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Studies on the Effect of Water Stress on Root Traits in Redgram Genotypes

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ABSTRACT

The experiment was conducted during July–November, 2019 at Regional Agriculture Research Station, Professor Jayashankar Telangana State Agricultural University, Palem, Nagarkurnool District, Telangana State, India. The main treatments had five red gram genotypes and water stress levels were taken as sub-treatment in 3 replications in factorial RBD using specialized root structure made with cement bricks. There was great variability in the yield performance of different Redgram genotypes under drought conditions. The experiment was conducted to select genotypes with efficient root architecture and associated traits under drought stress. Root studies were performed with the Delta T automatic root scanner. The SPAD chlorophyll meter was used to measure the SCMR value. The present study results revealed that genotype, Maruti showed significant superiority for character plant height and SCMR under non-stress, mild stress and severe stress conditions. The same genotype showed superior values for main root length under control and mild stress. Whereas, Laxmi recorded the highest plant height under severe stress and the same genotype also showed significant superiority for total plant dry weight, root dry weight and root area under severe stress. The genotype Laxmi showed significant character, root area and diameter superiority under mild stress. ICPL-20176 recorded significant superiority for main root length under severe stress and root tip for mild stress. The identified genotypes can be used as the parents in future drought-proof breeding useful for cultivating in water stress conditions.

KEYWORDS: Cultivars, redgram, root structures, root traits, water stress

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1. INTRODUCTION

Redgram is commonly known as Tur or Arhar in India and is the second important pulse crop in the country after gram (Chana). The ability of Redgram to produce high economic yields under soil moisture deficit makes it an important crop in rainfed and dry land agriculture and is important due to its efficient nitrogen-fixing ability, tolerance to drought and contribution to soil organic matter (Dolan et al., 2021; He et al., 2022). World major Redgram producing countries are India (37.50 lakh tonnes), Myanmar (6.76 lakh tonnes), Malawi (4.34 lakh tonnes), Tanzania (3.15 lakh tonnes) and Haiti (0.87 lakh tonnes).

Drought is detrimental for any crop production (Fahad et al., 2017; Lamaoui et al., 2018). Pigeonpea is grown in *kharif* season as a rainfed crop. It is considered as a drought tolerant legume on account of its deep root system (Pavani et al., 2022). Among the four maturity groups, extra early and early types complete their life cycle just after recession of the monsoon season. However, their reproductive phase more often encounters terminal drought. The situation becomes even worse for medium and long-duration Pigeonpea as their flowering and pod-filling stages coincides with acute soil moisture deficit in absence of any supplementary irrigation. Physiologist and breeders are positioned to breed Redgram plants with efficient root traits to improve productivity under drought (Comas et al., 2013, Sunita et al., 2018). However, a better understanding of root functional traits and how traits are related to whole plant strategies to increase crop productivity under different drought conditions is needed. Root traits associated with maintaining plant productivity under drought include small fine root diameters, long specific root length, and considerable root length density, especially at depths in soil with available water. Further, increase in the simulated root zone depth has been shown to increase leaf area, growth, photosynthesis, transpiration and yield of crops under drought (Jones and Zur, 1984). Drought tolerance is closely related to the distribution of root systems in the soil (Sarker et al., 2005). The vital plant support for plant adaptation to stress condition is the root system (Siddiqui et al., 2022). On sensing a moisture stress, roots continue further growing and protrude into deeper soil layers (Koevoets et al., 2016; Vyver and Peters, 2017). Large root system with greater root prolificacy and rooting depth, was shown to influence not only transpiration through soil moisture utilization but also influences shoot biomass production and harvest index (HI) under terminal DS (Drought stress) (Kashiwagi et al., 2013, Purushothaman et al., 2017, Kushwa et al., 2022).

Conducting research on root systems in field conditions is very laborious, expensive and time consuming (Subbarao et al., 1995). For the selection of drought tolerant genotypes, study on root traits related to below plant parts is essential. Among these traits, root traits (Root length density (RLD), Root dry weight (RDW), root surface area, average root diameter, root volume,) were found to be the major contributors to drought tolerance (avoidance) under rainfed condition (Uga et al., 2013, Geetha, 2022). In drought prone Southern Telangana Zone of Telangana, where recurrent droughts in July-November, 2019 is ever present restraint on maximum production of Pigeonpea, the genotypes with better root characteristics is a major research priority in order to recommend to the farmers. Hence, this study was taken up to know the variation in root traits of red gram genotypes with different durations under rainfed situation.

2. MATERIALS AND METHODS

An experiment was conducted during July–November, 2019 at Regional Agriculture Research Station, Professor Jayashankar Telangana State Agricultural University, Palem, Nagarkurnool district, Telangana state, India. The planting material Comprised of five Redgram genotypes *viz.*, Maruti, Asha, Laxmi, ICPL-20176 and ICPL-161 as main treatments and water stress levels are taken as sub treatment in three replications in factorial RBD in root structure. Sub treatment irrigation intervals includes control (Irrigation given at regular intervals) 2) Mild stress (with holding irrigation from 90 days to 97th days after Planting) 3) severe stress (with holding irrigation from 90 to 110th days after planting). The experiment was conducted in specialized constructed root structures made with cement bricks and red soil is filled in the cavity and raised the soil bed to 1.8 m level and under specially raised rectangular soil beds of size i.e., 15×2×1.5 m^3 (L×B×H) structure. The soil bed was watered and further filled with soil for better compaction. A spacing of 45 cm from row to row and 20 cm between plants was maintained and the crop was raised in protective root structure which is 6 ft. high from the ground level. Soil properties of the simulated soil bed were as follows. Bulk density: 1.58 mg m^{-3}, particle density: 2.53 mg m^3, water holding capacity: 39.4% and porosity: 40.4% further, bed is filled with red soil to represented normal field condition. The recommended packages of practices were adopted during the crop growth period for raising the healthy crop.

At flowering stage, observations were recorded on plant height, shoot fresh weight, root fresh weight, root to shoot ratio, main tap root length, total root diameter, total toot air, total number of lateral roots per plant, SPAD chlorophyll meter reading (SCMR), root dry weight and total plant dry weight. The root structures were dismantled during flowering stage or active vegetative growth stage of the crop and all the plants removed from the soil without damaging the roots by using water with jet pump. After roots have been removed from their surrounding soil environment in the laboratory or the field, a number of processing steps remain before root traits can be assessed, including washing, sorting and preserving the sample for further use. About five representative samples were collected under different stress level from each genotype and root studies were performed with Delta T automatic root scanner. In each entry, about five plants were tagged under different stress treatment and plant height was measured from base to top. The SPAD chlorophyll meter was used to measure from top, middle and bottom canopy leaves and average of the three readings was taken as SCMR value.

3. RESULTS AND DISCUSSION

Screening and selection of desirable genotype genotypes for drought tolerance is the first and foremost important step in pulse breeding program (Jincya et al., 2021). Keeping the above in view, five genotypes of Redgram were evaluated for root and shoot parameters under mild and severe stress conditions along with control. The results indicated parameter, plant height decreased with the increase in severity of water stress conditions (Table 1). Among the genotypes, Maruthi recorded highest plant height under control (Non-stress), mild stress and interaction with the value of 102.33 cm, 93.33 cm and 89.00 cm which was on par with genotype Asha, which recorded plant height of 101.67 cm and 91.13 cm under control and mild stress. Whereas, under severe stress genotype Laxmi recorded highest plant height value of (89 cm) which was on par with Maruthi (71.33 cm). Reduction in plant height under water stress occurs due to dehydration of the protoplasm, loss of turgidity, and low water potential that ultimately affect cell division and cell elongation (Dahanayake et al., 2015).

SPAD chlorophyll meter reading (SCMR), a reflection of leaf chlorophyll/ leaf nitrogen declined in stress treatment due to degradation of leaf chlorophyll content (Table 1). Genotype Laxmi, recorded significant superior performance for the trait SCMR with the value of 59.40, 56.23, 52.01 and 55.90 in control, mild stress, severe stress, and interaction. A significant positive relationship between WUE and SCMR was observed in groundnut (Bindu Madhava et al., 2003), suggesting that a quick determination of SCMR could reflect intrinsic mesophyll efficiency. Chlorophyll content (SPAD value) was directly proportional to amount of chlorophyll present in the leaves. Under irrigated and water stress conditions when the yield was regressed over SPAD value of these genotypes showed significant positive linear relationship (Jumrani and Bhatia, 2019).

Table 1: Effect of water stress on plant height (cm) and SCMR values in red gram cultivars

Genotypes	Plant height (cm)				SCMR			
	Control	Mild stress	Severe stress	Means	Control	Mild stress	Severe stress	Means
Maruti	102.33	93.33	71.33	89.00	59.40	56.23	52.07	55.90
Asha	101.67	91.13	48.30	80.37	55.17	47.33	46.53	49.68
Laxmi	79.67	72.60	71.67	74.64	53.60	52.60	48.07	51.42
ICPL-20176	84.67	76.20	67.33	76.07	51.90	51.30	46.67	49.96
ICPL-161	74.33	63.00	46.67	61.33	50.67	49.73	45.17	48.52
Means	88.53	79.25	61.06		54.15	51.44	47.70	
	CD	SEd±	SEm±			CD	SEd	SEm±
Genotypes	11.48	5.58	3.94		Genotypes	2.56	1.24	0.88
Stresses	8.90	4.32	3.06		Stresses	1.98	0.96	0.68
G×S	N/S	9.66	6.83		G×S	17.28	2.16	1.52

Trait main root length showed non significance value for genotypes and genotype×stress interactions (Table 2, Figure 1). Whereas, mean root length of all the genotype is highest under non-stress conditions (3889.57 mm), which is at par with mild stress treatment (3176 mm). Long tap root genotypes yielded higher under water stress (Jumrani and Bhatia, 2018). The results are in accordance with the reports of Geetha et al. (2012). The genotypes with longer roots have deeper root system would allow water extraction from lower soil profiles and thus, it is expected that the plant will perform better under moisture stress. Increase in root length is an adaptive mechanism or drought tolerant genotypes. Therefore, higher value may be used for the discrimination between drought tolerant and susceptible genotypes. Rauf and Sadqat (2008) stated that increase in root length occurred due to higher osmotic adjustment

Table 2: Effect of water stress on main root length (mm) and fresh weight in (g) red gram genotypes

Genotypes	Main root length (mm)				Root fresh weight (g pl^{-1})			
	Control	Mild stress	Severe stress	Means	Control	Mild stress	Severe stress	Means
Maruti	4800.00	3566.67	2469.33	3612.00	69.67	45.33	21.67	45.56
Asha	3722.33	3333.33	2526.67	3194.11	80.00	52.00	42.33	58.11
Laxmi	3181.50	2676.67	2221.33	2693.17	88.00	45.67	24.67	52.78
ICPL-20176	4400.00	3491.67	3114.33	3668.67	63.00	47.67	30.33	47.00
ICPL-161	3344.00	2811.67	1444.60	2533.42	57.33	27.67	20.00	35.00
Means	3889.57	3176.00	2355.25		71.60	43.67	27.80	
	CD	SEd±	SEm±		CD	SEd±	SEm±	
Genotypes	N/A	450.91	318.84		8.70	4.23	2.99	
Stresses	719.15	349.28	246.98		6.74	3.27	2.32	
G×S	N/A	781.01	552.25		N/A	7.32	5.18	

Figure 1: Roots of ICPL 8 and Maruthi varieties of redgram under water stress conditions

ability of drought genotypes. Petcu and Petcu, 2006 also indicated that increase in root length occurred at expense of lateral roots.

Root fresh weight declines with increase in intensity of stress (Table 2). Non-stress recorded significant superior value for root fresh weight (71.60 g plant^{-1}). Among genotypes, Laxmi recorded significantly superior root fresh weight value of 88g plant^{-1} under control. Whereas, under mild stress and severe stress situations genotype, Asha recorded significant superior value of 52 g plant^{-1} and 42.33 g plant^{-1}, respectively. The genotype×stress interaction showed non significance for root fresh weight. Even partial drying of root systems can lead to decreased allocation to vegetative shoots (Dry et al., 2001). It has been observed, that under severe water deficits, limited root growth may occur because of very low soil water availability and high soil impedance (Comas and Eissenstat, 2009). In this case, increased root hair and aquaporin production may play particularly important roles in compensating for reductions in root elongation and surface area production.

For the parameter total plant dry weight (Table 3) genotype ICPL-161 recorded highest value of 148.67

Table 3: Effect of water stress on total plant dry weight (g) and root dry weight (g) in red gram cultivars

Genotypes	Total plant dry weight (g plant^{-1})				Root dry weight (g plant^{-1})			
	Control	Mild stress	Severe stress	Means	Control	Mild stress	Severe stress	Means
Maruti	122.33	105.67	76.00	101.33	4.50	4.19	2.31	3.67
Asha	99.33	77.33	73.00	83.22	4.04	3.36	2.63	3.35
Laxmi	123.67	109.67	125.33	119.56	4.30	3.57	2.94	3.60
ICPL-20176	139.33	117.00	86.33	114.22	6.13	4.24	2.67	4.35
ICPL-161	148.67	165.33	97.33	137.11	2.59	1.70	1.24	1.84
Means	126.67	115.00	91.60		4.31	3.41	2.36	
	CD	SEd±	SEm±		CD	SEd±	SEm±	
Genotypes	33.28	16.16	11.43		1.08	0.53	0.37	
Stresses	25.78	12.52	8.85		0.84	0.41	0.29	
G×S	N/A	28.00	19.80		N/A	0.91	0.65	

g plant^{-1} which are on par with genotype ICPL-20176 (139.33 g plant^{-1}) and Laxmi (123.67 g plant^{-1}). Whereas, under mild stress condition, genotype ICPL-161 showed significantly superior performance of 165.33 g plant^{-1} and genotype Laxmi (125 g plant^{-1}) showed significant superior performance under severe water stress. Similar results are earlier reported by Sangakkaran et al., 2000. The variation in seedling growth characteristics was specific for genotypes under reduced water potential. Similar results were also reported in green gram and black gram (Kaur et al., 2017; Jincya et al., 2021).

Root area of main root (mm^2) showed non significance value under various stresses (control, mild and severe stress condition) and genotype×stress interactions (Table 4). Among the genotype, laxmi showed significantly superior value for parameter root area under non-stress (11163.13mm^2), mild stress (4964.14 mm^2) and severe stress (8852.33 mm^2). Root area can also be an indicator of the effects of soil strength on root growth (Qin et al., 2004).

Root diameter (mm) decline under stress condition compared to non-stress (Table 4). Among the genotypes, Asha showed significant superior value of 8.85mm under non-stress condition for trait root diameter. Under mild stress condition genotype laxmi, showed highest root diameter value of 3.99 mm which are par with Maruthi (3.55 mm) and Asha (3.37 mm) whereas under severe stress same genotype Laxmi recorded highest root diameter value of 3.36 mm which are on par with Maruthi (3.16 mm) and Asha (3.13 mm). In stress×genotype interactions, genotype Asha recorded highest root diameter value of 5.12 mm, which are on par with other genotypes. Decrease in root diameter has been proposed as a trait for increasing

Table 4: Effect of water stress on main root area (mm^2) and diameter (mm) in red gram cultivars

Genotypes	Root area main root (mm^2)				Root diameter (mm)			
	Control	Mild stress	Severe stress	Means	Control	Mild stress	Severe stress	Means
Maruti	4258.67	3961.80	2881.33	3700.60	5.06	3.55	3.16	3.92
Asha	3163.93	2735.67	2735.67	2878.42	8.85	3.37	3.13	5.12
Laxmi	11163.13	4964.14	8852.33	8326.54	4.49	3.99	3.36	3.95
ICPL-20176	6658.57	2422.23	2015.00	3698.60	5.64	3.10	3.08	3.94
ICPL-161	3704.45	2667.07	2764.00	3045.18	4.20	3.06	3.07	3.45
Means	5789.75	3350.18	3849.67		5.65	3.41	3.16	
	CD	SEd±	SEm±			CD	SEd±	SEm±
Genotypes	3906.21	1897.16	1341.49		Genotypes	1.00	0.49	0.34
Stresses	N/S	1469.53	1039.12		Stresses	0.78	0.38	0.27
G×S	N/S	3285.98	2323.54		G×S	1.73	0.84	0.60

plant acquisition of water and productivity under drought (Wasson et al., 2012). In addition to root morphological traits affecting water and nutrient acquisition through control of root length and surface area, root morphology also affects resource acquisition by influencing root growth rate, with finer roots associated with faster root growth rate (Robinson et al., 1991). Both woody and herbaceous plants adapted to dry conditions are found to have smaller diameter fine roots with greater SRL (Henry et al., 2011).

Total number of tips which is indication of lateral per plant decreases with increase in severity of stress (Table 5). Genotype, Asha recorded highest number of tips (71.67) which are on par with remaining genotypes. Whereas, in mild stress and stress×genotype interactions, ICPL-20176 recorded significantly superior root tip value of values of 226.67 and 108.44. Under severe water stress conditions genotype, Asha recorded highest tip 64 which are on par with remaining genotype. The number of root tips is a critical indicator of root function from water uptake to regulation of whole plant growth (Aiken and Smucker, 1996). Thus, the number of root tips is an important determinant of the plant's ability to absorb water and nutrients from the soil. Field pea had the greatest number of root tips up to late flowering stage as compared to chickpea and lentil (Liu et al., 2011). Bandyopadhyay and Mallick (2003) observed that root tips of lentil increased with crop age under different management practices. Saima et al., 2018 reported that shoot and root weights and lengths, root length stress index, dry matter stress index (DMSI) and plant height stress index showed considerable variations under drought conditions.

Table 5: Effect of water stress on number of lateral roots and root to shoot ratio in red gram cultivars

Genotypes	Number of lateral roots (Tips)				Root : Shoot ratio			
	Control	Mild stress	Severe stress	Means	Control	Mild stress	Severe stress	Means
Maruti	40.00	106.00	37.00	61.00	0.116	0.58	0.43	0.32
Asha	71.67	55.67	64.00	63.78	0.161	0.83	1.11	0.65
Laxmi	57.00	63.00	50.00	56.67	0.127	0.71	0.59	0.34
ICPL-20176	52.33	226.67	46.33	108.44	0.179	0.48	0.62	0.32
ICPL-161	49.00	33.00	43.67	41.89	0.070	0.41	0.59	0.24
Means	54.00	96.87	48.20		0.131	0.60	0.67	0.37
	CD	SEd±	SEm±			CD	SEd±	SEm±
Genotypes	43.04	20.91	14.78		Genotypes	0.26	0.13	0.09

Optimal root-to-shoot partitioning produces a balance between productivity and root water absorption (Voss-Fels et al., 2018) and plays a key role in drought adaptation (Table 5, Figure 2). Among the genotype, Asha recorded significantly superior values for root to shoot ratio under mild stress (0.83), severe stress (1.11) and genotype×stress interactions (0.65). Phenotypic plasticity in the root-to-shoot ratio can support productiveness under

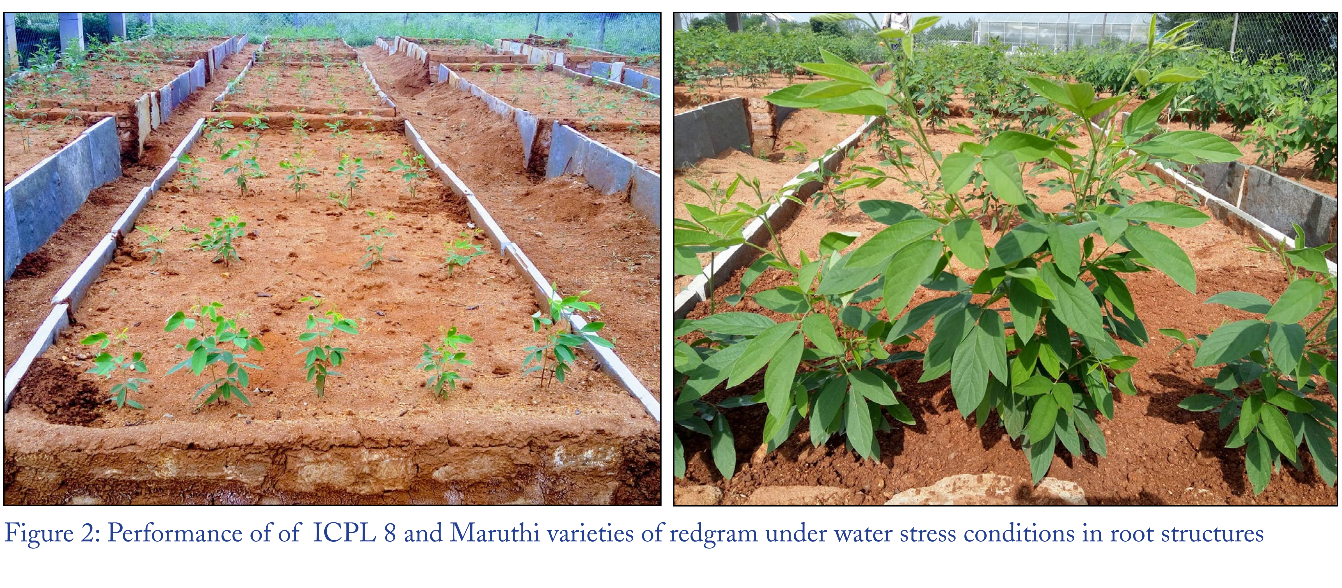

Figure 2: Performance of of ICPL 8 and Maruthi varieties of redgram under water stress conditions in root structures

water stress as plant growth potential reduces and root growth is favoured over the shoot to limit evaporation and extract water residuals (Correa et al., 2019). The higher root-to-shoot ratio of genotype supports a greater growth rate under drought stress (Bacher et al., 2021). Under water-stress conditions, shoot growth is restricted as more carbon is allocated to roots, which results in a higher root-to-shoot ratio (Correa et al., 2019). Deeper roots and more lateral root growth enable the plant to access more water during grain filling (Campos et al., 2004).

4. CONCLUSION

Maruti recorded superiority performance for plant height and SPAD Chlorophyll Meter Reading under non-stress, mild and severe stresses, and main root length under mild stress. Laxmi recorded highest plant height under severe stress and total plant dry weight, root dry weight and area under severe stress and root area and diameter under mild stress., while ICPL-20176 is for main root length under severe stress. Identified Redgram genotypes are used in climate resilience crop improvement.

5. ACKNOWLEDGEMENT

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