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Multivariate Analyses in Castor (*Ricinus communis* L.)

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ABSTRACT

Fifty four genotypes of castor representing the broad spectrum of variation were assessed for genetic divergence for twenty eight characters using Mahalanobis' D^2 statistic, cluster analysis and principal component analysis. On the basis of these three clustering methods nine and eight clusters were obtained for D^2 statistic and principal component analysis respectively.

Key words : Castor, Cluster analysis, D^2 analysis, Principal Component Analysis

Castor is one of the ancient oilseed crops of the world, which belongs to family Euphorbiaceae and genus Ricinus. The diversity of parents is of prime importance, since the crosses made between the genetically divergent parents are likely to throw desirable recombinants in the progenies. Traditionally Mahalanobis' D^2 statistic to measure genetic divergence as suggested by Rao (1952) has been used by different workers in castor. The present study was carried out with different methods of clustering based on D^2 analysis, hierarchical cluster analysis and principal component analysis.

MATERIAL AND METHODS

Fifty four castor (*Ricinus communis* L.) genotypes obtained from different research centers across the country were planted in randomized block design with three replications at Agricultural College Farm, Bapatla during *kharif* 2008-09 (Fig. 1). The inter- and intra-row spacing adapted was 90cm x 60cm. Each genotype was sown in three rows of 3m length and observations were recorded on ten plants from each genotype per replication or on plot basis for characters *viz.,* days to 50% flowering of primary raceme, stem length to primary raceme, number of nodes to primary raceme, total length of primary raceme, effective length of primary raceme, days to 80% maturity of primary raceme, secondary branches plant^{-1}, days to 50% flowering of secondary raceme, number of nodes to secondary raceme, stem length to secondary raceme, total length of secondary raceme, effective length of secondary raceme, days to 80% maturity of secondary raceme, number of tertiary branches per plant, days to 50% flowering of tertiary raceme, number of nodes to tertiary raceme, stem length to tertiary raceme, effective length of tertiary raceme, days to 80% maturity of tertiary raceme, 100 seed weight of primary raceme, 100 seed weight of secondary raceme, 100 seed weight of tertiary raceme, oil content, L/B ratio of seed, harvest index, seed yield plant^{-1} at 120 days, seed yield plant^{-1} upto 150 days and seed yield plant^{-1} upto 180 days. The data were statistically analyzed to study diversity by Mahalanobis' D^2 statistic as per Rao (1952), principal component analysis (PCA) as described by Jackson (1991) and cluster analysis as described by Anderberg (1993).

RESULTS AND DISCUSSION

On the basis of D^2 values and cluster analysis the fifty four genotypes were grouped into nine and eight clusters, respectively. Based on D^2 values, clustering pattern comprised nine clusters, out of which cluster II was the biggest cluster with 14 genotypes followed by clusters I and III which consisted of eleven genotypes , cluster V with eight genotypes, cluster VIII with five genotypes followed by cluster VII with two genotypes while the remaining clusters *i.e.* cluster IV, cluster VI and cluster IX consisted of single genotype in each (Table 1).

Based on Ward minimum variance dendrogram, the clustering pattern revealed that cluster IV and cluster VII had 12 genotypes each, cluster VIII with 10 genotypes followed by cluster I and cluster V comprising 7 genotypes. Cluster VI possessed 3 genotypes followed by cluster II with 2 genotypes. Whereas the remaining cluster III consitsed of 1 genotype as shown in Table1 and Fig 1.

Based on D^2 values the maximum intra-cluster D^2 value was 1737.736 for cluster VIII followed by cluster V, II, III, VII and I while it was zero for cluster IV, VI, and IX. The maximum inter-

Table 1. Genotypes of castor included in each cluster based on Mahalanobis' D^2 analysis and Ward's minimum variance method

Cluster No.	Based on D^2 value (Mahalanobis' analysis)		Based on cluster analysis (Ward's minimum variance method)	
	No. of genotypes	Name of the genotype	No. of genotypes	Name of the genotype
I	11	PPL 104, PPL 109, PPL 125, PPL 128, PPL 136, PCH 80, GCH 4, PPL 137, PCH 111,PPL 107, PPL 151	7	PPL 101, PPL 108, PPL 105, PPL 133, PPL 138, PPL 148, PPL 141
II	14	PPL 101, PPL 108, PPL 119, PPL 132, PPL 116, PPL 114, PPL 120, PPL 134, PPL 111,PPL131, PPL 135, PPL 112, PPL 118, PPL 145	2	PPL 102, PPL 149
III	11	PPL 121, PPL 122, PPL 144, PPL115, PPL103, PPL 126, PPL 110, M-574, PPL 123, PPL142, DPC-9	1	PPL 147
IV	1	PPL 113	12	PPL 104, PPL 109, PPL 107, PPL 125, PPL 128, PPL 136, GCH 4, PCH 111, PCH 80, PPL 137, PPL 117, KIRAN
V	8	PPL 140, PPL 150, PPL 143, PPL 105, PPL133, PPL138, PPL 148, PPL 141,	7	PPL 115, PPL 144, PPL121, PPL 122, PPL 103, PPL126, PPL151
VI	1	PPL 117	3	PPL 129, PPL 130, PPL 139
VII	2	PPL 102, PPL 149	12	PPL 106, PPL 110, PPL 112, PPL 113, PPL 118, PPL 120, PPL 114, PPL 119, PPL 131, PPL 135, PPL 132, PPL 134
VIII	5	PPL 129, PPL 130, PPL 139, KIRAN, PPL 106	10	PPL 111, PPL 145, DPC-9, M-574, PPL 116, PPL 142, PPL 143, PPL 123, PPL140, PPL 150
IX	1	PPL 147,	-	——

cluster D^2 value were observed between cluster VI and IX followed by cluster I and IX and the least inter-cluster distance was observed between cluster I and cluster VI (Table 2).

The distribution of genotypes based on PCA values were shown in 3D plot where the genotypes PPL 117 and PPL 147 were away from the axis genotypes on the basis of PCA I and PCA II scores (Table 3 and Fig 2).

The results obtained from the data on cluster means (Table 4) from the different characters based on D^2 statistic revealed that Cluster IV recorded low days to 50% flowering of primary raceme, stem length to primary raceme days to 50% flowering of secondary raceme, stem length to secondary raceme, days to 80% maturity of secondary raceme, days to 50% flowering of tertiary raceme, days to 80% maturity of tertiary raceme, and moderate seed yield plant^{-1} at 120 days, upto 150 days and up to 180 days. Cluster V recorded high seed yield plant^{-1} at 120 days and seed yield plant^{-1} up to 150 days. Cluster VIII recorded moderate mean values for all yield attributing characters, and recorded high seed yield plant^{-1} up to 180 days.

Based on the five principal components, a cumulative of 89.39% of variation formed the basis meant for the divergence into different clusters. Main principal components are presented in Table 3. The D^2 statistic showed that effective length of tertiary raceme, days to 50% flowering of tertiary raceme, stem length to tertiary raceme and seed yield plant^{-1} at 120 days contributed maximum towards genetic divergence Table 5.

All the three methods of grouping revealed a single concept of non- correspondence of genetic divergence and geographical diversity. Similar

Fig 1. Dendrogram showing relationship of 54 castor (Ricinus communis L.) genotypes in eight clusters as per hicrarchial cluster analyses.

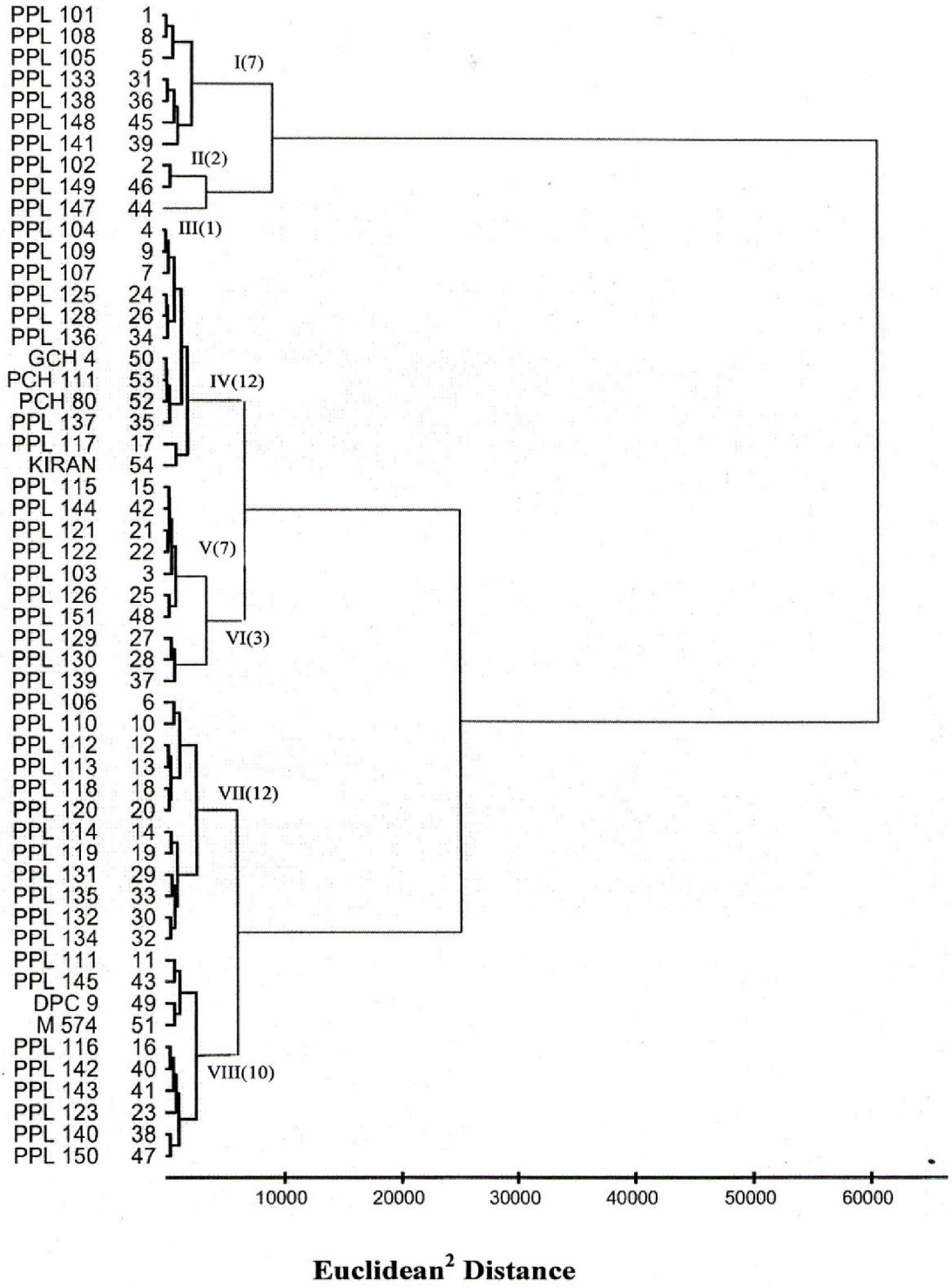
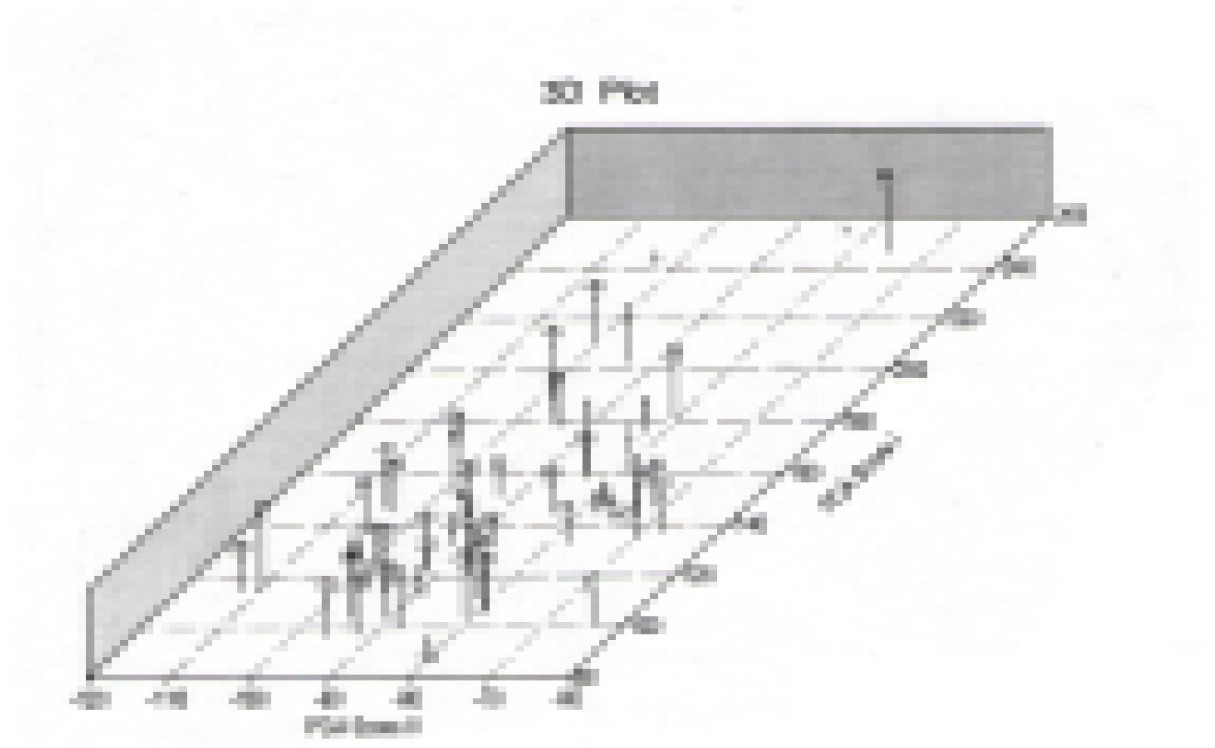


Table2. Averge intra- and inter-culster D^2 values based on Mahalanobis' D^2 and Euclidean^2 values of cluster analysis.

Cluster No	I	II	III	IV	V	VI	VII	VIII	IX
I	**536.74 (1906.44)**	2985.12 (3635.20)	1527.93 (12462.72)	1885.02 (12086.22)	4750.66 (6662.59)	1081.34 (10212.34)	10836.89 (3928.84)	1244.96 (4053.79)	20324.60
II		**865.40 (1117.12)**	1391.60 (5672.78)	1137.64 (22878.71)	1539.00 (14309.40)	3651.41 (19122.28)	4094.95 (10059.42)	2834.84 (9435.23)	10242.58
III			**844.32 (0)**	1568.90 (42169.76)	2510.18 (30833.20)	2480.71 (38621.39)	6528.68 (22766.89)	1632.16 (24300.27)	14648.81
IV				**0.00 (1321.41)**	2442.63 (2587.43)	1921.86 (2728.87)	6514.10 (5105.26)	2154.03 (5536.49)	12981.14
V					**1319.26 (978.46)**	6266.75 (2552.63)	2525.63 (2594.37)	4247.66 (2408.35)	7813.98
VI						**0.00 (1385.93)**	12793.44 (5257.52)	2039.34 (3854.80)	21728.09
VII							**558.55 (1594.62)**	9686.24 (2642.78)	2836.39
VIII								**1737.73 (1795.94)**	19061.79
IX									**0.00**

Figures in parentheses are Eucledian^2 values of cluster analysis
Bold and diagonal values indicate intra-cluster distances

Fig 2. Three dimensional graph showing relative position of 54 castor (*Ricinus communis* L.) genotypes based on PCA scores.



Numbers correspondent to the serial number of genotypes as in Fig 1

Table 3 Eigen values, proportion of the total variance represented by first seven principal components, cumulative per cent variance and component loading of different characters in castor (*Ricinus communis* L.).

Character	PC_1	PC_2	PC_3	PC_4	PC_5
Eigene Value (Root)	51763.560	6528.240	3807.820	2898.020	1916.790
% Var. Exp.	69.153	8.721	5.087	3.872	2.561
Cum. Var. Exp.	69.153	77.875	82.962	86.833	89.394
Days to 50% Flowering of Primary Raceme	0.224	0.051	0.081	0.215	0.181
Stem Length to Primary Raceme (cm)	0.235	0.047	0.357	-0.372	-0.091
Nodes to Primary Raceme	0.054	0.066	0.012	0.120	0.152
Total Length of Primary Raceme cm	0.042	-0.230	0.052	-0.026	-0.134
Effective Length of Primary Raceme	-0.068	-0.319	0.027	0.049	-0.197
Days to 80%maturity of Primary Raceme	0.196	0.063	0.184	0.209	0.027
Secondary Branches $Plant^{-1}$	0.112	0.149	0.092	-0.080	0.071
Days to 50% Flowering of Secondary Raceme	0.297	-0.133	0.193	-0.021	-0.008
Nodes to Secondary Raceme	0.040	0.094	0.040	-0.145	0.026
Stem Length to Sec Raceme cm	0.026	0.026	-0.002	0.109	-0.190
Total Length of Sec Raceme cm	0.130	-0.180	0.108	-0.119	0.031
Effective Length Sec Raceme cm	-0.039	-0.203	-0.030	-0.065	-0.059
Days to 80%maturity of Secondary Raceme	0.193	0.154	0.104	0.394	0.021
Tertiary Branches $Plant^{-1}$	-0.033	0.092	-0.026	-0.224	0.153
Days to 50% Flowering of Tertiary Raceme	0.333	-0.409	0.016	0.252	-0.153
Nodes to Tertiary Racemes	0.175	0.055	0.211	0.039	0.131
Stem Length to Tertiary Raceme cm	-0.125	-0.411	0.433	-0.153	-0.096
Effective Length of Tertiary Raceme	0.425	-0.284	-0.172	-0.105	0.266
Days to 80%maturity of tertiary Raceme	0.059	-0.025	-0.041	0.497	0.021
100 Seed Wt of Primary Raceme	-0.195	-0.076	0.068	-0.140	0.291
100 Seed Wt of Secondary Raceme	0.033	-0.067	0.293	-0.057	0.453
100 Seed Wt of Tertiary Raceme	-0.288	-0.103	0.142	0.228	0.429
Oil Content (%)	-0.209	-0.220	-0.183	0.015	-0.030
L/B Ratio of Seed	-0.119	-0.017	0.084	0.100	0.011
Harvest Index (%)	0.215	-0.062	-0.485	-0.166	0.250
Seed Yield $Plant^{-1}$ At 120 Days	-0.230	-0.421	-0.161	0.109	0.156
Seed Yield $Plant^{-1}$ up to 150 Days	0.199	-0.068	-0.221	-0.118	0.213
Seed Yield $Plant^{-1}$ upto 180 Days	-0.164	0.033	0.179	0.067	0.283

PC= Principal component

Table 4. Mean values of clusters estimated from 54 genotypes of castor(*Ricinus communis* L.) based on D^2 and cluster analyses for characters 1-14

Cluster No	Days to 50% flowering of Pri raceme	Stem length to pri raceme (cm)	Nodes to pri racem	Total length of pri raceme cm	Effective length of pri raceme	Days to 80% maturity of pri race	Second-ary branches plant^{-1}	Days to 50% flowering of sec raceme	Nodes to sec racem	Stem length to sec raceme cm	Total length of sec raceme cm	Effective length sec raceme cm	Days to 80%matu-rity of sec raceme	Tertiary branches plant^{-1}
I	54.4	89.7	16.6	39.5	33.7	93.1	2.4	78.2	9.3	59.4	31.3	25.3	110.2	3.6
	(81.7)	(153.0)	(24.8)	(48.3)	(41.2)	(116.0)	(2.6)	(114.)	**(14.3)**	**(102.4)**	(31.1)	(26.1)	(144.7)	(3.0)
II	72.3	114.0	22.0	42.5	35.3	104.8	**2.9**	98.2	11.0	90.1	32.4	27.0	130.7	3.1
	(86.2)	(191.7)	(25.8)	(51.1)	**(48.0)**	(129.0)	(2.2)	(133.7)	(14.3)	(96.3)	(43.7)	(37.8)	(153.)	(2.4)
III	60.0	96.2	17.2	45.2	38.7	95.9	2.6	91.1	10.5	81.5	36.9	31.0	119.9	3.0
	(116.0)	**(282.3)**	**(37.4)**	(37.1)	**(29.6)**	**(129.5)**	(2.3)	**(140.5)**	(7.7)	(73.8)	**(27.9)**	**(21.3)**	**(156.5)**	(3.6)
IV	76.0	103.9	22.0	**24.4**	22.2	107.0	2.8	92.0	8.15	95.1	21.5	25.0	124.5	3.3
	(53.7)	**(84.9)**	(16.3)	(37.3)	(31.4)	(92.4)	(2.4)	**(76.8)**	(8.7)	**(54.8)**	(29.1)	(24.3)	**(110.1)**	**(3.6)**
V	79.5	146.1	23.3	50.9	44.8	113.9	2.5	112.5	12.6	**116.6**	37.4	32.5	142.0	2.9
	(55.3)	(101.3)	(16.9)	(42.3)	(36.2)	(92.3)	(2.5)	(86.6)	(11.0)	(83.6)	(35.3)	(29.6)	(113.5)	(3.0)
VI	**52.0**	100.4	**16.0**	25.4	**19.4**	**85.5**	**2.1**	**72.0**	**6.6**	**35.2**	**12.8**	**18.5**	**107.0**	**4.0**
	(55.0)	(85.5)	**(15.4)**	(44.3)	(43.2)	**(91.0)**	(2.1)	(86.6)	(8.8)	(66.4)	**(46.5)**	**(41.3)**	(123.1)	**(1.8)**
VII	86.2	191.7	25.8	**51.1**	**48.0**	129.0	2.2	133.7	**14.3**	96.3	**43.7**	**37.8**	153.0	2.4
	(70.5)	(111.1)	(21.0)	**(36.0)**	(30.3)	(103.6)	**(2.9)**	(94.2)	(10.1)	(94.3)	(31.2)	(26.7)	(128.0)	(3.5)
VIII	56.3	**87.4**	16.0	37.7	35.5	92.6	2.1	85.3	9.7	70.0	38.8	34.4	122.2	**2.0**
	(70.0)	(106.3)	(19.8)	**(52.6)**	(45.7)	(102.9)	(2.6)	(100.5)	(10.7)	(93.4)	(40.3)	(34.7)	(130.5)	(2.3)
IX	**116.0**	**282.3**	**37.4**	37.1	29.6	**129.5**	2.0	**140.5**	7.7	73.8	27.9	21.3	**156.5**	3.6

(Bold values under each character indicate maximum and minimum values).

Figures in the parentheses indicate mean values as per cluster analysis

Table 4. Mean values of clusters estimated from 54 genotypes of castor(*Ricinus communis* L.) based on D^2 and cluster analyses form characters 15-28

Cluster No	Days to 50% flowering of Ter raceme	Nodes to Tertiary Raceme	Stem Length to Tertiary Raceme cm	Effective length of Ter raceme	Days to 80% maturity of Ter raceme	100 Seed Wt of Primary Raceme gm	100 Seed Wt of Secondary Raceme gm	100 Seed Wt of Teriary Raceme gm	Oil Con-tent (%)	L/B Ratio of Seed	Harvest Index (%)	Seed Yield/ Plant At 120 days gm	Seed Yield/ Plant up to 120 days gm	Seed Yield/ Plant up to 180 days gm
I	102.5	9.6	**66.7**	18.9	129.5	25.9	27.3	27.0	49.0	1.4	38.1	**91.8**	**139.5**	139.5
	(142.5)	(8.5)	**(42.4)**	(19.7)	(162.8)	(23.6)	(25.4)	(23.1)	(49.0)	(1.4)	(33.1)	**(24.1)**	**(62.6)**	(111.4)
II	125.9	7.8	34.0	20.6	150.1	22.3	23.7	22.4	47.1	1.4	36.5	35.7	82.6	125.0
	(153.7)	(5.5)	(30.3)	(25.2)	(172.5)	(26.7)	(28.9)	(26.7)	(47.4)	(1.4)	(33.8)	(0.0)	(35.7)	(111.0)
III	116.6	8.5	46.3	23.3	141.3	24.3	25.0	24.5	48.2	1.4	**38.4**	75.2	133.1	**142.6**
	(163.0)	(7.1)	(53.0)	(17.2)	(171.5)	(20.5)	(26.1)	(20.7)	(47.0)	(1.4)	**(30.2)**	(0.0)	(36.0)	**(90.50)**
IV	117.0	**9.9**	46.4	**13.7**	151.5	20.8	**21.9**	21.5	47.0	**1.3**	35.1	14.9	55.3	**81.5**
	(100.7)	**(9.4)**	(61.1)	**(18.4)**	(128.0)	(26.1)	**(26.8)**	(27.1)	(49.2)	**(1.4)**	(38.1)	(88.8)	(134.7)	**(134.7)**
V	139.5	8.6	51.2	19.5	161.3	24.3	25.9	23.5	**49.3**	1.4	32.9	28.1	69.5	108.5
	(112.9)	(8.1)	(43.7)	(21.7)	(137.3)	(23.4)	(25.2)	(23.6)	**(47.8)**	(1.4)	(38.1)	(96.6)	(136.3)	(136.3)
VI	**87.0**	6.5	37.0	15.3	**126.0**	23.7	22.1	24.0	47.1	1.4	34.2	54.3	93.4	93.4
	(113.6)	(9.2)	(86.4)	(20.9)	**(144.3)**	(21.9)	(22.7)	(21.3)	(46.6)	(1.5)	(38.4)	(51.3)	(126.4)	(132.0)
VII	153.7	**5.5**	**30.3**	**25.2**	**172.5**	**26.7**	**28.9**	**26.7**	47.4	1.4	33.8	**0.0**	**35.7**	111.0
	(120.7)	**(8.5)**	**(36.7)**	**(18.6)**	**(146.8)**	**(21.4)**	**(22.9)**	**(22.2)**	(46.4)	(1.4)	(34.9)	**(31.0)**	**(79.9)**	(111.5)
VIII	110.0	8.6	64.1	20.4	143.4	23.1	23.5	23.1	47.5	**1.5**	37.9	57.9	115.1	118.4
	(125.8)	(7.9)	(49.7)	(24.3)	(153.2)	(25.4)	(25.8)	(24.8)	(49.0)	**(1.4)**	(38.4)	(48.4)	(108.9)	(140.3)
IX	**163.0**	7.1	53.0	17.2	171.5	20.5	26.1	**20.7**	**47.0**	1.4	**30.2**	0.0	36.0	90.5

(Bold values under each character indicate maximum and minimum values).

Figures in the parentheses indicate mean values as per cluster analysis

Table 5. Contribution of different characters towards genetic divergence in 54 genotypes of castor (*Ricinus communis* L.)

S.No	Character	Times ranked first	% Contribution towards divergence
1	Days to 50% flowering of primary raceme	28	1.96
2	Stem length to lrimary raceme	59	4.12
3	Nodes to primary raceme	0	0.00
4	Total length of primary raceme	3	0.21
5	Effective length of primary raceme	5	0.35
6	Days to 80% maturity of primary raceme	18	1.26
7	Secondary branches plant^{-1}	0	0.00
8	Days to 50% flowering of secondary raceme	9	0.63
9	Nodes to secondary raceme	0	0.00
10	Stem length to secondary raceme	2	0.14
11	Total length of secondary raceme	8	0.56
12	Effective length secondary raceme	2	0.14
13	Days to 80%maturity of secondary raceme	49	3.42
14	Tertiary branches plant^{-1}	2	0.14
15	Days to 50% flowering of tertiary raceme	240	16.77
16	Nodes to tertiary racemes	3	0.21
17	Stem length to tertiary raceme	161	11.25
18	Effective length of tertiary raceme	435	30.40
19	Days to 80%maturity of tertiary raceme	34	2.38
20	100 seed weightt of primary raceme	24	1.68
21	100 seed weightt of secondary raceme	9	0.63
22	100 seed weightt of tertiary raceme	77	5.38
23	Oil content (%)	6	0.42
24	L/B ratio of seed	6	0.42
25	Harvest index (%)	76	5.31
26	Seed yield plant^{-1} at 120 days	154	10.76
27	Seed yield plant^{-1} At 150days	10	0.70
28	Seed yield plant^{-1} At 180 days	11	0.77

findings were also reported by Bhatt and Reddy (1987) and Sevagaperumal *et al.* (2000). In broad sense all the three methods of classifying genotypes into different groups are equally useful but heirarchial cluster analysis gave an additional advantage of identifying sub-clusters of the major groups at different levels so that each small group can be critically analysed. The genotypes PPL 106, PPL 129, PPL 130, PPL 139 and Kiran as resulted from D^2 analysis and PPL 101, PPL 105, PPL 108, PPL 133, PPL 138, PPL 141 and PPL148 as resulted from cluster analysis and PPL 117 and PPL 147 are more divergent genotypes and can be used in breeding programme for character improvement in castor.

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