



Plant architecture evolution for higher yields in cluster bean (*Cyamopsis tetragonoloba*) under arid conditions

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Received: 25 February 2019; Accepted: 07 September 2019

ABSTRACT

Cluster bean [*Cyamopsis tetragonoloba* (L.) Taub] is an annual legume well adapted to limiting soil moisture and wide range of temperature fluctuations. In order to realize the potential of the crop, systematic cluster bean improvement efforts in India were initiated since 1961. Early released varieties were identified through multilocation germplasm testing. Selections, hybridization and mutagenesis have been contributing to recent varieties with more shares emanating from hybridization. Some of the earlier released varieties are still popular with the farmers. The traits responsible for high yield in guar varieties have not been analyzed and probably resulting in release of similar types with no or marginal gains. Hence, present investigation was undertaken to evaluate popular varieties with respect to seed yield and other associated morpho-physiological traits. Thirty varieties procured from the Agriculture Research Station, Durgapura (SKRAU, Bikaner), CCHAU, Hisar and CAZRI, Jodhpur were evaluated during *kharif* 2013, 2014 and 2015 at the Central Research Farm, Central Arid Zone Research Institute, Jodhpur, India. The analysis of variance indicated non-significant variation for important yield and yield attributing traits like pods/plant, pod length, seed weight and nodes per plant. The various traits like branches per plant, number of clusters and pods per cluster complemented so as to have comparable number of pods per plant and yield. Most of the contribution to variance comes from environments indicating adaptive plasticity in cluster bean irrespective of varieties. The varieties released meticulously incorporated early partitioning and increased proportion of reproductive phase for high yield.

Key words: ANOVA, Cluster bean, Correlation, Path coefficient, Stability

Cluster bean [*Cyamopsis tetragonoloba* (L.) Taub] is an annual legume crop of arid regions grown during monsoon season under rainfed conditions. It is well adapted to limiting soil moisture and wide range of temperature (FAO 2007). While being capable of sustaining under extended period of drought it tolerates moderate soil salinity (Ashraf *et al.* 2005) contrary to most legume crops. It is mainly grown in hostile environment of Indian arid zone receiving over 5.3 million ha in the country with the production of 3.3 mt of which Rajasthan contributes more than 80% both in area and production (Anonymous 2016). The crop has occupied important industrial value contributing to considerable foreign exchange after the identification of gum rich endosperm during World War II. The guar gum has diversified uses in textile and paper industry, food processing, cosmetics, mining, pharmaceutical, explosive, petroleum, drilling, oil industries and refinery etc. In order to realize the potential of crop, systematic cluster bean improvement efforts in India were initiated in early 1960s. The diverse germplasm was collected from prime areas of

variability, viz. Gujarat, Rajasthan and Punjab for cluster bean improvement (Thomas and Dabas 1982, Dabas *et al.* 1982). Since then over 30 varieties have been released by the central variety release committee for fodder, seed and dual purposes. Initially, high yielding genotypes identified from evaluation of germplasm were released as varieties. Though both selections and hybridization programs are contributing to recent varieties share of varieties emanating from hybridization is more. The varieties developed over a period of time are still popular with the farmers. The traits responsible for high yield in guar varieties have not been analyzed and probably resulted in release of similar type of varieties with no or marginal gains. Hence, present investigation was undertaken to evaluate important varieties for the yield potential with respect to yield and yield attributing traits. The correlation, path analysis and stability analysis were done to understand the role of various traits in defining the yield in released varieties.

MATERIALS AND METHODS

Thirty varieties procured from the Agriculture Research Station, Durgapura (SKRAU, Bikaner), CCHAU, Hisar and CAZRI, Jodhpur were evaluated during *kharif* 2013, 2014 and 2015 at the Central Research Farm, Central Arid Zone Research Institute, Jodhpur, India. The experiment

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was laid out in randomized block design (RBD) with three replications. The genotypes were sown in two rows of 4 m length following spacing of 45×15 cm. The crop was raised with optimum management practices under rainfed conditions. Observations were recorded for the following characters: flower initiation (Fl Ini), 50% flowering (Fl 50%), plant height (Pt Ht), number of branches per plant (Br/Pt), nodes per plant (Nod/Pt), number of clusters on main stem (Cl Main) and branches (Cl Br), cluster length (Cl Lt), pods per cluster (Pod/Cl), pod length (Pod Lt), pods per plant (Pod/Pt), seeds per pod (Sd/Pod), 100 seed weight (Sd Wt) and yield per plant (Yld/Pt). Data were recorded on individual five plants per plot selected randomly and averaged for analysis. The recorded data for phenotypic characters were analyzed by determining their descriptive statistics using SAS Enterprise Guide version 9.3 software. Path coefficient analysis was carried out following Dewey and Lu (1959) and stability parameters as per Eberhart and Russell (1966) model.

RESULTS AND DISCUSSION

The analysis of variance showed non-significant variation for important yield attributing traits like pods per plant, pod length, 100 seed weight and nodes per plant including yield per plant. However, traits, viz. flower initiation, plant height, 50% flowering, branches per plant, clusters on main stem, clusters on branches, cluster length and pods per cluster along with seeds per pod varied significantly for the varieties studied. Environmental variation was significant for all the traits and interactions between varieties and environments were found non-significant only for seeds per pod. Yield of varieties was thus influenced in predictable manner with the change of environment. Evidently varieties compensated for branches per plant, clusters per plant and pods per cluster so as to have comparable number of pods per plant and yield per plant defining a modular architecture. Larger contribution to variance by environmental factor entails adaptive plasticity in cluster bean common to all varieties. A high varietal response to precipitation amount, frequency and associated environmental conditions has been responsible for high variance due to environment. Well distributed rains during 2014 resulted in high yield per plant (23.75 g) compared to remaining two years (2013 and 2015) that suffered from poor and fewer rain events.

Highest yield per plant (15.84 g) over the years was recorded in HG-884, while BG-1 gave the lowest yield per plant (7.61g) with an average of 11.98 g. The coefficient of variation (CV %) is appropriate statistics for comparing the extent of variation between different characters with different scales. The CV was found maximum for cluster on branches (37.36 %) followed by branches per plant (34.02 %). High range was also observed for plant height (86-132) and pods per plant (38.89-64.58). Higher level of diversity for clusters on branches and branches per plant may be because of inclusion of a few erect types that were un-branched (FS-277, RGC-1066 and AG-112).

Contrary to present findings a very high range of variation has been recorded in a study with 3835 accessions during 1988-1989 and 1989-1990 by Dwivedi and Bhatnagar (2002) for various characters, viz. yield per plant (0.4-71.0 g), plant height (15.0-238.0 cm), branches per plant (00-29.0), pods per plant (3.7-412.0), pods length (1.6-11.97 cm), seed per pod (2-14.77) and 50% flowering (25.0-76.0). The high level of variation in cluster bean has also been supported by various other studies (Dabas *et al.* 1981, Dwivedi *et al.* 1999). A narrow range observed for varieties for yield and yield attributing traits indicated development of similar plant architecture following uniform selection criteria by various workers. The most important trait that got selected while breeding for high yielding genotypes seems to be early flowering. The varieties under study flowered within 28-33 days of sowing that is towards minimum period recorded in the germplasm by Dwivedi and Bhatnagar (2002). It seems, early onset of reproductive phase with capacity to harvest photosynthate coupled with increased sink size in terms of more pods per cluster and pods per plant, seeds per pod, borne on optimum number of branches got incorporated in the desirable plant types represented in released varieties. Once optimized for the traits contributing to high yield within the available plant architecture further improvement ultimately ceased. However, though varieties differ non-significantly when compared with genotype-environment interaction, differences were significant compared to total error variance. The subtle but progressive improvement in yield potential of varieties was observed as newer varieties were better performing, showing a positive correlation (0.280) with year of release and average performance of varieties.

Genotypic and phenotypic correlations were high for yield with pods per plant (0.93 and 0.57 respectively), clusters on branches (0.35 and 0.30 respectively) and branches per plant (0.21 and 0.22 respectively). Similar correlations were reported by Morris (2010), Manivannan *et al.* (2015), Jukanti *et al.* (2015) and Boghara *et al.* (2016). However, days to 50% flowering had negative genotypic correlation with yield per plant (-0.29), pods per cluster and pods per plant signifying importance of early availability of sink for realizing higher yields (Table 1). Branches per plant had positive genotypic and phenotypic correlations with clusters on branches (0.97 and 0.69) and negative with clusters on main stem (-0.59 and -0.24), cluster length (-0.89 and -0.39) and pods per cluster (-0.74 and -0.41). Highly significant correlations of seed yield with branches per plant and pods per plant were also reported by Mahla and Kumar (2006). Thus, increasing branches per plant contributed to yield by bearing smaller but more clusters on branches compensating for clusters on main stem and pods per cluster. The physiological limitations in terms of available photosynthetic assimilates probably evolved to harmonize clusters per plant, cluster length and pods per cluster.

Pod length could not be improved significantly in the released varieties (~6 cm as against ~11 cm in the

Table 1 Correlation coefficient on the basis of Phenotypic and Genotypic level between different characters of cluster bean

Phenotypical cor. relation	Genotypic correlation													
	Fl Ini	Fl 50%	Pt Ht (cm)	Nod/ pt	Br/ Pt	Cl Main	Cl Br	Cl Lt (cm)	Pods/ Cl	Pod/ pt	Pod Lt (cm)	Seeds/ pod	100 seed wt (g)	Yld/pt (g)
Fl Ini	1	0.83	0.50	-0.05	0.14	0.37	0.16	0.07	-0.47	-0.53	-0.10	0.16	0.28	-0.29
Fl 50%	0.73**	1	0.58	-0.08	0.08	0.10	-0.04	0.09	-0.45	-0.49	-0.33	0.30	0.18	-0.31
Pt Ht (cm)	0.25**	0.33**	1	0.47	-0.14	0.18	-0.21	0.56	0.01	-0.61	0.41	0.55	-0.05	-0.33
Nod/Pt	0.04	0.11	0.34**	1	0.37	-0.28	0.33	0.11	-0.05	0.17	0.15	0.00	-0.12	0.29
Br/Pt	0.09	0.12	0.11	0.34**	1	-0.59	0.97	-0.89	-0.74	0.21	-0.59	-0.23	0.18	0.21
Cl Main	0.26**	0.19**	0.21**	0.11	-0.23**	1	-0.47	0.55	0.23	-0.31	0.40	0.09	0.04	-0.25
Cl Br	0.18**	0.05	-0.10	0.35**	0.68**	0.01	1	-0.82	-0.64	0.26	-0.60	-0.24	0.19	0.35
Cl Lt (cm)	0.12	0.14*	0.38**	0.18**	-0.38**	0.45**	-0.27**	1	0.78	-0.35	0.75	0.40	-0.25	-0.13
Pod/Cl	-0.25**	-0.22**	0.12*	0.17**	-0.40**	0.29**	-0.21**	0.59**	1	0.25	0.62	0.12	-0.21	0.18
Pods/Pt	-0.14*	-0.09	-0.04	0.07	0.13 *	0.13*	0.25**	-0.03	0.06	1	-0.61	-0.48	-0.01	0.93
Pod Lt (cm)	0.05	0.05	0.08	0.01	-0.120*	0.12	-0.09	0.17**	0.19**	-0.04	1	-0.07	-0.44	-0.57
Seed/pod	0.15*	0.19**	0.21**	0.18**	0.02	0.13*	0.01	0.18**	0.02	-0.04	0.22**	1	0.31	-0.05
100 Seed Wt (g)	0.19**	0.21**	0.00	0.06	0.07	0.12*	0.11*	-0.02	-0.08	0.12	0.06	0.20**	1	-0.16
Yld/Pt (gm)	-0.10	-0.06	0.02	0.15	0.22	0.15	0.30	-0.01	0.07	0.57	0.03	0.10	0.04	1

(Fl Ini=flower initiation, Fl 50% = 50% flowering, Pt Ht. = Plant height (cm), Br/Pt = Branch per plant, Nod/Pt= Nodes per plant, Cl Main = clusters on main branch, Cl Br = clusters on branch, Cl Lt = cluster length (cm), Pod/Cl = Pods per cluster, Pod/Pt = Pods per plant, Pod Lt = Pod length (cm), Sd/Pod = Seeds per pod, Sd Wt =100 seeds weight (g), Yld/Pt =Yield per plant(g).

* =significant at 1% level; **=significant at 5% level

germplasm) probably due to its high negative genotypic correlation with yield per plant (-0.57, 0.03) and associated traits, viz. pods per plant (-0.61, -0.04), branches per plant (-0.59, -0.12), 50% flowering (-0.33, 0.05) and seed index (-0.44, 0.05), while it is positively correlated with plant height (0.41, 0.08), cluster length (0.75, 0.17), pods per cluster (0.62, 0.19). This indicated that the taller, less or unbranched (single stem) varieties with longer clusters bearing more pods tended to have longer pods while early flowering high yielders having more branches per plant and

pods per plant tended to have smaller pods with low seed index. It also indicated the involvement of same set of genes or linked genes for defining cluster length and plant height, since inflorescence and flower are modifications of stem.

High positive path coefficients were observed for clusters on branches (4.60, 0.12), plant height (1.55, 0.018) and pods per plant (0.36, 0.50) (Fig 1). Very high correlation of yield with pods per plant with positive direct effect can be important trait for selection of high yielding types. Similarly, clusters on branches and plant height that mutually lead to

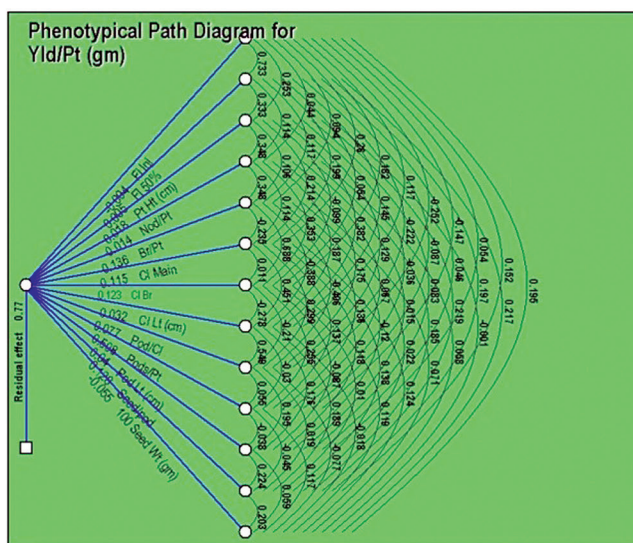
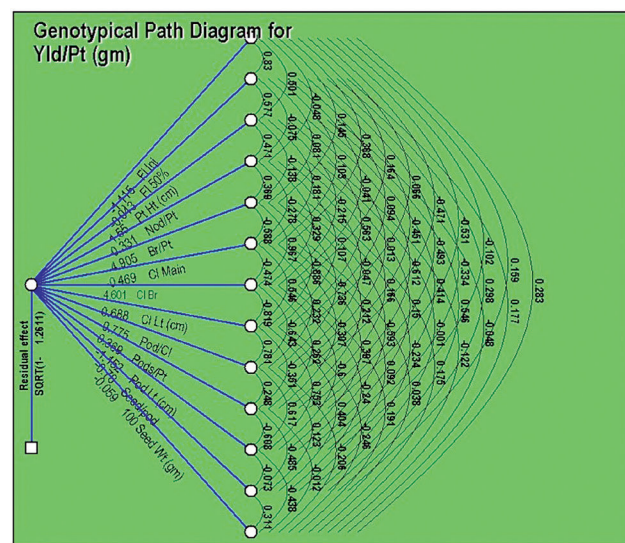


Fig 1 Genotypic (a) and phenotypic (b) path coefficient analysis for yield in cluster bean.

more branches with more clusters are important traits for seed yield. The negative direct effect of branches per plant with positive correlation indicated need to breed a plant type having optimum number of branches. Hence, there is still scope for optimization of the number of branches to maximize clusters on branches and pods per plant.

Since, all the traits showed significant variety $\times$ year interactions, different stability parameters were employed to understand the way in which performance of varieties is affected by environment. The huge variation in amount and pattern of rains received during three experimental years resulted in significant linear component of environment for all traits except pods per cluster. Variety $\times$ environment linear component was significant only for two traits, viz. clusters on main stem and yield per plant while pooled deviation component was significant for all the traits except pods length and seeds per pod. This indicated random response of traits to environment with some predictability for clusters on main stem and yield per plant.

Three stability parameters consisting of mean performance, regression coefficient “bi” and deviation from regression “ σ^2_{di} ” were used to evaluate varieties (Table 2). A genotype with a unit value for regression coefficient and minimum deviation from regression is considered to be stable (Eberhart and Russell 1966). However, none of the varieties deviated significantly from unity for yield. The two single stem (erect unbranched) genotypes RGC 1066 and AG-112 bore more clusters on main stem in better environment with significantly higher bi value than unity due to their better growth and increased number of nodes (Table 2). Early flowering short statured plant type probably contributed to stability of yield and efficiency to utilize better environment as suggested by negatively correlated yield bi values with mean flower initiation (-0.395), 50% flowering (-0.265) and plant height (-0.276). This again brings about the importance of early onset of reproductive phase and translocation of photosynthate. Moreover, indeterminate growth habit with early flowering enables plant to compensate for the available resources mainly in terms of water. Flowering date has been suggested to have major bearing on adaptation of a crop to the environmental conditions (Huyghe 1998).

The released varieties did not differ significantly for their yield ability. However, a gain of 28% was observed when yield was correlated with year of release. Yield of varieties was highly influenced by environment in predictable manner showing absence of interactions. Positively correlated traits having direct effect on yield, viz. clusters on branches, plant height and pods per plant are important contributors to yield. Varietal improvement while preserved the inherent phenotypic plasticity of guar providing mechanism for higher and stable yield, the performance was improved by incorporating early onset of well distributed sink. The sink size and distribution were optimized through interplay of various traits determining pods per plant and yield per plant, viz. branches per plant, cluster length and pods per cluster. However, possibilities

Table 2 Mean yield, regression coefficient (bi), coefficient of deviation from regression (σ^2_{di}) of cluster bean

Variety	σ^2_{di}	Mean	bi
HG-258	0.15	5.45	0.01
HG-365	0.30	5.76	0.07
HG-563	0.21	6.37	-1.56
HG-182	0.05	4.70	0.19
HG-832	0.05	4.13	1.13
HG-884	0.31	5.24	0.32
HG-119	0.04	4.99	1.03
HG-75	0.00	5.42	1.04
HG-870	0.00	5.71	2.89
HG 2-20	0.06	5.10	1.84
RGM-112	0.09	5.20	2.74
FS-277	0.46	5.41	2.92
RGC-471	0.04	5.05	-2.21
RGC-986	0.10	4.94	-1.79
RGC-1066	0.01	5.07	-1.67
RGC-936	0.17	4.59	-0.44
RGC-1002	0.05	4.76	-1.23
RGC-1017	0.74	4.98	-1.42
RGC-1038	0.00	4.22	1.24
RGC-1031	0.01	4.17	0.88
RGC-1033	0.19	4.76	0.42
RGC-1055	0.05	5.59	1.36
GG-1	0.01	5.60	0.90
GG-2	0.05	6.56	1.62
BG-1	0.01	4.56	0.08
BG-2	0.06	4.52	-0.40
BG-3	0.00	5.91	0.88
Agaita Guara-112	0.00	6.95	7.63
Guara-80	0.05	6.77	4.69
Maru Guar	0.01	6.90	6.83

Here, σ^2_{di} = coefficient of deviation from regression, bi = regression coefficient

could still be explored to optimize branches per plant and incorporate pod length so as to achieve a new balance among traits for even higher yields and stability.

ACKNOWLEDGMENT

Authors are acknowledging the financial assistance provided by Protection of Plant Varieties and Farmers' Rights Authority, Government of India, Ministry of Agriculture & Farmers Welfare, New Delhi under the project “Establishment of field gene bank in arid region”.

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