluable for breeding programmes is the diversity of local genetic resources. These tools can be applied to fundamental research on topics like gene expression, evolution, and crop plant improvement (Dudnik et al. [19] and Mario et al. [20]).

High genetic diversity in French bean is available in in India and many local varieties and primitive cultivars have not been fully utilized in genetic improvement programme due to minimal database are available about these genotypes. Thus, this study was initiated with the objectives of collecting French bean germplasm followed by characterization for generating a strong database for utilization in future crop improvement programme.

## 2. MATERIALS AND METHODS

The plant genetic materials for investigation comprised of 13 French bean genotypes collected from Guptakashi, Uttarakhand, 4 from Araku, Andhra Pradesh, one from Raikia, Kandhamal, two released varieties such as Arka Arjun and Arka Sukomal from IIHR, Bengaluru, Karnataka, 3 from Phulbani, Kandhamal, Odisha, 3 from Bhubaneswar, Odisha and one from Angul, Odisha (Table 1). Field evaluation and data collection of French bean genotypes was conducted at Central Horticulture Experiment Station (CHES-IIHR), Aiginia, Bhubaneswar, India of ICAR-Indian Institute of Horticulture Research, during rabi 2019-20. The site is located at $20.015^0$ N latitude, $85.053^0$ E longitude and 25.5 m above mean sea level. The rainfall code of the place is D1 E3 (B1A2B1) C1D1E2. The average temperature varies from $14^0$ C in winter, $40^0$ C in summer and $30^0$C in rainy season. Relative humidity varies between 49% and 90%. Seeds were sown on raised bed with 1m x 30cm spacing in RCBD (Randomized Complete Block Design) in three replications. Fertilizer applied at the rate 100:60:40 kg/ha $NH_4$: $P_2O_5$: $K_2O$ and good agricultural practices were adopted for successful raising of the crop.

### 2.1 Traits Recording and Scoring

The morpho-phenological trait for the genotypes were recorded as per international French bean descriptor of the International Board for Plant Genetic Resources [21], guidelines for the conduct of test for Distinctness, Uniformity, and Stability on French bean (PPV & FR authority, GOI, [18]) and other descriptors were considered from literatures. In total 38 qualitative traits are observed (Table 2). For qualitative traits particular scale is coded as per IBPGR descriptor for diversity analysis and elimination of repetition of data (Tables 3 and 4). The PCA, eigan and correlation values are estimated by using software package, Grapes 1.0.0. [22].

**Table 1. List of genotypes considered for investigation**

| Sl. No. | Genotypes/ Variety | Type | Source of collection |
|---|---|---|---|
| 1. | Arka Arjun | Commercial cultivar | IIHR, Bengaluru, Karnataka |
| 2. | Arka Sukomal | Commercial cultivar | |
| 3. | IIHR-B-PV-16 | Primitive | Guptakashi, Uttarakhand |
| 4. | IIHR-B-PV-4 | Primitive | |
| 5. | IIHR-B-PV-5 | Primitive | |
| 6. | IIHR-B-PV-9 | Primitive | |
| 7. | IIHR-B-PV-11 | Primitive | |
| 8. | IIHR-B-PV-12 | Primitive | |
| 9. | IIHR-B-PV-15 | Primitive | |
| 10. | IIHR-B-PV-17 | Primitive | |
| 11. | IIHR-B-PV-20 | Primitive | |
| 12. | IIHR-B-PV-21 | Primitive | |
| 13. | IIHR-B-PV-22 | Primitive | |
| 14. | IIHR-B-PV-24 | Primitive | |
| 15. | IIHR-B-PV-25 | Primitive | |
| 16. | IIHR-B-PV-26 | Primitive | Araku Velly, Andhra Pradesh |
| 17. | IIHR-B-PV-27 | Primitive | |

| Sl. No. | Genotypes/ Variety | Type | Source of collection |
|---|---|---|---|
| 18. | IIHR-B-PV-29 | Primitive | |
| 19. | IIHR-B-PV-30 | Primitive | |
| 20. | IC 632961 | Farmer grown variety | Raikia, Kandhamal, Odisha |
| 21. | Ayoka | Commercial cultivar | Phulbani, Kandhamal, Odisha |
| 22. | Phulbani local | Farmer grown variety | |
| 23. | Baisnavi | Commercial cultivar | |
| 24. | Anupam | Commercial cultivar | Bhubaneswar, Odisha |
| 25. | Ranar | Commercial cultivar | |
| 26. | Phalguni | Commercial cultivar | |
| 27. | Angul local | Farmer grown variety | Angul, Odisha |

**Table 2. List of morpho-phenological traits and assigned scale for different qualitative traits recorded in the study**

| Traits | Acronym | Description with scale |
|---|---|---|
| Growth habit | GH | Recorded for pole type and bush type; Determinate=1, indeterminate=2, semi determinate=3 |
| Twinning habit | TH | Recorded as per twinning or climbing nature of plant; Viny= 1, non-viny=9 |
| Stem pigmentation | SP | Observed at peak flowering stage; Absent= 0, present= + |
| Stem hairiness | SH | Presence or absence of space hair on stem; Absent= 0, present= + |
| Leaf colour | LC | Intensity of green colour at peak flowering stage; Pale green= 3, medium green= 5, dark green= 7 |
| Leaf shape | LS | Shape of central leaflet at peak flowering stage; Ovate= 1, rhombohedric= 2, cordate= 3 |
| Leaf pubescence | LP | Presence or absence of conspicuous hair on leaf surface; Hairy= +, smooth= 0 |
| Leaflet size | LLS | Size of central leaflet at peak flowering stage; Small= 1, medium= 2, large= 3 |
| Persistence of leaf | PL | Persistence of leaves when 90% of pods dry in plot; All leaf dropped= 3, intermediate= 5, all leaves peristent= 7 |
| Flower colour | FC | Observed in freshly opened flowers; White= 1, yellow= 2, pink= 3, violet= 4 |
| Standard petal pattern | SPP | Presence or absence of strips on outer surface of standard petal; Stripted= 1, non-stripted= 3 |
| Colour of standard petal | CSP | Observed in freshly opened flower; White=1, light green= 2, lilac= 3, carmine red=8, purple= 9 |
| Colour of wing | CW | Observed in freshly opened flower; White= 1, green= 2, lilac= 3, white with carmine stripes= 4 |
| Flower bud size | FBS | Relative size of flowers in inflorescence; Small= 1, medium= 2, large= 3 |
| Size of flower bracteolate | SBL | Size of bracteole at peak flowering stage; Small= 3, medium= 5, large= 7 |
| Colour of pod | CP | Intensity of colour in full grown immature pod; Purple= 1, green with purple stripe= 3, green with red stripes=5, green= 7, pale green= 8 |
| Pod shape | PS | Recorded in full grown immature pod; flat= 1, round= 2 |
| Pod curvature | PC | Recorded in full grown immature pod in relation to suture; Straight= 3, slightly curved= 5, curved= 7, recurving=9 |
| Pod pigmentation | PP | Presence or absence of other pigments in pod surface; Absent=1, present=9 |
| Position of pod | POP | Pod bearing habit in relation to portion of stem; Base= 1, center= 2, top= 3, combination= 4 |
| Pod stringiness | PSN | Presence of string in pod cross-section; Stringless= 0, few |

| Traits | Acronym | Description with scale |
|---|---|---|
| | | strings= 3, moderately stringy=5, very stringy= 7 |
| Pod pubescence | PPS | Hairy or smoothness pod recorded in full grown immature pod; Sparce= 1, intermediate= 2, glabrous= 3 |
| Shape of pod distal part | SPDP | Shape of distal part of pod excluding beak; Acute= 3, acute to truncate= 5, truncate= 7 |
| Pod beak position | PBP | Observed in full grown immature pod; Marginal= 1, non-marginal= 2 |
| Pod beak orientation | PBO | Curving of beak to dorsal or ventral side of pod; Upward= 3, straight= 5, downward= 7 |
| Pod cross-section | PCS | Shape of pod in cross-section along with seed; Very flat= 1, pear shaped= 2, round elliptic= 3, figure of eight= 4 |
| Pod wall fiber | PWF | Recorded in fully matured dry pod; Contracting= 3, leathery= 5, shattering= 7 |
| Pod colour at physiological maturity | PCPM | Intensity of colour in fully matured dry pod Pink= 3, pale yellow= 4, copper brown= 5, brown= 6, brown with pigmentation= 7 |

## 3. RESULTS

### 3.1 Characterization Based on Qualitative Traits

It is very essential for finding duplications in germplasm collections, characterization of individuals, accessions, and cultivars as well as choosing parental genotypes in breeding programmes.

#### 3.1.1 Plant growth traits

Plant growth traits is an important consideration for characterizing a set of genotypes as the traits has direct contribution towards plant architecture which influences the yield and its other components. The data on plant growth traits of studied twenty-seven genotypes are presented in Table 3 and Fig. 1. Duran et al. [23] adopted morphological descriptors such as leaf width, leaf length, leaf shape (cordate, ovate, rhombohedric, or hastate), growth habit, length of the fifth internode to characterize French bean landraces and cultivars from the Caribbean. Singh et al. [24] characterized 18 French bean genotypes as DUS morphological descriptors for the protection of novel varieties under the PPV and FR Rules of 2001 and inferred that time of flowering, stem anthocyanin colouration, leaflet size (at terminal leaflet of first flowering mode), plant growth type, plant twining habit, plant habit, intensity of green colour of leaf, shape of central leaflet are important morphological markers. Kanwar et al. [25] categorized 26 geographically diverse French bean genotypes for plant growth habit, stem pigmentation, hairiness on the stem, flower colour, hairiness on the flower, leaflet shape and reported significant differences among all the genotypes. Simon Yohannes et al. [26] showed that the growth traits measured were significantly differed due to the existence of inherent genetic variations among the French bean genotypes.

**Growth habit**

The investigation revealed that the studied French genotypes show maximum variation on the basis of different plant growth parameters i.e., eight genotypes are observed with bushy plant frame with determinate growth habits, one is with semi erect with semi-determinate and others eighteen genotypes show erect plant frame with indeterminate growth habits (Table 3, Figs. 1 and 2). Voysest [27] proposed classifications of French bean cultivars as per growth habit. Purseglove [1] and Singh et al. [15] reported a wide variability in growth habit in French bean. Garcia et al. [28], Rosales-Serna et al. [29] and Langarica et al. [30] demonstrated that indeterminate growth habit with climbing ability and extend physiological maturity leads to more productive than plants with determinate growth habit. Rosales-Serna et al. [29]; Beebe et al. [31]; Langarica et al. [30] found significant diversity for growth habit in French bean genotypes. Garcia et al. [28] and Langarica et al. [30] reported predominant presence of indeterminate, with non-climbing shoots in French bean genotypes. Albuquerque et al. [32] and Tsutsumi et al. [33] witnessed French bean exhibits wide agronomic traits variation, including cycle (early and late), growth habit (determinate and indeterminate), plant habit (erect, semi-erect, and prostrated). Rana et al. [34] evaluated 4274 germplasm accession of French bean from 58 countries and observed that morphological traits such as early plant vigour and indeterminate growth habit are predominant among 27 morphological traits. Rana et al. [34] noticed 43% accessions had indeterminate growth habit, 28% determinate and 29% were intermediate type. Choudhary, Bawa et al. [35]; Choudhary, Hamid et al. [36]; Singh [37] observed great diversity exists for plant type, growth habit in agro-ecological adaptation of landraces cultivated in a particular region. AlBallat and Al-Araby [38] indicated a wide genetic variability for indeterminate growth habit traits among 27 accessions. Dhaliwal [39] revealed plant growth type out of the 19 characters was found monomorphic and showed no variation amongst French bean genotypes which exhibited semi-determinate growth type. Jan et al. [40] revealed spreading growth type, vinyl twining habit frequently noticed among genotypes for growth habit and growth type during screening of 109 French bean.

### Twinning habit

Regarding twinning habits of the plant which confer climbing ability of plants revealed nineteen genotypes are found to be viny and eight genotypes are non-viny in nature (Table 3 and Fig. 1). Jan et al. [40] revealed considerable variations noticed among French bean genotypes for twinning habit. Jan et al. [40] and Sofi et al. [41] observed predominance of indeterminate vinyl/climbing types in French bean.

### Stem hairiness and pigmentation

As far as stem hairiness and pigmentation is concerned most of genotypes are reported with presence of conspicuous hair on stem and are non-pigmented whereas seven genotypes are having purple stem pigmentation (Table 3 and Fig. 1). Prashanth [42] grouped seven genotypes based on hairiness on the stem as glabrous and dense. Gupta et al. [43] and Ramteke and Murlidharan [44] reported that white-flowered genotypes exhibit no hypocotyl anthocyanin pigmentation, whereas the pigmentation is present in violet flowered genotypes. Kalauni et al. [45] characterized and witnessed variability in French bean genotypes for stem pigmentation and hairiness. Dhaliwal [39] inferred that presence of hypocotyl anthocyanin pigmentation is associated with violet flower colour.

### Leaf traits

The French bean genotypes showed noticeable variation on leaf colour (light green and dark green), leaf shape (cordate, ovate, rhombobatic, Hestate), leaflet size (small, medium and large) and leaf persistence (persistent, intermediate and dropped) presented in Table 3, Figs. 1 and 3.

### Leaf colour

The frequency table indicated that the studied French bean genotypes were varied as per green colour intensity i.e., light green and dark green (Table 3, Figs. 1 and 3) which corroborates with findings of many scientists. Bonetti et al. [46] evaluated 17 French bean cultivars based on leaf colour (very light green, light green, medium green, dark green, very dark green). Prakash and Singal [47] used leaf colour to categories seven grain and six vegetable pea varieties. Surendra and Singhal [48] classified seven grain and vegetable pea cultivars based on leaf colours (yellow green, blue green, green). Sultana [49] observed green and purple vein colours among 107 genotypes and leaf colour intensity varied from pale green to green to dark green in characterization of hyacinth bean. Jan et al. [40] revealed dark green leaf colour frequently noticed among genotypes during screening of 109 French bean.

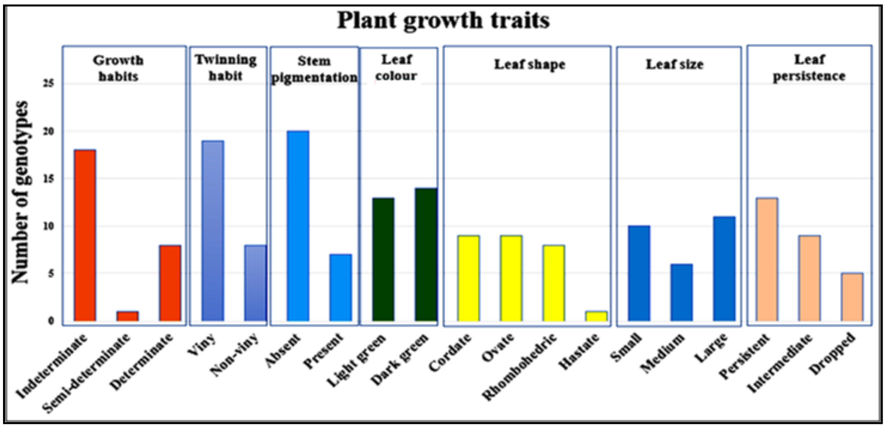


**Fig. 1. Frequency distribution of French bean genotypes for plant growth traits**

**Table 3. Qualitative traits of different French bean genotypes**

| Sl. No. | Genotypes | GH | SP | SH | LC | LSS | LP | LLS | LP | FC | SPP | CSL | CW | FBS | SBL | PC | PS | PC | PP | POP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | IC 632961 | 2 | 0 | + | 7 | 3 | + | 3 | 5 | 1 | 3 | 1 | 1 | 3 | 5 | 7 | 2 | 9 | 1 | 2 |
| 2. | PV-26 | 2 | + | + | 7 | 3 | + | 2 | 5 | 1 | 1 | 2 | 1 | 2 | 3 | 7 | 1 | 3 | 1 | 1 |
| 3. | PV-16 | 2 | 0 | + | 7 | 1 | + | 2 | 5 | 3 | 1 | 9 | 3 | 2 | 3 | 5 | 1 | 5 | 9 | 4 |
| 4. | PV-4 | 2 | 0 | + | 7 | 2 | + | 2 | 5 | 4 | 1 | 2 | 4 | 3 | 7 | 3 | 1 | 5 | 9 | 4 |
| 5. | PV-5 | 2 | 0 | + | 5 | 2 | + | 2 | 5 | 1, 3 | 3 | 1, 3 | 3 | 3 | 5 | 8 | 1 | 5 | 1 | 4 |
| 6. | PV-9 | 2 | + | + | 7 | 2 | + | 1 | 5 | 3 | 1 | 9 | 3 | 3 | 3 | 7 | 1 | 5 | 1 | 1 |
| 7. | PV-11 | 2 | 0 | + | 5 | 1 | + | 1 | 3 | 3 | 1 | 8 | 4 | 3 | 5 | 5 | 1 | 5 | 9 | 4 |
| 8. | PV-12 | 2 | 0 | + | 5 | 3 | + | 2 | 3 | 3 | 1 | 9 | 4 | 3 | 3 | 5 | 1 | 3 | 9 | 1 |
| 9. | PV-15 | 2 | 0 | + | 5 | 1 | + | 1 | 3 | 1 | 3 | 1, 3 | 3 | 2 | 5 | 5 | 1 | 5 | 9 | 4 |
| 10. | Arka Sukomal | 2 | 0 | + | 5 | 3 | + | 3 | 5 | 1 | 3 | 2 | 1 | 3 | 7 | 7 | 2 | 9 | 1 | 2 |
| 11. | PV-17 | 2 | 0 | + | 5 | 2 | + | 3 | 5 | 2, 3 | 1 | 1 | 1 | 2 | 3 | 7 | 1 | 5 | 1 | 4 |
| 12. | PV-20 | 2 | + | + | 7 | 1 | + | 1 | 5 | 4 | 1 | 9 | 3 | 2 | 3 | 3 | 1 | 5 | 9 | 1 |
| 13. | PV-21 | 2 | 0 | + | 7 | 1 | + | 1 | 5 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 1 | 5 | 9 | 4 |
| 14. | PV-22 | 2 | 0 | + | 7 | 1 | + | 1 | 5 | 1 | 3 | 1 | 1 | 2 | 5 | 7 | 1 | 3 | 1 | 4 |
| 15. | PV-24 | 2 | 0 | + | 5 | 2 | + | 3 | 5 | 1 | 3 | 1 | 1 | 2 | 5 | 8 | 1 | 7 | 1 | 4 |
| 16. | PV-27 | 3 | + | + | 5 | 3 | + | 3 | 5 | 1 | 3 | 2 | 1 | 1 | 3 | 8 | 1 | 3 | 1 | 2 |
| 17. | Ayoka | 2 | + | + | 5 | 1 | + | 1 | 3 | 1 | 3 | 2 | 1 | 1 | 3 | 7 | 2 | 9 | 1 | 2 |
| 18. | Ranar | 2 | + | + | 7 | 3 | + | 3 | 5 | 1 | 3 | 2 | 1 | 2 | 3 | 5 | 1 | 3 | 9 | 1 |
| 19. | Angul local | 2 | + | + | 5 | 3 | + | 3 | 5 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 1 | 3 | 9 | 2 |
| 20. | PV-25 | 1 | 0 | + | 5 | 3 | + | 3 | 5 | 1 | 3 | 2 | 1 | 1 | 5 | 5 | 1 | 3 | 9 | 2 |
| 21. | Arka Arjun | 1 | 0 | + | 7 | 2 | + | 3 | 5 | 1 | 3 | 2 | 1 | 3 | 7 | 8 | 2 | 7 | 1 | 2 |
| 22. | PV-29 | 1 | 0 | + | 7 | 3 | + | 3 | 5 | 4 | 1 | 9 | 3 | 3 | 7 | 8 | 2 | 5 | 1 | 4 |
| 23. | PV-30 | 1 | 0 | + | 5 | 2 | + | 3 | 5 | 1 | 3 | 2 | 1 | 2 | 3 | 7 | 2 | 5 | 1 | 2 |
| 24. | Anupam | 1 | 0 | 0 | 5 | 1 | + | 2 | 5 | 4 | 1 | 3 | 4 | 2 | 5 | 8 | 2 | 7 | 1 | 1 |
| 25. | Phulbani local | 1 | 0 | + | 7 | 1 | + | 1 | 3 | 1 | 3 | 2 | 1 | 3 | 7 | 7 | 2 | 5 | 1 | 2 |
| 26. | Phalguni | 1 | 0 | + | 7 | 2 | + | 1 | 5 | 1, 2 | 3 | 2 | 1 | 3 | 5 | 7 | 2 | 5 | 1 | 4 |
| 27. | Baisnavi | 1 | 0 | + | 7 | 2 | + | 1 | 5 | 4 | 1 | 9 | 3 | 3 | 7 | 8 | 1 | 5 | 1 | 4 |

**Table 4. Qualitative traits of different French bean genotypes**

| Sl. No. | Genotypes | PSN | PPS | SPDP | PBP | PBO | PCS | PWF | PCPM | STC | SS | STV | SCP | BS | SV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | IC 632961 | 7 | 1 | 5 | 1 | 3 | 3 | 3 | 5 | 2 | 3 | 1 | 0 | 7 | 1 |
| 2. | PV-26 | 5 | 2 | 5 | 1 | 3 | 1 | 3 | 5 | 3 | 2 | 1 | 0 | 7 | 3 |
| 3. | PV-16 | 7 | 3 | 7 | 1 | 3 | 1 | 5 | 7 | 2 | 3 | 9 | 5 | 7 | 3 |
| 4. | PV-4 | 7 | 2 | 7 | 1 | 5 | 1 | 7 | 7 | 2 | 5 | 1 | 0 | 7 | 3 |
| 5. | PV-5 | 7 | 2 | 5 | 1 | 5 | 1 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 3 |
| 6. | PV-9 | 5 | 3 | 3 | 1 | 5 | 2 | 5 | 6 | 1 | 2 | 1 | 0 | 7 | 2 |
| 7. | PV-11 | 5 | 1 | 7 | 1 | 5 | 1 | 5 | 6 | 2 | 3 | 9 | 2 | 7 | 3 |
| 8. | PV-12 | 3 | 3 | 5 | 1 | 3 | 1 | 3 | 5 | 2 | 3 | 9 | 7 | 7 | 3 |
| 9. | PV-15 | 5 | 3 | 7 | 1 | 5 | 1 | 5 | 6 | 2 | 3 | 9 | 1 | 5 | 3 |
| 10. | Arka Sukomal | 0 | 3 | 5 | 1 | 3 | 2 | 5 | 6 | 7 | 4 | 1 | 0 | 7 | 1 |
| 11. | PV-17 | 7 | 1 | 3 | 2 | 5 | 1 | 7 | 4 | 3 | 3 | 9 | 7 | 7 | 1 |
| 12. | PV-20 | 5 | 3 | 7 | 1 | 5 | 1 | 5 | 5 | 2 | 5 | 9 | 3 | 3 | 2 |
| 13. | PV-21 | 3 | 2 | 5 | 1 | 5 | 1 | 5 | 6 | 2 | 3 | 1 | 0 | 7 | 2 |
| 14. | PV-22 | 5 | 2 | 3 | 2 | 3 | 1 | 3 | 6 | 2 | 3 | 1 | 0 | 3 | 3 |
| 15. | PV-24 | 7 | 3 | 7 | 1 | 5 | 1 | 5 | 4 | 3 | 3 | 9 | 3 | 7 | 3 |
| 16. | PV-25 | 5 | 2 | 7 | 1 | 5 | 1 | 5 | 6 | 2 | 4 | 9 | 5 | 7 | 2 |
| 17. | Arka Arjun | 3 | 1 | 3 | 1 | 3 | 3 | 3 | 6 | 7 | 4 | 1 | 0 | 7 | 2 |
| 18. | PV-27 | 3 | 2 | 5 | 2 | 3 | 1 | 5 | 5 | 3 | 2 | 1 | 0 | 7 | 3 |
| 19. | PV-29 | 7 | 2 | 7 | 1 | 5 | 2 | 5 | 6 | 2 | 4 | 9 | 0 | 5 | 3 |
| 20. | PV-30 | 7 | 2 | 7 | 1 | 5 | 1 | 5 | 4 | 3 | 4 | 1 | 0 | 7 | 3 |
| 21. | Anupam | 5 | 2 | 7 | 1 | 7 | 4 | 3 | 6 | 4 | 3 | 1 | 0 | 7 | 3 |
| 22. | Ranar | 7 | 3 | 5 | 1 | 7 | 2 | 3 | 4 | 1 | 4 | 1 | 0 | 5 | 2 |
| 23. | Phulbani local | 0 | 3 | 3 | 2 | 7 | 2 | 5 | 4 | 7 | 3 | 1 | 0 | 7 | 2 |
| 24. | Ayoka | 7 | 3 | 5 | 1 | 5 | 3 | 3 | 4 | 1 | 4 | 1 | 0 | 7 | 3 |
| 25. | Phalguni | 5 | 3 | 3 | 2 | 7 | 4 | 5 | 6 | 7 | 3 | 1 | 0 | 7 | 1 |
| 26. | Baisnavi | 0 | 3 | 5 | 2 | 7 | 3 | 3 | 4 | 7 | 3 | 1 | 0 | 5 | 2 |
| 27 | Angul local | 5 | 2 | 5 | 1 | 3 | 2 | 5 | 7 | 1 | 4 | 1 | 0 | 7 | 2 |


**Bush type**

**Semi-erect plant**

**Erect plant** **Erect plant**

**Fig. 2. Different type of growth habit in studied French**


**Cordate** **Hastate** **Ovate** **Rhombobatic**

**Fig. 3. Different leaf shape in studied French bean**

**Leaf shape and size**

Leaflet shape is a certifying DUS characteristic for distinguishing genotypes. The data depicted that the French bean genotypes had varied leaf shape and size which helps in better characterization as it is a quite visible traits to naked to eye (Table 3, Figs. 1 and 3). Leaflet shape differs among the cultivars, but leaflets generally have broad bases and pointed tips (Singh et al. [15]. Duran et al. [23] adopted morphological descriptor leaf shape (cordate, ovate, rhombohedric, or hastate) to characterize French bean landraces and cultivars from the Caribbean. Amirul Islam et al. [50] evaluated 1105 French bean accessions for leaf shape. Bode et al. [51] observed a great variability for leaf shape in French bean. Lenkala et al. [40] grouped fifteen genotypes of Jack bean based on leaf density i.e., sparse, intermediate and dense. Rana et al. [34] evaluated 4274 germplasm accession of French bean from 58 countries and observed that ovate leaf shape is predominant among 27 morphological traits. Kalauni et al. [45] characterized and witnessed variability in French bean genotypes for leaf colour and leaflet shape. Jan et al. [40] reported two classes of leaf shape (Cordate and ovate) and 78.31% genotypes witnessed found cordate leaf shape predominantly. Jan et al. [40] reported three classes of leaf size i.e., large, medium, and small in French bean with large leaf size predominantly.

### 3.1.2 Flowering traits

French bean genotypes witnessed considerable variation in term of flower colour, shape and size under study which offer quick and easy identification methods for characterization (Table 3). The present investigation revealed that the flower colour of fifteen genotypes was white, four had pink flowers, four had violate flowers, one had purple flower, three had dual flower colour i.e., white & pink, white & yellow or yellow & pink (Figs. 4 and 5). The studied genotypes are grouped into two categories i.e., eleven genotypes with striped standard petal and sixteen with non-striped petal in flower (Table 3). The studied French genotypes showed different colour for standard petal noticeably, six with white colour standard petals, nine with light green, six with purple, two with white and lilac, one with carmine red and two with green standard petals (Figs. 4 and 5). Similarly, sixteen genotypes are witnessed with white, seven with lilac and four with purple colour of wings. The French bean genotypes are varied as per size of flower i.e., twelve genotypes had large size flowers, ten genotypes had medium and five had small flower size. As far as size of bracteolate concerned, the genotypes also showed considerable variation whereas all genotypes are found to be glabrous in flower hairiness.

Gepts [52] observed flower petal colour of blue to purple, pink to red and white in French bean genotypes. Papa and Gepts, [53], Langarica et al. [30] inferred that purple and pink flowers confer black seed coats. Duran et al. [23] reported outer base of the standard of the corolla classified as striped or smooth to characterize French bean landraces and cultivars from the Caribbean. Amirul Islam et al. [54] evaluated 1105 French bean accessions for primary colour of wings and primary colour of the standard petal traits. Bode et al. [50] observed a great variability for 19 qualitative descriptors like colour of standard flower and colour of wings in French bean. Doriana et al. [55] observed a great variability for colour of standard flower and colour of wings, in French bean. Okii et al. [56] grouped 284 French bean accessions into three group viz., white, plain red to dark lilac and purple-coloured flowers. Singh et al. [24] inferred that colour of standard petal and outer surface of standard petal are important morphological markers. Rana et al. [34] reported proportion of flower colour among 4274 French bean genotypes i.e., white (39%), pink (26%) and lilac (21%). Caproni et al. [57] observed absence of seed coat pattern (87%), striped 'base of standard' (83%), purple flower (78%) and black seed (70%) in Mesoamerican group. Kalauni et al. [44] characterized and witnessed variability in French bean genotypes for flower colour. Dhaliwal [39] revealed presence of hypocotyl anthocyanin pigmentation correlated with violet flower colour. Kanwar et al. [25] categorized 26 geographically diverse French bean genotypes for flower colour and hairiness on the flower and reported significant differences among all the genotypes. Jan et al. [40] studied standard of the flower in French bean genotypes and inferred that white flower colour was most predominant (44.86%) with stripping on outer standard petal (23.85%) in comparison to pink, white, red, violet, and yellow coloured flowers.

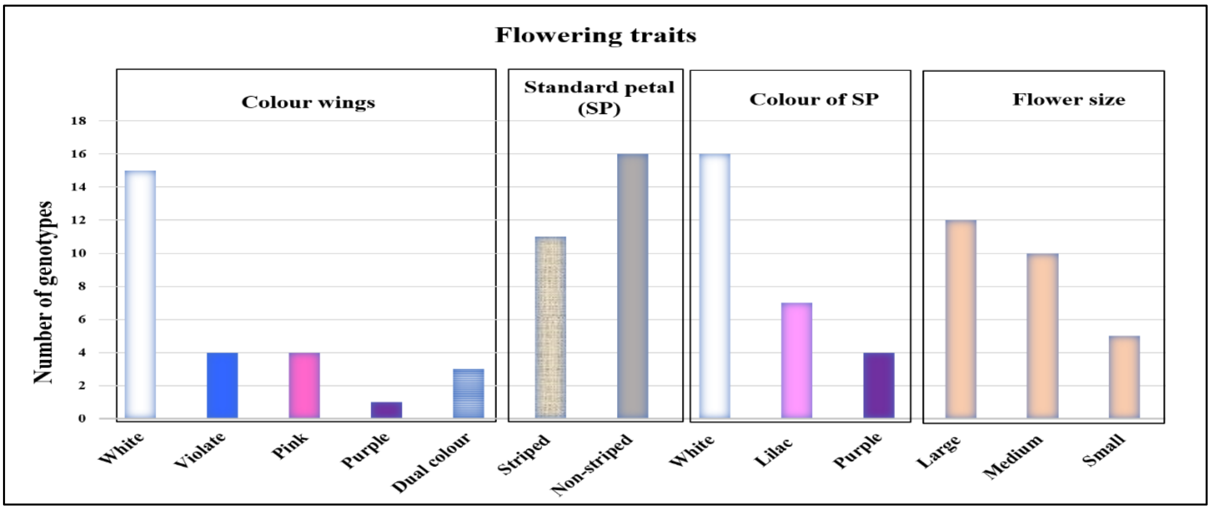


**Fig. 4. Frequency distribution of French bean genotypes for flowering traits**

**Fig. 5. Different flower colour in studied French bean**


**Fig. 6. Pod characteristics in studied French bean**

### 3.1.3 Fruiting traits

Pod characteristics traits are vital NBPGR descriptor to screen French bean genotypes as these observed with great diversity in term of pod colour, pod pubescence, pod curvature, pod shape, shape of pod curvature, pod pigmentation, pod position, pod orientation, beak shape, beak position, beak orientation, pod stringiness, pod cross-section, pod wall fiber, pod colour at physiological maturity is presented in Tables 4 and 5.

Amirul Islam et al. [54] evaluated 1105 French bean accessions for position of pod tip, form of pod and pod attributes traits. Massimo et al. [58] found statistically significant differences in pod morphological traits and slightly curved pod are predominant. Doriana et al*.* [55] observed a great variability for pod colour, pod cross-section, pod curvature, pod beak position, pod beak orientation in French bean. Singh et al. [24] characterized 18 French bean genotypes and inferred that pod curvature, pod shape of cross section (through seed), pod shape (in relation to suture), pod shape of distal part (excluding beak), pod colour, pod stringiness, pod pigmentation on pod shell are important morphological markers.

Rana et al. [34] evaluated 4274 germplasm accession of French bean from 58 countries and observed that morphological traits such as green colour pod, glabrous pod surface, straight pod are predominant among 27 morphological traits. Kalauni et al. [44] characterized and witnessed variability in French bean genotypes for pod colour, pod shape, pod cross-section, pod beak position and pod appearance. Kanwar et al. [25] categorized 26 geographically diverse French bean genotypes for pod colour at immature stage, orientation of pods, pod shape, pod pubescence and pod colour at physiological maturity and reported significant differences among all the genotypes. Jan et al. [40] revealed green colour of pods, acute to truncate pod shape, pigmentation on pods frequently noticed among 109 French bean genotypes.

**Pod colour**

Pod colour at immature stage is an important trait for classifying and grouping French bean genotypes under investigation (Table 3, Figs. 6 and 7). The data on pod colour revealed ten genotypes are observed with green pod, seven with light green pods, eight with green pods with red streaks and two with green with purple streaks. In most of genotypes, pigmentation was absent with green or light green pod colour. Okii et al. [56] observed green, light green and green with red stripes in French bean pod. Rana et al. [34] observed green pod colour as predominant pod colour in 87% accessions in French bean. Jan et al. [40] revealed green colour of pods in French bean was predominant in 84.40% genotypes in compared to green, pale green, and violet pods. He also noticed pigmentation on pods was noticed only in 35.77% genotypes, but in rest of genotypes, it was absent.

**Pod shape**

Pod shape is major trait of French bean which influence consumer preference and taken into consideration for grouping of genotypes. The data on fruit shape indicated that flat shape pod observed in eighteen genotypes and round shape pod in nine genotypes (Table 3, Figs. 6 and 7). Zaccardelli et al. [59] observed great variability in characterizing French bean genotypes for pod shape. Rana et al. [34] observed straight pod in 69 % French bean accessions. Kalauni et al. [44] found two with very flat among six genotypes. Jan et al. [40] witnessed concave pod shape was most common (in 93.75% genotypes) in comparison to convex, concave and straight pod shape in relation to suture.

**Pod curvature**

The present study on pod curvature witnessed six genotypes with straight pod, fourteen genotypes with slightly curved pod, three had curved pods and three had recurving pod curvature (Table 3, Figs. 6 and 7). Most of genotypes showed concave pod curvature than convex form (Arka Arjun). Muchui et al. [60] observed predominantly straight pods and few slightly curved pods in French bean. Neupane et al. [61] reported 43 accessions were slightly curved, 29 were straight and 7 accessions were curved among the eighty accessions of local and exotic French bean germplasm. Massimo et al. [58] found slightly curved pod are predominant in French bean. Jan et al. [40] found acute, truncate, and acute to truncate as shape of distal part of pods with maximum genotypes (63.30%) had acute to truncate shape.

**Pod position**

Pod position is an agronomical trait indicates the pod bearing habit of different genotypes. The data on pod position indicated that six genotypes bore pods in basal portion, nine bore pods in central portion and in twelve genotypes the pods found from base to top (Table 3). All genotypes are found with prostrate bearing habit of pods.

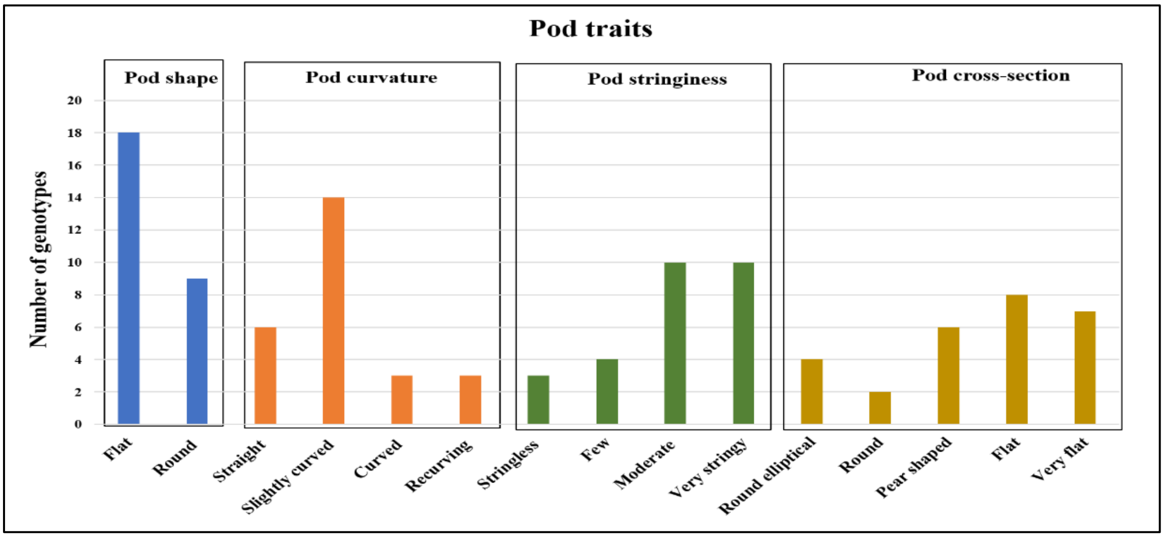


**Fig. 7. Frequency distribution of French bean genotypes for fruitng traits**

**Pod stringiness**

Pod stringiness is a valuable pod characteristic from consumer acceptable point of view. Less stringy pod is of more edible value than stringy one which was considered for grouping different genotypes under study. The data on pod stringiness is presented in Table 4. Jan et al. [40] noticed dry pods of maximum genotypes (55.04%) possessed strings, whereas in rest, it was absent.

**Pod pubescence**

Pod pubescence indicates the presence of sparce hairs on pod surface which influence the fruit shelf life and consumer acceptance. The data on pod pubescence is presented in Table 4 revealed twelve French genotypes were glabrous (without hair), eleven genotypes having intermediate hairs whereas four genotypes having sparce hair on pod surface. Kar et al. [62] reported eight genotypes with smooth pod surface and seven genotypes with pubescent pod surface among 15 French bean genotypes. Rana et al. [34] observed glabrous pod surface in 96 % French bean accessions.

**Pod beak shape**

The fruit trait has less agronomic importance though the studied French bean genotypes observed with different pod beak shape i.e., acute to truncate, truncate and acute is presented in Table 4. Duran et al. [23] adopted pod beak position to characterize French bean landraces and cultivars from the Caribbean.

**Pod beak orientation**

The observation on pod beak orientation is presented in Table 4 showed variation among studied genotypes though the traits has least agronomic importance. Bode et al. [50] observed a great variability for pod beak position, pod beak orientation, size of bracteole in French bean. Caproni et al. [57] panel revealed ‘marginal’ Pod Beak Position (PBP), ‘downward oriented’ Pod Beak Orientation (PBO) within Mesoamerican group while the ‘straight orientation’ is the most abundant condition within the Andean group. Kalauni et al. [44] found five with marginal, one with nonmarginal beak orientation among six genotypes.

**Pod cross-section**

The data on pod cross-section is presented in Table 4 revealed that French genotypes show considerable variation in pod cross section shape i.e., round elliptical, round, pear shaped, flat and very flat (Fig. 8) which has importance in consumers’ preference point of view. Kalauni et al. [44] found four with round elliptic pod cross-section among six genotypes. Jan et al. [52] reported cordate, elliptical, and ovate shape of cross section of pod in which cordate and elliptic shapes were most frequent.

**Pod wall fiber**

The study reported that French bean genotypes with contracting and leathery pod wall are less prone to shattering loss of seeds where shattering type of pod wall become easily split and seeds comes out. The studied genotypes are grouped into contracting, leathery and shattering (Table 4) which is crucial for crop improvement and seed production programme. Ashok et al. [63] adopted constriction on pod to screen and group seven French bean germplasms. Caproni et al. [57] panel revealed strongly contracting Pod Wall Fibre (PWF) within the Andean group of French beans [64].


**Fig. 8. Pod cross-section view in studied French bean**

**Pod colour at physiological maturity**

The data on pod colour at physiological maturity is presented in Table 4 revealed that French bean genotypes witnessed different colour i.e., copper brown, brown, pale yellow, brown with pigmentation at full maturity stage of pod.

**Principal component analysis**

A statistical method for multivariate analysis called principal component analysis (PCA) is used to estimate and decompose complicated and large datasets. The pattern of variation in 27 French bean genotypes was also investigated using principal component analysis (PCA) on the basis of correlation between twenty nine traits under study and extracted clusters, to assess the variety of the genotypes and their link to the traits that have been observed. All examined yield and yield traits were subjected to PCA. There was a total of 26 principal components (PCs) were found, although only ten of them were deemed significant because of eigenvalues greater than 1 which together contribute 80.87% of the total variability of the traits. The remaining non-significant PCs (eigenvalue <1) weren't sufficient for investigation (Table 5). PCA biplot depicted PC1 and PC2 which revealed 33% of the total variance cumulatively for twenty nine morphological traits in the studied genotypes. The PC1 and PC2 explained 20.03% and 13.32% of the total variance (Fig. 9). Depending on how differently they differ from one another in the traits, individuals were dispersed in various ordinates. The length of a vector in a biplot indicates, respectively, the primary component contribution of the traits and the quality of the depiction. The PCA biplot divided the traits into seven main groups based on homogeneity and dissimilarity. The group I included SH and SP, group II (GH, PWF, STV, PP, SCP, SV, SPDP), group III (PCPM, PSN, PDP, SS), group IV (FC, CSL, CW), group V (PS, LC, FBS, SBL), group VI (PBO, PC, CP, PCS, PS) and group VII (SS, PL, SPP, STC, PBP). The group I, II and III contributed significantly towards PC1 were strongly related with individuals of row clusters 1, 2 and 4 whereas, group III and IV contributed more towards PC2 related to clusters 1, 2,3 and 4 (Fig. 10).

The length of a vector in a biplot show, respectively, how well the qualities are represented and how much they contribute to the principal components. Groups I and IV; V and VII appear to be independent of one another for the qualities being researched based on the angles between the vectors derived from the middle point of biplots, which show positive (between I, II and III; V and VI) or negative (between I and V; IV and VII) interactions. Bigger circles indicate the centroid of the corresponding cluster (Fig. 9).

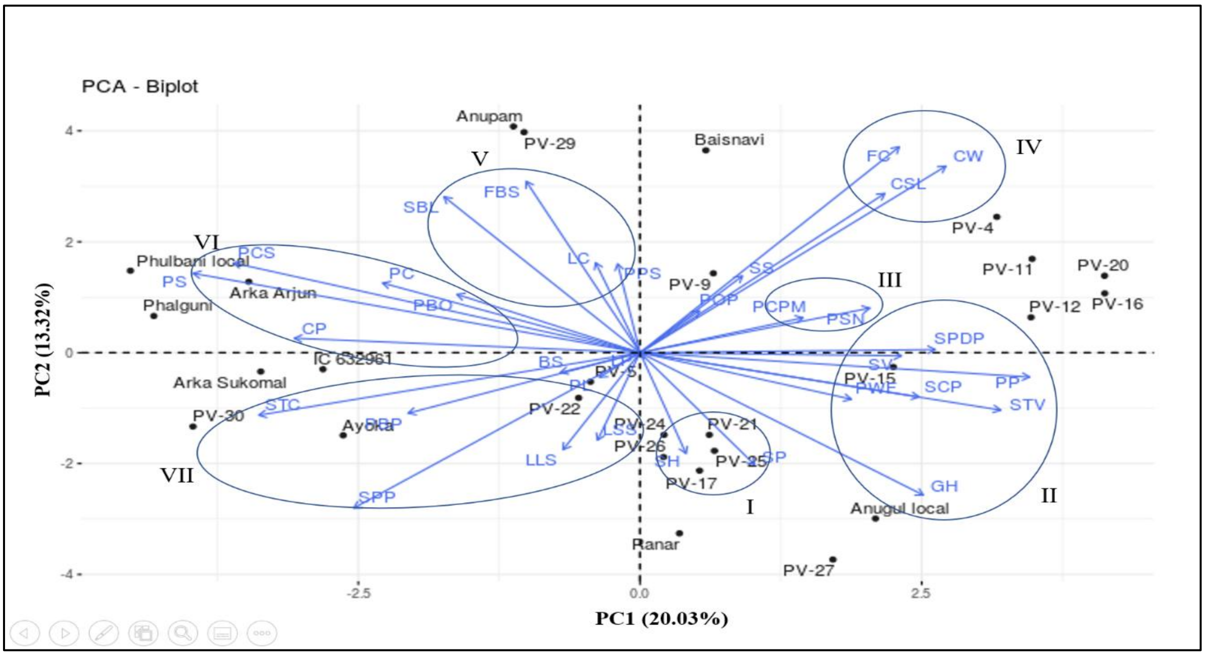


**Fig. 9. PCA-Biplot of twenty nine morphological traits for 27 French bean genotypes**

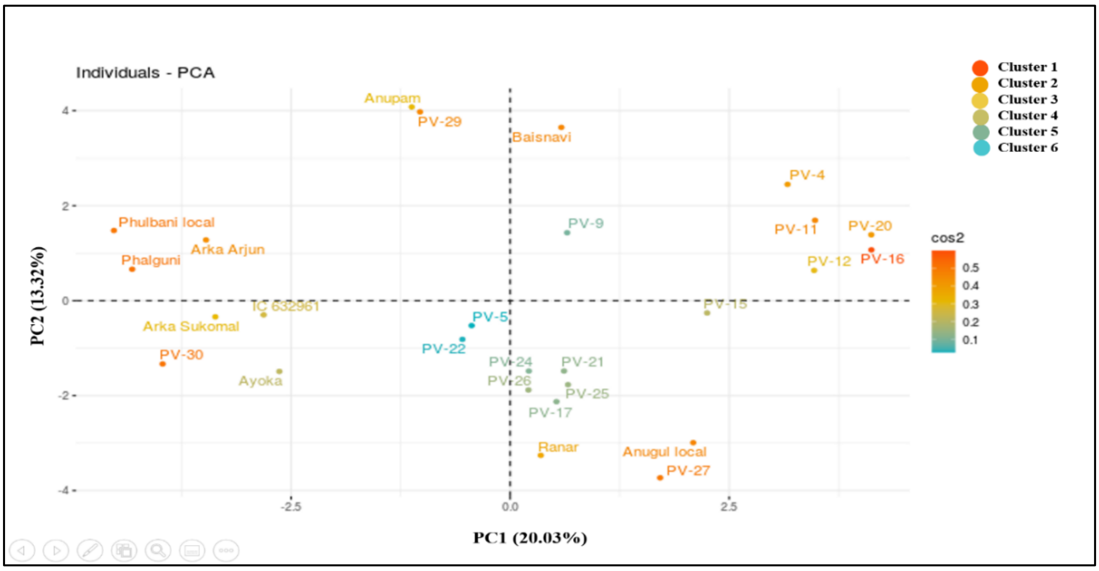


**Fig. 10. PCA showing clustering of 27 genotypes and traits contribution**

**Table 5. Extracted Eigenvalues and correlation values for twenty nine morphological traits**

| Variables | Principles components | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 |
| Extracted Eigenvalues | 6.61 | 4.397 | 2.689 | 2.381 | 2.144 | 2.062 | 2.027 | 1.712 |
| Explained variance (%) | 20.035 | 13.327 | 8.151 | 7.216 | 6.498 | 6.25 | 6.144 | 5.188 |
| Cumulative variance (%) | 20.035 | 33.363 | 41.514 | 48.73 | 55.227 | 61.477 | 67.621 | 72.809 |
| | **Morphological traits** | | | | | | | |
| GH | 0.528 | -0.539 | -0.058 | -0.131 | 0.284 | 0.123 | 0.269 | -0.004 |
| SP | 0.214 | -0.425 | -0.047 | -0.638 | -0.039 | 0.285 | -0.137 | 0.163 |
| SH | 0.086 | -0.382 | -0.39 | 0.201 | -0.15 | 0.028 | 0.427 | 0.414 |
| LC | -0.083 | 0.341 | -0.309 | -0.222 | -0.572 | 0.289 | 0.319 | 0.155 |
| LSS | -0.079 | -0.331 | 0.591 | -0.173 | -0.215 | 0.026 | 0.185 | 0.436 |
| LP | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LLS | -0.144 | -0.367 | 0.768 | 0.142 | -0.052 | -0.088 | 0.025 | 0.324 |
| PL | -0.076 | -0.093 | 0.487 | -0.026 | -0.575 | 0.087 | 0.172 | 0.167 |
| FC | 0.483 | 0.779 | 0.113 | -0.184 | 0.012 | -0.094 | 0.02 | 0.157 |
| SPP | -0.533 | -0.588 | -0.113 | 0.345 | -0.03 | 0.236 | -0.188 | -0.079 |
| CSL | 0.456 | 0.603 | -0.082 | -0.38 | 0.024 | -0.173 | 0.075 | 0.252 |
| CW | 0.57 | 0.706 | 0.035 | -0.049 | 0.136 | -0.111 | -0.046 | -0.121 |
| FBS | -0.212 | 0.649 | -0.041 | 0.024 | -0.045 | -0.182 | 0.404 | 0.162 |
| SBL | -0.365 | 0.59 | 0.112 | 0.503 | -0.072 | 0.229 | 0.169 | 0.093 |
| CP | -0.644 | 0.055 | 0.378 | -0.124 | 0.083 | -0.194 | 0.259 | -0.301 |
| PS | -0.832 | 0.3 | 0.076 | -0.046 | 0.222 | 0.057 | -0.224 | 0.161 |
| PC | -0.48 | 0.264 | 0.112 | 0.094 | 0.592 | 0.27 | 0.093 | 0.04 |
| PP | 0.726 | -0.092 | -0.232 | 0.195 | -0.073 | 0.168 | -0.301 | 0.139 |
| POP | 0.111 | 0.159 | -0.189 | 0.718 | -0.095 | -0.143 | 0.355 | -0.233 |
| PSN | 0.428 | 0.169 | 0.475 | 0.194 | -0.078 | 0.124 | 0.173 | -0.298 |
| PPS | -0.042 | 0.336 | -0.042 | -0.068 | -0.227 | -0.311 | -0.443 | 0.223 |
| SPDP | 0.55 | 0.012 | 0.313 | 0.423 | -0.031 | 0.328 | -0.268 | 0.151 |
| PBP | -0.432 | -0.229 | -0.408 | 0.024 | -0.319 | -0.497 | 0.024 | 0.023 |
| PBO | -0.341 | 0.22 | 0.022 | 0.383 | -0.231 | -0.314 | -0.357 | 0.148 |

| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 |
|---|---|---|---|---|---|---|---|---|
| PCS | -0.758 | 0.34 | -0.011 | -0.099 | 0.179 | 0.203 | -0.149 | 0.06 |
| PWF | 0.394 | -0.176 | -0.085 | 0.448 | 0.045 | -0.167 | 0.244 | 0.31 |
| PCPM | 0.304 | 0.132 | -0.437 | 0.033 | 0.18 | 0.552 | 0.289 | 0.118 |

## 4. CONCLUSION

To improve crops, germplasm characterization and evaluation is crucial. DUS characterization is a useful method for identifying and preventing duplication in crop plants. The manuscripts described considerable variation for qualitative traits viz., growth, flowering and fruiting traits in twenty-seven French bean genotypes. The investigation depicted predominance of indeterminate growth habit (66.7%), viny twinning stem (70.4%), non-pigmented stem (74.1%), dark green leaves (51.9%), white colour flowers (55.6%), non-striped standard petal (59.3%) with white colour, large size flower (44.4%), flat pod (66.7%), slightly curved pod shape (51.9%), very stringy pods (37%) with flat pod cross-section (29.6%) proved that there is wide genetic diversity exist in French bean genotypes. Some morphology traits like pod pubescence, pod beak shape and orientation, pod colour at physiological maturity having less importance for agronomic point view though witnessed remarkable variations due to broad genetic base among the genotypes. The detailed study on DUS characterization in French bean is one of major work has been conducted in Odisha for the very first time which generated a strong database and could be helpful for scientific personnel who are intended to contribute the crop breeding programme in future. The genotypes IC 632961 was found to be an elite cultivar having desirable morphological traits and associated traits can be recommended for French bean grower of Odisha.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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