Tropical Agricultural Research & Extension 27 (4): 2024

RESEARCH ARTICLE

EVALUATION OF MORPHOLOGICAL VARIATIONS IN FIFTEEN TRADITIONAL YARD LONG BEAN (*Vigna unguiculata* L.) ACCESSIONS IN SRI LANKA UNDER ORGANIC CONDITIONS

MBF Zamha[1], HAPA Shyamalee[2], AL Ranawake[1*]

[1]Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Sri Lanka

[2]Agriculture Research Station, Thelijjawila, Sri Lanka

Received: 03 September 2024, Accepted: 30November 2024, Published: 31 December 2024

ABSTRACT

The yard long bean, belonging to the family Fabaceae, holds significant popularity as a vegetable crop in Sri Lanka. Several indigenous yard long bean accessions are available in Sri Lanka, and assessing their morphological variability plays a vital role in utilizing the germplasm effectively for future breeding programs. The study focused on characterizing fifteen traditional yard long bean accessions gathered from various locations in Sri Lanka using four qualitative and nine quantitative traits. The study was conducted without using inorganic fertilizer and chemical pesticides. The morphological variation among the accessions was effectively assessed using Principal component analysis (PCA), cluster analysis, 2D scatter plot, and hierarchical dendrogram. Three principal components derived from the nine traits and scored more than one Eigenvalues cumulatively explained 79.31% of the total variance. Pod weight, pod diameter, and pod length contributed to principal component one (PC1), which explained 38.68% of the variance. Cluster analysis identified five morphologically distinct clusters at cluster distance of five. Cluster II comprised the accessions *TJ-Rathu* and *TJ-150* that had the highest mean number of pods per plant, and pod yield (7.84 g and 283.37 g, respectively) at the first three consecutive harvests. *TJ-150* recorded the highest pod yield per plant (289.8 g). Pearson's correlation analysis indicated that the number of pods per plant, correlated with the pod yield at 0.05 significance level. The qualitative and quantitative characteristics are expected to be valuable for future breeding programs, facilitating the improvement of yard long beans.

Keywords: Diversity, Morphological traits, Yard long bean accessions, Yield attributes

INTRODUCTION

The yard long *Vigna unguiculata* is an essential leguminous vegetable crop that belongs to the family Fabaceae. *Vigna unguiculata* species include four cultivars: Unguiculata, Biflora, Sesquipedalis, and Textiles (Padulosi and Ng, 1997). The yard-long bean originates from the Mid-west of Africa and Southern China (Quan, 1996; Bounnhong, 1997). It is also domesticated as a minor garden crop in many subtropical countries of Africa and America (Kumar, 2013). Yard long bean is extensively grown in South and Southeast Asian countries such as Malaysia, Thailand, Philipines, Indonesia, Bangladesh, Sri Lanka and South China (Benchasri *et al.* 2012; Rambabu *et al.* 2016). Thailand is one of the major producers of yard long beans (Nooprom and Santipracha, 2015) and yard long beans are also available in Europe, Oceania and South America (Jayasinghe *et al*. 2015).

Yard long is a low-calorie vegetable rich in protein (23.52% - 26.27%) and rich with vitamins and minerals such as iron, zinc, magnesium, manganese and fibre (Ano and Ubochi, 2008). Yard long bean's fibre content eases the digestive process and provides a feeling of consumption satisfaction (Rubatzky and Yamaguchi, 1997).

Corresponding author: lankaranawake@hotmail.com

The yard long is also a good quality animal feed and is generally planted to reduce soil erosion as cover crops (Singh *et al.* 1997; Srinivasan *et al.* 2012; Kumar, 2013). Yard long beans can be intercropped with sorghum and millet meanwhile can be involved in crop rotation (Sarutayophat 2008).

Adaptability of yard long beans

In nature, two types of yard long beans can be found: bush-type and vine-type. Among these, the vine-type yard long bean is the most prominent variety (Rambabu *et al.* 2016). Unlike the bush-type, which has a semierect growth pattern (Singh *et al.* 1997) and the vine-type yard long bean exhibits indeterminate growth (Coker *et al.* 2007). The indeterminate growth characteristic of the vine-type yard long bean allows it to have prolonged reproductive periods. This implies that even while harvesting is underway, new inflorescences could emerge, thereby guaranteeing a consistent and uninterrupted supply of fresh produce. (Sarutayophat, 2008). Yard long bean flowers have well-structured ensuring seed setting; The flower of the yard long bean is cleistogamous (Ullah *et al.* 2011) and opens in the early day and closes about mid-day after blooming (Phansak *et al*. 2005) providing a long time for pollination. Flowers result in droopy pods that hang in pairs. The pod yield of yard long bean is intricate, highly variable, and linked with several characters of the plant (Ullah *et al.* 2011). Pods can be harvested 55 – 60 days after sowing. A single pod consists of 8-12 mm long 20-25 seeds and seed colour has a broad variation (Rambabu *et al.* 2016).

Yard long bean is a crop that can withstand high temperatures and is not dependent on the length of daylight, making it well-suited for thriving in warm climates (Toppo and Sahu, 2020). Yard long bean desires full sunshine for their growth and development (Iannotti, 2021). It can bear extreme humidity and heat (Kamala *et al.* 2014). Extreme dry makes the pods hard (Toppo and Sahu, 2020). However, flowers and young pods are sensitive to unfavourable environmental conditions (Bounnhong, 1997). Yard long beans can be grown in a range of soils, from sandy loam to clay (Bounnhong, 1997) and the most reasonable ground is sandy loam, with a pH range of 5.6 – 7. Soil with excess nitrogen will result in many vegetative structures in the plant, such as more leaves than pods (Iannotti, 2021). The present study was also conducted without applying chemical fertilizer or pesticide during the economic crisis period in Sri Lanka.

Yard long bean is a popular crop grown in Sri Lanka and is widely known by the name “Mae”. It can be grown in *Yala, Maha* seasons and off seasons. The period between August and November is considered the off-season (Jayasinghe *et al*. 2015), where fields are left abandoned without yard long bean cultivation. There are possibilities for the improvement of new varieties suitable for different growing seasons in Sri Lanka (Nijamdeen *et al*. 2017).

Genetic Diversity of Yard long Bean

Genetic diversity is a crucial aspect of biodiversity and diversity within the species, between species and the ecosystem (Govindaraj *et al*. 2015). It paves the way for plant breeders in the selection process (Nkongolo, 2003). Knowing genetic diversity is essential for breeders to develop approaches for efficient germplasm management, utilization and parental selection (Bucheyeki *et al.* 2009).

There are several varieties of yard long beans available for cultivation with varying characteristics in Sri Lanka. *Hawari-Mae* is a vine-type variety with long, light green pods and black-colored seeds, ready for harvesting within 50-70 days after sowing. *Sena*, on the other hand, is a bush-type variant with fleshy green pods and cream-colored seeds with reddish brown hilum, suitable for harvesting in 45-50 days. Similarly, *Polon-Mae* is a vine-type with dark green pods and cream-colored seeds, while *Bushita* is a local bush-type option with medium-sized, light green pods and cream-colored seeds with brown hilum, both of which can be harvested in 60-70 days and 45-50 days after sowing, respectively. *BS1* is another bush-type variety, featuring light green pods with cream-colored seeds having brown patches, and it can be harvested 45-50 days after sowing. *Panadura Polon*, a bush-type variant with medium-sized pods having green color and purple patches, along with cream-colored seeds with black hilum, is also ready for harvesting in 45-50 days (Department of Agriculture, 2022). Modern crop varieties have been developed for well-furnished production conditions. Indigenous accessions or landraces of crops available within the genetic pool have higher adaptability for low-input agriculture in the marginal climate with varying stress conditions where their cultivation may contribute flexibly to the production shock. Therefore, it is essential to explore the genetic diversity available within the accessions of yard long beans. Genetic diversity within these accessions can be analysed from phenotypic variation using quantitative or qualitative traits in the individuals collected from similar species (Govindaraj *et al*. 2015). According to Huque *et al.* (2012), yard long bean genotypes showed maximum genetic diversity for traits like the number of pods per plant, the number of pods per peduncle, days to first flowering, and vegetable pod yield per plant.

Morphological Characterization of Yard long Bean

A morphological characterization is a tool for evaluating genetic diversity between and within plant populations. It is performed based on visible traits such as flower colour, pigmentation, growth habit, seed shape etc. It is still advantageous because they are essential to differentiate the mature plant from the genetic contamination in the field (Govindaraj *et al*. 2015). Morphological assessment plays a crucial role in both the conservation and selection of parents for genetic improvement studies. Additionally, it serves as an essential tool for generating data required for documenting duplicates (Vural and Karasu, 2007; Hegde and Mishra, 2009). The correlation between morphological characters and favourable traits serves as a valuable phenotypic marker during the selection process (Rambabu *et al*. 2016). Morphological characterization is based on quantitative and qualitative traits (Schut, Qi and Stam, 1997). Qualitative characterization is inexpensive, cheap and easy, and they do not need special procedures. In addition, quantitative traits are controlled by polygenes and are affected by environmental conditions (Liu and Furnier, 1993); thus, quantitative traits are vital for the genetic improvement of traits like yield and pod quality. The yard long bean exhibits remarkable morphological diversity, influenced by various growth conditions and varying preferences among growers across different regions (Singh *et al.* 1997). Mishra and Dash (2009), Stoilova *et al.* (2013) and Rambabu *et al.* (2016) morphologically analysed the variability of common bean accessions considering different morphological characteristics. The studies revealed significant variations among the evaluated accessions of yard long bean, highlighting the presence of favourable genotypes that hold great potential for enhancement by plant breeders. The yard long bean-like crops can be improved through hybridization followed by selection (Mishra and Dash, 2009).

To enhance yield in the breeding process, a key approach is to analyze the correlation between yield and its attributes. Mishra and Dash (2009) and Ullah *et al.* (2011) revealed that pods per plant as a promising indicator of yield.

Sri Lanka is considered one of the most biologically diverse countries in Asia (Braatz, 1992). Characterization of morphological traits are essential to render information for plant breeders (Rahman *et al.* 2017) to understand the genetic potential of genotypes (Bozokalfa *et al*. 2017) in traditional yard long bean accessions. The objectives of the present study were (i) to characterize traditional yard long bean accessions selected from different locations in Sri Lanka under organic conditions, (ii) to identify the diversity among the traditional yard long bean accessions, and (iii) to determine the yield determinants of traditional yard long beans.

MATERIALS AND METHODS

The study was conducted at Thelijawila Research Station, situated at coordinates 6° 01'04.5"N, 80°30'15.5"E, in the Matara district of Sri Lanka, spanning from June 2022 to September 2022. The research station is located at an altitude of ten meters above sea level, and it experiences an average annual rainfall of approximately less than 2500 mm. A total of fifteen traditional yard long bean accessions were randomly collected from various locations across Sri Lanka. The experiment was carried out using a randomized complete block design, comprising three replicates, with each replicate containing ten plants. The land was appropriately tilted after the rainy season, and ridges and furrows were prepared to ensure proper drainage. Prior to planting, the seeds were soaked for twenty-four hours to enhance germination, and they were prepared for planting once the radicles emerged. Planting involved placing two seeds per hole, spaced at 90 cm X 30 cm intervals. Following two weeks of seedling emergence, any excess plants were removed, retaining only one plant per hole. Chemical fertilizer or pesticides were not applied during the cropping season. To support the plants' growth, approximately 3-meter poles were placed at each hole on the ridges to serve as trails (*Supplementary figure 1*). Weeding was carried out manually at two and four weeks after planting.

Data Collection

The qualitative characterization involved record data on growth habit, flower color, pod color, and seed color. For quantitative analysis, plant height, days to first flowering, pod length, pod width, pod weight, number of seeds per pod, number of pods per peduncle, number of pods per plant, and pod yield per plant at the first two harvest. To ensure the accuracy of the analysis and minimize the potential impact of environmental factors such as pests and diseases, the pod yield from the first two harvests was considered for the analysis. This provided a concise and unadulterated view of the crop's initial genetic performance, free from any external influences that emerged during the subsequent growth stages.

Data Analysis

The data from all the variables underwent Analysis of Variance at a significance level of 5% to evaluate the significant variations within the accessions. Additionally, the data distribution was represented using the mean and standard deviation values. Principal Component Analysis (PCA) was employed to identify significant trait contributions. Eigenvalues were computed through PCA, and those surpassing the threshold value K=1.0, as proposed by Goodman (1972) were considered as influential traits. To assess the genetic relationship among the traditional accessions, cluster analysis based on Euclidean distances was employed. A 2D-scatterplot was constructed to visually examine the morphological similarities and dissimilarities of quantitative traits among the accessions. To investigate the relationship between yield and other traits, Pearson's correlation coefficient was computed. This allowed for the determination of yield determinants based on the associations between yield and the various traits. For data analysis, the IBM SPSS statistical software version 2011 (SPSS inc., 2011) was utilized.

RESULTS AND DISCUSSION

Among the fifteen traditional yard long bean accessions assessed, notable variations were found in their qualitative traits. Two accessions, namely *TJ-110* and *75*, displayed bush-type growth patterns, distinguishing them from the rest which exhibited a vine type growth (*Supplementary Table 1*).

Regarding flower color, a total of five categories were identified within the population: dark purple, light purple, white, purple and white. Interestingly, six accessions, namely *TJ-114, TJ-152, TJ-Rathu, 75, Sukumuit,* and *Kota-Mae*, showcased light purple flowers, while *TJ-110* stood out with its distinctive white flowers (Figure 1). Pod colour expressed a broad variation in the studied accessions: Dark green, dark green with the purple pod, light green pod with purple tip, light green pods, light green with purple pod, and purple pod with a green tip (*Supplementary figure 2*).

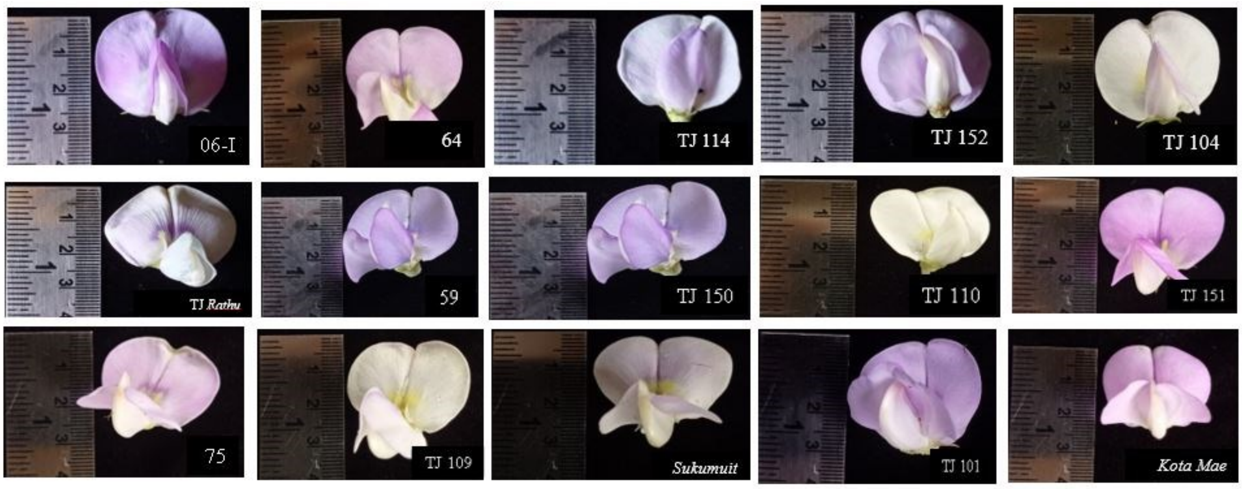


Figure 1: Morphological variation of flowers of fifteen traditional yard long bean accessions

Quantitative trait variation among the accessions

All investigated quantitative traits including plant height, days to first flowering, number of pods per peduncle, number of pods per plant, pod length, pod width, pod weight, pod yield, and number of seeds per pod exhibited significant variations ($p < 0.05$) (Table 2). Among the accessions, *TJ-Rathu* displayed the highest plant height, reaching 293.43 cm, while *TJ-110* showed the lowest plant height at 112.4 cm. Notably, Rambabu *et al.* (2016) observed an even broader range of plant height, spanning from 36.33 to 357.89 cm in their study.

The first flowering of the plants exhibited a range of 34 to 41 days. Among the varieties observed, *TJ-101, TJ-150, TJ-104*, and *64* took 41 days, while *06-I, 59,* and *TJ-151* only took 34 days to reach the first flowering stage (Table 2). On the other hand, *TJ-151* recorded the lowest pod yield of 51.4 g per plant and the shortest time for the first flowering (35 days). This reemphasizes the previous finding that early flowering and early harvesting are

Table 2: Agromorphological characteristics of studied yard long bean accessions.

Accession name	PH (cm)	DFF	NPP	NPPP	PL (cm)	PD (cm)	PW (g/ pod)	PY* (g/ plant)	NSP
06-I	272.37^{c}	34.67^{f}	1.9^{a}	6.5^{c}	31.2^{f}	1.11^{h}	8.27^{j}	65.07^{l}	15.4^{fg}
64	264.3^{e}	41^{a}	1.67^{abcd}	6.3^{c}	26.6^{i}	1.23^{ef}	11.3^{i}	116.9^{h}	18.3^{cd}
TJ-114	226.1^{i}	38.33^{cd}	1.73^{ab}	6.1^{c}	29.2^{g}	1.37^{cd}	12.47^{h}	130.77^{f}	19.77^{a}
TJ-152	227.6^{h}	37de	1.6^{bcde}	5.6^{d}	59.0^{b}	1.16^{g}	16.57^{e}	164.17^{d}	14.3^{h}
TJ-104	240.47^{g}	41^{a}	1.53^{def}	4.1^{fg}	29.3^{g}	1.21^{fg}	13.87^{g}	94.8^{j}	17.6^{de}
TJ-Rathu	293.43^{a}	40.33^{ab}	1.67^{abcd}	**8.4^{a}**	30.6^{f}	1.35^{d}	18.47^{d}	**276.9^{b}**	19.5^{ab}
59	223.4^{j}	34.67^{f}	1.43^{g}	4.0^{fg}	43.9^{c}	1.42^{c}	15.43^{f}	123.07^{g}	18.93^{bc}
TJ-150	262.93^{e}	41^{a}	1.53^{def}	**7.3^{b}**	32.9^{e}	1.36^{d}	20.87^{c}	**289.83^{a}**	18.03^{d}
TJ-110	112.4^{m}	40.33^{ab}	1.5^{ef}	6.2^{c}	27.4^{hi}	1.52^{b}	11.4^{i}	71.53^{k}	11.43^{j}
TJ-151	239.87^{g}	34.67^{f}	1.53^{def}	3.7^{gh}	28.0^{h}	1.21^{fg}	10.7^{i}	51.4^{n}	11.93^{ij}
75	156.3^{l}	38.33^{cd}	1.57^{cdef}	4.5^{e}	22.7^{j}	1.37^{d}	11.13^{i}	71.3^{k}	17.1^{e}
TJ-109	252.3^{f}	39^{bc}	1.77^{a}	6.4^{c}	30.6^{f}	1.33^{d}	14^{g}	153.4^{e}	15.2^{g}
Sukumuit	283.53$^{\mathbf{b}}$	40^{ab}	1.43^{g}	**2.2^{i}**	**75.3^{a}**	1.84^{a}	35.87^{a}	110.6^{i}	12.63^{i}
TJ-101	270.1^{d}	41^{a}	1.47^{ef}	3.4^{h}	42.2^{d}	1.5^{b}	31^{b}	197.27^{c}	15.17^{g}
Kota-Mae	210.4^{k}	36.33^{e}	1.7^{abc}	4.2^{ef}	27.5^{h}	1.27^{e}	8.83^{j}	54.77^{m}	16.13^{f}
Mean	235.7	38.5107	1.5953	2.564	35.7473	1.35	16.0120	131.452	16.0947
St.D	48.1664	2.46721	0.12118	1.67792	14.22991	0.17956	7.91697	74.68385	2.69254

Within each column, means not followed by the same letter are significantly different at a 5% level of probability as determined by DMRT.

PH: plant height, PY: pod yield, DFF: days for first flowering, PL: pod length, PD: pod diameter, PW: pod weight, NPP: number of pods per peduncle, NPPP: number of pods per plant, NSP: number of seeds per pod

*Cumulative per plant yield at first three harvestings associated with lower yields (Ullah *et al.* 2011). Ullah *et al.* (2011) also recorded an average of 34.24 days for the first flowering. Environmental factors such as temperature, altitude, and integral genetic factors decide the early flowering and late flowering of plants (Hadley *et al.1*983; Gerrano *et al.* 2015). Conducting multi-locational trials is essential to observe the dynamic patterns of days to first flowering among the various yard long bean accessions under study.

The number of pods per peduncle varied between one to two. Among all the accessions studied, *TJ-Rathu* exhibited the highest pod count per plant, with an average of 8.4 pods. The second-best performer in pod count was *TJ-150*, which recorded 7.3 pods per plant, showcasing a significant difference when compared to *TJ-Rathu*. Interestingly, even though *TJ-150* fell behind in pod count, it was recorded as the best among all other accessions in terms of yield per plant, with an average 289.83 g per plant. On the other hand, *TJ-Rathu* was the second highest in yield per plant, with per plant yield 276.9 g, indicating a significant difference in yield between the two accessions. *TJ-150* and *TJ-Rathu* significantly outperformed others in terms of pod yield.

Six categories of seed colours were observed in the accessions: Black, off-white, off-white with black tip, deep red, red, brown seeds with strips (*Supplementary Table 1*, Figure 2).

This research study's findings align with Noopram and Santipracha (2015) regarding flower color (dark purple and white with purple). However, there were vast variations in pod and seed colors, including dark green with purple pod, light green pod with purple tip, and light green with purple pods and red, deep red, and black seeds. Rambabu *et al.* (2016) found similar flower, pod, and seed colors, except for pink flowers.

The pod length in the studied accessions showed considerable variation (*Supplementary figure 2*), ranging from 22.7 cm (accession *75*) to 75.3 cm (*Sukumuit)*. Though *Sukumuit* recorded the significant highest pod length, it recorded the lowest pods per peduncle (2.2) and a below average per plant yield (110.6 g). The second most extended pod belonged to *TJ-152*, measuring 59.0 cm. Notably, around 73% of the population had pod lengths falling within the range of 20 to 40 cm, which is similar to the findings of Kamala *et al.,* (2014). In contrast, previous studies by Vidya *et al* (2002), Mishra and Dash (2009), and Benchasri and Bairaman (2010) reported a range of pod lengths, between 32 cm to 60 cm.

The average width across all accessions was 1.35 cm. The broadest pod width was observed in *Sukumuit*, measuring 1.84 cm, while the narrowest pod width was recorded in accession *06-I,* with a width of 1.11 cm. The pod weight showed considerable

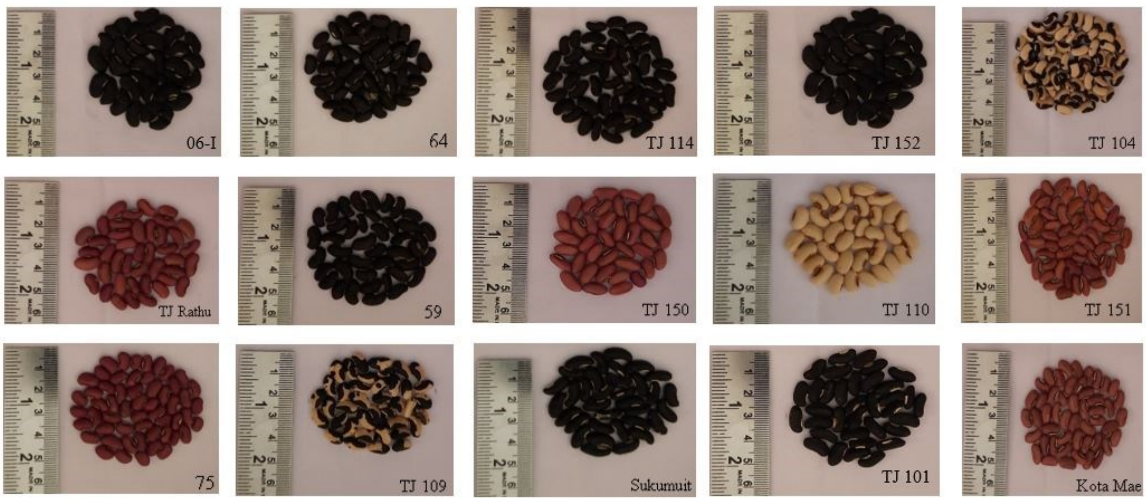


Figure 2: Morphological variation of seeds of fifteen traditional yard long bean accessions

variability, ranging from 8.27 g (accession *06 -I*) to 35.87 g (*Sukumuit*). *Sukumuit's* higher pod weight can be attributed to its increased pod length and width. Further, *Sukumith* recorded the second highest plant height (283.53) in the studied accessions.

In number of seeds per pod, *TJ-114* reported the highest value, 19.77 seeds per pod, closely followed by *TJ-Rathu* with 19.5 seeds per pod. However, *TJ-Rathu's* seed count was not significantly different from that of *TJ-114* and *59*. On the lower end, *TJ-110* exhibited the lowest number of seeds per pod, with 11.4 seeds per pod. The study revealed significant variation in pod length, width, weight, yield, and seed count among the different accessions of the plant (*Supplementary figure* 3). These findings provide valuable insights into the diversity and potential of these accessions for further breeding and agricultural purposes.

Principal Component Analysis (PCA) was utilized to visualize the diversity among fifteen traditional yard long bean accessions. The analysis yielded three principal components (PCs) with eigenvalues greater than one, collectively accounting for 79.31% of the total variance across nine phenotypic traits (Table 3). The first PC (PC1) alone had an eigenvalue of 3.481, explaining 38.68% of the variance, primarily resulting from variations in pod weight, width, and length among the different accessions. The second PC (PC2) encompassed traits like pod yield, number of seeds per pod, number of pods per plant, plant height, and days for first flowering, explaining 27.28% of the overall variance. The third PC (PC3) individually accounted for 13.346% of the total variance, where plant height played a significant role. However, when considering PC1 and PC2 together, they explained a substantial portion (65.9%) of the variance among the accessions. Huque *et al.* (2012) evaluated eighteen traits in thirteen yard long bean genotypes, reporting that five PCs cumulatively explained 68.82% of the variance.

Table 3: Principal components and variability contribution of nine traits assessed

Traits	*PC1	*PC2	*PC3
PH (cm)	0.214	0.616	0.679
DFF	0.35	0.562	-0.599
PL (cm)	0.806	-0.021	0.413
PD (cm)	0.835	-0.018	-0.294
PW (g/pod)	0.933	0.31	0.087
NPP	-0.758	0.236	0.275
NPPP	-0.593	0.627	-0.197
PY (g/plant)	0.21	0.901	-0.055
NSP	-0.353	0.636	0.005
Eigenvalues	3.481	2.456	1.201
Variance%	38.68	27.287	13.346
Cumulative variance (%)	38.68	65.967	79.313

*PC - principal component

PH: plant height, DFF: Days for first flowering, NPP: number of pods per peduncle, NPPP: number of pods per plant, PL: pod length, PD: pod width, PW; pod weight, PY: pod yield, NSP: number of seeds per pod.

The classification was based on yield and yield-attributing traits, and similar accessions were grouped together into clusters. The hierarchical agglomerative clustering process resulted in five distinct morphological groups of accessions, with the clustering distance set at eight (Figure 4). Each category represents a distinct group with a specific number of accessions.

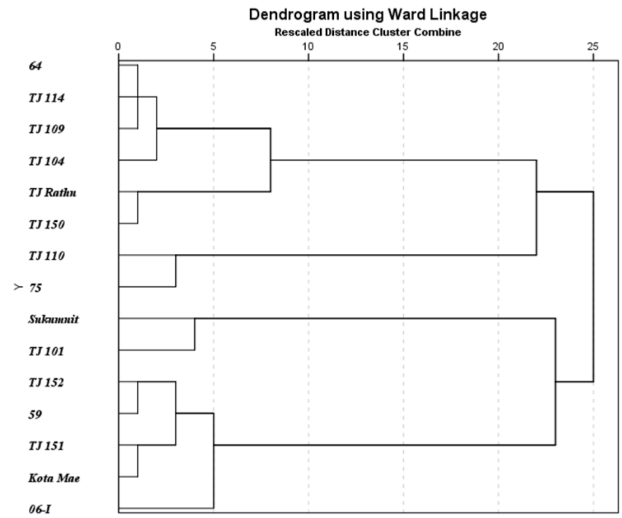


Figure 4: Hierarchical agglomerative clustering of fifteen traditional yard long bean accessions

Cluster analysis

Five clusters were identified at Euclidean cluster distance eight. Cluster I had four yard-long bean accessions in two subgroups. Subgroup one included *64*, *TJ-114*, and *TJ-109*, while the other had *TJ-104*. Subgroup two differed from subgroup one in pods per plant and yield. Subgroup one had around six pods per plant and a yield of 115-155 g per plant, while subgroup two had around four pods per plant and a yield of 94.8 g per plant. In Cluster II, both accessions *TJ-Rathu* and *TJ -150* had the highest mean number of pods per plant and pod yield (7.84 and 283.37 g, respectively), with other traits being similar. Cluster III contained two accessions, *TJ-110* and *75* with the lowest mean plant height (134.35 cm) due to both accessions having a bush-type growth habit. Cluster IV had two accessions, *Sukumuit* and *TJ-101*, recorded the lowest mean number of pods per plant (2.8 pods per plant) and the highest mean pod weight (33.44 g per pod). Cluster V was a diverse cluster with two subgroups. The first subgroup was categorized into two groups. *TJ -152* and *59* were in one subgroup with varying pod yield (120-165 g per plant) and number of seeds per pod (14-18 g per plant). *TJ-151* and *Kota-Mae* were included into a distinct subgroup exhibiting a wide range of characteristics. Their plant height varied between 210 and 240 cm, while the number of seeds per pod ranged from 11.93 to 16.13. Accession *06-I* stood out as it had the highest plant height and was categorized into a leading group in the cluster.

Similar studies were carried out by Zida *et al* (2021) for legumes resulted in five clusters in forty-four mung bean lines and Bozokalfa *et al* (2017) yielded five clusters in 36 genotypes of farmer-preferred cowpea for thirty-four traits. Furthermore, Madakbaş and Ergin (2011) also performed cluster analysis in fifty -one genotypes of turkish bean (*Phaseolus vulgaris* L.) and categorized five clusters. Cluster analysis aids in identifying the parental combinations that can be utilized for any breeding activities (Datta and Das, 2013).

The highest total variance was expressed by 2D scatter plot (Figure 5); each accession was plotted based on its first two PCs. The accessions occupying all four quadrants of the 2D scatter plot revealed a considerable diversity among the accessions. The diversity analysis performed by Huque *et al* (2012) and Kamala *et al* (2014) also reported a higher degree of diversity available within the yard long bean genotypes. This approach guarantees the inclusion of diverse accessions, enabling a comprehensive evaluation of their value in terms of diversity.

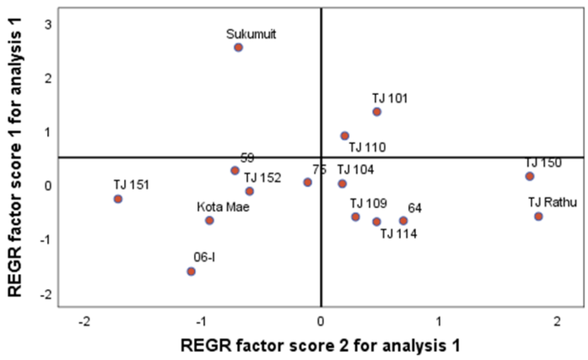


Figure 5: 2D-Scatter plot visualizing the diversity available within fifteen traditional yard long bean accessions.

Correlation between pod yield and yield attributing traits

The pod yield showed a significant correlation with the number of pods per plant (r = 0.516, α = 0.05) (Table 4). Similar findings have been reported in many studies (Vidya *et al.* 2002; Oommen and Kumar 2002; Sarutayophat 2008; Mishra and Dash 2009; and Ullah *et al.* 2011). Moreover, the number of pods per plant exhibited a positive correlation with the number of pods per peduncle (r = 0.590, α = 0.05). However, it's worth noting that the number of pods per peduncle was negatively correlated with both pod diameter (r = 0.586) and pod weight (r = 0.571) at 5% significant level. Furthermore, the pod weight was positively correlated with pod length (r = 0.756) and pod diameter (r = 0.754) at a higher level of significance (α = 0.01).

Table 4: Pearson's correlation coefficient of yield and yield contributing characters of yard long beans.

Traits	Plant height	Pod yield	Days to first flowering	Pod length	Pod diameter	Pod width	No. of pods per peduncle	No. of pods per plant
Pod yield	**0.495**							
Days to first flowering	0.102	0.5						
Pod length	0.335	0.147	0.008					
Pod diameter	-0.041	0.121	0.391	.548*				
Pod width	0.455	0.47	0.46	**.756****	**.754****			
No. of pods per peduncle	0.172	-0.054	-0.192	-0.455	**-.586***	**-.571***		
No. of pods per plant	0.068	**.516***	0.197	-0.458	-0.407	-0.388	**.590***	
No. of seeds per pod	0.277	0.432	0.144	-0.323	-0.249	-0.163	0.284	0.408

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

PH: plant height, DFF: Days for first flowering, NPP: number of pods per peduncle, NPPP: number of pods per plant, PL: pod length, PD: pod width, PW; pod weight, PY: pod yield, NSP: number of seeds per pod

CONCLUSIONS

The diverse growth habits, flower colors, pod characteristics, seed colors, and yields observed among the accessions underscore the rich genetic diversity within the yard long bean accessions. The promising accessions for future breeding programs include *TJ-150* and *TJ-Rathu*, which demonstrated high yields, *TJ-114* excelling in seed production, *Sukumuit* displaying the longest pods, highest per pod weight, and widest pod diameter, and early flowering *06-I* recording the maximum pods per peduncle. The distinct characteristics associated with each cluster through hierarchical agglomerative clustering offers valuable information for cultivar selection for breeding programs. The findings of correlation analysis indicated that pod yield was influenced by the number of pods per plant, which, in turn, is associated with the number of pods per peduncle. However, both pod diameter and pod weight have a negative correlation with the number of pods per peduncle. The clustering results, combined with correlation findings, contribute to the scientific understanding and practical implications for breeders aiming to develop improved varieties with specific qualitative and quantitative characteristics.

AUTHOR CONTRIBUTION

MBFZ conducted the study, collected and analyzed the data, and prepared the initial draft of the manuscript. HAPA and ALR supervised the study, with HAPAS providing access to research facilities and resources. ALR contributed to enhancing and finalizing the manuscript.

REFERENCES

Ano, A. O., & Ubochi, C. I. (2008). Nutrient composition of climbing and prostrate vegetable cowpea accessions. *African Journal of Biotechnology, 7*(20), 3792 –3795.

Benchasri, S. and Bairaman, C., 2010. Evaluation of yield, yield components and consumers' satisfaction towards yard long bean and cowpea in agricultural organic system. *Bulgarian Journal of Agricultural Science*, 16(6), pp.705–712.

Benchasri, S., Bairaman, C. and Nualsri, C., 2012. Evaluation of yard long bean and cowpea for resistance to *Aphis craccivora* Koch in southern part of Thailand. *Journal of Animal and Plant Sciences*, 22(4), pp.1024–1029.

Bounnhong, V., 1997. Yard long bean varietal trial. *The 15th Regional Training Course in Vegetable Production and Research*, pp.211–214.

Bozokalfa, M.K., Kaygisiz, A.T. and Eşiyok, D., 2017. Genetic diversity of farmer-preferred cowpea (*Vigna unguiculata* L. Walp) landraces in Turkey and evaluation of their relationships based on agromorphological traits. *Genetika*, 49(3), pp.935–957.

Bucheyeki, T.L., Gwanama, C., Mgonja, M., Chisi, M., Folkertsma, R. and Mutegi, R., 2009. Genetic variability characterization of Tanzania sorghum landraces based on simple sequence repeats (SSRS) molecular and morphological markers. *African Crop Science Journal*, 17(2), pp.71–86. DOI:10.4314/acsj.v17i2.54201.

Coker, C., Ely, M. and Freeman, T., 2007. Evaluation of yard long beans as a potential new crop for growers in the Southeastern United States. *HortTechnology*, 17(4), pp.592–594.

Datta, S. and Das, L., 2013. Characterization and genetic variability analysis in *Capsicum annuum* L. germplasm. *SAARC Journal of Agriculture*, 11(1), pp.91–103.

Gerrano, A.S., Adebola, P.O., Rensburg, W.S.J.V. and Laurie, S.M., 2015. Genetic variability in cowpea (*Vigna unguiculata* L.) genotypes. *South African Journal of Plant and Soil*, 32 (3), pp.165–174.

Goodman, M.M., 1972. Distance analysis in biology. *Systematic Biology*, 21(2), pp.174–186. DOI: https://doi.org/10.2307/2412287.

Govindaraj, M., Vetriventhan, M. and Srinivasan, M., 2015. Importance of genetic diversity assessment in crop plants and its recent advances: An overview of its analytical perspectives. *Genetics Research International*, 2015, p.431487. DOI: 10.1155/2015/431487.

Hadley, P., Roberts, E.H., Summerfield, R.J. and Minchin, F.R., 1983. A quantitative model of reproductive development in cowpea (*Vigna unguiculata* (L.) Walp.) in relation to photoperiod and temperature, and implications for screening germplasm. *Annals of Botany*, 51(4), pp.531–543. DOI: https://doi.org/10.1093/oxfordjournals.aob.a086497.

Hegde, V.S. and Mishra, S.K., 2009. Landraces of cowpea, *Vigna unguiculata* (L.) Walp., as potential sources of genes for unique characters in breeding. *Genetic Resources and Crop Evolution*, 56(5), pp.615–627. DOI: https://doi.org/10.1007/s10722-008-9389-8.

Huque, A.M., Hossain, M.K., Alam, N., Hasanuzzaman, M. and Biswas, B.K., 2012. Genetic divergence in yard long bean (*Vigna unguiculata* (L.) Walp. Ssp. Sesquipedalis Verdc.). *Bangladesh Journal of Botany*, 41(1), pp.61–69.

Jayasinghe, R.C., Premachandra, W.D. and Neilson, R., 2015. A study on *Maruca vitrata* infestation of yard-long beans (*Vigna unguiculata* subspecies sesquipedalis). *Heliyon*, 1(1). DOI: 10.1016/j.heliyon.2015.e00014.

Kamala, V., Aghora, T.S., Sivaraj, N., Rao, T., Pandravada, S.R., Sunil, N., Mohan, N., Varaprasad, K.S. and Chakrabarty, S.K., 2014. Germplasm collection and diversity analysis in yard long bean (*Vigna unguiculata* subsp. sesquipedalis) from Coastal Andhra Pradesh and Odisha. *Indian Journal of Plant Genetic Resources*, 27(2), pp.171–177. DOI: 10.5958/0976-1926.2014.00013.8.

Kumar, D.K., 2013. Proteome analysis of organically grown yard long bean [*Vigna unguiculata* subsp. sesquipedalis (L.) Verdcourt]. Postgraduate thesis, Centre for Plant Biotechnology and Molecular Biology, College of Horticulture, Vellanikkara, Thrissur, Kerala, India.

Liu, Z. and Furnier, G.R., 1993. Comparison of allozyme, RFLP, and RAPD markers for revealing genetic variation within and between trembling aspen and bigtooth aspen. *Theoretical and Applied Genetics*, 87(1), pp.97–105. DOI: 10.1007/BF00223752.

Madakbaş, S.Y. and Ergin, M., 2011. Morphological and phenological characterization of Turkish bean (*Phaseolus vulgaris* L.) genotypes and their present variation states. *African Journal of Agricultural Research*, 6 (28), pp.6155–6166. DOI:10.5897/AJAR11.1361.

Mishra, H.N. and Dash, S.R., 2009. A study on variability, character association and path analysis for green pod yield in yard long bean [*Vigna unguiculata* subsp. sesquipedalis (L.) Verdcourt]. *Vegetable Science*, 36(3), pp.319–322.

Nijamdeen, T.W.G.F.A., de Mel, P.K.J. and Malathy, P., 2017. Evaluation of growth and yield performance of selected lines of yard long bean (*Vigna unguiculata* subsp. sesquipedalis) during off season in mid-country wet zone. *Proceedings of the Open University Research Sessions (OURS 2017)* of the Open University of Sri Lanka, Sri Lanka, 26th–27th October 2017, pp.419–423.

Nkongolo, K.K., 2003. Genetic characterization of Malawian cowpea (*Vigna unguiculata* (L.) Walp) landraces: diversity and gene flow among accessions. *Euphytica*, 129(2), pp.219–228. DOI: https://doi.org/10.1023/A:1021935431873.

Nooprom, K. and Santipracha, Q., 2015. Effect of varieties on growth and yield of yard long bean under Songkhla conditions, Southern Thailand. *Modern Applied Science*, 9(13), p.247. DOI:10.5539/mas.v9n13p247.

Padulosi, S. and Ng, N.Q., 1997. Origin, taxonomy, and morphology of *Vigna unguiculata* (L.) Walp. In: B.B. Singh, D.R. Mohan Raj, K.E. Dashiell and L.E.N. Jackai, eds. 1997. *Advances in Cowpea Research*. Ibadan, Nigeria: Japan International Research Center for Agricultural Sciences and International Institute of Tropical Agriculture, pp.1–12.

Phansak, P., Taylor, P.W.J. and Mongkolporn, O., 2005. Genetic diversity in yard long bean (*Vigna unguiculata* ssp. sesquipedalis) and related *Vigna* species using sequence tagged microsatellite site analysis. *Scientia Horticulturae*, 106(2), pp.137–146. DOI: https://doi.org/10.1016/j.scienta.2005.03.010.

Quan, G., 1996. Yard long bean varietal trial. *The 14th Regional Training Course in Vegetable Production and Research*, Nakornpathom, AVRDC, pp.243–249. Available at: https://kb.psu.ac.th/psukb/bitstream/2010/5871/1/311769.pdf [Accessed 13 November 2023].

Rambabu, E., Reddy, K.R. and Kamala, V., 2016. Morphological characterization of yard long bean – an under-exploited vegetable. *International Journal of Science and Nature*, 7(2), pp.344–348.

Rubatzky, V.E. and Yamaguchi, M., 1997. Peas, beans, and other vegetable legumes. In: *World Vegetables*. New York: Chapman Hall (ITP), pp.474–531. DOI: https://doi.org/10.1007/978-1-4615-6015-9_22.

Sarutayophat, T., 2008. Evaluation of germplasm and comparison between pedigree and single seed descent methods in yard long bean (*Vigna unguiculata* ssp. sesquipedalis (L.) Verdc). PhD. Prince of Songkla University.

Schut, J.W., Qi, X. and Stam, P., 1997. Association between relationship measures based on AFLP markers, pedigree data and morphological traits in barley. *Theoretical and Applied Genetics*, 95, pp.1161–1168. DOI: 10.1007/s001220050677.

Singh, B.B., Rohan Raj, D.R., Dashiell, K.E. and Jackai, L.E.N., 1997. *Advances in Cowpea Research*. Ibadan, Nigeria: Japan International Research Center for Agricultural Sciences and International Institute of Tropical Agriculture.

SPSS IBM, 2011. *IBM SPSS statistics for Windows, version 20.0*. New York: IBM Corp.

Srinivasan, R., Yule, S., Chang, J.C., Malini, P., Lin, M.Y., Hsu, Y.C. and Schafleitner, R., 2012. Towards developing a sustainable management strategy for legume pod borer, *Maruca vitrata* on yard-long bean in Southeast Asia. In: *Proceedings of the Regional Symposium on High Value Vegetables in Southeast Asia: Production, Supply and Demand*, AVRDC, pp.24-26.

Stoilova, T., Pereira, G. and Tavares-De-Sousa, M., 2013. Morphological characterization of a small common bean (*Phaseolus vulgaris* L.) collection under different environments. *Journal of Central European Agriculture*, 14(3), pp.1–11. DOI:10.5513/JCEA01/14.3.1277.

Toppo, S. and Sahu, S., 2020. Studies based on performance of different genotypes of yard long bean (*Vigna unguiculata* subsp. sesquipedalis (L.) Verdic.). *Journal of Pharmacognosy and Phytochemistry*, 9(3), pp.1810–1812.

Ullah, M.Z., Hasan, M.J., Rahman, A.H.M.A. and Saki, A.I., 2011. Genetic variability, character association and path analysis in yard long bean. *SAARC Journal of Agriculture*, 9(2), pp.9–16. Available at: https://www.sac.org.bd/archives/journals/sja_v_9_i_2_2011.pdf [Accessed 13 November 2023].

Vidya, C., Sunny, K.O. and Vijayaragava, K., 2002. Genetic variability and heritability of yield and related characters in yard-long bean. *Journal of Tropical Agriculture*, 41(1), pp.11–13.

Vural, H. and Karasu, A., 2007. Variability studies in chickpea (*Cicer arietinum* L.) varieties grown in Isparta, Turkey. *Revista Científica UDO Agrícola*, 7 (1), pp.35–40.

Zida, W.-P.F.M.S., Batieno, T.B.J., Ouedraogo, T.J. and Sawadogo, M., 2021. Agromorphological evaluation of 44 lines of mung bean (*Vigna radiata* (L.) Wilczek) introduced in Burkina Faso. *European Scientific Journal*, 17(40), p.20. DOI:10.19044/esj.2021.v17n40p20.

***Supplementary Figure 1*: Accessions planted at the field**

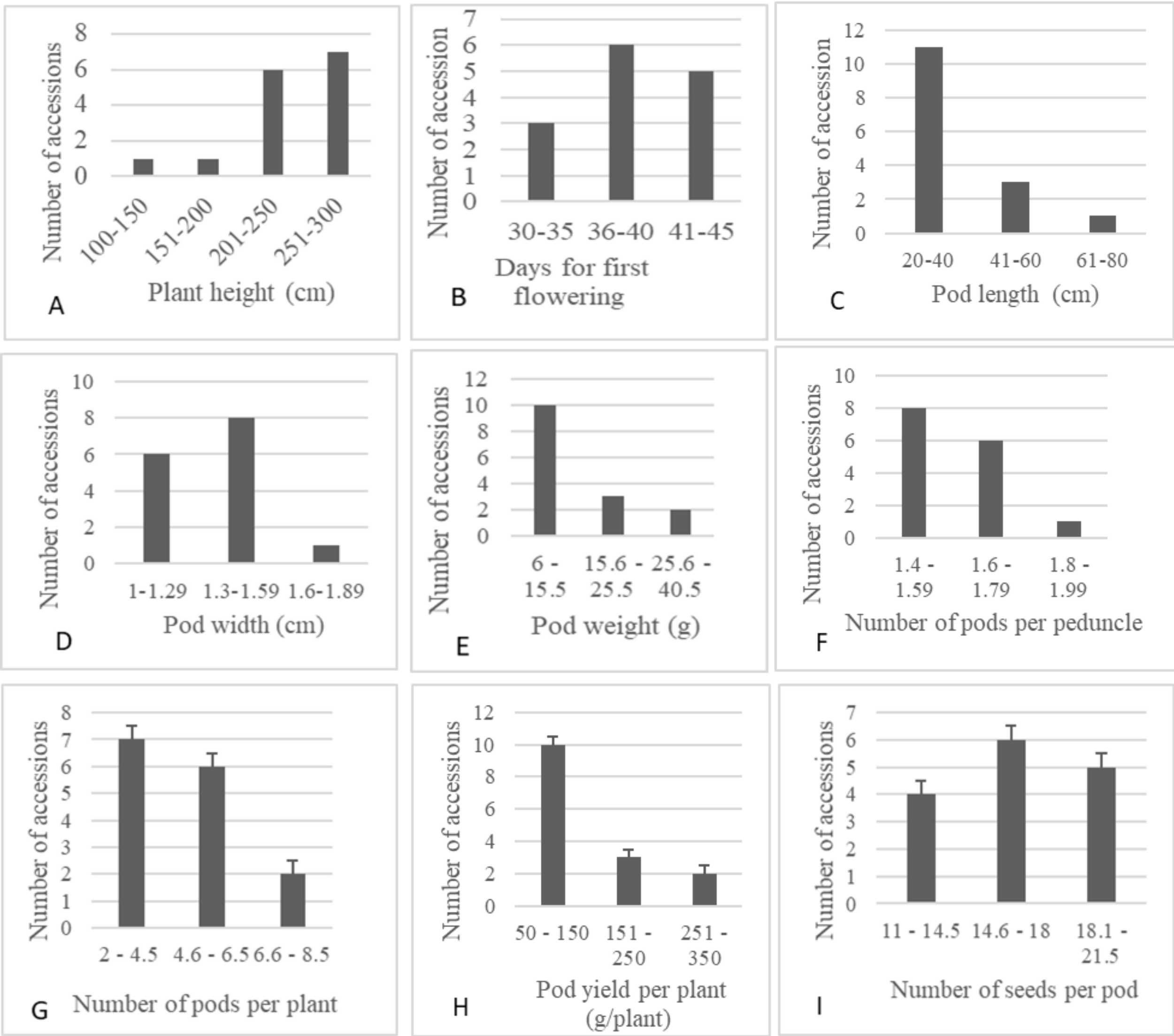
Supplementary Table 1: **Qualitative traits of fifteen traditional yard long bean accessions.**

Accession name	Growth habit	Flower colour	Pod colour	Seed colour
06-I	VT	DP	DG	Black
64	VT	DP	DGP	Black
TJ-114	VT	LP	LGPT	Black
TJ-152	VT	LP	LGPT	Black
TJ-104	VT	WP	LGP	Off-White with Black Tip
TJ-Rathu	VT	LP	LG	Deep red
59	VT	P	DGP	Black
TJ-150	VT	P	PGT	Red
TJ-110	BT	W	LG	Off White
TJ-151	VT	DP	LGPT	Brown with strips
75	BT	LP	LG	Deep red
TJ-109	VT	WP	DGP	Off White with Black Tip
Sukumuit	VT	LP	LG	Black
TJ-101	VT	DP	DGP	Black
Kota-Mae	VT	LP	LG	Brown with strips

VT: vine type, BT: bush type, DP: dark purple, LP: light purple, W: white, P: purple, WP: white with purple, DG: dark green, DGP: dark green with the purple pod, LGPT: light green pod with purple tip, LGP: light green with the purple pod, LG: light green, PGT: purple with a green tip.

***Supplementary Figure 2*: Morphological variation of pods of fifteen traditional yardlong bean accessions.**

A; *Sukumuit*, B: TJ-152, C: TJ-101, D: 59, E: TJ-151, F: TJ-150, G: TJ-*Rathu*, H: TJ-114, I: 06-I, J: TJ-104, K: *Kota-Mae*, L: 64, M: TJ-109, N: 75, O: TJ-110



***Supplementary Figure 3*: Morphological trait distribution of traditional yard long accessions**

A: Plant height, B: Days for first flowering, C: Pod length, D: Pod width, E: Pod weight, F: Number of pods per peduncle, G: Number of pods per plant, H: Pod yield per plant, I: Number of seeds per plant