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Research Article

Evaluation of mutants and association studies in non-lodging clusterbean (*Cyamopsis tetragonoloba* (L.) Taub.) mutant lines for yield and yield attributing traits

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Abstract
Fifteen cluster bean genotypes including the parent MDU 1 and fourteen determinate M_5 generation cluster bean mutants were evaluated to determine the correlation and path analysis among yield and yield attributing characters. The genotypic correlation coefficient was observed to be higher in magnitude than the phenotypic correlation coefficient for most of the characters studied. The correlation analysis indicated the positive association of pod yield per plant with plant height, number of clusters per plant, total number of pods per plant, pod length, pod girth, pod weight, days to last harvest and number of seeds per plant. The path coefficient analysis indicated that the number of clusters per plant exhibited a very high positive direct effect on pod yield per plant at the genotypic level. ACMC-020-10 was identified as the best determinate mutant of MDU 1.

Key words: Cluster bean, Correlation coefficient, Non-lodging, Path analysis

INTRODUCTION

Cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] (Syn. *C. psoraliodies* D.C.), also known as “guar” in India is a tall and bushy drought resilient vegetable crop grown on the sandy soils of arid and semi-arid regions of India. The crop belongs to the family Fabaceae and is believed to have originated from its Africanp rogenitor,*Cyamopsis senegalensis* (Gillette, 1958). India is the global leader in cluster bean production with about 90 per cent of the world’s total production. (APEDA, 2019-2020). Rajasthan, Gujarat, Punjab and Haryana are the main growing belts of cluster bean in India. The young vegetable pods of this under exploited vegetable crop are a cheap source of energy (17 Kcal), protein (3. 3g), fat (1. 5 g), carbohydrate (10. 9 g), vitamin A (65. 4 IU), vitamin C (48 mg), calcium (58 mg) and iron (4.4 mg) for every 100 g of an edible portion (Ashwini *et al*., 2019). Apart from being a nutritious vegetable, guar is used as a fodder crop, as a green manure which has massive industrial demand due to galactomannan content. The galactomannan obtained from the seed endosperm is used in paper making, cosmetics, food, pharmaceuticals, oil and petroleum industries. Recently, this camel crop is gaining popularity among the farmers of Southern Indian states of Tamil Nadu, Karnataka, Andhra Pradesh and Telangana, but the tall nature of the crop makes it susceptible to crop lodging, especially in areas with strong wind and heavy downpour. Hence it is important to develop varieties with non-lodging nature without compromising yield.

Correlation studies give a better idea of association among various yield attributing traits and yield, which helps in the identification of genotypes with elite characters, which in turn results in the genetic improvement of yield. The contribution of various independent characters on the dependent characters, directly and indirectly, are measured using a standardized partial regression of coefficient called as path coefficient analysis. The traits that are positively correlated with yield are of great importance to plant breeders for the purpose of selection. An efficient breeding programme with efficient selection can be achieved when there is inter-dependence of yield and yield attributing traits. However, all the changes in the yield attributing traits need not be expressed by changes in the yield, as the degrees of positive and negative correlations between yield and its components and among the components themselves varies (Boghara *et al.,*2016). A study of the association of these traits helps in the selection of genotypes and also suggests the advantage of a selection scheme for more than one character at a time, as the improvement of one trait can bring in the improvement of all positively related characters.

The present research was undertaken to investigate the correlation and path analysis in the determinate mutant accessions of cluster bean, developed through gamma rays and electron beam irradiation of MDU 1 variety. This helps in the effective selection of favourable genotypes with high yield potential.

MATERIALS AND METHODS

The breeding material used in the present study comprised of fourteen determinant mutant accessions of clusterbean, developed through irradiation of MDU 1 variety with gamma rays (400 Gy and 500 Gy) and electron beam (200 Gy), along with the parent MDU 1 **(Table 1).** The genotypes were developed through rigorous selection from M_2 to M_5 generation to develop non-lodging, early maturing plants with high yields. The parental variety MDU 1 is a high yielding clusterbean variety rich in vegetable protein and dietary fibres, developed from Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai by selection from IC 432117. It has a yield potential of 200-300 g pods per plant, but is susceptible to crop lodging due to its indeterminate nature. The experiment was conducted in the college main orchard of the Department of Horticulture, Agricultural College and Research Institute, Madurai during summer 2021 in a Randomized block design (RBD) with three replications. Each accession was raised in three rows at a spacing of 45 x 30 cm and was provided with proper irrigation, fertilizers and plant protection measures throughout the growth period. The data were recorded in thirteen quantitative and nutritional characters *viz.* plant height (cm), days to first flowering, the number of clusters per plant, the number of pods per cluster, the total number of pods per plant, pod length (cm), pod girth (cm), days to the last harvest, pod weight (g), the number of seeds per pod (g), protein content (%), galactomannan content (%) and pod yield per plant (g). TNAUSTAT software was used for the statistical analysis of the data.

RESULTS AND DISCUSSION

The mean values comparison of the best genotypes

Table 1. Genotypes studied along with the mutagens used for irradiation

Genotypes	Origin of mutant
ACMC-020-01	MDU 1 (500Gy gamma rays)
ACMC-020-02	MDU 1 (500Gy gamma rays)
ACMC-020-03	MDU 1 (500Gy gamma rays)
ACMC-020-04	MDU1 (400Gy gamma rays)
ACMC-020-05	MDU 1 (400Gy gamma rays)
ACMC-020-06	MDU 1 (400Gy gamma rays)
ACMC-020-07	MDU 1 (400Gy gamma rays)
ACMC-020-08	MDU 1 (500Gy gamma rays)
ACMC-020-09	MDU 1 (500Gy gamma rays)
ACMC-020-10	MDU 1 (500Gy gamma rays)
ACMC-020-11	MDU 1 (200Gy electron beam)
ACMC-020-12	MDU 1 (200Gy electron beam)
ACMC-020-13	MDU 1 (200Gy electron beam)
ACMC-020-14	MDU 1 (200Gy electron beam)
MDU 1 (check)	Selection from IC 432117

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along with the parental variety MDU 1 for all the thirteen characters are given in **Table 2**. Among the 15 genotypes studied the parental variety MDU 1 had the highest pod yield per plant (332.7 g) along with a few yield contributing characters *viz.,* plant height (155.1 cm), the number of clusters per plant (21.5) and the total number of pods per plant (150.8) and days to the last harvest (100.8). Even if MDU 1 had the highest number of clusters per plant, the number of pods per cluster was the lowest (3.50) when compared to all the 14 identified mutants. Other yield attributing traits *viz.,* pod length, pod girth pod weight, the number of seeds per pod and the quality parameters like guar gum content and protein content were low in MDU 1 when compared to the best-identified mutants. Hence, it is cleared that the highest pod yield of the parental genotype MDU 1 when compared to the mutants, was due to the tall plant stature, which also has the disadvantage of making the crop susceptible to crop lodging. Hence, it was important to select the best mutant genotypes with determinate nature and pod yield per plant comparable to the parental variety MDU 1.

MDU 1 took comparatively more days for the first flower opening (24.1) when compared to some of the best mutant genotypes identified viz. ACMC-020-07 (22.9), ACMC-020-08(22.9), ACMC-020-10(23.3) and ACMC-020-11 (22.3)) and also took noticeably more number of days (100.8) to complete its life cycle when compared to the mutants which completed their life cycle within 79 to 87 days. Since the life cycle of the mutants were short, they had better productivity when compared to the parent MDU 1 and could compensate for the yield reduction due to reduced plant height.

Table 2. General mean and range of the 13 characters studied

S. No.	Characters	Mean ± SE	Range	CD (0.05)
1	Plant height (cm)	74.27 ± 0.79	46.3 - 155.1	2.39
2	Days to first flowering	23.75 ± 0.24	22.3 - 25.2	0.73
3	Number of clusters per plant	10.11 ± 0.39	5.8 - 11.5	1.18
4	Number of pods per cluster	7.33 ± 0.13	3.5 - 10.2	0.39
5	Total number of pods per plant	82.85 ± 0.78	36.7 - 117.7	2.37
6	Pod length (cm)	13.13 ± 0.05	9.2 - 16.4	0.15
7	Pod girth (cm)	2.31 ± 0.03	1.8 - 2.9	0.09
8	Days to last harvest	84.15 ±0.27	80.4-100.8	0.83
9	Pod weight (g)	2.03 ± 0.13	1.4 - 2.3	0.39
10	Number of seeds per pod	9.37 ± 0.16	8.3 - 10.1	0.49
11	Protein (%)	2.31 ± 0.02	2.1- 2.3	0.06
12	Galactomannan (%)	28.84 ± 0.02	28.1 - 29.9	0.06
13	Pod yield (g)	174.74 ± 2.53	100.6 - 332.7	7.68

Table 3. Comparison of mean values of the best mutant genotypes identified with the parental variety MDU 1

S. No.	Characters	Parent	Best mutant lines				
		MDU 1	ACMC-020-04	ACMC-020-07	ACMC-020-08	ACMC-020-10	ACMC-020-11
1	Plant height (cm)	155.1	73.9	73.4	65.9	72.2	69.6
2	Days to first flowering	24.1	24.9	22.9	22.9	23.2	23.3
3	Number of clusters per plant	21.5	10.1	11.5	9.9	11.1	10.4
4	Number of pods per cluster	3.5	8	10	9.7	10.2	9.1
5	Total number of pods per plant	150.8	87.5	110.9	104.6	117.7	95.9
6	Pod length (cm)	13	14.1	14.3	13.1	16.4	15.4
7	Pod girth (cm)	2.2	2.4	2.5	2.4	2.9	2.6
8	Days to last harvest	100.8	85.1	81.1	80.4	81.9	80.4
9	Pod weight (g)	2.1	2.3	2.3	2.3	2.3	2.3
10	Number of seeds per pod	9.8	10	9.7	10.1	9.8	9.7
11	Protein (%)	2.3	2.8	2.5	2.5	2.2	2.5
12	Galactomannan (%)	28.5	28	28.7	28.6	29	29.2
13	Pod yield (g)	332.7	200.2	226.3	225.8	253.9	211.5

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Among the 14 mutant lines identified, ACMC-020-10 (500 Gy gamma rays) was observed to be the best non-lodging genotype with respect to pod yield per plant (253.9 g), number of pods per cluster (10.2), the total number of pods per plant (117.7), pod length (16.4 cm), pod girth (2.9 cm) and pod weight (2.1 g). ACMC-020-04 (200 Gy electron beam) was the tallest non-lodging mutant accession (75.9 cm) and ACMC-020-11(200 Gy electron beam) had the earliest flower opening (22 days). The maximum number of clusters per plant was observed in 500 Gy gamma irradiated treatment ACMC-020-07 (11.5) whereas, ACMC-020-04 (200 Gy electrons beam) had the highest pod weight (2.30 g) and protein content (2.83%). Galactomannan content (29.9 %) was comparatively higher in ACMC-020-06 (400 Gy gamma rays) when compared to other mutants and the parent MDU 1. Also, ACMC-020-08 (500 Gy gamma rays) exhibited superiority with respect to the number of seeds per pod (10.1) and pod weight (2.3 g). The mean values comparison of the best genotypes along with the parental variety MDU 1 for all the thirteen characters are given in **Table 2** and the general mean for all the characters studied along with the range is given in **Table 3**.

For most of the characters studied, the magnitude of genotypic correlations was higher than the phenotypic correlations indicating the strong inherent relationship between these characters and the similarity of the polygenes governing these traits **(Table 4)**. Few traits *viz*., days to first flowering and galactomannan content had a slightly higher magnitude of phenotypic correlation when compared to a genotypic correlation which indicated the influence of the environment. Similar observations were reported by Saroj *et al*. (2013) in redgram and Shoba (2018) in black gram.

Pod yield per plant expressed a significant and positive correlation with plant height (0.719), the number of clusters per plant (0.853), the total number of pods per plant (0.951), pod length (0.574), pod girth (0.532), pod weight (0.839), days to last harvest (0.569) and the number of seeds per plant (0.751). Therefore, these characters appeared to be the most important associates of pod yield per plant. Similar correlations were reported in cluster beans by Manivannan *et al*. (2015) and Jukanti *et al*. (2015). Hence, simultaneously selecting any of these associated traits, which are highly heritable and easy to measure, will be most practicable.

Plant height also showed a significant and positive correlation with the number of clusters per plant (0.943), days to last harvest (0.895) and the total number of pods per plant (0.696). Here, it is important to develop non-lodging tall plants with a longer harvesting period in order to improve the pod yield per plant. Days to first flowering had a significant and negative correlation with the number of pods per cluster (-0.479). It is believed that with a reduction in the number of days to the first flower opening, more number of pods develop per cluster. Similar results were observed in clusterean by Choyal *et al.* (2018) and Muthuselvi *et al.* (2017) and in blackgram by Shanthi *et al.,* (2019), Kumar *et al.* (2013) and Usharani and Anandakumar (2015).

Table 4.Genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients among yield components in clusterbean mutant accessions

Traits	PH	DFF	NOC/P	NOP/C	TNP/P	PL	PG	DLH	PW	NOS/P	PRN	GUM	PY
PH	1	0.014	0.943*	-0.315	0.696*	0.010	-0.080	0.895*	0.246	0.227	-0.005	-0.148	0.719*
DFF	0.022	1	-0.067	-0.479*	-0.292	-0.272	-0.377	0.284	-0.300	-0.213	0.132	-0.229	-0.263
NOC/P	0.932*	-0.046	1	-0.041	0.882*	0.256	0.211	0.837*	0.504*	0.354	0.161	-0.045	0.853*
NOP/C	-0.314	-0.443*	-0.037	1	0.421	0.711*	0.780*	-0.429	0.721*	0.414	0.355	0.233	0.307
TNP/P	0.695*	-0.271	0.872*	0.421	1	0.568*	0.570*	0.546*	0.818*	0.587*	0.299	0.018	0.951*
PL	0.010	-0.245	0.253	0.707*	0.567*	1	0.879*	0.046	0.918*	0.653*	0.280	0.192	0.574*
PG	-0.080	-0.352	0.204	0.765*	0.563*	0.869*	1	-0.070	0.818*	0.475*	0.195	0.352	0.532*
DLH	0.891*	0.248	0.820*	-0.426	0.545*	0.046	-0.071	1	0.163	0.117	-0.116	-0.093	0.569*
PW	0.205	-0.184	0.427	0.586*	0.682*	0.771*	0.698*	0.113	1	0.910*	0.340	0.022	0.839*
NOS/P	0.215	-0.144	0.315	0.274	0.538 *	0.594 *	0.461	0.088	0.751 *	1	0.400	-0.375	0.751*
PRN	-0.007	0.117	0.161	0.351	0.295	0.278	0.190	-0.117	0.292	0.353	1	-0.477*	0.292
GUM	-0.149	-0.213	-0.046	0.231	0.018	0.192	0.350	-0.094	0.039	-0.344	-0.473*	1	-0.131
PY	0.717*	-0.243	0.845*	0.307	0.950*	0.573*	0.526*	0.568*	0 .703*	0.680*	0.291	-0.130	1

PH: Plant height, DFF: Days to first flowering, NOC/P: Number of clusters per plant, NOP/C : Number of pods per cluster, TNP/P: Total number of pods per plant, PL: Pod length, PG: Pod girth, DLH: Days to last harvest, PW: Pod weight, NOS/P: Number of seeds per pod, PNR: Protein content, GUM: Galactomannan content, PY: Pod yield per plant.
* Significant at 5 % level of significance

The nature and degree of yield attributing characters on pod yield per plant can be computed using the correlation values. The partitioning of the observed correlation coefficient into direct and indirect effects of independent variables on the dependent variable is done using path coefficient analysis. The estimated direct and indirect effects were categorized as negligible (0.00-0.09), low (0.10-0.09), moderate (0.20-0.29), high (0.30-0.99) and very high (>0.99), based on the scales recommended by Lenka and Mishra (1973). In the present experiment, path coefficient analysis of twelve traits was carried out using genotypic correlation values (**Table 5**).

Very scanty information is available on the cause and effect relationship between pod yield and yield contributing characters in clusterbean. Path analysis revealed that the eight characters *viz.* plant height (0.353), the number of clusters per plant (1.727), the number of pods per cluster (0.669), pod girth (0.745), pod weight (0.401), days to last harvest (0.081), the number of seeds per pod (0.555) and protein content (0.019) exhibited a positive direct effect on pod yield per plant at the genotypic level. These findings are in agreement with the findings of Pathak *et al*. (2011). Among these traits studied, the number of clusters per plant exerted a very high positive direct effect on pod yield per plant, whereas days to the last harvest and protein content exhibited a negligible positive effect on pod yield per plant. The remaining five traits expressed a high positive direct effect on pod yield per plant. The high direct effect of the traits in this study indicated the true relationship of the traits with pod yield per plant and hence selection would be rewarding in the crop yield improvement. These findings are in agreement with the findings of Pathak *et al*. (2011). Days to first flowering (-0.082), the total number of pods per plant (-1.851), pod length (-0.703) and galactomannan content (-0.053) had a negative direct effect on pod yield per plant. From these characters, the total number of pods per plant and pod length exhibited a very high and negative direct effect, respectively on pod yield per plant, while days to first flowering and galactomannan content expressed only negligible negative direct effect. These results are in agreement with the findings of Prasanna and Gabrial (2018) and Reddy *et al.* (2017) in clusterbean.

Among the traits studied, the total number of pods per plant had a very high positive indirect effect to pod yield per plant via the number of clusters per plant (1.523) and a high positive indirect effect via pod girth (0.424), pod weight (0.327) and the number of seeds per pod (0.326). Also, pod length had a high positive indirect effect to pod yield per plant via the number of clusters per plant (0.443), the number of pods per cluster (0.476), pod girth (0.655), pod weight (0.368) and the number of seeds per pod (0.362). These indirect effects had supported the low magnitude directs effect as well as resulted in high significant positive correlation with pod yield per plant.

Table 5. Genotypic path coefficient matrix expressing direct and indirect effects for 13 characters in 14 mutant accessions along with parent MDU 1.

Traits	PH	DFF	NOC/P	NOP/C	TNP/P	PL	PG	DLH	PW	NOS/P	PRN	GUM	Correlation coefficients with pod yield per plant
PH	**0.353**	-0.001	1.628	-0.211	-1.287	-0.007	-0.060	0.072	0.099	0.126	0.000	0.008	0.719*
DFF	0.005	**-0.082**	-0.115	-0.321	0.540	0.192	-0.281	0.023	-0.120	-0.118	0.003	0.012	-0.263
NOC/P	0.333	0.006	**1.727**	-0.028	-1.632	-0.180	0.157	0.068	0.202	0.197	0.003	0.002	0.853*
NOP/C	-0.111	0.039	-0.071	**0.669**	-0.779	-0.500	0.582	-0.035	0.289	0.230	0.007	-0.012	0.307
TNP/P	0.246	0.024	1.523	0.281	**-1.851**	-0.399	0.424	0.044	0.327	0.326	0.006	0.001	0.951*
PL	0.003	0.022	0.443	0.476	-1.051	**-0.703**	0.655	0.004	0.368	0.362	0.005	-0.010	0.574*
PG	-0.028	0.031	0.364	0.522	-1.054	-0.618	**0.745**	-0.006	0.328	0.264	0.004	-0.019	0.532*
DLH	0.316	-0.023	1.445	-0.287	-1.011	-0.032	-0.052	**0.081**	0.065	0.065	-0.002	0.005	0.569*
PW	0.087	0.025	0.871	0.482	-1.513	-0.645	0.610	0.013	**0.401**	0.505	0.007	-0.001	0.839*
NOS/P	0.080	0.017	0.612	0.277	-1.087	-0.459	0.354	0.009	0.365	**0.555**	0.008	0.020	0.751*
PRN	-0.002	-0.011	0.278	0.237	-0.553	-0.197	0.146	-0.009	0.136	0.222	**0.019**	0.025	0.292
GUM	-0.052	0.019	-0.078	0.156	-0.033	-0.135	0.262	-0.008	0.009	-0.208	-0.009	**-0.053**	-0.131

PH: Plant height, DF : Days to first flowering, NOC/P: Number of clusters per plant, NOP/C : Number of pods per cluster, TNP/P: Total number of pods per plant, PL: Pod length, PG: Pod girth, DLH: Days to last harvest PW: Pod weight, NOS/P: Number of seeds per pod, PNR: Protein content, GUM: Galactomamman content
Residual effect: 0.0460
Direct effects for the corresponding characters are indicated by bold figures

Table 6. Best mutant genotypes of MDU 1 forvarious desirable characters

S. No.	Desirable characters	Best mutants with their mutagenic dosage
1	Higher values for all the yield attributing characters except for flowering	ACMC-020-10 (500Gy gamma rays)
2	Earliest flower opening with minimum number of days to final harvest	ACMC-020-11 (200Gy electron beam)
3	Maximum number of clusters per plant	ACMC-020-07 (400Gy gamma rays)
4	Tallest determinate plant withhighest galactomannan content	ACMC-020-06 (400Gy gamma rays)
5	Maximum number of seeds per pod with minimum number of days to final harvest	ACMC-020-08 (500Gy gamma rays)
6	Highest protein content and maximum pod weight	ACMC-020-04 (400Gy gamma rays)

The residual value was observed to be 0.0460, which is negligible and explained that there was no major role of other independent variables that were not studied in the present experiment on the dependent variable. The dependent variables considered in the study alone are sufficient to create a better impact on the pod yield per plant. The best mutant genotypes of MDU 1 for various desirable characters are given in **Table 6**.

From this study, ACMC-020-10 was identified as the best mutant of MDU 1 with the highest pod yield per plant and determinate nature. All the identified mutants had higher yields with shorter crop cycles contributing towards better crop productivity compared to the parent. Based on the correlation studies and path analysis, the main pod yield contributing characters in clusterbean genotypes studied were plant height, the number of clusters per plant, the number of pods per cluster, the total number of pods per plant, pod length, pod girth, days to the last harvest, pod weight and the number of seeds per pod. Selection based on these traits could be beneficial for identifying determinate mutants with a higher yield.

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