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Genetic Diversity, Variability and Heritability for Root, Shoot and Water Use Efficiency Traits in Castor *(Ricinus communis* L.) Genotypes

P Lakshmamma*, Lakshmi Prayaga, C Lavanya and C Sarada
ICAR-Directorate of Oilseeds Research, Rajendranagar, Hyderabad-500030, Telangana

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The present study aimed to estimate the genetic diversity; variability and heritability in 64 castor genotypes for root, shoot and water use efficiency (WUE) traits and further identify the suitable genotypes for a drought resistance breeding programme. Characters like plant height, leaf area index (LAI), stem girth and total dry matter (TDM) were significantly correlated (>0.70) with root volume and root dry weight. The genotypes were ranked based on the index in ascending order considering five important characters *viz*; LAI, stem girth, root volume, root dry weight and TDM using principal component analysis and 15 genotypes with high performance in terms of shoot and root characters were selected. These genotypes comprised 48-1, RG 2124, RG 2169, RG 2155, RG 2074, GCH-5, RG1963, RG 2094, DCS-99, RG 2153, DCS-78, RG 27, RG 1618, RG 2147 and RG 1673. High general combining ability (GCV) and heritability (>80%) for plant height, root volume, root dry weight, TDM and LAI indicate sufficient variability for selection for these characters. Heterosis was high for TDM, root dry weight, volume and LAI. Superior heterobeltiosis was observed for TDM, root volume and root dry weight. The hybrid GCH-5 with its significant heterosis, heterobeltiosis and standard heterosis for key root traits like root volume, root dry weight and TDM is worth exploring under water scarce conditions.

Key Words: Castor, Heritability, Root traits, WUE traits

Introduction

Castor, a crop more tolerant to water deficit is cultivated both as a rain-fed crop in marginal lands under harsh conditions with minimum inputs in Southern India and as an irrigated crop under intensive management conditions in North - Western India. Castor cultivation under rainfed situations is limited due to untimely and erratic rainfall exposing the crop to moisture stress at critical stages *i.e.* flowering/maturity of either one or more than one of the three spike orders *viz*., primaries, secondaries or tertiaries, more so with the latter due to cessation of monsoon season and reducing the productivity to 300 kg/ha. A large portion of these losses can be reduced through crop improvement and better drought-adapted genotypes.

Several morpho-physiological traits play a significant role in crop adaptation to drought stress during soil drying (Subbarao *et al.*, 1995). Genetic variability for traits related to drought tolerance *viz.*, water use efficiency (WUE), root characteristics (biomass, length density and depth) is scattered in germplasm accessions and may be productive when incorporated to high yielding agronomic back ground. Selection for these traits in a breeding program could result in more accurate targeting of factors limiting yield there by increasing the rate of yield improvement.

Significant improvement in productivity through enhanced WUE (Condon *et al.*, 2004; Impa *et al.*, 2005) and root traits (Li *et al.*, 2005) have been demonstrated in crops like groundnut. However, measuring WUE in large populations is difficult. Identification and use of surrogate traits for WUE that are simple and have low environmental variations under drought conditions would be more effective. Significant positive correlation of SPAD chlorophyll meter reading (SCMR) (Sheshashayee *et al.*, 2006), ^{18}O (Bindu Madhava *et al.*, 1999) and negative correlation of specific leaf area (SLA), ^{13}C (Wright *et al.*, 1994) with WUE has been established in crops like peanut.

The objective of the present study was to assess the genetic variability, heritability and genetic diversity in a set of promising genotypes of castor for the traits related to drought tolerance. In addition, the study also aimed to estimate the magnitude of heterosis for major traits related to drought tolerance in a set of four hybrids along with their parents.

**Author for Correspondence: E-mail:lakshmiparvathaneni@rediffmail.com*

Materials and Methods

Construction of Root Structures

For screening castor germplasm and breeding lines for WUE and root traits, two structures were constructed at Narkhoda farm of Directorate of Oilseeds Research (DOR), Hyderabad. Each structure of 30 m length, 1.5 m height and 2.4 m width on either side of central 30 cm permanent wall with side collapsible walls was constructed with hollow cement bricks. The structure was secured by erecting wooden poles on either side which were held together tightly with a wire. Small drainage holes were made at regular intervals. The structures were filled with red sandy loam soil and watered regularly to allow compaction. When the bulk density of the structure reached the bulk density of that of field, sowings were done. FYM was added @ 5 t/ha. Four plants were sown per replication with spacing of 90 x 60 cm with recommended dose of fertilizers.

Genotypes

Sixty four castor genotypes including 37 germplasm lines and 27 breeding lines were sown in two structures with 32 genotypes per structure during *rabi* 2009-10. The germplasm lines with preliminary tolerance to wilt, jassids, drought and with high yield and breeding lines including four released hybrids along with their eight parents *viz.*, DCH-177 (DPC-9 x DCS-9), DCH-519 (M-574 x DCS-78), GCH-4 (VP-1 x 48-1), GCH-5 (Geeta x SH-72) and 15 parents of the experimental hybrids were studied. All the 23 parents were agronomically superior plant types with medium plant height (90-130 cm), early to medium flowering (30-55 days to 50% flowering) and maturity (100-130 days to first picking), strong stem with good branching potential (AICRP on Castor, DOR, 2006). Several parental lines like 48-1, DCS-9, DCS-78, DCS-99, DCS-100, DCS-106, DPC-9, M-574 were resistant to Fusarium wilt which is the major disease compared with 100% wilt susceptible check JI- 35.

Observations

Plants were grown for 90 days as the root growth was active till that time. Observations on growth parameters *viz.*, plant height, number of different order branches, leaf number, leaf area, stem girth, WUE traits like SPAD (soil plant analytical development) chlorophyll meter reading (SCMR) measuring leaf chlorophyll content, specific leaf area (SLA), relative water content (RWC), excised leaf water retention capacity (ELWRC) were recorded. SLA was computed by measuring leaf area and dry weight [(SLA = leaf area (dm^2) / leaf dry weight (g)]. RWC was recorded as per procedure given by Dhopte and Manuel (2002). For ELWRC measurement, the leaves with petioles were excised and fresh weight was recorded at different time intervals. ELWRC was calculated based on the percentage of weight loss of leaves from initial weight over a period of time (Clarke and Mc Caige, 1982) and expressed as percent water loss (ELWL). Plants were uprooted and washed by using water jet and root characters *i.e*. root length, root volume, root dry weight, plant growth parameters and TDM were recorded. Root volume was measured by quantifying the amount of water displaced by roots. Powdered leaf samples were sent to National Facility of Isotope Ratio Mass Spectrometer (IRMS) at University of Agricultural Sciences (UAS), Bangalore for measuring stable isotopes ^{13}C and ^{18}O which act as surrogates for WUE.

Statistical Analysis

Analysis of variance

The mean values of the data recorded from the above quantitative and physiological characters were used to study differences between genotypes for various characters with analysis of variance technique (Panse and Sukhatme, 1985). Principal component analysis was done (Dunteman, 1994) to select efficient castor genotypes with high performance in terms of shoot and root characters. The genotypes were ranked based on the index in ascending order to select efficient genotypes with high ranks. The phenotypic and genotypic correlation coefficients were calculated using the method given by Johnson *et al.* (1955).

Genetic diversity

The genetic divergence was measured by the Mahalanobis' D^2 analysis and genotypes were grouped using Tocher's method (Rao, 1952). The grouping depends on the principle that intra-group distances should be far less than inter-group distances. A principal component analysis based on Mahalanobis' D^2 (Mahalanobis, 1936) was carried out using the INDOSTAT statistical software (INDOSTAT Services, Hyderabad, India) to determine the traits most effective in discriminating between accessions. The first two components explaining the maximum variance were selected for the ordination analysis, and the correlation between the original traits and the respective principal component was calculated. The principal components with *eigen* values >1.0 were selected.

Heterosis

Three types of heterosis-heterosis, heterobeltiosis and standard heterosis was calculated for quantitative traits like plant height up to primary spike (cm), leaf number, stem girth (cm), physiological traits like LAI, TDM and root traits *viz*., root length (cm), root volume (ml) and root dry weight (g) as the percentage increase or decrease of the hybrids over the parental mean, better parent or standard check, respectively (Liang *et al*., 1972).

Results

Root and Shoot Growth

The mean performance and range for different root and shoot characters of the 64 castor genotypes is presented in Table 1. The genotypes varied significantly for all the quantitative and physiological traits evaluated. Plant height up to primary spike was as low as 19 cm to as high as 160 cm with a mean of 63 cm. Node number up to primary spike which is an indication of maturity also varied from 7 to 22 nodes with a mean of 14 nodes. Among the physiological and root traits, LAI, TDM, root volume, root dry weight and ELWRC depicted higher variability. Greatest variation was observed in TDM as depicted by the high standard deviation value recorded for the trait. This was followed by root volume and dry weight.

Root volume and root dry weight were significantly correlated with TDM, stem girth and plant height (> 0.80) while root length did not show significant correlation with shoot characters *viz*., plant height, LAI, stem girth, TDM (r=0.15 to 0.47) (Table 1). In addition, correlation between shoot characters and TDM indicated that LAI is significantly and positively correlated with TDM (0.80) followed by stem girth (0.77) while plant height and leaf number were not significantly correlated with TDM. SCMR which measures leaf chlorophyll content based on light transmittance at blue and red wavelengths and manifested to leaf nitrogen, again related to SLA and WUE did not show strong correlation with TDM (Lakshmamma *et al*., 2010) though recorded negative correlation (-0.62) with SLA. Even SLA and ^{13}C which shows the efficiency of RuBisCO there by mesophyll capacity (Wright *et al*., 1994) also did not show good relation with TDM in this study (Lakshmamma *et al*., 2010). ^{18}O which act as surrogate for transpiration efficiency and stomatal conductance (gs) showed positive correlation with TDM (0.49) and high ^{18}O shows high amount of water transpired which is directly related to yield (Bindu Madhava *et al*., 1999). ^{13}C and ^{18}O were negatively correlated (-0.62).

Selection of Genotypes

Several promising genotypes for root traits, LAI and other morphological characters were identified based on their significantly higher values (Table 2). Genotypes

Table 1. Range, mean, correlation coefficient values for different root and shoot characters in castor genotypes

Character	Range	Mean	Correlation coefficients				
			Shoot characters	Root characters			TDM
				Length	Volume	Dry weight	
Plant height (cm)	19 -160	63	Plant height	0.47	0.85	0.82	0.69
Leaf Number	7 - 45	19	LAI	0.15	0.69	0.71	0.80
Node Number	7 - 22	14	Stem girth	0.45	0.82	0.84	0.77
Secondary branch number	0-12	4	TDM	0.26	0.84	0.88	
Tertiary branch number	0-5	1	SCMR				-0.03
Stem girth (cm)	4.9-10.5	7.0	SLA				0.08
LAI	0.29 - 5.45	1.71	^{13}C				-0.034
SLA (dm^2/g)	1.55-2.77	2.05	^{18}O				0.49
SCMR	43.2 – 57.5	49.2	SCMR vs SLA	-0.62			
TOM (g/plant)	55 - 452	175	$d^{13}C$ vs $d^{18}O$	-0.62			
Root length (cm)	125 - 235	169					
Root volume (ml)	48 - 372	143					
Root dry weight (g/plant)	8.0 – 58.1	23.5					
Root/shoot	0.08 - 0.39	0.16					
TDM/LA	0.98 - 8.45	2.46					
RWC (%)	75.1 - 95.1	88.3					
ELWRC (water loss in 2 hrs)	9.1-41.0	18.4					

Table 2. Genotypes with better root and shoot characters in castor

Lines with	Per plant	Germplasm/breeding lines
Root length	>185 cm	48-1, RG1515, RG1618, RG1626, RG1668, RG1938, RG1963, RG2074, RG2094, RG2096, RG2106, RG21 07, RG2114, RG2124
Root volume	>185 ml	48-1, DCS-78, DCS-99, GCH-5, RG27, RG1618, RG1673, RG1963, RG2074, RG2094, RG2124, RG2147, RG2153, RG2155
Root fresh weight	>194 g	48-1, DCS-78, DCS-99, GCH-5, RG27, RG1618, RG1673, RG1963, RG2094, RG2124, RG2147, RG2153, RG2155, RG2169
Root dry weight	>31 g	48-1, DCS-78, DCS-99, DCS-101, GCH-5, RG27, RG1618. RG1673, RG1963, RG2074, RG2094, RG2106, RG2124, RG2147, RG2153, RG2155, RG2169
Root/Shoot	>/0.19	RG15, RG27, RG1515, RG1618, RG1963, RG2040, RG2054, RG2064, RG2074, RG2094, RG2106, RG2107, RG2114, RG2124, RG2169
Plant height	>88 cm	48-1, Geetha, DCS-99, DCS-101, DCS-106, GCH-5, RG27, RG1673, RG1963, RG2074, RG2094, RG2124, RG2147, RG2155, RG2169
Stem girth	>8.3 cm	48-1, Geetha, DCS-78, DCS-99, GCH-5, RG27, RG1596, RG1618, RG1673, RG2074, RG2124, RG2147, RG2153, RG2155, RG2169
LAI	>2.5	48-1, Geetha,DCS-9, DCS-99, DCS-100, DCS-101, DCS-106, GCH-5, M-574, RG2094, RG2124, RG2153, RG2155, RG2169
TDM	>218 g	48-1, Geetha, DCS-78, DCS-99, DCS-100, DCS-101, GCH-5, RG27, RG1596, RG1673, RG2074, RG2124, RG2153, RG2155, RG2169
SCMR	>50	SH-72, DCS-96, RG27, RG109, RG1520, RG1596, RG1618, RG1626, RG1628, RG1673, RG1938, RG2001, RG2054, RG2106, RG2114
SLA	<1.75	DCS-78, GCH-5, RG27, RG109, RG247, RG1596, RG1626, RG1649, RG1673, RG1953, RG1963, RG2054, RG2064, RG2074, RG2106, RG2107

were ranked by developing an index based on principal components taking into consideration five important characters which showed strong positive correlations. These traits include root volume, root dry weight, stem girth, LAI and TDM. Top 15 genotypes along with their index values, growth and root characters are presented in Table 3. These genotypes include 48-1, RG 2124, RG 2169, RG 2155, RG 2074, GCH-5, RG 1963, RG 2094, DCS-99, RG 2153, DCS-78, RG 27, RG 1618, RG 2147 and RG 1673. Among these selected genotypes, 48-1 recorded highest leaf number, stem girth, root dry weight, LAI and TDM. RG 2124 recorded highest plant height, root volume, root fresh weight and root dry weight is on par with 48-1. RG 27 and RG 2074 recoded low SLA, high root shoot ratio. RG 27, RG 1618 and RG 1673 recorded high SCMR. Genotypic differences among selected genotypes were not significant for RWC and ELWRC. Data on ^{13}C and ^{18}O of the selected genotypes is also presented. ^{13}C and ^{18}O were negatively correlated (-0.62).

Among the hybrids studied, DCH-519 recorded high RWC (94.8) and ELWRC (9.1% water loss after 2 hours). Its parents also showed high percent RWC and ELWRC (M-574 with 93.1, 11.4 and DCS-78 with 89.2 and 13.3 percent RWC and excised leaf water loss). In general, female parents *viz*., Geeta, VP-1, M-574, DPC-9 showed less leaf water loss after 2 hrs with excision. High RWC and less excised leaf water loss of DCH-519 hybrid and its parents (M-574, DCS-78) show the drought tolerance capacity of this hybrid. Though female parents (VP-1, Gaeta, M-574,) of the hybrids (GCH-4, GCH-5, DCH-519) tested showed less excised leaf water loss (ELWL) after 2 hrs of excision, except DCH-519 where the male parent (DCS-78) also recorded low ELWL, other two hybrids did not show low ELWL indicating the heritability of this trait from male parent as reported by Rao *et al.* (1998).

Variability, heritability and genetic divergence: The coefficient of variation (CV), both genotypic and phenotypic indicated that there were significant differences among the genotypes for all the characters studied while the phenotypic coefficient of variation (PCV) is higher than genotypic coefficient of variation (GCV) for all the characters indicating the influence of environment (Table 4). The CV is especially high for the characters like plant height, root volume, root fresh weight, root dry weight, TDM and LAI. Heritability was maximum for root volume and minimum for root length. Majority of the traits *viz.*, plant height and node number up to primary spike, fresh and dry weight of root and shoot, TDM and LAI recorded high heritability (>80). The genetic advance expected in the next generation was higher in root volume and LAI suggesting the role of dominance variance and their highly predictable

Table 3. Ranking, root, shoot growth characters and WUE traits of selected genotypes in castor

Genotype	Index (PCA*)	Rank	Plant height (cm)	Leaf No.	Node No. on primary	Stem girth (cm)	LAI	TDM (g/ plant)	SCMR	SLA (dm^2/ g)	Root length (cm)	Root volume (ml)	Root dry wt. (g/ plant)	RWC (%)	ELWRC (% water loss after 2hrs)	^{13}C	^{18}O
48-1	2.602	1	92.5	45	17	10.5	5.45	452	46.8	2.433	197	350	58.1	89.6	21.7	-22.618	22.394
RG2124	1.933	2	159.4	22	19	8.5	2.70	341	50.7	2.146	197	372	56.7	94.0	15.4	-21.701	22.713
RG2169	1.552	3	134	15	18	8.9	4.10	277	45.1	2.497	179	305	50.3	88.2	14.9	-21.543	19.765
RG2155	1.363	4	105.5	31	18	8.3	3.83	372	47.6	2.205	176	244	46.6	93.0	18.9	-21.375	21.886
RG2074	1.287	5	93.5	19	17	8.9	2.43	226	49.5	1.547	197	259	43.2	91.8	14.6	-20.038	19.576
GCH-5	1.251	6	99.0	27	17	8.9	2.98	312	50.3	1.809	179	269	42.3	92.5	12.8	-21.748	22.471
RG1963	1.219	7	107	18	22	7.4	1.8	213	48.7	1.707	203	217	37.1	84.7	18.8	-20.512	19.990
RG2094	1.205	8	88.5	11	20	8.2	2.66	210	48.5	1.991	206	232	38.0	90.2	10.6	-19.838	19.059
DCS-99	1.072	9	101.5	30	15	9.1	3.11	261	50.0	1.995	184	219	36.9	90.1	13.5	-21.471	22.586
RG2153	0.956	10	75.5	25	14	8.4	3.05	316	45.3	2.220	176	205	37.6	94.9	15.3	-21.554	23.116
DCS-78	0.890	11	85.5	24	14	8.7	1.94	300	49.2	1.748	168	248	43.1	89.2	13.3	-21.333	20.842
RG27	0.763	12	93.0	22	19	8.7	1.44	218	57.1	1.625	180	217	40.6	86.0	13.5	-20.223	19.202
RG1618	0.760	13	80.0	18	18	8.9	1.74	145	57.5	2.515	189	226	34.7	83.2	20.4	-19.857	18.615
RG2147	0.712	14	113	17	21	8.4	2.02	212	46.9	2.255	168	283	31.1	90.6	23.2	-21.697	22.864
RG1673	0.603	15	87.5	17	16	8.4	1.55	250	56.4	1.702	168	225	37.0	85.6	15.1	-19.838	19.378
Mean			63.3	19	14	7.0	1.71	174.9	49.2	2.053	169	143	23.5	88.3	18.4		
SEm±			7.12	3.3	0.99	0.71	0.32	22.3	2.2	0.18	13.4	15	4.0	2.36	2.65		
CD(0.05)			20.1	9.4	2.8	2.0	0.90	62.9	6.2	0.51	37.9	43	11.1	6.6	7.5		
CV(%)			15.9	24.7	10.0	14.2	26.3	18.0	6.3	12.4	11.2	15	23.8	3.8	20.3		

*PCA=Principal component analysis

Table 4. Coefficient of variability, heritability and genetic advance values for root and shoot characters

Character	Coefficient of variation		Heritability % (broad sense)	Genetic advance as % of mean 5%
	GCV	PCV		
Plant height	45.3	48.1	88.6	87.8
Leaf number	28.4	37.5	57.6	44.5
Node number	23.5	25.5	84.6	44.5
Stem girth	14.4	20.2	51.0	21.3
Root length	9.9	14.9	44.4	13.6
Root volume	51.0	53.2	91.8	100.7
Root dry weight	47.8	53.4	80.2	88.2
Shoot dry weight	39.9	43.7	83.5	75.2
TDM	40.2	43.7	84.2	75.9
LAI	56.6	62.3	82.6	106.0

behavior. Low genetic advance in the next generation for the traits like stem girth and root length indicate the role of additive variance.

Sixty-four genotypes were classified into 10 clusters using Euclidean^2 distances following the Mahalanobis method (Table 5). Cluster means for the high heritability traits were also presented. Cluster I included maximum genotypes (49) followed by cluster V with 7 genotypes while the remaining clusters included single genotype. The intra cluster distance among seven genotypes (7.52) was higher than 49 genotypes in Cluster I (6.95). The genotype RG 2124 is genetically divergent to the 49 genotypes in Cluster I based on inter cluster distance while RG 2107 in cluster II and 48-1 and RG-2124 in clusters VIII and X were also genetically divergent with each other. The genotype RG-2124 was also genetically divergent with a wilt and leaf hopper resistant male line, DCS-106 in cluster VII.

In the present study, four hybrids *viz.*, DCH-177, DCH-519, GCH-4 and GCH-5 along with their parents were evaluated to estimate the presence and magnitude of heterosis for physiological and root traits related to drought tolerance (Table 6). Among the four hybrids, GCH-5 alone recorded significantly positive mid parent,

Table 5. Cluster groups, distance and cluster means for root and shoot characters

Cluster groups	Intra cluster distance	Group with more inter cluster distance	Plant height	Root volume	Root DW	TDM	LAI
1 (49 genotypes)	6.95	X	51.9	110	18.7	153	1.45
II (RG2107)	0	VIII, X	59.5	146	21.1	76	0.69
III (GCH-5)	0		99.0	269	42.3	312	2.98
IV (DCS-78)	0		85.5	248	43.1	300	1.94
V (7 genotypes)	7.52		94.6	237	37.4	208	1.95
VI (RG2155)	0		105.5	244	46.6	372	3.87
VII (DCS-106)	0	X	105.0	138	18.7	193	3.66
VIII (48-1)	0		92.5	350	58.1	452	5.45
IX (RG2169)	0		134.0	305	50.3	277	4.12
X (RG2124)	0		159.5	372	56.7	341	2.70

Table 6. Heterosis and Heterobeltiosis of hybrids studied in castor

Hybrids	Plant height	Leaf no.	Stem girth	LAI	TDM	Root length	Root volume	Root dry weight
Mid Parent Heterosis								
DCH-177	-5.7	0.0	6.8	-19.0	17.6	0.53	-9.2	-13.1
DCH-519	-36.8	-23.7	-13.5	3.86	-38.2	0.76	-41.3	-44.1
GCH-4	-32.8	-33.9	-27.9	-68.6	-50.7	-18.4	-58.1	-66.1
GCH-5	6.7	33.3	7.6	27.2	51.1	11.6	76.4	60.2
Standard Heterosis								
DCH-177	-42.2	2.5	-5.3	30.8	30.9	-17.4	-31.1	-23.4
DCH-519	-37.5	-7.5	-3.03	62.1	11.0	-3.2	-23.2	-11.4
GCH-4	-36.7	7.5	-6.8	-27.4	4.1	-16.0	-33.9	-35.03
GCH-5	54.7	35.0	34.9	100.0	126.6	4.1	92.1	114.7
Heterobeltiosis								
DCH-177	-9.8	-12.5	-4.6	-35.9	-5.6	-1.7	-24.3	-30.4
DCH-519	-53.2	-24	-26.4	-11.1	-49.2	-0.9	-56.6	-59.4
GCH-4	-56.2	-51.1	-14	-80.2	-68.3	-26.7	-73.6	-78
GCH-5	-5.7	8.0	6.0	3.8	36.6	7.9	55.9	42.4

standard heterosis and heterobeltiosis for root traits like root length, root volume and root dry weight. The hybrid GCH-5 was also heterotic for other important physiological and morphological traits like plant height up to primary spike, leaf number, stem girth, LAI and TDM while the other three hybrids recorded significantly negative heterosis for all the traits except DCH-177 for stem girth and TDM and DCH-519 for LAI.

Discussion

The quantification of the existing genetic variability for the traits of interest is essential in any breeding programme to understand the genetic structure of the population and their ultimate use in development of high yielding genotypes. Genotypes selected for the study represent the sources of tolerance to major biotic stresses like Fusarium wilt and leaf hopper *etc*., which include 37 germplasm and 27 parents for the development of high yielding parents or hybrids resistant to both biotic and abiotic stresses. The present study indicated the potential of genotypes for further exploitation of the existing variability with an emphasis on traits related to drought tolerance.

The study established the presence of a large genotypic and phenotypic variation for root and shoot traits in a set of 64 castor genotypes. The characters like plant height, root volume, root dry weight, TDM and LAI with significant genetic variability and heritability (>80%) were of special interest as they will be less influenced by environment and phenotypic selection for improvement of these characters would be effective. Root volume was significantly correlated with plant height, TDM and stem girth. Among them, plant height (0.88) and TDM (0.84) were heritable and thus can be used as selection criteria for traits related to drought tolerance. However among the shoot characters, LAI was significantly correlated with TDM. Least heritability for root length indicates its sensitivity to environment and phenotypic selection may not be that effective. The traits with high GCV, heritability also showed high genetic advancement and highly amenable for phenotypic selection. High heritability coupled with high genetic advancement for these characters is largely governed by additive gene action, which is highly amenable for visual selection (John *et al.*, 2006).

Majority of the genotypes (49) were classified in one group (Cluster I) for characters like plant height, root volume, root dry weight, TDM and LAI indicating geographical diversity of germplasm lines collected did not play much role in the genetic diversity especially for traits related to drought tolerance. Similar results were reported for seed yield and yield components by Durgarani *et al.* (2007). As majority of the germplasm accessions studied showed tolerance to Fusarium wilt, the possibility of linkage with drought tolerance is worth exploring in future studies. 48-1, RG 2124 and GCH-5 which were ranked as best genotypes for shoot and root characters formed as separate clusters indicating their genetic diversity for root traits. The greater inter cluster genetic diversity between RG-2124 with the genotypes in Cluster I (49), Cluster II (RG-2107) and Cluster VII (DCS-106) indicate the potential of generating genetic diversity either by recombination breeding or bi-parental mating design.

Parents like 48-1, DCS-78, DCS-99 with significantly higher root volume (>185 ml) can be directly used as male parents for generation of hybrids with drought tolerance, while the other 10 germplasm accessions *viz.*, RG-27, RG-1618, RG-1673, RG-1963, RG-2074, RG-2094, RG-2124, RG-2147, RG-2153 and RG- 2155 with higher root volume may be further used in breeding programme. As root volume was significantly correlated with plant height, TDM and stem girth, tall plant types with high TDM (>218 g) *viz.*, 48-1, Geetha, DCS-78, DCS-99, DCS-100 and DCS-101 along with germplasm accessions viz., RG-27, RG-596, RG-1673, RG-2074, RG-2124, RG-2153, RG-2155 and RG-2169 have a potential to develop high yielding varieties and hybrids with resistance to drought.

The magnitude of heterosis for root volume varied from -58.1 to 76.4% (mid-parent), -33.9 to 92.1% (standard heterosis) and -73.6 to 55.9% (heterobeltiosis). Among the four hybrids, GCH-5 alone recorded significantly positive mid parent, standard and heterobeltiosis for heritable root traits like root volume and root dry weight. The hybrid GCH-5 was also heterotic for other important physiological and morphological traits like plant height up to primary spike, leaf number, stem girth, LAI and TDM.

Among the 64 genotypes studied, 48-1, RG 2124 and GCH-5 were ranked as best genotypes for shoot and root characters. Root volume, root dry weight and TDM showed high general combining ability (GCV), heritability (>80%), heterosis and superior heterobeltiosis. These traits also showed high genetic advancement and highly amenable for phenotypic selection. Large genotypic variation available in the working germplasm for WUE and root traits related to drought tolerance can be utilized for applied breeding programme. The new sources of drought tolerance can be used for physiological and genetic studies and in drought resistance breeding programme. Root volume but not root length is the key trait that can be used as selection criteria.

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