

Morphological description of chickpea (*Cicer arietinum* L) genotypes using DUS characterization

Abstract

The cultivated chickpea (*Cicer arietinum*) holds great importance as a pulse crop in India. The identification and classification of diverse genotypes are crucial for implementing effective strategies to improve this crop. In this study, we conducted a comprehensive morphological characterization of desi chickpea genotypes using the DUS (Distinctness, Uniformity, and Stability) descriptors suggested by the Protection of Plant Varieties and Farmers' Rights Authority, Government of India, in 2018. Our objective was to identify and classify diverse chickpea genotypes based on 17 different qualitative traits observed in a field experiment. Among the 17 DUS traits examined, we found that one trait exhibited a consistent phenotype (monomorphic), six traits displayed two distinct phenotypes (dimorphic), nine traits exhibited three distinct phenotypes (trimorphic), and only one trait showed more than three phenotypic variations (polymorphic) among all the chickpea genotypes studied. This indicates the presence of significant genetic variability within the chickpea germplasm, offering potential for assigning different morphological profiles for varietal identification and characterization. Using Shannon's diversity indices, we estimated a high level of diversity within the chickpea germplasm, particularly for traits such as seed colour, foliage colour, pod size, leaflet size, and seed shape. The characterization of these genotypes enabled the development of distinct profiles for each line, facilitating their identification and evaluation as elite chickpea lines.

Keywords: Chickpea, DUS characterization, Shannon's diversity index

Introduction

Chickpea (*Cicer arietinum* L.) is an important cool season legume crop with a genome size of 738 Mb [1]. It is also known as Gram, Bengal gram, Egyptian pea, Chana, or Kabuli chana. Garbanzo bean is one of the first grain legumes to be domesticated by humans in old world [2]. It also exhibits the ability to enhance soil fertility through symbiotic nitrogen fixation, whereby it converts atmospheric nitrogen into a form usable by plants [3]. This process contributes to the overall improvement of soil health and productivity [4]. It is highly nutritious encompassing of vitamins, minerals, and vital amino acids, including lysine,

Comment [BF1]: Environmental factors causing genetic variability not explained

Comment [BF2]: Farmer's ?

methionine, threonine, valine, and leucine, as well as β -carotene, calcium, phosphorus magnesium, and potassium” [5-10]. It is currently cultivated in more than 50 countries across the globe. India accounts for more than 65% of the global production of desi type chickpea. Therefore, it influences the global yield trends [11]. Currently, 15.004 million hectares of area are used to cultivate chickpea, with a productivity of 1,057.8 kg per hectare and a production of 15.87 mt per year worldwide [11]. As estimated 73.78 % (10.943mha) of the world's total chickpea area and 73.45 % (11.91m tonnes) come from India [12].

Modern plant breeding and agricultural systems have narrowed the base for the genetic diversity of cultivated chickpea and to explore new sources of variation that might be used in plant breeding programmes [13-15]. Genetic diversity is a basic requirement to begin any crop improvement programme [16-23]. Breeders need to include diverse germplasm lines in the breeding programmes to break the yield plateau and attain sustainable gains [24-34]. There is an imperative requirement for the systematic characterization and evaluation of Cicer species to utilize target traits [35]. When analysing genotype performance without being predisposed by environmental influences, qualitative features provide an easy technique to measure genetic variation [36-39]. Morphological characterization studies are carried out by employing morphological markers, which are highly heritable traits [36-39]. They are cheap, simple, does not necessitate the use of sophisticated laboratory techniques and quick to score [36-39].

The evaluation of seed quality typically involves assessing varietal purity, which encompasses both physical and genetic characteristics. A variety or cultivar is a group of cultivated plants that can be clearly distinguished by various traits, such as morphological, physiological, cytological, or chemical features. When a variety is reproduced either sexually or asexually, it retains its distinctive characteristics. In the context of crop varieties, plant morphological traits have long been recognized as essential descriptors for conducting Distinctness, Uniformity, and Stability (DUS) testing and classifying varieties [40]. Therefore, any morphological characteristic that is closely associated with and significantly contributes to increased seed yield would be advantageous for yield improvement. Morphological descriptors are not only valuable for DUS testing and varietal classification nonetheless also for assessing diversity and revealing phylogenetic relationships among different lines. By conducting morphological characterization, breeders can identify recurring parents and gain insights into the genetic diversity of chickpea germplasm lines [8-9]. This information proves valuable for developing improved varieties with a broader genetic base

[41]. Consequently, establishing a comprehensive understanding of the relationships between chickpea genotypes is crucial for effectively planning strategies and crop breeding programs [42].

In the present investigation, we aimed to examine the morphological descriptors of different chickpea genotypes and analyse their consistency over multiple years using various qualitative parameters. By employing these tools, we can assess the stability of morphological traits and their usefulness as indicators of varietal purity and genetic relationships among different chickpea genotypes.

Comment [BF3]: Synchronize with the objectives in the abstract, especially concerning desi chickpea characterization

Materials and Method

The present investigation was conducted during the Rabi 2022 at the Research Farm Department of Genetics & Plant Breeding, College of Agriculture, RVSVV, Gwalior, Madhya Pradesh, India. The experimental material consisted of 78 diverse chickpea genotypes. The evaluation of different genotypes was performed in three replications using a Randomized Complete Block Design (RCBD). Each entry was grown in four row measuring 3.0 m in length in each replication. The inter-row and intra-row spacing were maintained at 30×10 cm, respectively. The recommended agronomical and plant protection practices were implemented to ensure successful crop cultivation.

Comment [BF4]: Use the international language

Data pertaining to 17 different morphological descriptors were recorded on 10 randomly selected plants, following the DUS (Distinctness, Uniformity, and Stability) as guideline provided by the Protection of Plant Varieties and Farmers' Rights Authority, Government of India [43] for chickpea.

Comment [BF5]: Describe the parameters used

To estimate the diversity present within the genotypes, the phenotypic frequencies of these traits were employed, and the Shannon-Weaver Diversity Index was calculated. The index (H) was computed according to the methodology presented by Negassa [44] to assess the current level of diversity using following formulae:

$$H = -\sum [p_i \times \log p_i]$$

Where, p_i is the portion of the total numbers of entries belonging to the i^{th} class.

The clustering of genotypes based on their morphology was done using algorithm UPGMA (Unweighted Paired Group Method using Arithmetic Averages) using NTSYS-pc (numerical taxonomy and multivariate analysis system) 2.02i. [45]

Results and Discussion

The limited genetic diversity in chickpea poses a challenge to crop improvement efforts, necessitating the expansion of the genetic base to fully exploit the genetic potential of these lines. Therefore, the assessment of genetic diversity is a fundamental requirement for developing effective crop improvement strategies in chickpea [46]. Analysing genetic diversity based on qualitative traits represents an important approach for identifying and enhancing crop varieties [36-38]. In this investigation, an attempt was made to group and distinguish chickpea genotypes based on variations present in their morphological and seed-related characteristics. These traits were carefully examined to unravel the genetic diversity within the chickpea genotypes under investigation. Using descriptors, each genotype was identified and characterized. The investigation focused on agro-morphological traits, and it was observed that although some lines shared common qualitative features, they could still be differentiated from one another based on their monomorphic traits. This highlights the presence of distinct genetic variations among the lines, even in cases where only a few characteristics differ. Notably, the genetic base has been narrowed due to selective breeding for yield improvement [47].

Morphological characterization

The 78 genotypes were characterized based on the different morphological traits as described in the DUS guidelines [43] and details are given in Table 1, Fig. 1a and Fig. 1b. Anthocyanin colouration of stem being an important trait observed before flowering of plants was recorded in two categories *i.e.*, presence or absence. Out of the 78 genotypes, 61 showed the presence of anthocyanin pigmentation in the stem, while the remaining 17 genotypes exhibited the absence of anthocyanin coloration. The genotypes were further classified based on the height of the stem at the initiation of the first flower. Three categories were identified: low stem height (<8 nodes at initiation of first flower) with 14 genotypes, medium stem height (8-15 nodes at initiation of first flower) with the highest representation of 60 genotypes, and high stem height (>15 nodes at initiation of first flower) with only four genotypes. Plant growth habit was another distinguishing feature for varietal characterization. Among the 78 genotypes, 25 were classified as erect types, 50 as semi-erect types, and the remaining three as spreading types. Variation in foliage colour intensity was also investigated. Thirteen genotypes exhibiting light green foliage, 36 genotypes medium green foliage, whereas the remaining 29 genotypes having dark green foliage. The size of leaflets also exhibited notable variation. They were categorized into three main groups: small leaflets (≤ 10.0 mm) observed

in 23 lines, medium-sized leaflets (10.0-15.0mm) in 24 lines, whilst large leaflets (>15.0mm) in the 31 genotypes.

The colour of the flower is a prominent visual trait and is commonly utilized as a marker gene in genetic studies and breeding endeavours in chickpea [48] (Kumawat et al., 2020). In this study, the genotypes were examined for flower: colour, revealing three distinct variations. Among the 78 genotypes, 14 genotypes exhibited white flowers, 55 genotypes displayed pink flowers, whilst the remaining nine genotypes showed blue-coloured flowers. Another characteristic evaluated was the presence of stripes on the standard of the petal. Out of the 78 genotypes, 16 genotypes were found to have no stripes, while the remaining 62 genotypes exhibited stripes on the standard of the petal. Additionally, the genotypes were assessed for the number of flowers per peduncle on the standard. Limited variation was observed among the genotypes in terms of the numbers of flowers per peduncle. Only three genotypes displayed twin flowers per peduncle, while the remaining 75 genotypes exhibited a single flower per peduncle. Various other reports are available on the morphological characterization of the chickpea crop [49-58].

The investigation focused on the study of peduncle length during the pod development stage, which led to the classification of experimental genotypes into three groups based on their peduncle characteristics: short, medium, and long. Among the analysed genotypes, 49 exhibited a peduncle length of less than 5mm (short), 20 genotypes had a length ranging from 5-10mm (medium), whilst nine genotypes displayed a peduncle length exceeding 10mm (long). Furthermore, the genotypes were categorized into three groups based on their plant height. Fourteen genotypes were considered as short, with a height of 45cm. Fifty-seven genotypes fell into the medium category, displaying a height range of 45-65cm. Lastly, only seven genotypes were classified as tall, surpassing a height of 65cm. The genotypes were also analysed based on pod size, resulting in three groups. Fourteen genotypes had small-sized pods, measuring less than 15mm. Forty-one genotypes possessed medium-sized pods, ranging from 15-20mm. However, 23 genotypes displayed large-sized pods, exceeding 20mm in size. Another observed parameter was the numbers of seeds per pod. Among the analysed genotypes, 64 genotypes contained one seed per pod, while the remaining 14 genotypes exhibited two seeds per pod. These genotypes with large and extra-large pods may be selected for screening purposes, particularly for exportation and utilization in chickpea hybridization programs. The findings of this study are consistent with previous

research conducted by Upadhyaya et al. [59], Kaul et al. [60], Bayahi et al. [55], Shrivastava et al. [61], Solanki et al. [62], and Gyandev et al. [63].

Seed-related traits were assessed approximately 30 days after harvesting to determine their significance in categorizing chickpea genotypes and their relevance in consumer preference and marketing. Among these traits, seed colour and seed size were identified as key traits for grouping chickpea varieties [62] and were also found to be highly valued by consumers [62]. Based on the variation in seed colour, the genotypes were classified into eight distinct groups: brown (22), dark brown (22), beige (6), black (3), creamy beige (4), green (6), orange (5), and yellow (10). Seed shape displayed three major variations: angular type in 39 genotypes, pea-shaped in 17 genotypes, and Owl's head seed shape in 22 genotypes. The seed testa texture exhibited two main groups, with rough texture found in 12 genotypes while smooth texture in 66 genotypes. Seed ribbing analysis resulted in the categorization of genotypes into two groups, with 43 genotypes displaying ribbing whereas 35 genotypes lacking ribbing. No variations were observed in seed type, as all genotypes belonged to the desi type. Genotype identification based on discernible morphological characteristics were conducted and reported by various researchers [64-73,40,62,48,42]. These studies contributed to the comprehensive understanding of chickpea genotypes and their morphological variations.

Shannon's diversity indices

Diverse parents are the prime requirement of any hybridization programme. Frequency distribution of diversity index was estimated using H' index for 17 qualitative traits (Table 2). The Shannon's diversity indices estimated for 17 morphological traits ranged from 0 to 1.825 with a mean value of 0.743. The H' index of the trait seed colour was observed to be higher (1.825) among all the traits while seed type had minimum value (0.00). These findings align with similar observations reported by previous studies [74-76, 41]. These studies also support the notion that seed colour is a highly diverse trait, while seed type exhibits minimal diversity.

Qualitative cluster analysis

A qualitative cluster analysis was conducted on 78 chickpea genotypes using algorithm UPGMA using NTSYS pc 2.02i, considering 17 qualitative traits (Table 3). The resulting dendrogram, as shown in Fig.2, illustrates the similarities among the genotypes based on the

measured qualitative variables. This dendrogram highlights the effectiveness of the methodology employed in this study for classifying chickpea genotypes.

The dendrogram revealed two distinct clusters, *viz.*, Cluster A and Cluster B. Cluster A comprised 16 genotypes, while Cluster B consisted of 62 genotypes. Within Cluster B, further subdivision occurred into two subgroups denoted as 'b₁' and 'b₂'. Subgroup 'b₁' contained three genotypes, whereas Subgroup 'b₂' encompassed 59 genotypes. Subgroup 'b₁' was then divided into two additional subgroups, one comprising three genotypes and the other comprising 56 genotypes. Furthermore, these 56 genotypes were segregated into two clusters, one consisting of 37 genotypes and the other comprising 19 genotypes. Mishra et al. (2022) [37] constructed dendrogram, obtained from 53 soybean genotypes for five qualitative traits. The dendrogram depicted two distinct clusters. The cluster-I consisting nineteen genotypes further divided into two groups, while in cluster-II remaining 34 genotypes further divided into two subgroups with 9 and 25 genotypes respectively. Basak et al. [77] constructed dendrogram using landraces for 17 qualitative traits of 81 tomato landraces. The dendrogram revealed the formation of distinct clusters representing different groups of landraces. Likewise, Kumar et al. [78] studied on 50 barley genotypes using 18 qualitative traits and constructed a dendrogram.

Conclusion

Enhancing seed production and improving yield in crops such as chickpea (*Cicer arietinum*) is crucial for meeting global food demands. Morphological characteristics that are associated with increased seed production can be effectively utilized in breeding programmes to achieve these goals. Systematic characterization of germplasm enables more efficient utilization of the genetic material, offering advantages over traditional selection methods. Studies have revealed a substantial amount of diversity present in chickpea germplasm lines, particularly in traits such as seed colour, foliage colour, pod size, leaflet size, and seed shape. These traits play an important role in determining market and consumer preferences, making them desirable targets for improvement. The presence of diverse morphological characteristics in chickpea germplasm offers a wide range of options for plant breeders to select and develop improved varieties. By conducting a thorough investigation, researchers can establish a distinct morphological profile of different chickpea lines. This profile served as a valuable resource for identification, characterization, and evaluation of elite chickpea genotypes. Plant breeders can utilize this information to make informed decisions while selecting suitable genotypes for field trials and seed production.

Comment [BF7]: The conclusion is too long and general and does not focus on the research results.

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UNDER PEER REVIEW

Table 1 List of morphological traits with descriptors

| S. No. | Descriptors | States | Stage of observation |
|--------|---|---|----------------------------|
| 1 | Stem Anthocyanin pigmentation | Absent, Present | Before flowering |
| 2 | Stem height at initiation of first flower | Low (<8 nodes), medium (8-15 nodes) and high (>15 nodes) | 50 % flowering |
| 3 | Plant: Growth habit | Semi erect (20-40° from vertical), semi spreading (40-60° from vertical) and spreading (60-80° from vertical) | 50 % flowering |
| 4 | Plant: Colour of foliage | Light green, medium green and dark green | 50 % flowering |
| 5 | Leaflet size (mm) | Small (<10mm), medium (10-15mm) and large (>15mm) | 50 % flowering |
| 6 | Flower: Number per peduncle | Single and twin | 50 % flowering |
| 7 | Flower: colour | White, pink and blue | 50 % flowering |
| 8 | Flower: stripes | Absent and present | 50 % flowering |
| 9 | Peduncle length (mm) | Short (<5mm), medium (5-10mm) and long (>10mm) | Pod development |
| 10 | Plant: height | Short (<45 cm), medium (45-65 cm) and tall (>65 cm) | Fully developed green pods |
| 11 | Pod: Length | Small (< 15 mm), medium (15-20 mm) and large (>20 mm) | Harvest maturity |
| 12 | Number of seeds per pod | One and more than one | Harvest maturity |
| 13 | Seed colour | Beige, Creamy beige, Green, Yellow, Orange, Brown, Dark brown, Grey, Black | 30 days after harvest |
| 14 | Seed shape | Pea shaped, owl's head and angular | 30 days after harvest |
| 15 | Seed testa texture | Smooth, rough and tuberculated | 30 days after harvest |
| 16 | Seed ribbing | Absent and present | 30 days after harvest |
| 17 | Seed type | Desi and kabuli | 30 days after harvest |

Table 2 Frequency distribution and Shannon-weaver diversity index for various morphological traits of chickpea genotypes

| S. No. | Descriptors | Score | Genotype frequency | Percentage contribution (%) | Shannon's diversity index |
|--------|--|-------|--------------------|-----------------------------|---------------------------|
| 1 | Stem Anthocyanin pigmentation | | | | 0.52 |
| | Absent | 1 | 17 | 21.79 | |
| | Present | 9 | 61 | 78.20 | |
| 2 | Stem Height at initiation of first flower | | | | 0.662 |
| | Low (<8 nodes) | 3 | 14 | 17.94 | |
| | Medium (8-15 nodes) | 5 | 60 | 76.92 | |
| | High (>15 nodes) | 7 | 4 | 5.12 | |
| 3 | Plant: Growth habit | | | | 0.775 |
| | Erect (20-40° vertical) | 3 | 25 | 32.05 | |
| | Semi spreading (40-60° vertical) | 5 | 50 | 64.10 | |
| | Spreading (60-80° vertical) | 7 | 3 | 3.84 | |
| 4 | Plant: Colour of foliage | | | | 1.023 |
| | Light green | 1 | 13 | 16.66 | |
| | Medium green | 2 | 36 | 46.15 | |
| | Dark green | 3 | 29 | 37.17 | |
| | Greenish purple | 4 | 0 | 0 | |
| 5 | Leaflet size (mm) | | | | 1.089 |
| | Small (<10mm) | 3 | 23 | 29.48 | |
| | Medium (10-15mm) | 5 | 24 | 30.76 | |
| | Large (>15mm) | 7 | 31 | 39.74 | |
| 6 | Flower: Number per peduncle | | | | 0.163 |
| | Single | 1 | 75 | 96.15 | |
| | Twin | 3 | 3 | 3.84 | |
| 7 | Flower: colour | | | | 0.803 |
| | White | 1 | 14 | 17.94 | |
| | Pink | 2 | 55 | 70.51 | |
| | Blue | 3 | 9 | 11.53 | |
| 8 | Flower: stripes | | | | 0.507 |
| | Absent | 1 | 16 | 20.51 | |
| | Present | 9 | 62 | 79.48 | |
| 9 | Peduncle length (mm) | | | | 0.890 |
| | Short (<5mm) | 3 | 49 | 62.82 | |
| | Medium (5-10mm) | 5 | 20 | 25.64 | |
| | Long (>10mm) | 7 | 9 | 11.53 | |
| 10 | Plant: Height | | | | 0.753 |
| | Short (<45 cm) | 3 | 14 | 17.94 | |
| | Medium (45-65 cm) | 5 | 57 | 73.07 | |
| | Tall (>65 cm) | 7 | 7 | 8.97 | |
| 11 | Pod: size (Length) | | | | 1.006 |
| | Small (<15mm) | 3 | 14 | 17.94 | |
| | Medium (15-20mm) | 5 | 41 | 52.56 | |
| | Large (>20mm) | 7 | 23 | 29.48 | |
| 12 | Number of seeds per pod | | | | 0.470 |

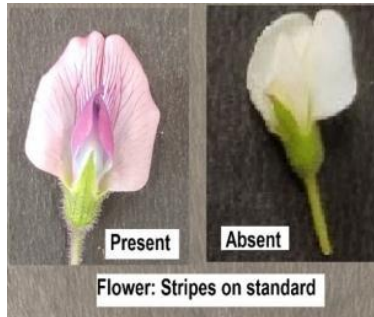
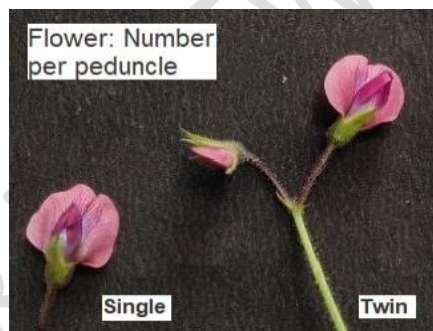
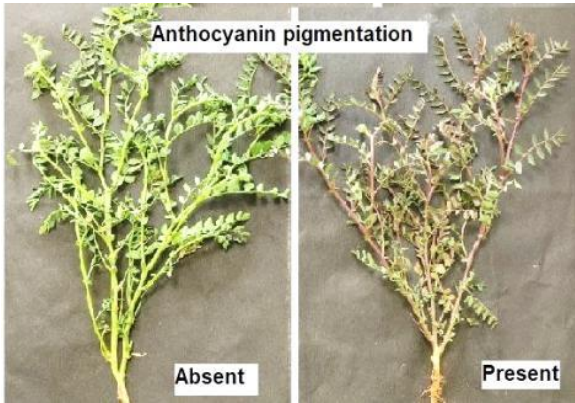
| | | | | | |
|-----------|----------------------------|---|----|-------|-------|
| | One | 1 | 64 | 82.05 | |
| | More than one | 3 | 14 | 17.94 | |
| 13 | Seed colour | | | | 1.825 |
| | Beige | 1 | 6 | 7.69 | |
| | Creamy beige | 2 | 4 | 5.12 | |
| | Green | 3 | 6 | 7.69 | |
| | Yellow | 4 | 10 | 12.82 | |
| | Orange | 5 | 5 | 6.41 | |
| | Brown | 6 | 22 | 28.20 | |
| | Dark brown | 7 | 22 | 28.20 | |
| | Grey | 8 | 0 | 0 | |
| | Black | 9 | 3 | 3.84 | |
| 14 | Seed: shape | | | | 1.035 |
| | Pea shaped | 1 | 17 | 21.79 | |
| | Owl's head | 2 | 22 | 28.20 | |
| | Angular | 3 | 39 | 50 | |
| 15 | Seed: Testa texture | | | | 0.429 |
| | Rough | 1 | 12 | 15.38 | |
| | Smooth | 2 | 66 | 84.61 | |
| | Tuberculated | 3 | 0 | 0 | |
| 16 | Seed: Ribbing | | | | 0.687 |
| | Absent | 1 | 43 | 55.12 | |
| | Present | 9 | 35 | 44.87 | |
| 17 | Seed: Type | | | | 0.000 |
| | Desi | 1 | 78 | 100 | |
| | Kabuli | 3 | 0 | 0 | |

Table 3 Agro-morphological characterization of desi chickpea based on DUS descriptors

| S.No. | Genotypes | Anthocyanin Pigment | Stem Height | Growth habit | colour of foliage | Leaflet size | number per peduncle | Flower colour | Flower: stripes | peduncle length | Plant: height | Pod size | Number of seeds per pod | Seed colour | Seed shape | Seed testa texture | Seed ribbing | Seed type |
|-------|-------------|---------------------|-------------|--------------|-------------------|--------------|---------------------|---------------|-----------------|-----------------|---------------|----------|-------------------------|-------------|------------|--------------------|--------------|-----------|
| 1 | ICCV-201111 | 9 | 7 | 3 | 2 | 5 | 1 | 2 | 9 | 5 | 7 | 7 | 1 | 7 | 2 | 2 | 9 | 1 |
| 2 | JG-36 | 9 | 5 | 5 | 1 | 5 | 1 | 2 | 9 | 3 | 5 | 3 | 1 | 4 | 2 | 2 | 9 | 1 |
| 3 | GCP-101 | 9 | 5 | 5 | 3 | 3 | 1 | 2 | 1 | 3 | 5 | 3 | 3 | 4 | 2 | 2 | 9 | 1 |
| 4 | ICCV-201105 | 9 | 5 | 5 | 3 | 7 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 7 | 2 | 2 | 9 | 1 |
| 5 | ICCV-201209 | 9 | 3 | 3 | 2 | 3 | 1 | 3 | 9 | 5 | 3 | 3 | 1 | 6 | 2 | 2 | 9 | 1 |
| 6 | ICCV-201113 | 9 | 3 | 5 | 2 | 7 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 4 | 2 | 2 | 9 | 1 |
| 7 | ICCV-201118 | 9 | 5 | 3 | 2 | 7 | 1 | 2 | 9 | 5 | 5 | 5 | 1 | 4 | 2 | 2 | 9 | 1 |
| 8 | ICCV-201212 | 1 | 5 | 7 | 1 | 7 | 1 | 2 | 9 | 3 | 7 | 5 | 3 | 6 | 2 | 2 | 9 | 1 |
| 9 | ICCV-201217 | 9 | 7 | 3 | 1 | 5 | 1 | 3 | 1 | 5 | 7 | 5 | 1 | 4 | 3 | 1 | 9 | 1 |
| 10 | ICCV-201102 | 1 | 7 | 5 | 3 | 7 | 1 | 2 | 9 | 7 | 7 | 5 | 1 | 7 | 3 | 2 | 9 | 1 |
| 11 | ICCV-201218 | 9 | 5 | 3 | 3 | 3 | 1 | 1 | 9 | 3 | 5 | 3 | 1 | 6 | 2 | 2 | 9 | 1 |
| 12 | ICCV-201108 | 9 | 5 | 3 | 1 | 5 | 1 | 3 | 9 | 5 | 5 | 5 | 1 | 6 | 3 | 1 | 9 | 1 |
| 13 | CHAFFA | 1 | 3 | 3 | 1 | 3 | 1 | 2 | 1 | 7 | 5 | 3 | 1 | 6 | 3 | 2 | 9 | 1 |
| 14 | JG-24 | 9 | 5 | 3 | 3 | 7 | 1 | 2 | 9 | 3 | 5 | 3 | 1 | 6 | 3 | 1 | 9 | 1 |
| 15 | ICCV-201114 | 9 | 5 | 3 | 3 | 5 | 1 | 3 | 9 | 5 | 5 | 3 | 1 | 7 | 3 | 2 | 9 | 1 |
| 16 | ICCV-201107 | 9 | 5 | 5 | 3 | 3 | 1 | 3 | 9 | 7 | 5 | 3 | 1 | 6 | 3 | 2 | 1 | 1 |
| 17 | SAGL 22-101 | 9 | 5 | 5 | 3 | 5 | 1 | 2 | 9 | 5 | 5 | 5 | 1 | 6 | 1 | 2 | 1 | 1 |
| 18 | SAGL 22-102 | 9 | 5 | 5 | 3 | 7 | 1 | 2 | 9 | 7 | 5 | 5 | 1 | 7 | 3 | 2 | 9 | 1 |
| 19 | SAGL 22-103 | 9 | 5 | 5 | 2 | 7 | 1 | 2 | 9 | 3 | 3 | 5 | 1 | 5 | 1 | 2 | 1 | 1 |
| 20 | SAGL 22-104 | 9 | 5 | 5 | 2 | 5 | 1 | 2 | 9 | 7 | 5 | 5 | 1 | 7 | 1 | 1 | 1 | 1 |
| 21 | SAGL 22-105 | 1 | 3 | 5 | 2 | 5 | 1 | 1 | 1 | 5 | 3 | 5 | 3 | 5 | 1 | 2 | 1 | 1 |
| 22 | SAGL 22-106 | 9 | 5 | 3 | 2 | 7 | 1 | 2 | 9 | 5 | 5 | 3 | 1 | 7 | 3 | 2 | 1 | 1 |
| 23 | SAGL 22-107 | 9 | 5 | 5 | 3 | 7 | 1 | 2 | 9 | 3 | 5 | 3 | 1 | 4 | 3 | 2 | 1 | 1 |
| 24 | SAGL 22-108 | 9 | 5 | 5 | 3 | 5 | 3 | 2 | 9 | 7 | 5 | 7 | 1 | 7 | 1 | 2 | 1 | 1 |

| S.No. | Genotypes | Anthocyanin Pigment | Stem Height | Growth habit | colour of foliage | Leaflet size | number per peduncle | Flower colour | Flower: stripes | peduncle length | Plant: height | Pod size | Number of seeds per pod | Seed colour | Seed shape | Seed testa texture | Seed ribbing | Seed type |
|-------|--------------|---------------------|-------------|--------------|-------------------|--------------|---------------------|---------------|-----------------|-----------------|---------------|----------|-------------------------|-------------|------------|--------------------|--------------|-----------|
| 25 | SAGL 22-109 | 9 | 5 | 3 | 1 | 7 | 3 | 2 | 9 | 5 | 5 | 5 | 1 | 6 | 3 | 2 | 9 | 1 |
| 26 | SAGL 22-111 | 9 | 5 | 3 | 2 | 3 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 7 | 3 | 2 | 9 | 1 |
| 27 | SAGL 22-112 | 9 | 5 | 5 | 2 | 7 | 1 | 3 | 9 | 3 | 5 | 5 | 1 | 4 | 3 | 2 | 9 | 1 |
| 28 | SAGL 22-113 | 9 | 5 | 3 | 2 | 7 | 1 | 2 | 9 | 3 | 5 | 7 | 1 | 6 | 1 | 2 | 1 | 1 |
| 29 | SAGL 22-114 | 9 | 5 | 5 | 2 | 7 | 3 | 2 | 9 | 7 | 5 | 7 | 1 | 6 | 3 | 2 | 9 | 1 |
| 30 | SAGL 22 -115 | 9 | 3 | 3 | 2 | 5 | 1 | 2 | 9 | 3 | 3 | 7 | 1 | 4 | 3 | 2 | 9 | 1 |
| 31 | SAGL-152403 | 9 | 3 | 5 | 2 | 5 | 1 | 2 | 9 | 3 | 3 | 5 | 1 | 7 | 3 | 2 | 9 | 1 |
| 32 | SAGL-152254 | 9 | 5 | 3 | 3 | 7 | 1 | 2 | 1 | 3 | 5 | 5 | 3 | 1 | 2 | 2 | 1 | 1 |
| 33 | SAGL-162370 | 9 | 5 | 5 | 2 | 7 | 1 | 1 | 9 | 7 | 5 | 5 | 1 | 1 | 2 | 2 | 1 | 1 |
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| 40 | SAGL-162376 | 1 | 5 | 5 | 3 | 7 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 6 | 2 | 2 | 1 | 1 |
| 41 | SAGL-152314 | 9 | 5 | 5 | 3 | 7 | 1 | 2 | 9 | 5 | 5 | 7 | 1 | 7 | 2 | 2 | 1 | 1 |
| 42 | SAGL-162375 | 9 | 5 | 5 | 2 | 5 | 1 | 2 | 1 | 3 | 5 | 5 | 1 | 6 | 1 | 2 | 1 | 1 |
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| 44 | SAGL-152242 | 1 | 5 | 5 | 1 | 5 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 1 | 1 | 2 | 1 | 1 |
| 45 | SAGL-152238 | 9 | 5 | 5 | 1 | 7 | 1 | 2 | 9 | 5 | 5 | 7 | 1 | 7 | 1 | 2 | 1 | 1 |
| 46 | SAGL-162390 | 9 | 5 | 5 | 3 | 5 | 1 | 2 | 9 | 5 | 5 | 5 | 1 | 7 | 2 | 1 | 9 | 1 |
| 47 | RVSSG-69 | 9 | 7 | 3 | 3 | 5 | 1 | 2 | 9 | 3 | 7 | 5 | 3 | 7 | 3 | 2 | 9 | 1 |
| 48 | SAGL-152256 | 9 | 5 | 5 | 2 | 5 | 1 | 2 | 9 | 5 | 5 | 5 | 1 | 5 | 3 | 1 | 9 | 1 |
| 49 | SAGL-152208 | 9 | 5 | 3 | 3 | 3 | 1 | 2 | 9 | 5 | 5 | 5 | 1 | 3 | 1 | 2 | 1 | 1 |
| 50 | SAGL-152303 | 1 | 5 | 5 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 1 | 1 | 2 | 1 | 1 |

| S.No. | Genotypes | Anthocyanin Pigment | Stem Height | Growth habit | colour of foliage | Leaflet size | number per peduncle | Flower colour | Flower: stripes | peduncle length | Plant: height | Pod size | Number of seeds per pod | Seed colour | Seed shape | Seed testa texture | Seed ribbing | Seed type |
|-------|-------------|---------------------|-------------|--------------|-------------------|--------------|---------------------|---------------|-----------------|-----------------|---------------|----------|-------------------------|-------------|------------|--------------------|--------------|-----------|
| 51 | SAGL-152404 | 9 | 3 | 5 | 3 | 3 | 1 | 2 | 9 | 3 | 3 | 7 | 3 | 7 | 3 | 1 | 9 | 1 |
| 52 | SAGL-152236 | 1 | 3 | 5 | 1 | 5 | 1 | 1 | 1 | 3 | 3 | 5 | 1 | 2 | 1 | 2 | 1 | 1 |
| 53 | SAGL-152252 | 1 | 3 | 5 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 5 | 1 | 1 | 2 | 2 | 1 | 1 |
| 54 | SAGL-152349 | 9 | 5 | 5 | 3 | 5 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 6 | 3 | 1 | 9 | 1 |
| 55 | SAGL-152347 | 9 | 3 | 5 | 2 | 7 | 1 | 3 | 9 | 3 | 3 | 7 | 1 | 7 | 2 | 2 | 9 | 1 |
| 56 | SAGL-162371 | 1 | 5 | 5 | 2 | 5 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 2 | 1 | 2 | 1 | 1 |
| 57 | SAGL-152342 | 1 | 5 | 5 | 2 | 7 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 2 | 1 | 2 | 1 | 1 |
| 58 | SAGL-152334 | 9 | 5 | 5 | 3 | 7 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 5 | 1 | 2 | 1 | 1 |
| 59 | RVSSG-75 | 9 | 3 | 5 | 2 | 5 | 1 | 2 | 9 | 3 | 3 | 7 | 1 | 6 | 3 | 1 | 9 | 1 |
| 60 | JG-14 | 9 | 5 | 5 | 2 | 5 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 7 | 3 | 2 | 9 | 1 |
| 61 | JG-11 | 9 | 5 | 5 | 3 | 3 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 4 | 3 | 2 | 9 | 1 |
| 62 | NG-47 | 9 | 5 | 3 | 3 | 5 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 6 | 3 | 2 | 9 | 1 |
| 63 | JGG-1 | 1 | 3 | 7 | 2 | 3 | 1 | 1 | 9 | 5 | 3 | 5 | 1 | 5 | 3 | 1 | 1 | 1 |
| 64 | RVG-205 | 1 | 3 | 3 | 3 | 7 | 1 | 2 | 9 | 3 | 3 | 5 | 1 | 3 | 3 | 2 | 9 | 1 |
| 65 | RVG-201 | 9 | 5 | 3 | 3 | 5 | 1 | 2 | 9 | 3 | 5 | 5 | 3 | 7 | 2 | 2 | 1 | 1 |
| 66 | VISHAL | 9 | 3 | 5 | 3 | 7 | 1 | 3 | 9 | 3 | 3 | 5 | 1 | 7 | 3 | 2 | 9 | 1 |
| 67 | JG-63 | 9 | 3 | 5 | 3 | 3 | 1 | 2 | 9 | 3 | 3 | 5 | 3 | 6 | 3 | 2 | 1 | 1 |
| 68 | RVSSG-85 | 9 | 5 | 5 | 3 | 3 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 6 | 3 | 2 | 9 | 1 |
| 69 | RVG-210 | 1 | 5 | 3 | 2 | 5 | 1 | 1 | 1 | 3 | 5 | 7 | 1 | 2 | 1 | 2 | 1 | 1 |
| 70 | SAGL-161032 | 1 | 5 | 5 | 2 | 7 | 1 | 1 | 1 | 5 | 5 | 7 | 1 | 3 | 1 | 2 | 1 | 1 |
| 71 | SAGL-163603 | 9 | 5 | 5 | 2 | 7 | 1 | 2 | 9 | 7 | 5 | 7 | 1 | 9 | 3 | 2 | 1 | 1 |
| 72 | SAGL-161008 | 9 | 5 | 3 | 2 | 7 | 1 | 2 | 9 | 5 | 5 | 7 | 1 | 9 | 2 | 2 | 1 | 1 |
| 73 | SAGL-162008 | 9 | 5 | 3 | 2 | 3 | 1 | 2 | 9 | 3 | 5 | 5 | 3 | 9 | 3 | 2 | 9 | 1 |
| 74 | SAGL-161001 | 9 | 5 | 5 | 3 | 7 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 3 | 3 | 2 | 1 | 1 |
| 75 | RVSSG-68 | 9 | 5 | 5 | 2 | 3 | 1 | 2 | 9 | 3 | 5 | 3 | 3 | 3 | 3 | 2 | 9 | 1 |
| 76 | JG-315 | 9 | 5 | 5 | 2 | 3 | 1 | 2 | 9 | 3 | 5 | 5 | 1 | 6 | 3 | 1 | 9 | 1 |
| 77 | JG-74 | 9 | 5 | 5 | 2 | 3 | 1 | 2 | 9 | 3 | 5 | 3 | 3 | 4 | 3 | 1 | 9 | 1 |
| 78 | ICC-4958 | 9 | 5 | 5 | 3 | 3 | 1 | 2 | 9 | 3 | 5 | 5 | 3 | 6 | 3 | 2 | 1 | 1 |



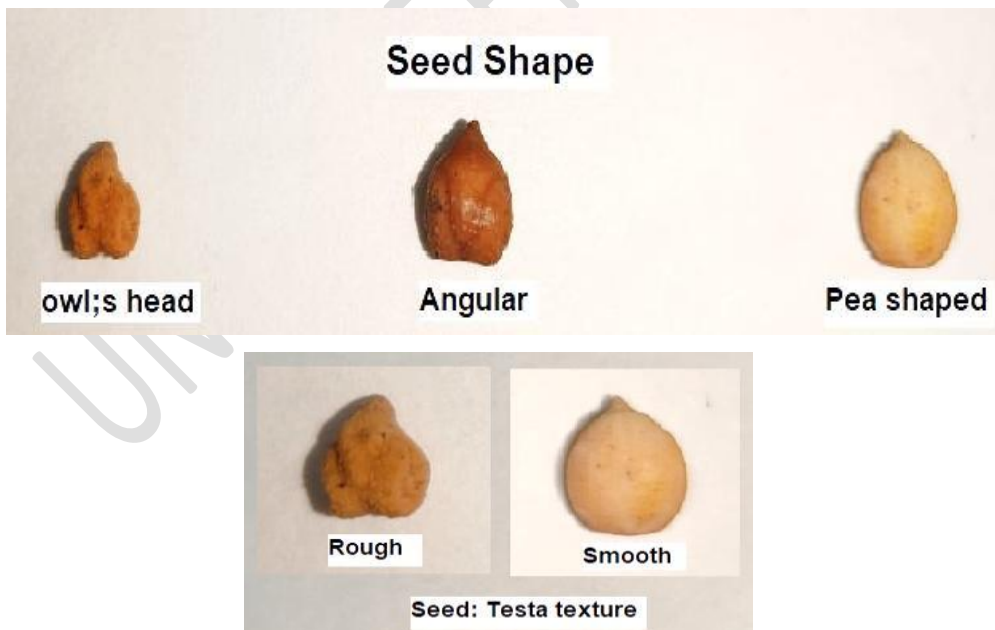
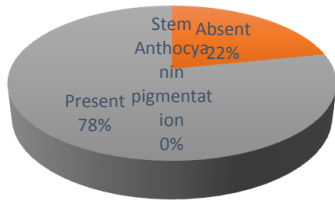


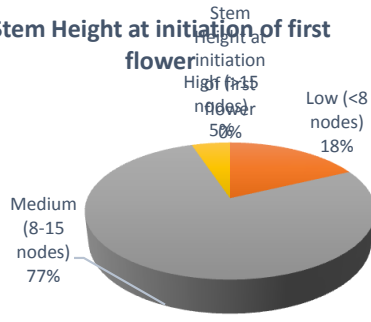
Fig. 1a Pictorial representation of agro-morphological traits in chickpea

Stem Anthocyanin pigmentation



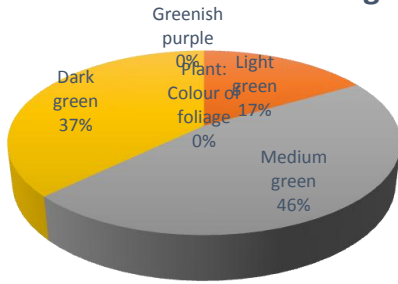
- Stem Anthocyanin pigmentation
- Absent
- Present

Stem Height at initiation of first flower



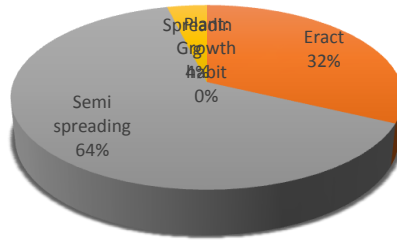
- Stem Height at initiation of first flower
- Low (<8 nodes)
- Medium (8-15 nodes)
- High (>15 nodes)

Plant: Colour of foliage



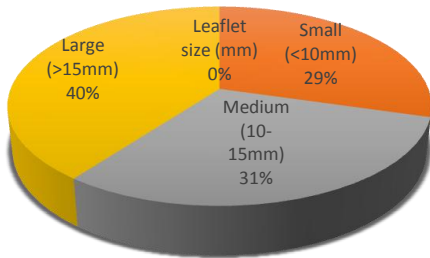
- Plant: Colour of foliage
- Light green
- Medium green
- Dark green
- Greenish purple

Plant: Growth habit



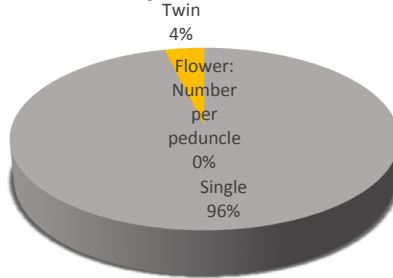
- Plant: Growth habit
- Erect
- Semi spreading
- Spreading

Leaflet size (mm)

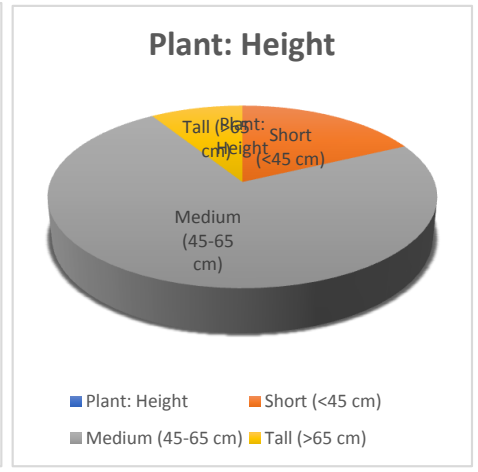
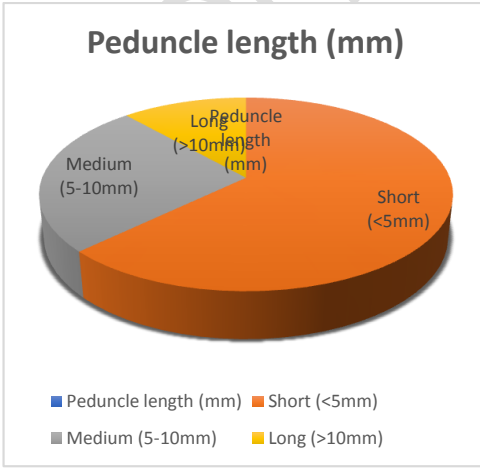
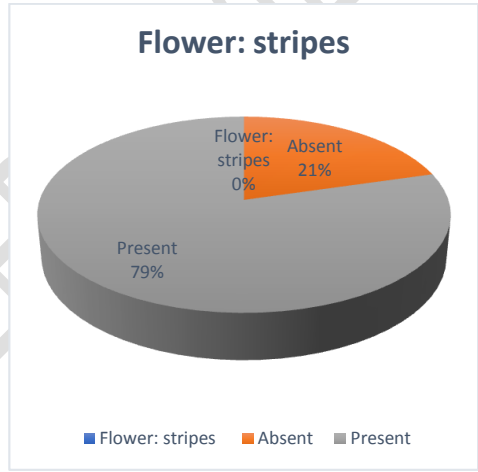
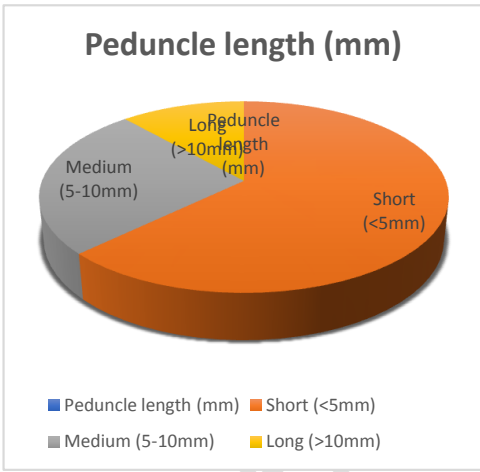
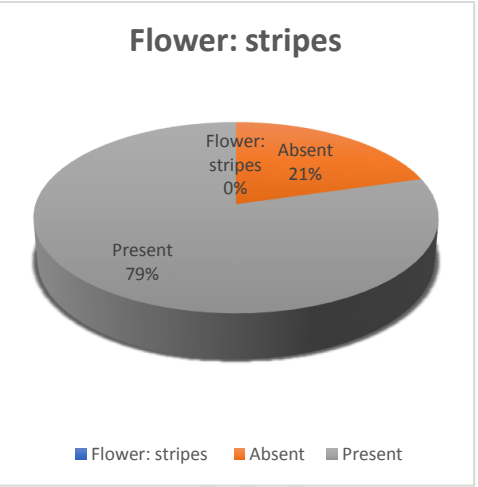
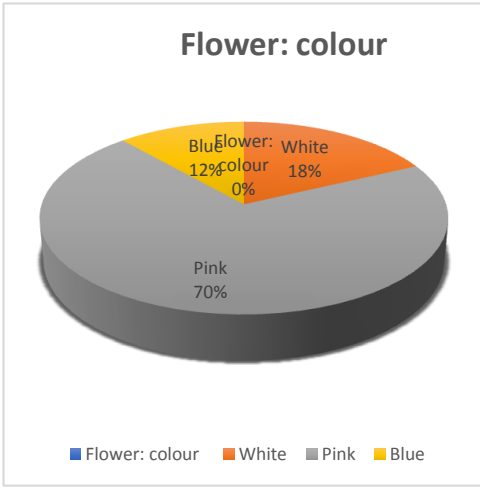


- Leaflet size (mm)
- Small (<10mm)
- Medium (10-15mm)
- Large (>15mm)

Flower: Number per peduncle



- Flower: Number per peduncle
- Single
- Twin



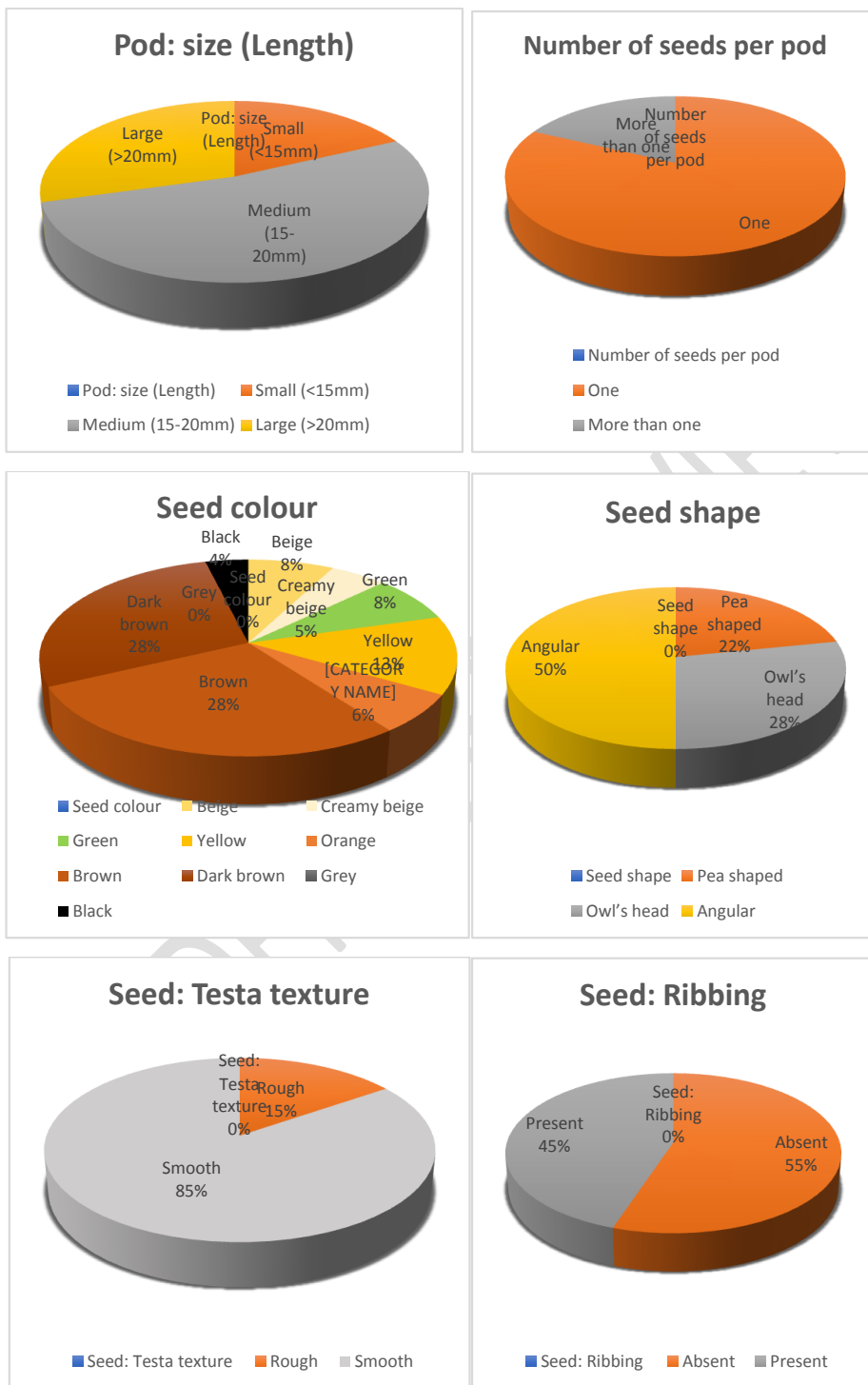


Fig. 1b Diagrammatic representation of different agro-morphological traits in chickpea

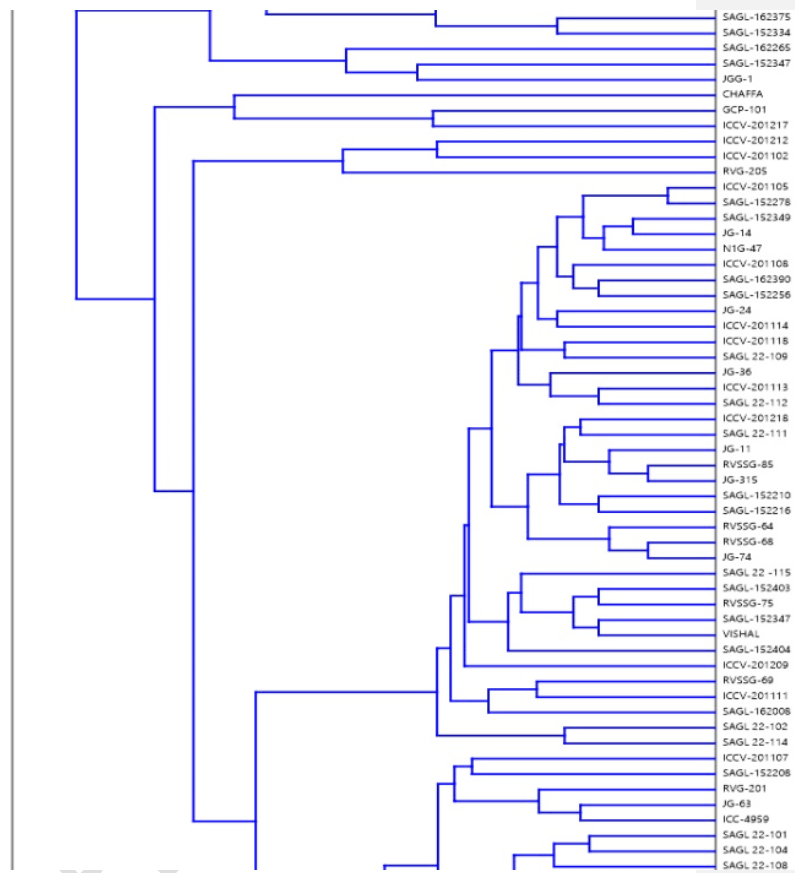


Fig. 2 UPGMA dendrogram based on morphological variability in qualitative traits of 78 Chickpea genotypes

UNDER