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Morpho-phenological characterization and genetic analysis of dolichos bean germplasm from Uttar Pradesh, India

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Abstract

The true characterization of elite germplasm is of utmost importance for accelerating the crop breeding programme. The Indian dolichos bean [*Lablab purpureus* (L.) var. *typicus* Prain] has the potential to improve nutritional and food security. In the present investigation, a total of 21 genotypes of dolichos bean, comprising local collections mainly, along with one standard check (Kashi Sheetal) were evaluated in a complete randomized block design with three replications for two consecutive years, 2021–22 to 2022–23 for the perusal of the genetic variability. Analysis of variance revealed significant differences among all the genotypes for all the characters. PCV and GCV estimates revealed very little influence of environment on the expression of traits under study. High heritability (>90%) estimates coupled with high genetic advance as a percent of the mean were observed for flower attributes, pod length, average weight of 10 pods, pod yield and protein content. The principal component analysis revealed that the first two components cumulatively accounted for more than 50% of total variability. The present investigation revealed that the genotypes, RLBDL-S-8, RLBDL-S-14 and RLBDL-S-4-5 were stable across the years and genotype RLBDL-S-8 exhibited the highest yield potential, which can be used effectively in the development of high yielding varieties of dolichos bean in the Bundelkhand region. The study also revealed the presence of wide genetic variability in the studied local accessions which is a prerequisite for the genetic improvement of crop plants. High heritability and genetic advancement indicated the scope of selection in the crop improvement.

Introduction

Dolichos bean [*Lablab purpureus* (L.) var. *typicus* Prain] with 2n = 22 chromosomes (She and Jiang, 2015), is one of the oldest crops among cultivated plants belonging to the Fabaceae family. It is commonly known as Indian bean, hyacinth bean, lablab bean, country bean, Egyptian bean, tonga bean and field bean in English, sem in hindi and avare in the Kanarese. Dolichos bean is cultivated in both sub-tropical and tropical conditions. It is native to tropical Asia, most likely in India and from there it was brought to China, Sudan and Egypt (Ayyangar and Nambiar, 1935; Shen *et al*., 2023).

Dolichos bean is a multi-purpose crop that is grown for various requirements for pulse, vegetable and forage (Shen *et al*., 2023). The tender as well as shelled pods are used as vegetable and the dried seeds are used as pulse. The foliage acts as a fodder and manure (Dewangan *et al*., 2018). It is a vigorous trailing, twining herbaceous perennial but generally cultivated as an annual crop and propagated through the seed. It has a pole and bushy type growth habit. The pole types are photosensitive whereas, the bushy types are photo-insensitive (Shivashankar and Kulkarni, 1989). These types of plants do not have much difference with respect to pods. Two botanical varieties that are identified in India are often regarded as distinct species. The garden type, *Lablab purpureus (L.)* var. *typicus* Prain is one of them commonly known as lablab bean which is a twining herb with soft edible pods having less fibre in their pod walls cultivated as an annual. The second type is *Lablab purpureus (L.) var. lignosus* Prain is known as a field bean grown for dry seeds and generally used as a pulse (Raghu *et al*., 2018).

Dolichos beans have the capability to adapt in a wider range of unfavourable climates, including dry, semi-arid, sub-tropical and humid climates, which grow better with the annual rainfall of 600 and 800 mm (Yadav *et al*., 2003). The crop prefers relatively a cool season, with sowing taking place in July and August and fruiting begins in winter. The pods are a significant source of minerals including Ca, P and Fe as well as carbohydrates, proteins, fats and dietary fibre (Naeem *et al.*, 2009).

Despite its many uses and advantages, its cultivation is carried out only in a limited area and crops remain underexploited due to photosensitivity, low productivity, irregularity in flowering, long growth habit and consumer preferences regarding pod size, shape, colour and aroma (Vaijayanthi *et al.*, 2018). Dolichos bean plant and pod characters exhibit a wide range of variability across the nation and the variability can be used to evolve a high-yielding type. The success of any breeding programme and improvement of the specific trait through selection particularly depends on the genetic variability present in the available germplasm of the crop (Parmar *et al.*, 2013). Whether observed variability is inherited or due to environmental alone is difficult to judge. Additionally, understanding heritability is essential for selection-based development as it indicates the degree to which a character will be passed on to succeeding generations (Singh *et al.*, 2019). When heritability and genetic advance are evaluated together, the heritable component of the variance can be identified more precisely (Lahari *et al.*, 2022). A study of relationships between different traits, particularly those between yield and other morphological traits, is necessary because yield is an essential complex character that results from the interaction of plant characters (Singh *et al.*, 2018). Nevertheless, if the contribution of different traits to yield is measured using path coefficient analysis, selection of yield through highly correlated characters becomes simple (Dewey and Lu, 1959). Previously, little efforts have been put forward in the genetic improvement of dolichos bean in the Bundelkhand region, particularly in the Jhansi district of Uttar Pradesh. None of the reports is available pertaining to the detailed description and investigation of dolichos bean chractarization and evaluation in the Jhansi district of Bundelkhand. Dolichos bean is a promising and profitable crop in the Bundelkhand region of Uttar Pradesh. However, due to a lack of substantial studies on this particular crop in the Bundelkhand region of Uttar Pradesh, much progress has not occurred in its genetic improvement. Hence, a smaller number of public sector varieties are available for this particular region. Thus, realizing the potential of this legume vegetable, the present investigation is the first of its kind in the Jhansi district of Bundelkhand region which was executed to tap the local germplasm of Dolichos bean to determine the extent of genetic variability, heritability, genetic advance and interaction among various yield and contributing traits. The study was planned with the objectives of chracaterization and identification of suitable lines and resource material for the further genetic improvement of the dolichos bean.

Materials and methods

Experimental site

The present investigation was carried out by conducting field experiments for two consecutive years during the kharif season of 2021–22 and 2022–23, at the research farm of the Department of Vegetable Science, Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, India. Geographically, the experimental site is located between 25.31° N latitude, 78.33° E longitude and at an altitude of 227 m above the mean sea level.

Genetic material

The experimental material for this study comprised of 21 different local accessions of dolichos bean obtained by local collection from Sultanpur and Jhansi districts of Uttar Pradesh. The majority of the lines were collected from different villages of Sultanpur district of Uttar Pradesh *viz.* RLBDL-S-1, RLBDL-S-1-1, RLBDL-S-1-2, RLBDL-S-2, RLBDL-S-3, RLBDL-S-4, RLBDL-S-4-5, RLBDL-S-5, RLBDL-S-6, RLBDL-S-7, RLBDL-S-8, RLBDL-S-9, RLBDL-S-10, RLBDL-S-11, RLBDL-S-12, RLBDL-S-13 and RLBDL-S-14. Four local collections were from the Jhansi district of Uttar Pradesh *viz.* RLBDL-S-15(J-1), RLBDL-S-16(J-2), RLBDL-S-17(J-3) and RLBDL-S-18(J-4). The commercially released variety, Kashi Sheetal, was used as a check variety and its seeds were obtained from ICAR-IIVR, Varanasi, Uttar Pradesh.

Sampling of plants and collection of data

Among 21 genotypes, eight plants of each genotype were raised in randomized block design with three replications for two years. The plants were trained to pandal at a spacing of 0.75 m between plants and 2.0 m between rows. The data was collected on five randomly chosen equally competitive plants in each genotype in each replication for recording observation on various agro-morphological, quality and yield parameters *viz.*, days to first flowering, days to 50% flowering, days to first picking, length of inflorescence (cm), number of flowers per inflorescence, number of pods per inflorescence, pod length (cm), pod width (cm), average weight of 10 pods (g), 100 seed weight (g), protein content (%), dry matter content (%), chlorophyll content (mg/100 g), pod yield per plant (kg), pod yield per plot (kg) and pod yield per hectare (q) and their mean was calculated.

Statistical analysis

The data recorded on different parameters were subjected to statistical analysis for estimation of various genetic parameters and to find out the degree of association among different characters and their contribution to the pod yield.

Analysis of variance

ANOVA was computed for replicated data (RBD) in each character as per the standard statistical procedure (Panse and Sukhatme, 1957). The significance test was done by referring to the values of F Table (Fisher and Yates, 1963).

Coefficient of variation

The formula for the calculation of coefficient of variation (GCV and PCV) was followed as suggested by Burton and Devane (1953)

$$\text{PCV }(\%) = \frac{\sqrt{\sigma^2 p}}{\bar{x}} \times 100$$

$$\text{GCV }(\%) = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100$$

PCV and GCV values were further categorized as low, moderate and high as indicated by Sivasubramanian and Menon (1973) given as low = 0–10%, medium = 10–20% and high = >20%.

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Genetic parameters

Heritability in a broad sense was estimated by using the formula suggested by Burton and Devane (1953). The estimates of broad sense heritability were also classified into three categories as suggested by Hanson *et al.* (1956) i.e. low = 0–30%, medium = 30–60% and high = >60%. Genetic advance was computed as suggested by Johnson *et al.* (1955). The correlation coefficients were calculated using the formula given by Johnson *et al.* (1955) to investigate the degree of relationship between various traits. The correlation coefficients were calculated using the formula given by Johnson *et al.* (1955). The corrplot was presented through R statistical programme. Path coefficient analysis was computed as per Wright (1921) and Dewey and Lu (1959). The genetic divergence among genotypes has been studied using non-hierarchical Euclidean cluster analysis, which was first reported by Beale (1969) and further refined by Spark (1973). The R statistical 'hclust' package program (R Studio Team, 2020; https://rstudio.com) was used for dendrogram construction.

Results

Variance analysis

The pooled ANOVA analysis for the years 2021–22 and 2022–23 revealed the significant mean sum of square for all the characters (Table 1), indicating the existence of inherent variability in the experimental material rendering isolation of superior genotypes. It implies that the local germplasm collections of dolichos bean under study would respond positively to selection and can be instrumental in the genetic improvement of the Indian bean. The analysis of variance (ANOVA) confirmed substantial differences in pod yield and other characters of dolichos bean under study. The significant variation was revealed by pooled ANOVA analysis for all the studied traits among all the lines. The variation due to replications was found to be non-significance at both 5% and 1% levels of significance for all the characters under study. The year × genotype (G × E) interaction was found significant for number of pods per inflorescence, pod length, protein content, dry matter content, pod yield per plant and pod yield per hectare. These results indicated wide scope for improvement of the desired traits through organized dolichos bean breeding programmes.

Morpho-phenological and qualitative characterization of dolichos bean germplasm

The pooled data analysis of two years (2021–22 to 2022–23) for phenological, morphological, quality and yield components of dolichos bean genotypes revealed substantial genetic variation which is a pre-requisite for the selection of genotypes for hybrid breeding programme (Table 2). The pooled estimates of days to first flowering in the dolichos bean genotypes varied from 95.17 to 124.83 days with an average of 115.22 days to first flowering. The RLBDL-S-8 depicted the earliest days to first flower appearance (Table 2). Likewise, the days to 50% flowering varied from 109.33 to 135.83 number of days and the genotype RLBDL-S-8 was found earliest with respect to days to 50% blooming, followed by RLBDL-S-4-5 with the mean of 125.90 days. Days to first picking ranged from 124.83 to 179.33 days with a mean value of 159.99 days. The least days to first picking were observed for RLBDL-S-8 (124.83 days) and the maximum for the genotype RLBDL-S-7 (179.33 days). Inflorescence length varied from 5.86 cm (RLBDL-S-1) to 25.99 cm (RLBDL-S-8) with a mean of 12.73 cm. The average number of flowers per inflorescence was 15.72, with a range of 9.64–22.03 flowers. The highest number of flowers per inflorescence were observed for RLBDL-S-8 (22.03) followed by RLBDL-S-13 (21.08). The average number of pods per inflorescence was 9.89, with a range of 5.27–14.23. The highest number of pods per inflorescence were recorded in RLBDL-S-12 (14.23). The average pod length was 9.53 cm, where RLBDL-S-16 (J-2) exhibited the maximum pod length (12.08 cm) and it was significantly at par with the pod length of Kashi Sheetal. The average pod width was 1.60 cm and the highest pod width was documented in the genotype of RLBDL-S-9 (2.12 cm) and the smallest in RLBDL-S-4-5 (1.18 cm). The highest average 10 pods weight (79.25 g) was recorded in the genotype RLBDL-S-14 and RLBDL-S-12 showed the lowest (28.22 g) pod weight. The 100 seed weight ranged from 32.21 g [RLBDL-S-17 (J-3)] to 49.48 g (RLBDL-S-14). The adjusted mean of 12 genotypes performed better over the average mean value of 40.46 g. RLBDL-S-14 recorded the highest 100 seed weight of 49.48 g, followed by RLBDL-S-8 (49.45 g). The protein content of the pods varied from 20.5 to 26.34% with a mean of 23.95%. The highest protein content was recorded in RLBDL-S-8 (26.34%) and the lowest in RLBDL-S-10 (20.5%). The value of dry matter content varied from 11.85 to 18.38%, with a mean of 15.04%. Among the genotypes highest dry matter content was recorded in the genotype RLBDL-S-7 (18.38%) and the lowest in RLBDL-S-4-5 (11.85%). The value of chlorophyll content ranged from 36.79 to 56.25 mg, with a mean value of 47.40 mg. The highest chlorophyll content was observed in RLBDL-S-15(J-1) (56.25 mg) and the lowest was recorded in the genotype RLBDL-S-1 (36.79 mg). The pod yield per plant ranged from 1.61 to 6.47 kg with a mean of 2.67 kg. The maximum pod yield per plant was found in RLBDL-S-8 (6.47 kg) and the lowest in RLBDL-S-12 (1.61 kg). The pod yield per plot ranged from 12.92 to 51.78 kg with an average of 21.53 kg. The maximum pod yield per plot was found in RLBDL-S-8 (51.78 kg) and the lowest for RLBDL-S-12 (12.92 kg). The pod yield per hectare ranged from 107.73 to 431.58q with a mean of 179.46q. Among the studied genotypes the highest pod yield per hectare was observed for RLBDL-S-8 (431.58q) and the lowest for RLBDL-S-12 (107.73q). The studied genotypes, RLBDL-S-8 (431.58q) and RLBDL-S-14 (389.87) exhibited significantly high yield as compared to standard check variety Kashi Sheetal.

Genetic parameters of variability, heritability and genetic gain

The assessment of variability parameters revealed that there was tremendous amount of variation among the genotypes for different characters. The GCV and PCV values provide insight into the magnitude of genetic variation. The heritability assessed in conjunction with estimates of genetic advance provide an indication of genetic gains in the following generation, or the change in average values between generations. The estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance of pooled data analysis are presented in Table 3. Over the years, pod yield per plant recorded highest GCV and PCV (46.43 and 47.31%, respectively), followed by pod yield per plot, pod yield per hectare, length of inflorescence, average weight of 10 pods, number of pods per inflorescence, number of flowers per inflorescence and pod length. The characters pod width, 100 seed weight and dry matter content reported moderate GCV and PCV values. Whereas, days to 50% flowering showed low GCV (5.49%) and PCV (7.96%),

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Table 1. AVOVA for agro-morphological and yield traits under pooled seasons

Characters	Source of variation				
	Replication	Year	Genotypes	Year × Genotypes	Error
df	**2**	**1**	**20**	**20**	**82**
DFF	91.33	1.14	322.92***	15.81	41.59
DF50	121.3	70.12	339.63***	16.71	52.61
DFP	69.94	2.57	1520.92***	24.95	86.78
LI	2.05	2.38	179.09***	0.71	1.23
NFPI	0.87	0.62	76.81***	1.23	1.13
NPPI	0.61	0.29	47.59***	2.74***	0.86
PL	0.37	1.23	23.22***	1.12***	0.54
PW	0.02	0.07	0.37***	0.02	0.02
PW10	24.55	106.04**	1072.48***	9.23	14.15
SW100	12.48	27.81	142.56***	3.56	7.49
PC	0.47	0.81	12.89***	0.77**	0.41
DMC	1.81	8.17***	23.15***	1.21***	0.44
CC	3.19	13.12	136.84***	4.89	10.18
PYPP	0.15	0.434**	9.30***	0.13***	0.05
PYPPL	7.34	16.41**	591.57***	5.92**	3.33
PYPH	511.91	1150.62**	41,090.26***	411.49**	231.55

*, **, *** significant at 5%, 1% and 0.1% level of significance.
(df, degrees of freedom; DFF, days to first flowering; DF50, days to 50% flowering; DFP, days to first picking; LI, length of inflorescence; NFPI, number of flowers per inflorescence; NPPI, number of pods per inflorescence; PL, pod length; PW, pod width; PW10, average weight of 10 pods; SW100, 100 seed weight; PC, protein content; DMC, dry matter content; CC, chlorophyll content; PYPP, pod yield per plant; PYPPL, pod yield per plot; PYPH, pod yield per hectare).

followed by days to first flowering, days to first picking, protein content and chlorophyll content.

In the present study, high heritability (96.72%) coupled with high genetic advance (93.16%) were found for the traits, pod yield per plot, followed by pod yield per hectare, pod yield per plant, length of inflorescence, average weight of 10 pods, number of flowers per inflorescence, number of pods per inflorescence, dry matter content, pod length, pod width and 100 seed weight. The traits are least impacted by the environment because of the high heritability, which also suggests a substantial proportion of genotypic variance. The traits, days to first picking, protein content and chlorophyll content exhibited high heritability with moderate genetic advance. Similarly, days to 50% flowering exhibited moderate heritability (47.62%) and low genetic advance (7.81%), followed by days to first flowering. These traits are under the genetic control of both additive and non-additive gene actions.

Euclidean cluster analysis

All the 22 genotypes were categorized into five different clusters in such a way that average intra cluster distance remained minimal. The 22 genotypes are grouped into five clusters. The check variety Kashi Sheetal remained separate from all other local collections and was designated in cluster I. The two accessions, RLBDL-S-14 and RLBDL-S-8 remained together and designated as members of cluster II. The maximum number of genotypes were grouped in cluster III (14 genotypes) (Fig. 1a).

Interaction analysis

The correlation analysis revealed positive as well as negative correlation among different phenological and yield-related traits (Table S1, Fig. 1b). The highest and the significant positive correlation was exhibited by average weight of 10 pods with the pod yield per plant followed by length of inflorescence, 100 seed weight and protein content. The number of flowers per inflorescence, number of pods per inflorescence and pod length showed significant positive correlation with pod yield per plant. The present findings suggested that these characters can be employed for the selection of high-yielding genotypes.

Principal component analysis

The principal component analysis (PCA) was performed for phenotypic and yield-related traits of dolichos bean to examine the pattern of dispersal in experimental data. The PCA analysis revealed that the first two components, PC1 and PC2 explained >50% of total variation i.e. 43.2% and 19.7%, respectively (Fig. 2a). The variables exhibiting positive association were grouped together. The results of PCA also placed the check variety Kashi Sheetal (designated as number 22 in PCA results Fig. 2a) separately from other groups like cluster dendrogram results. The character exhibiting the maximum percentage of contribution towards the total genetic variation was pod yield per plant, length of inflorescence and average weight of 10 pods (Fig. 2b). The pod weight and pod length exhibited the least

Table 2. Mean performance of different dolichos bean genotypes (pooled data)

S. no	Genotypes	DFF	DF50	DFP	LI	NFPI	NPPI	PL	PW	PW10	SW100	PC	DMC	CC	PYPP	PYPPL	PYPH
1	RLBDL-S-1	120.17	130.67	161.83	12.45	18.98	12.67	11.08	1.77	59.58	41.95	24.18	15.72	36.79	3.44	27.57	229.76
2	RLBDL-S-1-1	117.67	127.67	157.67	13.06	20.06	12.23	11.32	2.08	29.42	42.17	24.90	16.66	38.36	1.65	13.24	110.35
3	RLBDL-S-1-2	117.00	123.50	159.00	18.38	18.05	10.98	11.21	1.64	43.50	36.74	24.22	17.32	46.20	2.48	19.84	165.35
4	RLBDL-S-2	119.17	131.50	161.17	10.81	17.08	11.28	9.79	1.87	37.75	42.01	23.12	15.77	48.65	1.67	13.42	111.83
5	RLBDL-S-3	122.00	128.33	162.50	9.15	16.22	6.83	7.05	1.72	45.75	41.34	24.05	17.60	41.64	2.49	19.97	166.39
6	RLBDL-S-4	117.33	130.17	173.67	6.61	10.57	6.62	7.64	1.87	31.82	37.87	22.53	17.90	49.49	2.53	20.24	168.65
7	RLBDL-S-4-5	103.17	110.00	128.67	20.25	17.48	7.35	10.22	1.18	49.88	34.60	24.68	11.85	49.74	2.31	18.50	154.20
8	RLBDL-S-5	103.00	111.33	132.50	20.00	15.42	8.59	11.11	1.40	49.69	42.71	25.51	12.46	47.39	2.96	23.69	197.37
9	RLBDL-S-6	117.17	126.50	168.17	11.90	16.11	11.35	9.40	1.83	39.17	38.24	22.85	13.02	45.04	2.51	20.15	167.99
10	RLBDL-S-7	118.83	128.17	179.33	13.15	15.95	12.18	8.15	1.36	29.56	40.14	23.37	18.38	45.41	2.68	21.48	179.00
11	RLBDL-S-8	95.17	109.33	124.83	25.99	22.03	12.59	10.83	1.52	68.63	49.45	26.34	16.09	50.92	6.47	51.78	431.58
12	RLBDL-S-9	117.17	128.50	172.67	10.77	14.82	10.38	7.63	2.12	34.31	36.67	21.95	16.70	47.45	2.12	17.01	141.80
13	RLBDL-S-10	117.17	128.00	172.83	8.13	12.78	10.46	6.94	1.38	51.40	42.06	20.50	13.16	49.32	1.90	15.23	126.97
14	RLBDL-S-11	114.50	127.67	173.83	11.90	17.93	10.82	10.51	1.45	39.98	41.66	22.36	14.36	49.71	2.21	20.05	167.12
15	RLBDL-S-12	111.67	127.83	158.50	15.32	16.17	14.23	4.88	1.44	28.22	45.41	24.64	15.65	48.01	1.61	12.92	107.73
16	RLBDL-S-13	119.83	130.00	174.67	18.88	21.08	13.81	7.60	1.58	35.67	33.58	22.28	15.42	42.90	2.32	18.58	154.83
17	RLBDL-S-14	107.00	116.33	136.33	14.17	16.61	11.43	11.33	1.50	79.25	49.48	25.51	13.54	46.86	5.85	46.78	389.87
18	RLBDL-S-15(J-1)	124.83	135.83	161.83	7.57	12.48	6.90	11.84	1.29	58.73	33.70	25.35	13.32	56.25	2.33	18.66	155.51
19	RLBDL-S-16 (J-2)	122.33	131.33	167.67	6.74	9.98	6.17	12.08	1.65	50.93	41.19	25.09	12.47	56.16	2.29	18.36	153.07
20	RLBDL-S-17(J-3)	118.33	130.83	169.33	6.19	10.73	5.27	9.28	1.54	38.16	32.21	24.21	14.50	49.62	2.63	21.05	175.47
21	RLBDL-S-18(J-4)	116.17	130.50	162.67	5.86	9.64	5.73	10.43	1.43	49.80	46.39	25.21	14.04	49.40	1.70	13.66	113.82
22	Kashi Sheetal (Check)	102.00	107.67	122.67	21.57	25.30	13.33	12.07	2.25	74.33	67.42	18.14	12.65	50.86	5.29	31.79	265.00
	Mean	115.22	125.90	159.98	12.72	15.72	9.89	9.53	1.60	45.29	40.45	23.94	15.04	47.39	2.67	21.53	179.46
	S.E.M.	2.63	2.96	3.80	0.45	0.43	0.38	0.30	0.05	1.53	1.11	0.26	0.27	1.30	0.09	0.74	6.21
	CD (0.05)	7.38	8.31	10.67	1.27	1.21	1.06	0.84	0.16	4.31	3.13	0.74	0.76	3.65	0.27	2.09	17.42
	CV	5.59	5.76	5.82	8.71	6.76	9.40	7.73	8.87	8.30	6.76	2.69	4.45	6.73	9.06	8.47	8.47

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Table 3. Components of genetic variability for different characters in dolichos bean genotypes

Character	Range	Mean ± SE	GCV	PCV	Heritability (broad sense)	Genetic advance as percent of mean
DFF	95.17–124.83	115.22 ± 2.63	5.94	8.16	53.00	8.91
DF50	109.33–135.83	125.90 ± 2.96	5.49	7.96	47.62	7.81
DFP	124.83–179.33	159.99 ± 3.80	9.66	11.28	73.36	17.05
LI	5.86–25.99	12.73 ± 0.45	42.77	43.65	96.02	86.35
NFPI	9.64–22.03	15.72 ± 0.43	22.59	23.58	91.76	44.57
NPPI	5.27–14.23	9.89 ± 0.38	28.19	29.72	89.99	55.09
PL	4.88–12.08	9.53 ± 0.30	20.38	21.80	87.41	39.26
PW	1.18–2.12	1.60 ± 0.05	15.27	17.67	74.75	27.21
PW10	28.22–79.25	45.30 ± 1.53	29.32	30.47	92.58	58.11
SW100	32.21–49.48	40.46 ± 1.11	11.72	13.53	75.03	20.92
PC	20.5–26.34	23.95 ± 0.26	6.02	6.60	83.28	11.32
DMC	11.85–18.38	15.04 ± 0.27	12.93	13.67	89.38	25.18
CC	36.79–56.25	47.40 ± 1.30	9.69	11.80	67.45	16.40
PYPP	1.61–6.47	2.67 ± 0.09	46.43	47.31	96.32	93.88
PYPPL	12.92–51.78	21.53 ± 0.74	45.98	46.75	96.72	93.16
PYPH	107.73–431.58	179.46 ± 6.21	45.98	46.75	96.71	93.15

(GCV, genotypic coefficient of variation; PCV, phenotypic coefficient of variation; DFF, days to first flowering; DF50, days to 50% flowering; DFP, days to first picking; LI, length of inflorescence; NFPI, number of flowers per inflorescence; NPPI, number of pods per inflorescence; PL, pod length; PW, pod width; PW10, average weight of 10 pods; SW100, 100 seed weight; PC, protein content; DMC, dry matter content; CC, chlorophyll content; PYPP, pod yield per plant; PYPPL, pod yield per plot; PYPH, pod yield per hectare).

contribution to total variation. The results suggested that genotypes included in the study had great diversity for various characters. The present diversity can be used in one of two ways, either by reintroducing hybridization, which would then lead to the creation of improved lines, or alternatively, by directly subjecting these lines to selection for isolation of superior genotypes.

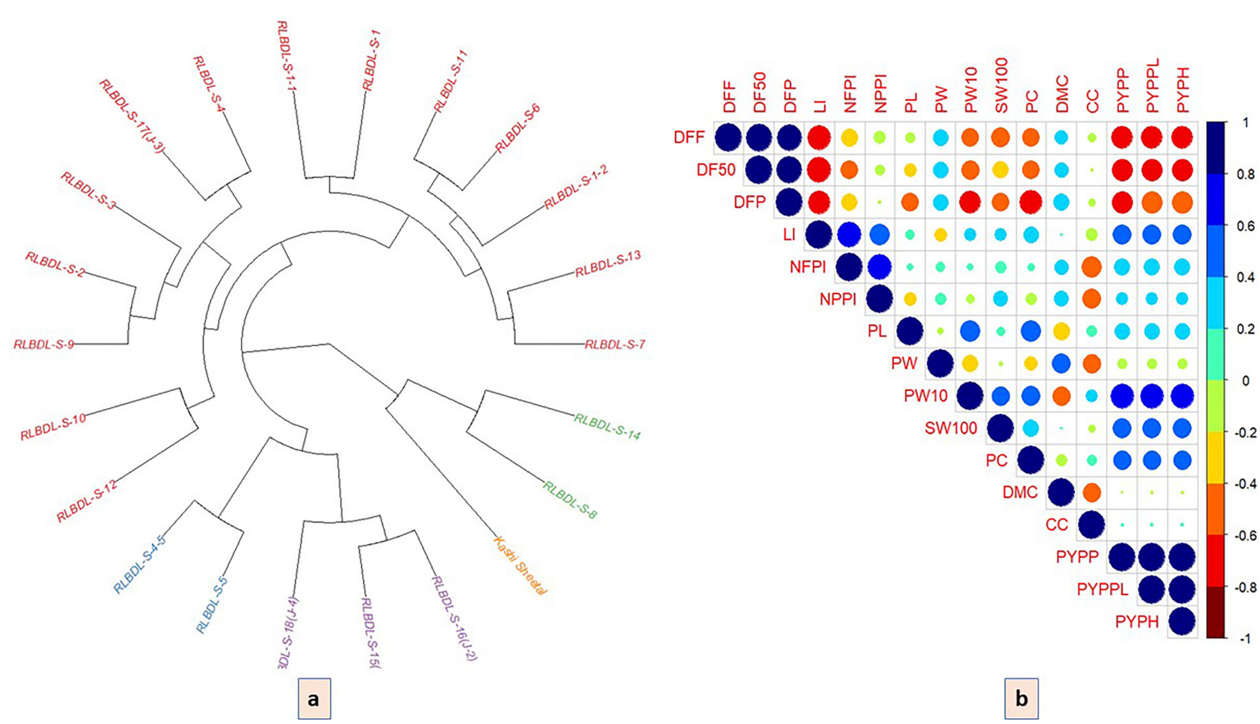

Figure 1. (a) Cluster dendrogram for 22 dolichos bean genotypes based on Euclidean cluster analysis. The 22 genotypes are grouped in five clusters. The check variety Kashi Sheetal remained separate from all other local collections and was designated in cluster I. The two accessions, RLBDL-S-14 and RLBDL-S-8 remained together and designated as members of cluster II.

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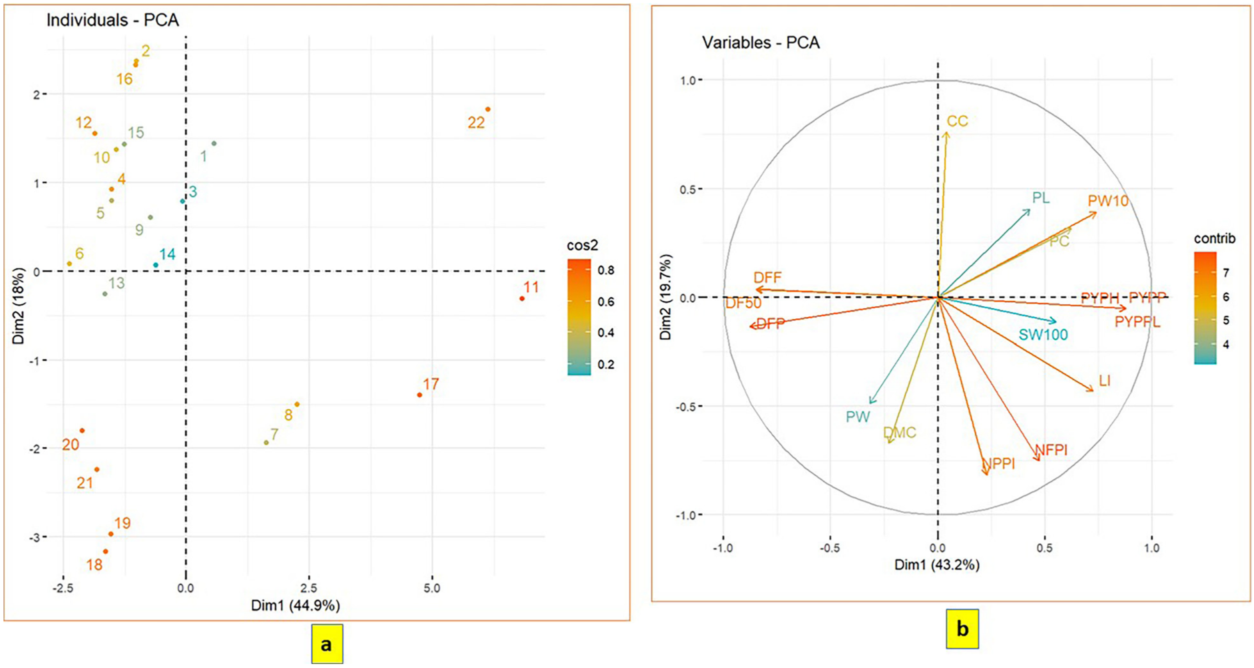

Figure 2. Principal component analysis of 22 dolichos bean genotypes based on phenotypic traits. (a) PCAbiplot analysis-based classification of 22 accessions of dolichos bean. The check variety ' Kashi Sheetal' designated as number 22, remained separated from other groups (b) The PCA also depicts the role of individual phenotypic trait in total variation.

Path co-efficient analysis

The results pertaining to direct effects are presented in Table 4. The path analysis revealed that at the genotypic level, 9 out of 13 traits had positive direct effect on pod yield (Table 4), namely, length of inflorescence, days to first flowering, average weight of 10 pods, dry matter content, days to 50% flowering, 100 seed weight, pod length, pod width and chlorophyll content. However, days to first picking, number of flowers per inflorescence, number of pods per inflorescence and protein content had a negative direct effect on pod yield. Similarly, at phenotypic level, the average weight of 10 pods contributed the greatest positive direct effect on pod yield followed by dry matter content, length of inflorescence, pod width, protein content, number of pods per inflorescence, chlorophyll content, 100 seed weight, days to 50% flowering and days to first picking. Whereas, days to first flowering, number of flowers per inflorescence and pod length exhibited direct negative effect on pod yield.

The results of indirect effects revealed that length of inflorescence influenced the pod yield indirectly in positive direction through number of flowers per inflorescence, number of pods per inflorescence, pod length, average weight of 10 pods, 100 seed weight, protein content and dry matter content at both genotypic and phenotypic levels. Average weight of 10 pods recorded positive indirect effect on pod yield *via* length of inflorescence, number of flowers per inflorescence, pod length, 100 seed weight, protein content and chlorophyll content whereas, through other traits, it had negligible indirect effects.

Discussion

The identification of elite parental lines for heterosis breeding and genetic improvement of crop plants based on phenological, phenotypic and genetic variability analysis is of utmost importance (Singh *et al.*, 2021). Determination of genetic diversity is useful for the success of crop improvement programmes for the development of superior genotypes (Singh *et al.*, 2018). The higher genetic distance between parents generally contributes to higher heterosis in the progeny (Joshi and Dhawan, 1966; Anand and Murty, 1968; Singh *et al.*, 2018). In the present investigation, the pooled variance analysis over the years revealed significant differences among all the genotypes for all the traits, which is a pre-requisite for the success of any crop genetic improvement programme and for the development of high-yielding varieties in the era of climate change. The current findings are in accordance with the results of Kushwah *et al.* (2021) for phenological traits and with Srungarapu *et al.* (2022) for the agronomic, yield traits in chickpea and Mohan *et al.* (2014) in dolichos bean.

The PCV and GCV values were categorized as low (0–10%), moderate (10–20%) and high (>20%) (Sivasubramanian and Menon, 1973). High magnitude of GCV and PCV was observed for pod yield, length of inflorescence, number of flowers per inflorescence, number of pods per inflorescence, average weight of 10 pods and pod length indicating that the simple selection will be effective for the genetic improvement of these traits. Thus, simple selection procedures can be utilized in the studied local germplasm of dolichos bean for the isolation and development of elite breeding lines. The moderate estimates of PCV and GCV have been reported previously by Patel *et al.* (2022) for pod length, pod weight and numbers of pod per plant, indicating low response to selection for these traits. Likewise, moderate to high estimates of GCV were reported in another study by Kumar *et al.* (2021), Gamit *et al.* (2020), Singh *et al.* (2017), and Mohan *et al.* (2014). In the present study, the moderate estimates of GCV and PCV were observed for pod width, 100 seed weight, dry matter content and they were low for days to first flowering, days to 50% flowering, days to first picking and protein

Table 4. Genotypic and phenotypic path coefficient analysis

Traits		DFF	DF50	DFP	LI	NFPI	NPPI	PL	PW	PW10	SW100	PC	DMC	CC
DFF	G	**1.026**	0.445	−1.207	−1.198	0.337	0.002	−0.008	0.039	−0.292	−0.213	0.297	0.120	−0.013
	P	**−0.223**	0.003	0.002	−0.112	0.008	−0.010	0.004	0.022	−0.204	−0.009	−0.019	0.054	−0.002
DF50	G	1.077	**0.424**	−1.246	−1.277	0.378	0.001	−0.013	0.040	−0.317	−0.163	0.301	0.134	−0.001
	P	−0.146	**0.004**	0.002	−0.114	0.009	−0.005	0.006	0.020	−0.249	−0.006	−0.019	0.058	−0.001
DFP	G	0.957	0.408	**−1.294**	−1.029	0.299	0.000	−0.023	0.036	−0.421	−0.183	0.471	0.166	−0.010
	P	−0.127	0.003	**0.003**	−0.118	0.009	−0.001	0.011	0.023	−0.377	−0.008	−0.039	0.097	−0.001
LI	G	−0.834	−0.367	0.904	**1.473**	−0.655	−0.005	0.006	−0.024	0.140	0.087	−0.210	0.004	−0.020
	P	0.127	−0.003	−0.002	**0.197**	−0.021	0.034	−0.003	−0.015	0.146	0.005	0.019	0.003	−0.007
NFPI	G	−0.423	−0.195	0.473	1.178	**−0.819**	−0.007	0.003	0.015	0.045	0.076	−0.050	0.122	−0.059
	P	0.063	−0.001	−0.001	0.148	**−0.028**	0.046	−0.002	0.008	0.046	0.004	0.005	0.070	−0.020
NPPI	G	−0.210	−0.064	0.038	0.827	−0.647	**−0.009**	−0.012	0.020	−0.071	0.129	0.116	0.141	−0.053
	P	0.034	0.000	0.000	0.105	−0.020	**0.065**	0.006	0.014	−0.073	0.007	−0.010	0.082	−0.018
PL	G	−0.147	−0.102	0.546	0.169	−0.046	0.002	**0.054**	−0.009	0.365	0.039	−0.381	−0.181	0.018
	P	0.027	−0.001	−0.001	0.022	−0.002	−0.013	**−0.030**	−0.003	0.372	0.003	0.032	−0.101	0.006
PW	G	0.367	0.153	−0.423	−0.329	−0.112	−0.002	−0.004	**0.110**	−0.247	−0.014	0.172	0.233	−0.049
	P	−0.055	0.001	0.001	−0.034	−0.003	0.010	0.001	**0.089**	−0.228	−0.001	−0.015	0.126	−0.015
PW10	G	−0.454	−0.203	0.826	0.312	−0.056	0.001	0.030	−0.041	**0.659**	0.187	−0.322	−0.209	0.022
	P	0.061	−0.001	−0.001	0.039	−0.002	−0.006	−0.015	−0.027	**0.742**	0.010	0.028	−0.122	0.008
SW100	G	−0.529	−0.167	0.573	0.308	−0.151	−0.003	0.005	−0.004	0.298	**0.414**	−0.246	0.006	−0.009
	P	0.079	−0.001	−0.001	0.035	−0.004	0.019	−0.003	−0.002	0.276	**0.026**	0.021	0.002	−0.002
PC	G	−0.473	−0.198	0.946	0.481	−0.064	0.002	0.032	−0.029	0.329	0.158	**−0.644**	−0.086	0.016
	P	0.066	−0.001	−0.002	0.058	−0.002	−0.010	−0.015	−0.020	0.321	0.008	**0.065**	−0.054	0.004
DMC	G	0.267	0.123	−0.466	0.011	−0.217	−0.003	−0.021	0.055	−0.299	0.005	0.120	**0.461**	−0.048
	P	−0.040	0.001	0.001	0.002	−0.007	0.018	0.010	0.038	−0.303	0.000	−0.012	**0.297**	−0.016
CC	G	−0.133	−0.006	0.124	−0.293	0.478	0.005	0.009	−0.053	0.142	−0.037	−0.102	−0.219	**0.101**
	P	0.011	0.000	0.000	−0.032	0.013	−0.026	−0.004	−0.030	0.141	−0.001	0.006	−0.108	**0.043**

Bold figures = direct effect, residual effect = genotypic (0.3217) and phenotypic (0.2525).

content. Noorjahan *et al.* (2019) and Patel *et al.* (2016) also reported moderate estimates for PCV and GCV in dolichos bean for days to flowering and picking. It suggests that these traits would be less responsive to selection than the traits having high estimates of GCV. There is a very low or narrow difference between GCV and PCV values over the years for majority of the traits, which indicated the less influence of environment and the variation present is due to the genotypes. The broad sense heritability ranged from 47.62% (days to 50% flowering) to 94.72% (pod yield per plot). High heritability estimates were observed for majority of the traits in the present investigation which indicated the true presence of genetic variability in the studied local collections of dolichos bean. These findings suggest the implication of selection procedures for the improvement of dolichos bean (Patel *et al.*, 2016; Kumar *et al.*, 2021; Lahari *et al.*, 2022; Thasneem *et al.*, 2022). High genetic advance was also documented in Indian bean by Thasneem *et al.* (2022), Kumar *et al.* (2021), Gamit *et al.* (2020), Afsan and Roy (2020), and Peer *et al.* (2018) for days to first harvest, length of inflorescence, number of flowers per plant, number of pods per plant, average 10 pod weight, 100 seed weight, pod yield, pod length and pod width, all of which are comparable to the results of previous studies. The cumulative high estimates of heritability accompanied by high genetic advance for majority of traits suggested that a large proportion of phenotypic variability is due to genotypic variation, hence a reliable selection could be done for improvement of such traits. The results also suggested the contribution of additive genetic action in controlling these traits. The cluster analysis grouped the 22 lines including one standard check Kashi Sheetal into five different clusters indicating the wide range of variability for the exploitation to develop improved breeding lines and varieties suitable for Bundelkhand region of Uttar Pradesh in India.

The pod yield per plant showed the highest and significant positive association with the average weight of 10 pods, followed by inflorescence length, 100 seed weight, number of flowers per inflorescence, number of pods per inflorescence, pod length and protein content as per correlation coefficient analysis. The positive association for the related traits has been depicted earlier by Chaitanya *et al.* (2014), Gupta *et al.* (2017), Shulee *et al.* (2020), Thorat *et al.* (2020) and Attar *et al.* (2022) in dolichos bean. Whereas, days to first flowering, days to 50% flowering and days to first picking exhibited negative and significant associations with pod yield per plant. These results are in agreement with the findings of Thorat *et al.* (2020) and Chaitanya *et al.* (2014) in dolichos bean. The positive association among the studied traits indicated the scope for simultaneous improvement of these traits in a breeding programme. The results indicate that the dolichos bean yield potential can be increased by applying the strong selection to length of inflorescence, number of flowers per inflorescence, number of pods per inflorescence, pod length, average weight of 10 pods, 100 seed weight and protein content. The direct impact of a character indicates their relationship and direct selection for these attributes would be beneficial for increasing the yield potential. A critical perusal of path coefficient analysis revealed that high direct effects on pod yield per plant were exerted by length of inflorescence, average weight of 10 pods, 100 seed weight, pod width, dry matter content and days to 50% flowering. It is evident from correlation results that average weight of 10 pods had a positive significant correlation with pod yield per plant and rest of the traits also had a positive correlation with yield. These results clearly indicate the true genetic relationship between these traits and direct selection through these traits will be rewarding to improve the yield. Similar type of findings were also reported by Geetha and Divya (2021), Bansod *et al.* (2021) and Attar *et al.* (2022) in dolichos bean. The present investigation is first of its kind in the Bundelkhand region involving local collections, which is instrumental in the further genetic improvement of dolichos bean. The local collections are the reservoir of genes and tapping of local germplasm is of utmost importance for the crop improvement programmes in the era of climate change. In this context, the present investigation would pave the way for initiating dolichos bean breeding programme in the harsh conditions of Bundelkhand region which is characterizaed as dry and hot region.

Conclusion

The phenological, phenotypic and variance analysis for pod yield and its component traits suggested the existence of an adequate amount of variability among the experimental material and hence, a greater scope for the improvement of desired characters through selection is there. High heritability estimates coupled with high genetic advance as a percent of mean indicated that the traits under study are having predominant role of additive gene action and phenotypic selection will be rewarding. From correlation studies, it was observed that pod yield per plant had a significant positive association with the average weight of 10 pods, 100 seed weight, length of inflorescence, pod length and protein content. The positive direct effect on pod yield per plant was exhibited by days to 50% flowering, length of inflorescence, pod width, average weight of 10 pods, 100 seed weight, dry matter content and chlorophyll content. Based on mean performance, cluster studies and other genetic parameters, genotypes RLBDL-S-8, RLBDL-S-14, RLBDL-S-4-5 and RLBDL-S-5 were found to be better performing and these genotypes can be used as potential donors for increasing yield and agro-morphological characters in further breeding programmes. Among these RLBDL-S-8 outperformed all the accessions under study with respect to yield traits and can be a potential source for developing high-yielding genotypes in dolichos bean.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1479262124000091.

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