Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; SP2: 179-184

Sowmya P
ICAR-CRIDA-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Telangana, India

Vanaja M
ICAR-CRIDA-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Telangana, India

Sunita V
ICAR-CRIDA-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Telangana, India

Raghuram Reddy P
ICAR-CRIDA-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Telangana, India

Correspondence
Sowmya P
ICAR-CRIDA-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Telangana, India

Genetic advance for physiological parameters in two high yielding castor (*Ricinus communis* L.) genotypes under irrigation and moisture stress

Sowmya P, Vanaja M, Sunita V and Raghuram Reddy P

Abstract
During Kharif-2014, a field study was conducted with two high yielding CRIDA castor genotypes, *viz*., CRC-2 and CRC-9along with the check 48-1under irrigated and moisture stress conditions to assess their variability and genetic advance for seed yield and physiological traits *viz*., ELWRC, RWC, Pn, gs, Tr and WUE. Significant variability was observed among the genotypes for all the characters studied.CRC-9 performed better than the check for the four physiological traits studied *viz*., ELWRC, Pn, gs and WUE under both irrigated and moisture deficit stress conditions. Whereas, CRC-2 performed better than the check for two physiological traits *viz*., gs and Tr under moisture deficit conditions only.High heritability with high genetic advance was recorded for Pn under both the conditions studied while for gs and Tr under moisture deficit stressonly indicating the predominance of additive gene action in inheritance of these characters. Hence, these traits can be taken into consideration for the improvement of castor.

Keywords: Castor, genotypes, seed yield, physiological traits, genetic variability, genetic advance

Introduction
Castor bean (*Ricinus communis* L.) is a tropical non-edible oil plant of high commercial importance. Castor bean is monotypic species of the family Euphorbiaceae has a wide range distribution in tropical and subtropical regions (Dapke *et al.,* 2016) [16]. The major production of castor bean comes from India, China and Brazil, which contributes more than 90% of global production. The productivity of the country in 2011-12 is 1417 kg ha-1 with world average of 850 kg ha-1 (Anonymous, 2013) [2]. Gujarat is the leading castor growing state in India and contributes more than 70% of the production from about 47% of the area (Dapke *et al.,* 2016) [16].

While a full understanding of the physiological and genetic basis of yield is still incomplete, progress has been made in developing selection technologies that may improve the efficiency of experimental breeding and the physiological traits conferring survival were strongly favored for most of the crop's evolution (Reynolds *et al.*, 1999) [30]. Crop physiologists have identified a number of traits that would help the breeder in development and identification of moisture stress tolerant genotypes with high yield potential (Basu *et al.,* 2004) [5]. Apparently, morpho-physiological traits for growth and development have the greatest impact on the adaptation of plants to the target environments with theaim of achieving a maximum productivity (Rahman *et al.,* 2016) [27].

Materials and methods
During Kharif-2014, a field study was conducted with two CRIDA castor genotypes, *viz*., CRC-2, CRC-9and a check 48-1 at Hayathnagar Research Farm, Central Research Institute for Dry land Agriculture (CRIDA), Hyderabad. The trial was sown on July 26th, 2014 in RBD with three replications each for irrigated conditions and for moisture deficit stress conditions with two meters apart of these two treatments. The irrigated plots were maintained stress free by withholding irrigation at initiation of primaries moisture deficit stress treatment was imposed till wilting symptoms were appeared and then the stress was relieved. Five plants from each treatment were randomly selected in each replication of all the genotypes. Three replications were maintained in the field for each treatment. Each genotype was sown in 5m length of three rows with plant to plant spacing of 30cm and 1m between rows.

The crop received 249 mm rainfall spreading in 19 rainy days (>2.5 mm) during the crop growth period, the crop experienced rainless period of more than 10 days during vegetative stage, 31 days during initiation to maturation of primaries and initiation of secondaries and 97 days during maturation of secondaries and initiation to maturation of tertiaries. During the crop growth period, the average temperature was 30.3°C with minimum and maximum of 4.5°C and 35.6°C respectively.

Physiological Parameters

Photosynthetic rate (Pn), stomatal conductance (gs) and transpiration rate (Tr): A portable photosynthesis system (LI-6400, LI-COR, USA) was used to record photosynthetic rate (Pn-µmol CO2m-2s-1), stomatal conductance (gs- cm s-1), transpiration rate (Tr- mmol H2O m-2 s-1) on fully expanded young leaves for each treatment between 9:30 and 12:00hrs. Intrinsic water use efficiency (WUE- µmol CO2 mmol-1 H2O) was calculated as the ratio of Pn and Tr i.e. WUE = Pn/Tr.

Relative water content (RWC): RWC was determined according to Barr and Weatherley (1962). Fresh weight of the young fully expanded leaf was taken and soaked the leaf for 4 hours and after soaking, the leaves were quickly and carefully blotted dry with tissue paper prior to determination of turgid weight. Finally, the samples were dried in an oven at 65 °C for 48 hours to determine dry weights.

RWC = [(fresh weight – dry weight)/ (turgid weight –dry weight)] × 100

Excised leaf water retention capacity (ELWRC): ELWRC was measured as method of Rao et al. (1998) [28]. Third leaf from top were excised and weights were taken at zero min,15, 30, 45, 60, 90, 120, 150, 180, 240, 300, 360 minutes. Then curves were drawn to record the moisture percent actually retained by the leaf when it was excised from the plant and expressed in %.
ELWRC = [initial weight at that specific time/Initial weight] × 100.

Genetic Analysis

- Heritability in broad sense (H2 or h2) (Falconer,1989)
- Phenotypic and genotypic correlations (Miller *et al.*, 1958)
- Genotypic (σ2 g) and Phenotypic variances (σ2 ph) (Comstock and Robinson, 1952).
- Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) (Singh and Chaudhary, 1985).
- Statistical analysis - Analysis of variance (ANOVA)-STAR (Statistical Tools For Agricultural Research)

Table 1: Weather data during crop growth period-Kharif-2014

	Temp		RH	
	Max. (°C)	Min. (°C)	Max (%)	Min (%)
Average	30.3	14.4	84. 8	49.7
Minimum	21.3	4.5	42	24.0
Maximum	35.6	31	100.0	49.7

Total Rainfall = 249 mm Number of rainy days (>2.5 mm) = 19 days

Results and Discussion

Data on six physiological parameters *viz*., photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (Tr), intrinsic water use efficiency (WUE), ELWRC and RWC were recorded for the two genotypes *viz.*, CRC-2 and CRC-9 along with the check 48-1 during Kharif-2014 under both irrigated and moisture stress conditions. The mean performances and percentage superiority (% sup.) of seed yield and physiological traits of the two genotypes over check under irrigated and moisture stress conditions are presented in Table-2(a) and Table-2(b) respectively.

Seed yield (g/pl): Under irrigated conditions, the seed yield was highest for CRC-2 (41.45g/pl) while for CRC-9 it was lower than the check recording 29.18 g/plwhile the check 48-1 recorded 36.45g/pl [Table-2 (a)].
Under moisture stress condition also CRC-2 recorded the highest seed yield of 27.68g/pl while CRC-9 recorded 22.21 g/plwhich was on par with the check 48-1 (22.57 g/pl). The % of superiority over check 48-1 for CRC- 2 was 13.72% and 22.64% under irrigated and moisture stress conditions respectively. Whereas, for CRC-9 the % superiority over check under irrigated conditions was inferior while under moisture deficit stress conditions it was on par with the check 48-1 [Table-2(b)].

Physiological components

Excised leaf water retention capacity (ELWRC): ELWRC values at the end of 420 min of excision of leaves was highest for CRC-9 (73.96%) followed by 48-1 (70.63%) andCRC-2 (64.57%).This results indicated that high ELWRC was retained by CRC-9 with better leaf moisture even after 420 min of excision whereas, CRC-2 and check 48-1 showed lower leaf moisture content for the same duration.

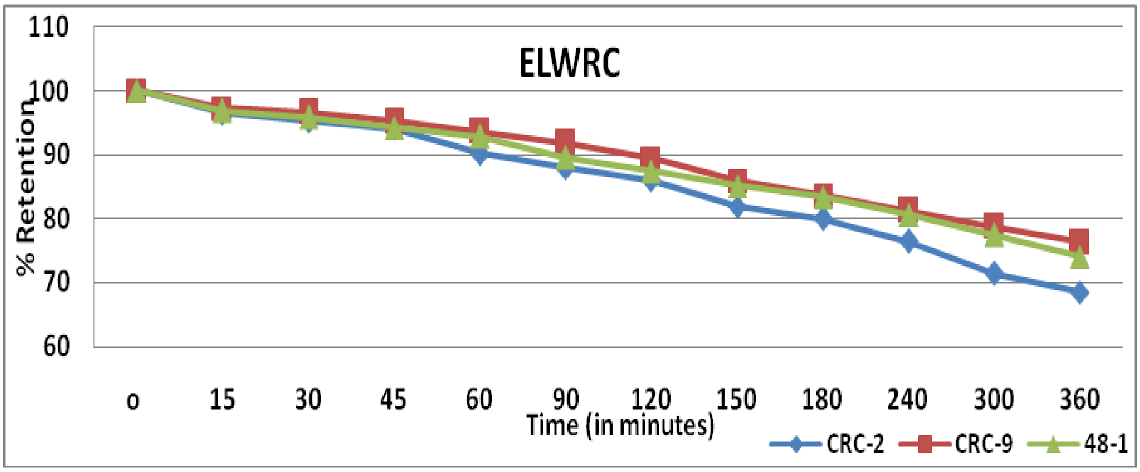

Fig 1: ELWRC of three castor genotypes

Relative water content (RWC): RWC was higher for CRC-2 with 73.89% under irrigated conditions while for CRC-9it was 69.73% and for check it was73.54% under irrigated conditions. While under moisture stress, RWC was higher for check (48-1) with 69.68% followed by CRC-9 (64.69%) andCRC-2 (59.62%).These results showed that none of the genotypes studied were superior to the check under both the conditions.

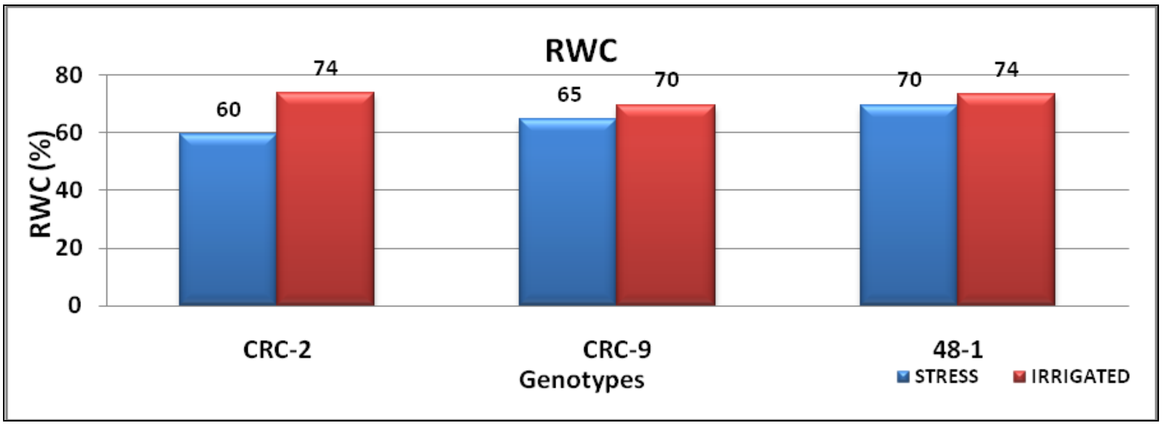

Fig 2: RWC of three castor genotypes under irrigated and moisture deficit stress conditions

Photosynthetic rate (Pn- **µmol CO_2 m^{-2} s^{-1}):** Under irrigated conditions,CRC-9 (39.57 µmol CO_2 m^{-2} s^{-1}) recorded higher Pn values than CRC-2 (33.7 µmol CO_2 m^{-2} s^{-1}) followed by check 48-1(29.87 µmol CO_2 m^{-2} s^{-1}).Under moisture deficit stress also CRC-9 recorded higher Pn values of 36.9 µmol CO_2 m^{-2} s^{-1} followed by CRC-2 (28.77 µmol CO_2 m^{-2} s^{-1}) and the check 48-1(20.9 µmol CO_2 m^{-2} s^{-1}).The results showed that % superiority over check for CRC-9 was 32.47% under irrigated conditions, while it was 76.56% under moisture deficit stress. Whereas, for CRC-2, it was 12.82% under irrigated conditions while under stress conditions it was 37.66%.

Stomatal conductance (gs- cm s^{-1}): The genotypeCRC-9 (0.65 cm s^{-1}) showed higher gs than CRC-2 (0.58 cm s^{-1}) and 48-1 (0.45cm s^{-1}) under irrigated conditions. Whereas, under moisture deficit stress, the two genotypesCRC-2 and CRC-9 showed similar gs of 0.42 cm s^{-1} but higher than 48-1 (0.21cm s^{-1}). The results showed that % superiority over check for CRC-9 was 30% under irrigated conditions while it was 100% undermoisture deficit stress conditions. Whereas, for CRC-2, it was 16% under irrigated conditions while under stress conditions it was 100%.

Transpiration rate (Tr- mmol H_2O m^{-2} s^{-1}): Tr was higher for CRC-9 with 9.61 mmol H_2O m^{-2} s^{-1} followed by CRC-2 (8.67 mmol H_2O m^{-2} s^{-1}) and check 48-1.Under moisture deficit stress conditions, Tr was higher for CRC-2 (8.08 mmol H_2O m^{-2} s^{-1}) than CRC-9(7.85 mmol H_2O m^{-2} s^{-1}) and 48-1. The results showed that % superiority over check for CRC-9 was 17.77% under irrigated conditions while it was 51.84% undermoisture deficit stress conditions. Whereas, for CRC-2, it was 6.25% under irrigated conditions while under stress conditions it was 56.29%.

Water use efficiency (WUE- µmol CO_2 $mmol^{-1}$ H_2O): Under irrigated conditions, CRC-9 recorded higher WUE of 4.12µmolCO_2 $mmol^{-1}$ H_2O than CRC-2 (3.89µmol CO_2 $mmol^{-1}$ H_2O) and 48-1 (3.66µmol CO_2 $mmol^{-1}$ H_2O). Under moisture deficit stress, CRC-9 recorded higher WUE of 4.70 µmolCO_2 $mmol^{-1}$ H_2O followed by CRC-2(3.56 µmol CO_2 $mmol^{-1}$ H_2O) and 48-1 (4.04 µmol CO_2 $mmol^{-1}$ H_2O). The results showed that % superiority over check for CRC-9 was 12.48% under irrigated conditions while it was 16.28% under moisture deficit stress conditions. Whereas for CRC-2 it was 6.15% under irrigated conditions while under stress conditions it was -12%.

With limited available moisture under rain-fed conditions, the crops need to have efficient physiological mechanisms such as ELWRC to rationalize its use. This trait can be used for screening germplasm for drought tolerance in castor and the trait is heritable (Rao *et al.*, 1998) [28]. In blackgram, the genotype with better ELWRC recorded high seed yield (Jyothi Lakshmi *et al.*, 2009) [18] revealing the importance of this trait for selecting drought tolerant genotype. ELWRC was also shown to be associated with some of the key plant characters which have a great bearing on seed yield in rapeseed (Thurling *et al.*, 1980) [34]. In pearl millet, the hybrid ICMH 356 with high seed yield had better ELWRC, hence it was suggested as trait to screen drought tolerance (Vijayalakshmi *et al*., 2012) [36]. RWC is also an important indicator for plants to withstand drought and used to quantify tolerance to moisture stress (Virginia, 2012) [37]. Decrease in RWC was observed in sorghum hybrid under moisture deficit stress at all growth stages (Yadav *et al.*, 2005) [38]. In the present study, the selected castor genotype CRC-9 was found better for both ELWRC and RWC and is expected to tolerate moisture stress. Both CRIDA castor lines- CRC-2 and CRC-9 recorded higher Pn, gs, Tr and WUE over the check 48-1 under both irrigated and moisture deficit stress conditions. Better WUE was recorded by CRC-9 than 48-1under both irrigated and moisture deficit stress conditions, whereas CRC-2fared well than 48-1only under irrigatedcondition. Among the selected two genotypes, CRC-9 performed better than CRC-2 and 48-1 for all the physiological traits under both irrigated and drought conditions. Among the genotypes, the Pnof CRC-9 was less affected with moisture deficit stress than CRC-2 and 48-1 and with improved WUE. As this genotype was able to maintain better plant water status and it is evident from its better ELWRC and RWC. High leaf WUE is one of the criteria of drought-tolerance and a water-savingstrategy in plant growth (Liu *et al.*, 2012) [22].

Decrease in the photosynthesis under water stress in plants was reported by Liu *et al.*, (2011) [21] as drought decreases stomatal conductance which in turn limit the availability of CO_2 for photosynthesis (Pessarakli, 2001) [26]. Hirayama *et al.*

(2006) [15] suggested that plants exposed to moisture deficit stress, close their stomata to maintain their inner moisture content and consequently their transpiration rate will be decreased. Drought stress causes not only a substantial damage to photosynthetic pigments, but it also leads to deterioration of thylakoid membranes and thus, a reduction in photosynthetic capacity in plants exposed to drought stress is expected (Huseynova *et al.*, 2009, Anjum *et al.*, 2011, Kannan and Kulandaivelu, 2011) [17, 1, 19]. Munoz *et al.* (1998) [25] opined that the genotypes with high yield potential and with high yield under water limited condition are generally associated with reduced WUE mainly because of high water use (Blum, 2005) [6]. Improved WUE on the basis of reduced water use is expressed in improved yield under water-limited conditionsonly when there is need to balance crop water use against a limited and known soil moisture reserve. However, under most dryland situations where crops depend on unpredictable seasonal rainfall, the maximization of soil moisture use is a crucial component of drought avoidance, which is generally expressed in lower WUE (Blum, 2005) [6].

Water-use efficiency is often considered an important determinant of yield under stress and evenas a component of crop drought resistance. It has been used to imply that rain-fed plant production can beincreased per unit water used, resulting in more crop per drop (Blum, 2009) [7]. In other drought environments where stress may develop at any time during the season there is no consistent relationship between plant production and WUE (Condon *et al.*, 2002) [29]. On the other hand, the increase in WUE with drought was primarily may be because of stomatal conductance, and thus water loss declined more than carbon fixation (Edwards *et al.*, 2012) [10]. Previous reports have revealed that some genotypes may have more WUE than others, and artificial selection on genotypes with high WUE has been investigated as a means to improve crops with increased yield in water-limited environments (Condon *et al.*,2002; Rebetzke *et al.*,2002) [29, 8]. Vijayalakshmi *et al.* (2014) [34] reported that higher WUE in greengram was due to low stomatal conductanceand less transpiration.

Table 2 (a): Mean performances of castor genotypes over check for seed weight and physiological components under irrigated and moisture deficit stress conditions

Genotype	**Seed yield (g/pl)**		**Pn (µmol CO_2 m^{-2} s^{-1})**		**gs (cm s^{-1})**		**Tr (mmol H_2O m^{-2} s^{-1})**		**WUE (µmol CO_2 mmol^{-1} H_2O)**		**Relative water content (RWC)**	
	Irr (Rk)	**Str (Rk)**	**Irr (Rk)**	**Str (Rk)**	**Irr (Rk)**	**Str (Rk)**	**Irr (Rk)**	**Str (Rk)**	**Irr (Rk)**	**Str (Rk)**	**Irr (Rk)**	**Str (Rk)**
CRC-2	41.45 (1)	27.68 (1)	33.70 (2)	28.77 (2)	0.58 (2)	0.42 (1)	8.67 (2)	8.08 (1)	3.89 (2)	3.56 (3)	73.89 (1)	59.62 (3)
CRC-9	29.18 (3)	22.21 (3)	39.57 (1)	36.90 (1)	0.65 (1)	0.42 (1)	9.61 (1)	7.85 (2)	4.12 (1)	4.70 (1)	69.73 (3)	64.69 (2)
48-1	36.45 (2)	22.57 (3)	29.87 (3)	20.90 (3)	0.50 (3)	0.21 (2)	8.16 (3)	5.17 (3)	3.66 (3)	4.04 (2)	73.53 (2)	69.68 (1)

Irr- irrigated, str-stress, Rk-ranks

Table 2 (b): Percentage superiority (% sup.) over check (48-1) of castor genotypes over check for seed weight and physiological components under irrigated and moisture deficit stress conditions

Genotype	**Seed yield (g/pl)**		**Pn (µmol CO_2 m^{-2} s^{-1})**		**Gs (cm s^{-1})**		**Tr (mmol H_2O m^{-2} s^{-1})**		**WUE (µmol CO_2 mmol^{-1} H_2O)**		**Relative water content (RWC)**	
	Irr % sup.	**Str % sup.**	**Irr % sup.**	**Str% sup.**	**Irr% sup.**	**Str% sup.**	**Irr% sup.**	**Str% sup.**	**Irr % sup.**	**Str % sup.**	**Irr % sup.**	**Str % sup.**
CRC-2	13.72	22.64	12.82	37.66	16.00	100	6.25	56.29	6.15	-12.00	0.49	-14.43
CRC-9	-19.95	-1.60	32.47	76.56	30.00	100	17.77	51.84	12.48	16.28	-5.17	-7.16

Irr- irrigated, str-stress

The ANOVA results revealed that seed yield and all the physiological parameters (except WUE) showed significant variability for the genotypes and also for moisture levels (Table-3).

Table 3: Analysis of variance for physiological parameters **in castor genotypes** **Significance at p<0.05 and **Significance at p <0.01*

		Mean sum of squares				
Source	**DF**	**Seed yield**	**Pn**	**gs**	**Tr**	**WUE**
Replication	2	62.203	4.927	0.009	0.557	0.039
Genotypes	2	118.676**	248.345**	0.053*	7.328**	1.002*
Moisture levels	1	599.118**	137.227**	0.227**	14.187**	0.296
G x ML	1	23.437	15.274	0.006	2.166	0.427
Error	2	12.874	4.851	0.008	0.836	0.192
CV (%)		11.99	6.97	18.63	11.54	10.91

Correlations: The genotypic (r_G) and phenotypic correlations (r_P) for all the physiological parameters and seed yield under both irrigated and moisture deficit stress conditions are presented in Table-4. Seed yield showed significant and positive correlation for Pn, gs and Tr while significantly negatively correlated with WUE under moisture deficit stress conditions. It was observed that Pn is significantly and positively correlated genotypically with gs under both irrigated and moisture deficit conditions. Flexas *et al.* (2002) [13] observed significant and positive correlation of Pn with Tr in grape wine, gswith Tr in sugarcane (Silva *et al.*,2013) [33], while in rice significant and positive correlation of Pn with gs (Giuliani *et al.*, 2013) [14] and gs with Tr (Barbour *et al.*, 2010) [3]. The positive correlation between the seed yield and the photosynthesis in wheathas been reported earlier by Makino *et al.* (2011) [24]; with gs in maize (Shaibu *et al.*, 2015) [31]. The non-significant correlation between yield and photosynthetic rate was noted in bread wheat (Evans 1993, 1998) [11, 12], with gs in soybean (Liu *et al.*, 2012) [22] with Tr and WUE in Brassicas (Sharma, 2015) [32].

Table 4: Genotypic and phenotypic correlations for physiological parameters of castor genotypes under irrigated and moisture deficit stress conditions

		Seed yield		Pn		gs		Tr		WUE	
		Irri	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**
Pn	r_G	-0.183	0.998**	1.00	1.00	0.998**	0.946*	0.995**	0.875	-0.995**	0.773
	r_P	-0.107	-0.881	1.00	1.00	0.690	0.735	0.974*	0.748	0.679	0.512
gs	r_G	0.102	0.997**			1.00	1.00	0.999**	0.995**	-0.997**	0.444
	r_P	-0.111	-0.781			1.00	1.00	0.744	0.993**	0.731	-0.192
Tr	r_G	-0.174	0.997**					1.00	1.000	-0.986*	0.306
	r_P	-0.229	-0.009					1.00	1.000	-0.609	-0.182
WUE	r_G	-0.233	-0.999**							1.00	1.00
	r_P	-0.460	0.018							1.00	1.00
Seed yield	r_G	1.00	1.00								
	r_P	1.00	1.00								

*Significance at $p<0.05$ and **Significance at $p<0.01$

Genotypic and phenotypic variability, heritability and genetic advance as percent of mean (GAM %): The variances, coefficient of variations, heritability and genetic advance as percent of mean (GAM) were presented in Table-5. For all the physiological parameters, the phenotypic variance was higher than the genotypic variance and similarly phenotypic co-efficient of variation (PCV) was also higher than genotypic co-efficient of variation (GCV) indicating the influence of environment in both irrigated and moisture deficit stress conditions. Under irrigated conditions, seed yield and gs showed moderate heritability with moderate GAM. High heritability with high GAM was found for Pn. Under moisture deficit stress, seed yield showed moderate heritability with low GAM whilehigh heritability with high GAM was found for Pn and Tr. Khatun *et al.* (2015) [20] reported high heritability with high GAM for Pn in upland rice. Hubick *et al.* (1986) [16] reported high heritability for transpiration rate in peanut. Majidi *et al.* (2015) [23] reported moderate heritability for seed yield in Brassica for drought tolerance. Moderate heritability for gs was reported by Basnayake *et al.* (2015) [4] in sugarcane under water-limited conditions.

Table 5: Co-efficient of variation, variances, heritability and genetic advance for physiological parameters of castor genotypes under irrigated and moisture deficit stress conditions

	Genotypic Variance		Phenotypic Variance		GCV		PCV		Heritability		GAM (%)	
	Irri	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**	**Irri**	**Stress**
Seed Yield	9.41	2.638	18.94	22.78	8.59	6.72	12.19	19.75	0.497	0.316	12.49	4.71
Pn	23.65	60.68	24.30	70.64	14.14	26.99	14.34	29.12	0.973	0.859	28.75	51.55
Gs	0.004	0.01	0.009	0.020	10.41	30.29	16.75	40.46	0.386	0.560	15.06	45.78
Tr	0.52	2.22	0.57	3.42	8.22	21.19	8.58	26.31	0.916	0.648	16.21	35.15
WUE	0.01	0.30	0.02	0.66	2.66	13.29	3.81	19.58	0.485	0.461	3.93	18.80

Conclusion: CRIDA castor genotype CRC-9 performed better than the check for the four physiological traits studied *viz*., ELWRC, Pn, gs and WUE under both irrigated and moisture deficit stress conditions. However, CRC-2 performed better than the check for two physiological traits *viz*., gs and Tr under moisture deficit conditions only. Pn, gs and Tr registered high heritability with high GAM under moisture deficit stress conditions and can be considered as important physiological traits for the crop improvement of castor under drought conditions.

Acknowledgements
We acknowledge the Director, CRIDA and Head, Division of Crop Sciences for providing both field and lab facilities to conduct experiments.

References
1. Anjum SA, Xie X, Wang L. Morphological, physiological and biochemical responses of plants to drought stress. Afr. J Agric. Res. 2011; 6:2026-2032.
2. Anonymous. Annual report Castor. Directorate of Oilseeds Research, Hyderabad, 2013.
3. Barbour MM, Warren CR, Farquhar GD, Forrester GUY, Brown H. Variability in mesophyll conductance between barley genotypes, and effects on transpiration efficiency and carbon isotope discrimination. Plant, Cell Environ. 2010; 33:1176-1185.
4. Basnayake Jackson PA, Inman-Bamber NG, Lakshmanan P. Sugarcane for water-limited environments. Variation in stomatal conductance and its genetic correlation with crop productivity. J Exp. Bot. 2015; 66(13):3945-3958.
5. Basu MS Chunilal, Prakash C Nautiyal. Breeding strategies to increase water use efficiency of groundnut. In: Basu MS and Singh NB (Eds.), by Groundnut Research in India, 2004, 38-47.
6. Blum A. Drought resistance, water-use efficiency, and yield potential are they compatible, dissonant, or mutually exclusive? Aust. J Agric. Res. 2005; 56:1159-1168.
7. Blum A. Effective use of water (EUW) and not water- use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res. 2009; 112:119-123.
8. Condon AG, Richards RA, Rebetzke GJ, Farquhar GD. Improving intrinsic water use efficiency and crop yield. Crop Sci. 2002; 42:122-131.
9. Dapke JS, Naik MR, Singh AP, Baraskar VV, Narwade AV, Indivar Prasad. Genetic association yield with different agronomic traits in castor (*Ricinus communis* L.). International Journal of Biological Research. 2016; 1(1):47-49.
10. Edwards CE, Brent EE, Robertson C, Clungd Mc, Ping L, Weiniga C. Quantitative Variation in Water-Use Efficiency across Water Regimes and Its Relationship

with Circadian, Vegetative, Reproductive, and Leaf Gas-Exchange Traits. Mol. Plant. 2012; 5(3):653-668.
11. Evans LT. Crop Evolution, Adaptation and Yield. CUP, Cambridge, MA, USA, 1993.
12. Evans LT. Greater crop production: whence and whither?. In Feeding a World Population of More Than Eight Billion People – A Challenge to Science (eds J.C. Waterlow, D.G. Armstrong, L. Fowdenand& R. Riley), pp. 89–97. Oxford University Press, Cary, NC, USA, 1998.
13. Flexas J, Medrano H. Drought inhibition of photosynthesis in C3 plants: Stomatal and Non-stomatal Limitations Revisited. Ann. Bot. 2002; 89:183-189.
14. Giuliani R, Koteyeva N, Voznesenskaya E, Evans MA, Cousins AB, Edwards GE. Coordination of Leaf Photosynthesis, Transpiration, and Structural Traits in Rice and Wild Relatives (*Genus Oryza*). Plant Physiol. 2013; 162:1632-1651.
15. Hirayama M, Wada Y, Nemoto H. Estimation of drought tolerance based on leaf temperature in upland rice breeding. Breeding Sci. 2006; 56:47-54.
16. Hubick KT, Farquhar GD, Shorter R. Correlation between wateruse efficiency and carbon isotope discrimination in diverse peanut (*Arachis*) germplasm. Aust. J Plant Physiol. 1986; 13:803-816.
17. Huseynova M, Suleymanov SY, Rustamova SM, Aliyev JA. Drought-induced changes in photosynthetic membranes of two wheat (*Triticum aestivum* L.) cultivars. Russian Biokhim. 2009; 74:1109-1116.
18. Jyothi Lakshmi N, Vanaja M, Maheswari M, Yadav SK, Raghuram Reddy P, Venkateswarlu B. Excised leaf water retention capacity (ELWRC) technique for screening blackgram genotypes for yield. J Food Legumes. 2009; 22(3):211-212.
19. Kannan ND, Kulandaivelu G. Drought induced changes in physiological, biochemical and phytochemical properties of *Withania somnifera* Dun. J Med. Plants Res. 2011; 5:3929-3935.
20. Khatun T, Hanafi M, Yusop MR, Wong MY, Salleh FM Ferdous J. Genetic Variation, Heritability and Diversity Analysis of Upland Rice (*Oryza sativa* L.) Genotypes Based on Quantitative Traits. Bio Med Res. Int, 2015. http://dx.doi.org/10.1155/2015/290861.
21. Liu C, Liu Y, Guoa K, Fana D, Li G, Zhenga Y, Yuc L, Yangc R. Effect of drought on pigments, osmotic adjustment and antioxidant enzymes in six woody plant species in karst habitats of southwestern China. Environ. Exper. Bot. 2011; 71:174-183.
22. Liu G, Yang C, Xu K, Zhang Z, Li D, Wu Z, Chen Z. Development of yield and some photosynthetic characteristics during 82 years of genetic improvement of soybean genotypes in northeast China. Aust. J Crop Sci. 2012; 6(10):1416-1422.
23. Majidia MM, Rashidib F, Sharafi Y. Physiological traits related to drought tolerance in Brassica. Int. J Plant Prod. 2015; 9(4):541-560.
24. Makino A. Photosynthesis, Grain Yield, and Nitrogen Utilization in Rice and Wheat. Plant Physiol. 2011; 155:125-129.
25. Munoz P, Voltas J, Araus JL, Igartua E, Romagosa I. Changes over time in the adaptation of barley releases in north-eastern Spain. Plant Breed. 1998; 117:531-535.
26. Pessarakli M. Handbook of Plant and Crop Physiology (2nd ed). Marcel Dekker Inc., New York, 2001.
27. Rahman M, Barma NCD, Biswas BK, Khan AA, Rahman J. Study on morpho-physiological traits in Spring Wheat (*Triticum Aestivum* L.) under rainfed condition. Bangladesh J Agric. Res. 2016; 41(2):235-250.
28. Rao GD, Vanaja M, Lakkneni KC, Reddy PR. Stability of excised leaf water retention capacity (ELWRC) technique for screening castor genotypes. J Oilseeds Res. 1998; 15:280-287.
29. Rebetzke GJ, Condon AG, Richards RA, Farquhar GD. Selection for reduced carbon isotope discrimination increases aerial biomass and grain yield of rainfed bread wheat. Crop Sci. 2002; 42:739-745.
30. Reynolds MP, Rajaram S, Sayre KD. Physiological and Genetic Changes of Irrigated Wheat in the Post–Green Revolution Period and Approaches for Meeting Projected Global Demand. Crop Sc. 1999; 39:1611-1621.
31. Shaibu AS, Adnan AA, Rabiu IU. Genetic Correlation and Contribution of Some Physiological Traits to Yield in Some Selected Maize Genotypes. Int. J Res. in Sci. Tech. 2015; 5(4):1-11.
32. Sharma P. Relationship of photosynthesis and related traits to seed yield in oilseed Brassicas. J Appl. Nat. Sci. 2015; 7(2):851-856.
33. Silva MA, Jifon JL, Santos CM, Jadoski CJ, Silva JAG. Photosynthetic Capacity and Water Use Efficiency in Sugarcane Genotypes Subject to Water Deficit during Early Growth Phase. Braz. Arch. Biol. Technol. 2013; 56(5):735-748.
34. Thurling N, Das LD. The Relationship for Pre-Anthesis Development and Seed Yield of Spring Rape (*Brassica napus* L.). Aust. J Agric. Res. 1980; 31(1):25-36.
35. Vijayalakshmi D, Vijay SK, Ramakrishnan PS, Sundaram S, Vijayalakshmi C. Effects of Exogenous ABA application On Stomatal Regulation of Gas Exchange Parameters and Calculated Water Use Efficiency In Major Pulses Of Tamil Nadu, India. Ind. J Agric. Res. 2014; 48(4):324-328.
36. Vijayalakshmi T, Varalaxmi Y, Jainender S, Yadav SK, Vanaja M, Jyothilakshmi N *et al*., Physiological and Biochemical Basis of Water-Deficit Stress Tolerance in Pearl Millet Hybrid and Parents. Amer. J Plant Sci. 2012; 3:1730-1740.
37. Virginia S, Pagan M, Cooper M, Kantartzi SK, Lightfoot DA, Meksem K *et al*., Genetic Analysis of Relative Water Content (RWC) in Two Recombinant Inbred Line Populations of Soybean (*Glycine max* (L.)Merr.). J Plant Gen. Sci. 2012; 1(2):46-53.
38. Yadav SK, Jyothi Lakshmi N, Maheswari M, Vanaja M, Venkateswarlu B. Influence of water deficit at vegetative, anthesis and grain filling stages on water relations and grain yield in sorghum. Ind. J Plant Physiol. 2005; 10(1):20-24.