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Influence of Shade on Genotypic Performance of Clusterbean (*Cyamopsis tetragonoloba*, L. Taub.) under Hot Arid Conditions

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Abstract: Twelve varieties of guar were evaluated in shade and open environments. Analysis of variance for varieties showed non-significant variations for days to 50% flowering and pods per plant for both shade and open environments while nodes per plant, cluster length, pods per cluster and seeds per pod were non-significant in shade only with other traits being significantly variable in both the environments. As expected for a species of dry habitat, shade avoidance mechanism for most of the traits showed increase in the value under shade however, a small reduction in days to flowering and number of branches was recorded. Yield was significantly correlated with nodes per plant, branches per plant and pods per plant under both the open and shaded environment. However, cluster on branches was though positive in both the environments, it was significant only under shade. Path analysis for shade environment indicated maximum direct effect by cluster on branches followed by days to flower initiation, cluster length and nodes per plant. The increase in yield was accompanied by increase in cluster length, pods per cluster, pod length and seeds per pod indicating increased efficiency of plant under 35% reduced radiation and associated heat stress, probably proved beneficial for seed yield.

Key words: ANOVA, clusterbean, *Cyamopsis tetragonoloba*, correlations, genetic variability, path analysis, yield.

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Clusterbean (*Cyamopsis tetragonoloba* (L.) Taub), popularly known as clusterbean is drought hardy crop grown mainly in Thar Desert covering regions of India and Pakistan. Clusterbean, probably also originated in –this region and is characterized as a short day erect or bushy annual (Purseglove, 1981). It attained an industrial importance and export value for its multipurpose seed borne gum (galactomannan) (Lee *et al*., 2004; Rodge, 2008). In 2017-18 alone, 419952 tons of clusterbean gum worth US$ 647 million was exported from India (Thombare *et al*., 2016; APEDA, 2018). Clusterbean seed is composed of three main components, expressed as percentage: seed coat 14-17%, endosperm 35-42% (mostly galactomannan), and embryo 43-47% (Goldstein and Alter, 1959).

Hot arid climate prevailing in western Rajasthan suits the cultivation of clusterbean which can survive extended periods of drought and high salinity (Francois *et al*., 1990; Ashraf *et al*., 2005). Obviously, the clusterbean has evolved to sustain the harsh climate characterized by intermittent drought spells; high solar radiation and temperature and nutrient poor soils of the region. In hot arid environment, high air temperature and low humidity are the two factors thought to be critical for reductions in photosynthetic capacity. However, extremely high summer irradiance prevalent in this region is particularly severe that not only directly limits the photosynthetic activity but also contributes to enhanced environmental temperature and soil moisture depletion, further accentuating the adverse effect on photosynthetic activity.

The clusterbean possesses highly developed physiological mechanism to tolerate the three important abiotic stresses i.e., high temperature, high irradiance and moisture deficit. Morphologically, woody clusterbean plants are dark green and are covered by pubescence for efficient reflection of solar radiations whereas it seems to be efficient in energy dissipation and quenching of free radicals to survive absorbed extra light energy. However, the acclimation to solar radiation is an active process requiring energy for efficient enactment that is expected to inhibit the realization of potential of the varieties in the open fields. In an study with three clusterbean genotypes, Vyas *et al.* (1996) reported an increase in yield at 25% shading accompanied by an increase in the plant height, nodes per plant and yield attributes like pods per plant, seed per pod and seed size. The study indicated genotypic differences also although very few genotypes were investigated. The biggest challenge is thus to understand the effect of extreme climatic conditions on growth and yield of clusterbean and develop genotypes especially suited to adverse growth conditions prevailing in the arid region.

Yield improvement program, selection of superior parents is an essential prerequisite i.e., possessing better heritability and genetic advance along with *per se* performance for various traits (Khan *et al.*, 2005). Correlation analysis provides the information of interrelationship of significant plant traits and hence, leads to a directional model for direct and/or indirect improvement in grain yield (Khan *et al.*, 2004). Correlation and path studies give an idea about the contribution of different characters to seed yield (Vandana and Dubey, 1993). Hence, current studies were conducted to estimate the genetic variability, heritability, correlations and association among yield and yield attributing traits between different genotypes of clusterbean under shade and open conditions.

Materials and Methods

Plant materials and field evaluation

Twelve morphologically diverse varieties were evaluated during kharif 2017 in Central Arid Zone Research Institute (26.3°N and 73.02°E), Jodhpur, India. Six of them viz., HVG 2-30, M-83, FS-277, AG-112, RGC-197 and RGC-1066 were single stem while HG2-20, HG-884, RGC-1038, RGC-1017, RGC-986 and HG-365 were branched. Of these M-83 and HVG 2-30 were smooth and glabrous while rests all were pubescent. The experiment 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 x 15 cm. The crop was raised with optimum management practices both under open and shaded conditions. The shade was created by a plastic dome fitted in rainout shelter. The shading achieved was about 35% of the average irradiation (3.2-6.8 µmol m^{-2} sec^{-1}) received per day during clusterbean growing season (July-November). Shading was calculated using line quantum sensor with meter attached (LQM 70-10-S).

Morphological characterization

Observations were recorded on individual plant basis for the following morphological characters: plant height (PH, cm), nodes per plant (NP), branches per plant (BP), clusters on main stem (CM) and branches (CB), cluster length (CL, cm), pods per cluster (PDC), pod length (PDL, cm), pods per plant (PDP), seeds per pod (SPP), 100 seed weight (SW, g) and yield per plant (YP, g), while days to flower initiation (FI) and 50% flowering (50% F) were recorded on the plot basis.

Statistical analysis

The genotypic and phenotypic components of variance, coefficients of variability, broad sense heritability and genetic advance were estimated by adopting the formulae suggested by Allard (1960) and Singh and Chaudhary (1977) using pooled data and under both environments. As correlation alone cannot explain relationships among the characters therefore, path coefficient

Table 1. Summary of analysis of variance (ANOVA) for different morpho-physiological characters

Source	Replication			Variety			Environment	V X E	Error		
DF	2			11			1	11	46		
	Pooled	Shade	Open	Pooled	Shade	Open	Pooled	Pooled	Pooled	Shade	Open
FI	199.74	71.05	107.56	97.15***	68.97**	43.889*	203.34**	74.81**	70.43	30.27	24.44
50%F	161.67	48.22	93.39	55.66**	29.64	41.64	190.12**	90.38**	86.67	31.77	39.28
PH	62106.52	268.09	213.90	8725.42***	10574.21***	1971.40***	63308.68**	3577.82	8896.37	4420.17	656.01
BR	3.39	1.35	0.48	576.88***	268.15***	321.94**	0.06	9.61	40.20	16.71	10.27
ND	156.30	0.15	2.96	176.39***	123.16	103.10**	180.5 **	93.17	185.15	113.67	21.59
CM	26.15	0.08	8.88	163.96***	106.36**	136.40**	10.89	33.44	149.57	48.64	22.13
CB	16.51	14.92	1.34	1311.63***	600.96***	730.35**	19.01*	34.49	102.44	46.44	36.32
CL	10.46	3.19	0.84	52.56***	25.00	40.82***	5.55*	21.44	63.77	29.10	21.41
PDC	9.46	2.42	1.54	33.23**	24.46	20.07**	0.22	19.11	48.56	26.13	11.13
PDL	3.84	1.51	0.60	22.50**	12.49***	13.38***	4.01**	4.82	10.35	2.60	4.37
PDP	303.15	172.42	86.41	2053.39**	869.24	1678.46	382.72 *	403.28	3572.62	1322.03	1756.28
SPP	6.74	0.84	2.55	10.31**	5.87	11.07*	1.68*	8.48*	18.84	6.64	5.56
SW	0.77	0.69	0.07	10.61***	5.03**	6.65**	0.22 *	3.77**	5.15	3.14	0.94
YP	103.48	6.91	12.32	99.77**	72.26**	78.42**	41.09**	55.72**	118.01	37.70	29.39

DF = Degree of freedom, FI = Flower initiation, 50% F = 50% Flowering, PH = Plant height (cm), BR = Branch per plant, ND = Nodes per plant, CM = Clusters on main branch, CB = Clusters on branch, CL = Cluster length (cm), PDC = Pods per cluster, PDL = Pod length (cm), PDP = Pods per plant, SPP = Seeds per pod, SW = 100 seeds weight (g), YP =Yield per plant(g)

analysis was carried out following Dewey and Lu (1959). The recorded data for phenotypic characters were analyzed by determining their descriptive statistics using OPSTAT software (Sheoran *et al*., 1998).

Results and Discussion

Analysis of variance (ANOVA)

The analysis of variance (Table 1) of pooled data, indicated significant genotypic variation for all important yield attributing traits. Environmental variations were also significant for all the traits except branches per plant, clusters on main stem and pods per cluster. Interactions between varieties and environments were found significant for days to flower initiation, days to 50% flowering, seeds per pod, 100 seeds weight and yield per plant.

Varieties showed non-significant variations for days to 50% flowering and pods per plant for both in shade and open environment while nodes per plant, cluster length, pods per cluster and seeds per pod were non-significant in shade environment only with other traits being significantly variable in both the environments. A high varietal response to shade associated environmental conditions has been responsible for high variance due to environment for days to flowering, plant height and yield per plant. The shade significantly increased the plant height and delayed onset of flowering with increase in yield. This indicated detrimental influence of solar radiation on productivity of plant in open environment.

Determination of mean, range values, coefficient of variations and genetic parameters

The coefficient of variation, range, mean, heritability [h^2 (%)], genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV), genetic advance (GA) and genetic advance as per cent of mean (GAM) were estimated for pooled and both the environments (Table 2). Maximum increase under shade was for plant height (99.51%) over open (59.19%) followed by yield per plant (53.88%) over open (4.50%). Most of the traits showed increase in the value under shade however, a small reduction in days to flowering and number of branches was recorded. Maximum increase in yield (Table 3) was recorded for a single stem clusterbean variety M-83 (196.32%), followed by branched varieties RGC-1017 (136.84%) and HG 2-20 (105.37%). All of the varieties except two single stem pubescent types, RGC-197 and RGC-1066 exhibited an increase in yield under shade (Table 2). Similar results were reported by Vyas *et al.* (1996) for clusterbean and Mauro *et al.* (2013) for *Medicago truncatula* and *Trifolium subterraneum*.

Table 2. Genetic parameters for different characters in clusterbean

Traits		FI	50% F	PH	BR	ND	CM	CB	CL	PDC	PDL	PDP	SPP	SW	YP
C.V.		0.50	0.62	11.38	38.96	16.06	21.55	53.91	21.01	16.37	9.38	30.18	7.29	4.11	71.25
Range		28-34	30-38	43.3-176.6	0-8.3	9.3-22.6	4.3-14	0-18.3	2.6-7.5	2.3-8.6	4.3-7.8	13.3-57.6	5.7-8.9	3.25-5	1.4-10.95
Mean	Pooled	31.43	34.32	88.64	2.77	14.31	7.50	3.73	5.07	4.63	5.87	30.19	7.82	4.06	5.86
	Shade	30.86	33.81	118.09	2.69	15.77	8.02	3.80	5.38	4.90	6.02	30.92	8.04	4.05	6.93
	Open	31.97	34.89	59.19	2.86	12.84	6.99	3.65	4.76	4.35	5.71	29.46	7.61	4.06	4.50
h^2 (%)	Pooled	54.51	27.99	37.10	89.77	32.89	42.36	85.78	33.35	28.75	62.21	24.63	22.46	60.78	35.44
	Shade	54.24	22.39	55.78	91.20	28.01	52.93	89.24	19.31	22.52	74.11	9.50	20.38	42.32	48.58
	Open	54.09	30.38	55.99	88.46	35.93	70.14	78.54	47.35	46.49	63.06	24.35	49.84	81.46	57.48
GCV (%)	Pooled	3.88	2.25	11.26	103.46	10.34	18.60	109.98	15.32	12.91	9.48	15.33	4.03	9.40	18.64
	Shade	4.14	1.91	13.48	104.51	8.99	19.67	110.13	10.46	11.99	9.67	8.53	3.46	8.00	18.36
	Open	3.36	2.45	11.50	101.87	11.56	25.43	107.19	20.34	15.25	10.19	16.55	6.59	10.66	29.53
PCV (%)	Pooled	5.26	4.25	18.49	109.19	18.03	28.58	118.75	26.52	24.07	12.02	30.89	8.50	12.05	31.31
	Shade	5.62	4.04	18.05	109.44	16.99	27.03	116.58	23.79	25.26	11.23	27.66	7.66	12.30	26.34
	Open	4.57	4.44	15.37	108.31	19.29	30.36	120.95	29.55	22.36	12.84	33.54	9.33	11.81	38.96
GA	Pooled	1.86	0.84	12.52	5.60	1.75	1.87	7.83	0.92	0.66	0.90	4.73	0.31	0.61	1.34
	Shade	1.94	0.63	24.49	5.52	1.55	2.36	8.14	0.51	0.57	1.03	1.60	0.26	0.43	1.83
	Open	1.63	0.97	10.49	5.67	1.83	3.06	7.16	1.37	0.93	0.95	5.20	0.73	0.81	2.19
GAM (%)	Pooled	5.90	2.45	14.13	201.93	12.22	24.94	209.83	18.22	14.26	15.40	15.67	3.93	15.09	22.86
	Shade	6.28	1.86	20.74	205.60	9.80	29.48	214.31	9.47	11.72	17.14	5.41	3.22	10.72	26.36
	Open	5.09	2.78	17.73	197.37	14.28	43.87	195.69	28.83	21.42	16.67	16.82	9.58	19.81	46.13
% change over open		-3.48	-3.10	99.51	-6.09	22.78	14.78	4.05	13.18	12.70	5.42	4.96	5.68	-0.38	53.88

CV% = Coefficient of variation, h^2 = Heritability (%), GCV = Genotypic coefficient of variation, PCV = Phenotypic coefficient of variation, GA = Genetic advance, GAM = Genetic advance as per cent of mean, FI = Flower initiation, 50% F = 50% Flowering, PH = Plant height (cm), BR = Branch per plant, ND = Nodes per plant, CM = Clusters on main branch, CB = Clusters on branch, CL = Cluster length (cm), PDC = Pods per cluster, PDL = Pod length (cm), PDP = Pods per plant, SPP = Seeds per pod , SW = 100 seeds weight (g), YP = Yield per plant(g).

The coefficient of variation (CV%) is appropriate statistics for comparing the extent of variation between different characters with different scales. The CV% was maximum for yield per plant (71.25%) followed by clusters per branch (53.91%) and branches per plant (38.96%) in pooled analysis. Highest heritability (broad sense) for pooled (89.77 %) and both environments (shade and open) was observed for branches per plant followed by clusters on branches, pod length, days to flower initiation, indicating the least influence of environment in their expression (Table 2), thus suggesting that selection for these traits based on phenotypic

Table 3. Comparison of varietal yield (g) under shade and open conditions

Varieties	Yield in Shade (g)	Yield in Open (g)	% change over open
HVG 2-30	4.72	3.83	23.08
M-83	5.64	1.90	196.32
FS-277	6.89	3.55	94.20
AG-112	6.89	4.72	45.85
RGC-197	5.81	6.11	-4.84
RGC-1066	5.56	6.01	-7.52
HG2-2-20	9.60	4.67	105.37
HG-884	8.67	5.33	62.74
RGC-1038	7.53	5.48	37.40
RGC-1017	7.22	3.05	136.84
RGC-986	6.01	4.88	23.10
HG-365	8.65	7.67	12.73

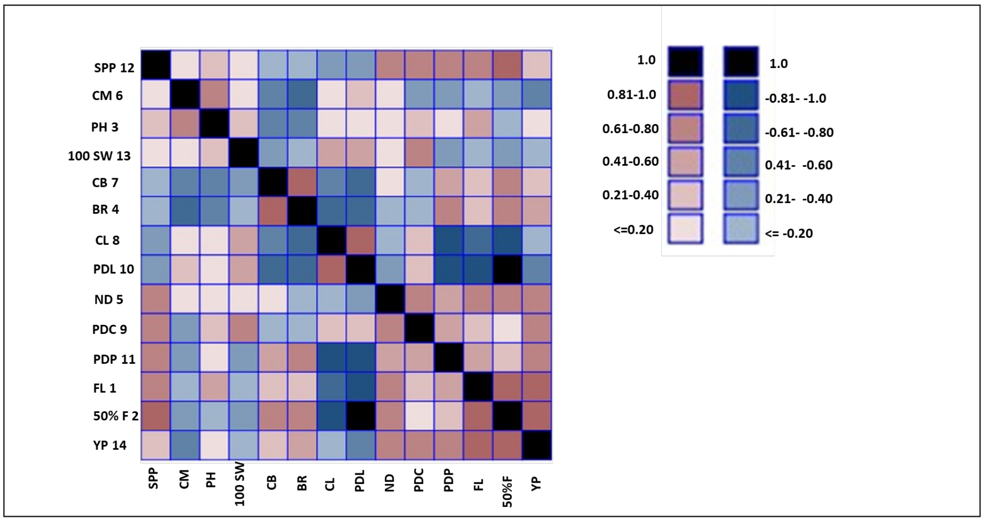

Fig. 1a. Genotypic correlation of different traits under open environment.

appearance would be reliable in the future. These results are in accordance with Rai *et al.* (2012) whereas, in conflict with those of Kapoor and Bajaj (2014). GCV for pooled ranged from 2.25 for days to 50% flowering to 109.98 for clusters on branches. High GCV was observed for branches per plant (103.46). Similarly for shade it ranged from 1.91 to 110.13 and for open environment and 2.45 to 107.19 for days to 50% flowering and cluster on branches respectively. The magnitude of PCV was in general higher than corresponding genotypic coefficient of variation indicating the higher influence of environmental factors in their expression. These results are similar to those of Dwivedi (2009) and Malaghan (2012) which indicate that greater the genetic variability among the parents, more are the chances of further improvement. High genetic advance as percentage of mean (GAM) for pooled and both shade and open environment was observed for number of clusters on branches and branches per plant. High genetic advance coupled with high heritability could have resulted from low environment interactions and high variations for the traits and are in accordance with the findings of Gipson and Balakrishnan (1990) and Saini *et al.* (2010).

Correlation coefficient and path analysis

A perusal of results (Fig. 1a,b) revealed greater genotypic correlations than their corresponding phenotypic correlations indicating the preponderance of genetic variance

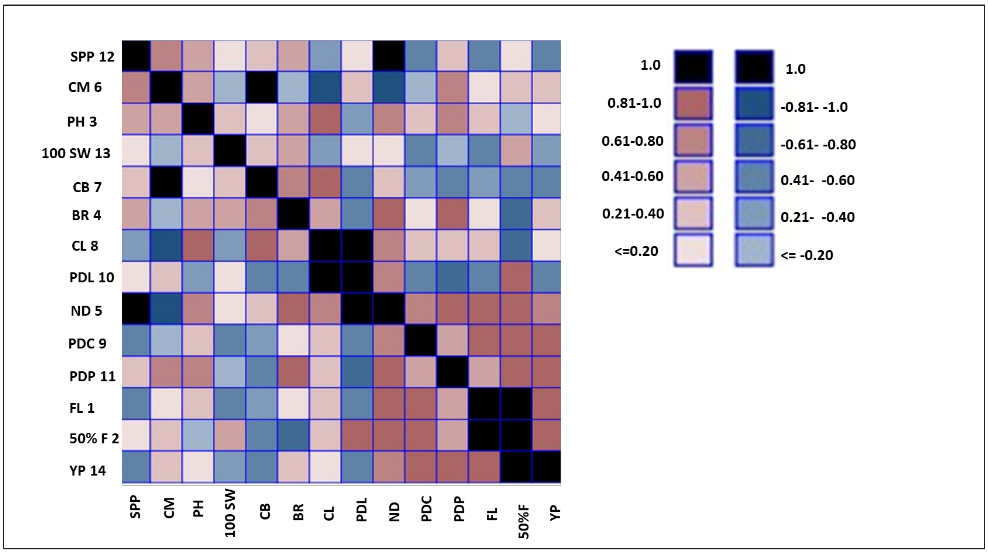

Fig. 1b. Genotypic correlation of different traits under shade environment.

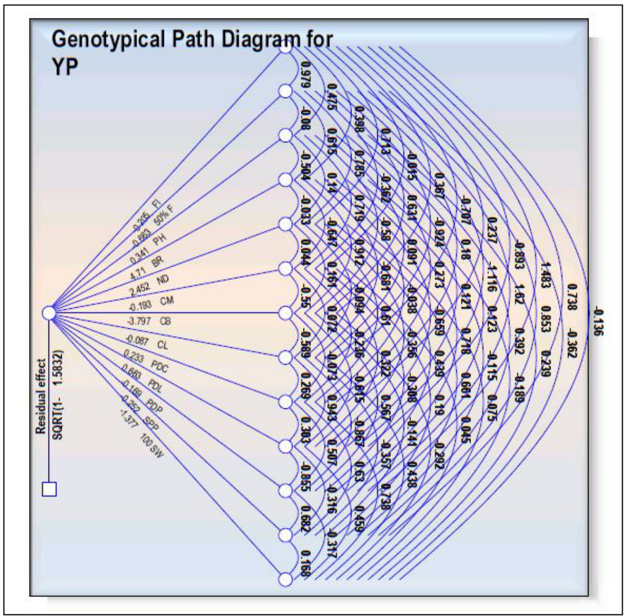

Fig. 2a. Genotypic path coefficients for shade environment.

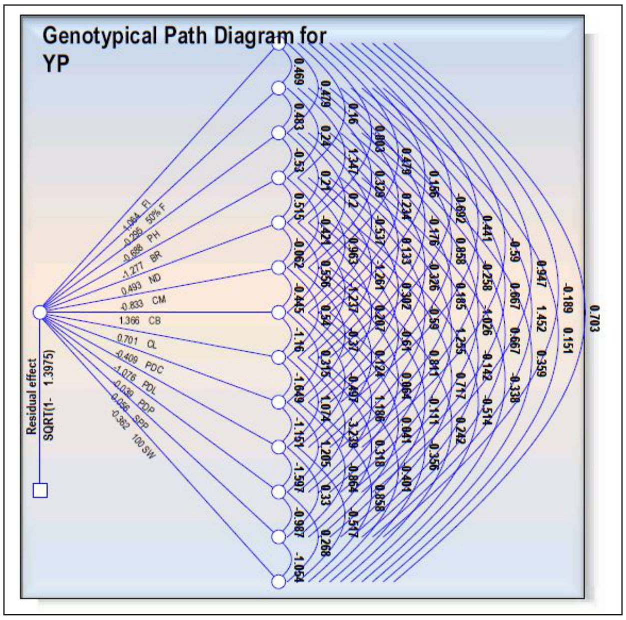

Figure 2b. Genotypic path coefficients for open environment.

in expression of characters (Gill *et al*., 1995). Genotypic correlations for open environment (Fig. 1a) were higher and significant for yield with days to 50% flowering (0.996) followed by days to flower initiation (0.811), pods per plant (0.744), pods per cluster (0.716), nodes per plant (0.630), branches per plant (0.410) and seeds per pod (0.363). Genotypic correlations were also positive for shade environment (Fig. 1b) for nodes per plant (0.858), branches per plant (0.800) and pods per plant (0.644). Clusters on main stem and pod length were negatively correlated with yield in both the environments, whereas cluster length, 100 seed weight and plant height were negatively correlated with yield only in shade. Similar results were reported in open environment by Akhtar *et al*. (2015), Manivannan *et al*. (2015), Jukanti *et al*. (2015) and Boghara *et al*. (2016), in partial agreement with Rohman and Hussain (2003) while contradicts from Kalpande *et al*. (1997).

Cause and effect relationship of seed yield in path analysis for shade environment (Fig. 2a) indicated maximum direct effect by cluster on branches (1.36) followed by days to flower initiation (1.06), cluster length (0.70) and nodes per plant (0.49). Pods per plant (1.62), branches per plant (1.36) and nodes per plant (0.75) exhibited positive indirect effect through Clusters on branches. Indirect effects of pods per plant (1.00), nodes per plant (0.85) and seeds per plant (0.74) through days to flower initiation and pod length (0.75), seeds per pod (0.22) and cluster on branches (0.37) through cluster length were also important. Similar results were in conformity with findings of Patil (2014) under open environment study. Days to flowering and cluster length contributed substantially towards yield in open also but indirectly. Plant height exhibited negative direct effect (-0.68) on yield per plant (Arumugarangarajan *et al.*, 2000; Manivannan and Anandakumar, 2013).

In path analysis for open environment (Fig. 2b), the maximum direct effect on yield was shown by branches per plant (4.71) followed by nodes per plant (2.45), pod length (0.663), plant height (0.341) and pods per cluster (0.233). Direct effect and correlation of pod length was reported by Brindha *et al.* (1997). Direct effect and positive association of plant height on yield was in conformity with the finding of Hanchinamani (2003). Indirect effects of pods per plant (3.38), 50% flowering (2.89) and days to flowering initiation (1.87) through branches per plant and 50% flowering (1.92), days to flower initiation (1.74), seeds per pod (1.62) and pods per plant (1.07) through nodes per plant were also important. Cluster length (0.67) and pods per cluster (0.20) exerted positive effect indirectly through Pod length. The study revealed that selection favoring branches, nodes, pods per clusters and may bring out desired improvement towards enhancing the yield However, main challenge remains to break negative correlations among yield and the pod length.

The increase in plant height in the shade was due to increased inter-node length and increased nodes per plant that probably resulted in more clusters on main stem (Table 2). The increase in yield was accompanied by increase in cluster length, pods per cluster, pod length and seeds per pod indicating increased efficiency of plant under reduced radiation and associated heat stress. Shading elongates hypocotyl, petiole, leaf blade, internodes, stem and branches but supresses shoot branching and accelerates flowering time (Franklin, 2008; Casal, 2012; Casal, 2013; Nozue, 2015). All of these responses can be helpful for promoting survival when there is competition for light from neighbouring plants. The elongation of plant height and cluster length is also correlated with pod length and seed weight, which becomes rewarding in shade. Similar results were reported by Ma and Li (2019) in Arabidopsis. The ability of plants to adjust their morphology, physiology and phenology to sub-optimal light conditions is well documented (Cai, 2011; Bande *et al*., 2013). Contrary to present study longer period of vegetative growth was associated with shading and a delay in reproductive development (Mauromicale *et al*., 2010; Cai, 2011). These differences for character correlations and their effects observed among environments might be due to alteration of phenological development and plant architecture.

Conclusion

As expected for a plant species of dry habitat, shade avoidance mechanism facilitated growth and yield in clusterbean under present investigations. Inhibition of detrimental effect of high light intensity received in 35% shade probably proved beneficial for seed yield. Shade had more pronounced effect on plant height, however, most of the other agronomic and yield attributing traits also modified favorably. The character correlations and their effects were modified with shade probably due to alteration of phenological development and plant architecture.

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Competing Interests

Authors declare that they have no competing interests.

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