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RESEARCH ARTICLE

Moisture Induced Changes in Root Attributes and Selection Indices for Drought Tolerance in Desi, Kabuli and Wild Chickpea Accessions

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Root traits i.e. root length (RL), root weight (RW) and root area (RA) and root indices i.e. root length density (RLD) and root:shoot ratio (RSR) were evaluated in leaves of desi, kabuli and wild chickpea accessions at 70 DAS under receding moisture conditions (control, 50% and 75% reduction). The tolerance of desi genotypes was recorded to be significantly higher than kabuli and wild accessions. Check desi genotype PBG 7 was observed to be tolerant to moisture stress with 13.15% and 34.04% decline in root length density as well as root length under 50% moisture reduction conditions respectively. However, wild accessions sustained low stress injuries in terms of low membrane permeability index (MPI) (12.76 and 28.46%) and less decline in cellular respiration (26.06 and 43.23%) highlighting their resistance at 50 and 75% moisture reduction respectively. The tolerance capacity of the desi genotypes was attributed to high root area that contributed directly to root length density (P=0.89) and was instrumental in maintaining yield stability.

Key Words: ***Cicer*** **species, Moisture stress, Path coefficient analysis (PCA), Root traits, Selection indices**

Introduction

Chickpea (*Cicer* spp.) is an important *rabi* pulse crop of India as the country accounts for 75% of the total world production (Ahsan *et al.*, 2018). It is an important source for vegetarian protein. The major chickpea producing regions are the arid and semi-arid areas globally, including South Asia and sub-Saharan Africa, where residual soil moisture is the only source to fulfil plant water requirement.

Increasing incidence of abiotic stress due to change in global precipitation levels, increasing temperature due to global warming and decline in the water strata has immensely added to the adversity. All has led to a water deficit condition in soil and prevailing consistency of such conditions over a longer period of time renders the plant to suffer at every stage i.e. prior to germination and till maturity. The low water availability at the terminal stage affect the pod formation, causing up to 40–50% yield losses, and resulting in stagnancy in chickpea productivity (Fang *et al.*, 2010; Kashiwagi *et al.*, 2015). The yield losses reported in crops facing terminal drought stress at the reproductive phase are greater than the drought stress at vegetative stage (Krishnamurthy *et al.*, 2010).

Water deficiency alters the shoot and root systems of the plant by inducing complex morphological, physiological and biochemical mechanisms. Amongst morphological modifications an increase in root depth, biomass and density facilitates efficient water uptake under terminal drought conditions (Turner *et al.*, 2001). Consistent water availability is necessary for reproductive success and ultimately for crop grain yield (Kato *et al.*, 2008). Thus, the chickpea germplasm that descend the rhizosphere via the root length elongation and increase in root hairs surface under moisture stress are less susceptible and have low or negligible effect of the same on the yield (Turner *et al.*, 2001). Root traits have been shown to influence not only transpiration via soil moisture utilisation but also yield attribute *viz*., harvest index under terminal drought (Zaman-Allah *et al.*, 2011).

Thus, the current study focusses on comparative responses in the behavioural changes in root traits of desi, kabuli and wild chickpea accessions under receding moisture conditions at 70 DAS (days after sowing).

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Materials and Methods

Plant material

Ten *Cicer* accessions (Desi: GL 12020, PBG 7, PBG 5, PDG 4, GNG 1581, Kabuli: HK-10-103, GNG 2285 and three wild chickpea accessions *C. judaicum 185B, C. judaicum 185* and *C. judaicum 182*) were procured from Pulses Section, Department of Plant Breeding and Genetics, PAU Ludhiana. PBG 7, PBG 5 and PDG 4 are three released varieties by Punjab Agricultural University (PAU, 2021).

Chickpea accession	Check
PBG 7	Irrigated conditions
PBG 5	Irrigated conditions in humid areas
PDG 4	Rainfed conditions

Desi (GL 12020, GNG 1581), Kabuli (HK-10-103, GNG 2285) and wild accessions (*C. judaicum 185B, C. judaicum 185* and *C. judaicum 182*) were selected to draw the comparisons under receding moisture conditions.

Cylinder culture

The lysimetric culture (as described by Kashiwagi *et al.*, 2005 with slight modifications) were grown in 18 cm diameter and 1.6 m tall PVC pipes in a randomised block design (3 treatments i.e. control, 50% and 75% reduction with respect to irrigation) with 3 replications in the first and second *Rabi* trials (Fig. 1). The PVC pipes were placed in 1.2 m deep soil pits with a spacing of 30 cm between adjacent pipes and 3 feet spacing within replications. A 2 m pit was dug and a polythene sheet was placed in order to avoid water leaching within successive treatments. The PVC pipes were filled with an equi-mixture of sand and soil. The soil-sand mixture was air dried 15 days before the sowing. Soil moisture content was calculated as below:

$$\frac{\text{(Wet weight of soil-Dry weight of soil)}}{\text{Dry weight of soil}} \times 100$$

Each PVC pipe was filled with 10 kg of mixture of sand and soil with same soil level in all the pipes. Initially, in each pipe 1 litre of water was added into each treatment. After the irrigated water had penetrated the soil profile, 2 kg of dry soil was added over the surface of each pipe. At the time of sowing, five seeds were planted in each pipe. Irrigation was done at regular interval of five days with respect to irrigation treatment i.e., 1 litre of water was added in control during each irrigation followed by 500 ml and 250 ml of water in the treatment i.e. 50% and 75% reduction, respectively. The plants were grown in rainout shelter to avoid moisture from precipitation. Plants were harvested at 70 days after sowing (DAS) by placing the pipes in running water, with the soil-sand mixture which was removed gently. After three-fourth of the mixture was removed, the PVC were erected and plants are gently slipped out and the data was recorded on root traits and stress indices.

Root attributes

Root area and root length density (RLD) was measured using root scanner (Delta T-root Scan software). The mean of three roots were expressed in mm^2 and g cm^{-3} /plant, respectively.

Three random plants were harvested and roots of the plant were dipped into the measuring cylinder. After removing soil particles, the roots were stretched to measure the root length (cm).

Fig. 1. Field view of lysimetric screening of chickpea accessions

Morphophysiological parameters

The plants were air dried for 2h to remove excess water and then fresh root and shoot weights (g) were measured. The root and shoot fresh weight were compared and root:shoot ratio was calculated.

For estimation of allocation of resources towards the shoot, shoot weight: root length density (SW: RLD) (g $g^{-1}cm^3$) was calculated.

Three plants from each replication were selected and their plant length was measured and their average values are expressed in cm/plant. The number of leaflets was counted in three plants at 70 DAS.

Selection indices

The damage in leaves due to moisture stress was measured in terms of membrane permeability index (MPI) by the method of Fletcher and Drexlure (1980). Leaflets (0.1 g) were washed and kept in distilled water for 24 h. The electrical conductivity (EC) was measured using a conductivity meter (Mettler Toledo FEP 30). After recording, the same tissue was kept for boiling in water bath for 30minutes and after cooling the EC was measured again. MPI was calculated as below:

$$\text{MPI (\%)} = \frac{\text{EC after boiling- EC before boiling}}{\text{EC after boiling}} \times 100$$

The effect of moisture stress on cellular respiration (viability) of leaves was determined by the method of Steponkus and Lamphear (1967). Leaf tissue (0.1 g) was placed in water and was subjected to two temperature treatments *viz*., at 25^0C and 49^0C for 1.5 h. Thereafter, 10 ml of 2,3,5-triphenyl-tetrazoliumchloride (TTC) solution was added per tube for 24 h at 25 ºC in dark. Rinsing of the incubated tissue was done with distilled water, then 4 ml of 95% ethanol was added for 24 h and optical density (O.D.) was recorded in a spectrophotometric cuvette at 530 nm in relation to formazon.

$$\text{Cellular respiration in terms of \% TTC reduction} = (OD_h/OD_c) \times 100 \quad \text{(h=heat treated, c=control)}$$

Statistical analysis

Tukey's HSD through SPSS 16.0 was used to validate the differences within treatments and accessions for lysimetric screening. Correlation within various attributes was determined using Pearson's correlation coefficients. Path coefficient analysis using polynomial regression coefficients between root length density and morphophysiological parameters were analysed using Microsoft office Excel version 2010. Percent increase or decrease data was calculated at 50% and 75% receding moisture conditions with respect to control conditions to assess the tolerance capacity of chickpea accessions.

Results and Discussion

In general, there was a reduction of 29.29 and 50.45% in root weight at 50% and 75% moisture content respectively (Table 1). The fine tuning of partitioning of photosynthates between below and above ground organs is disrupted whenever plant comes across stressful situations. Genotypes did not depict a static trend in root:shoot biomass reduction after exposure to water reduction. Desi check genotype PBG 5 expressed a minimum decline of 10.80% at 50% moisture reduction with respect to control. PDG 4 depicted an interesting behaviour though showing a decline of 11.52% in root weight at 75% reduction, but an increase of 21.63% in root weight when moisture content reduced to 75% from 50%.

Table 1. Root traits and root indices of chickpea accessions under receding moisture conditions

	Root weight (g)			Root length (cm)			Root:Shoot ratio		
Chickpea Accessions	Control	50%Reduction	75%Reduction	Control	50%Reduction	75%Reduction	Control	50% Reduction	75%Reduction
GL 12020	7.70±0.22^{c}	6.06±0.12^{b}	4.57±0.05^{d}	52.00±0.06^{e}	49.46±0.11^{d}	46.31±0.11^{d}	0.90±0.02^{d}	0.94±0.02^{d}	0.79±0.01^{d}
PBG 7	6.94±0.04^{e}	4.96±0.01^{d}	3.68±0.03^{f}	37.74±0.29^{i}	50.59±0.16^{c}	53.80±0.09^{c}	0.92±0.01^{d}	0.73±0.01^{e}	0.71±0.01^{e}
PBG 5	8.62±0.02^{a}	7.69±0.07^{a}	6.66±0.03^{a}	51.99±0.08^{e}	47.56±0.13^{e}	37.78±0.20^{f}	0.96±0.01^{d}	1.18±0.03^{c}	1.07±0.01^{c}
PDG 4	7.37±0.05^{d}	5.36±0.04^{c}	6.52±0.05^{b}	43.55±0.07^{g}	39.79±0.09^{g}	37.14±0.40^{f}	0.96±0.01^{d}	0.96±0.01^{d}	1.51±0.03^{b}
GNG 1581	8.09±0.01^{b}	6.28±0.22^{b}	5.49±0.03^{c}	56.38±0.10^{c}	50.99±0.13^{c}	44.54±0.14^{e}	1.71±0.05^{b}	1.69±0.07^{a}	2.17±0.06^{a}
GNG 2285	6.64±0.14^{f}	5.49±0.05^{c}	4.06±0.01^{e}	82.24±0.18^{a}	63.50±0.39^{b}	57.67±0.26^{b}	0.46±0.02^{f}	0.71±0.01^{e}	0.68±0.01^{e}
HK-10-103	8.59±0.04^{a}	7.54±0.01^{a}	3.51±0.01^{g}	75.01±0.12^{b}	73.22±0.30^{a}	60.64±0.14^{a}	0.92±0.01^{d}	0.91±0.01^{d}	0.63±0.04^{e}
C judaicum 185B	1.74±0.04^{i}	0.63±0.04^{g}	0.38±0.01^{h}	54.68±0.29^{d}	49.55±0.39^{d}	43.76±0.16^{e}	0.66±0.01^{e}	0.44±0.03^{f}	0.32±0.01^{f}
C judaicum 185	2.43±0.07^{h}	1.21±0.01^{f}	0.32±0.02^{h}	46.75±1.17^{f}	41.05±0.18^{f}	37.32±0.90^{f}	1.48±0.01^{c}	1.27±0.10^{bc}	1.08±0.03^{c}
C judaicum 182	2.86±0.01^{g}	1.74±0.01^{e}	0.36±0.01^{h}	39.54±0.54^{h}	38.21±0.49^{h}	33.12±0.20^{g}	1.99±0.02^{a}	1.31±0.01^{b}	0.37±0.01^{f}

Data was subjected to tukey's test. Each value represents mean value ± S.D. Mean values marked with same alphabets are significantly not different. Data pooled for both years (2015-16 and 2016-17) for control, 50% reduction and 75% reduction.

Table 2. Morpho-physiological parameters of chickpea accessions under receding moisture conditions

	Shoot weight (g)			Plant height (cm)			Number of leaves		
Chickpea Accessions	Control	50% Reduction	75%Reduction	Control	50% Reduction	75%Reduction	Control	50% Reduction	75%Reduction
GL 12020	8.52±0.01^{e}	6.49±0.04^{d}	5.79±0.04^{b}	83.47±0.24^{bc}	78.49±0.14^{c}	73.12±0.11^{c}	64.19±0.32^{c}	50.24±0.29^{c}	23.59±0.22^{g}
PBG 7	7.57±0.07^{d}	6.76±0.01^{c}	5.20±0.01^{d}	70.62±0.33^{bc}	81.13±0.35^{b}	83.52±0.08^{b}	70.53±0.62^{a}	44.44±0.38^{d}	39.82±0.07^{b}
PBG 5	9.02±0.02^{f}	6.53±0.06^{d}	6.21±0.03^{a}	81.10±0.16^{bc}	71.66±0.05^{e}	60.33±0.03^{g}	65.87±0.08^{b}	51.37±0.59^{bc}	29.32±0.14^{e}
PDG 4	7.70±0.02^{d}	5.59±0.05^{e}	4.31±0.04^{e}	74.80±1.14^{bc}	65.48±0.11^{f}	61.64±0.26^{f}	58.85±0.24^{e}	52.97±0.06^{b}	31.89±0.10^{d}
GNG 1581	4.84±0.13^{c}	3.74±0.02^{f}	2.57±0.05^{f}	80.78±0.08^{bc}	74.40±0.98^{d}	66.32±0.36^{d}	53.26±0.28^{f}	44.67±0.64^{d}	40.95±0.11^{a}
GNG 2285	14.80±0.33^{g}	7.73±0.01^{b}	6.08±0.13^{a}	114.37±0.53^{a}	76.98±2.33^{c}	82.61±0.31^{b}	61.43±0.92^{d}	56.63±0.44^{a}	27.17±0.45^{f}
HK-10-103	9.35±0.04^{g}	8.30±0.11^{a}	5.59±0.10^{c}	108.35±0.21^{a}	104.40±0.44^{a}	87.32±0.29^{a}	54.57±0.47^{f}	44.09±0.57^{d}	34.03±0.34^{c}
C. judaicum 185B	2.62±0.03^{b}	1.43±0.01^{g}	1.18±0.01^{g}	75.29±0.23^{ab}	71.81±0.13^{e}	63.45±0.24^{e}	43.58±0.29^{g}	32.65±0.46^{f}	27.30±0.54^{f}
C. judaicum 185	1.64±0.01^{b}	0.96±0.08^{h}	0.30±0.03^{i}	61.79±1.59^{c}	58.18±0.16^{g}	60.48±0.94^{g}	43.08±0.06^{g}	33.61±0.98^{e}	26.61±0.30^{f}
C. judaicum 182	1.44±0.01^{a}	1.33±0.02^{g}	0.97±0.03^{h}	59.14±0.96^{c}	54.17±0.52^{h}	45.68±0.20^{h}	44.06±0.67^{g}	28.49±1.07^{g}	18.34±0.22^{h}

Data was subjected to tukey's test. Each value represents mean value ± S.D. Mean values marked with same alphabets are significantly not different. Data pooled for both years (2015-16 and 2016-17) for control, 50% reduction and 75% reduction.

Table 3. Root traits and root indices of chickpea accessions under receding moisture conditions

	RLD (gcm^{-3})			Root area (mm^{-2})			SW:RLD (g/gcm^{-3})		
Chickpea Accessions	Control	50% Reduction	75% Reduction	Control	50% Reduction	75% Reduction	Control	50% Reduction	75% Reduction
GL 12020	1.32±0.21^{b}	0.87±0.11^{abc}	0.80±0.06^{de}	1062.60±13.68^{d}	1447.90±16.29^{d}	1559.90±13.89^{d}	4.61±1.10^{c}	3.36±0.96^{a}	3.83±1.02^{a}
PBG 7	1.41±0.07^{b}	1.33±0.09^{ab}	1.23±0.02^{a}	1145.00±9.87^{c}	1512.50±8.88^{d}	1657.00±14.77^{d}	5.36±1.02^{c}	5.11±1.15^{d}	4.24±1.62^{d}
PBG 5	1.09±0.20^{c}	1.01±0.15^{abc}	0.94±0.02^{bcd}	1108.00±18.09^{cd}	1594.00±17.74^{c}	2691.40±15.90^{a}	8.47±0.98^{b}	6.60±1.77^{c}	6.63±1.67^{b}
PDG 4	0.93±0.06^{d}	0.78±0.01^{bc}	0.63±0.01^{c}	1485.00±12.06^{a}	2223.20±9.16^{a}	2406.80±21.14^{b}	8.28±2.14^{b}	7.20±2.78^{b}	6.87±1.16^{b}
GNG 1581	1.61±0.04^{a}	1.35±0.02^{a}	1.21±0.11^{b}	1333.70±10.09^{b}	1945.00±11.44^{b}	2435.20±17.21^{b}	3.01±0.16^{f}	2.78±0.78^{e}	2.14±0.90^{f}
GNG 2285	1.58±0.07^{a}	1.14±0.02^{ab}	1.04±0.21^{abcd}	874.26±9.00^{f}	1275.00±20.08^{e}	1590.10±14.12^{d}	9.39±3.01^{a}	6.79±1.11^{c}	6.15±1.65^{c}
HK -10- 103	1.58±0.08^{a}	1.10±0.11^{ab}	1.08±0.14^{abc}	2181.70±23.11^{c}	3968.60±24.45^{b}	7926.00±13.37^{c}	5.93±1.19^{d}	7.62±1.89^{a}	5.30±1.76^{d}
C. judaicum 185B	1.08±0.21^{c}	0.68±0.04^{c}	0.88±0.34^{cd}	721.22±11.11^{g}	847.90±9.44^{g}	997.80±8.15^{f}	2.47±0.45^{g}	2.10±0.22^{f}	1.49±0.05^{g}
C. judaicum 185	1.37±0.37^{b}	1.13±0.37^{ab}	0.98±0.15^{abcd}	825.68±16.44^{f}	727.90±7.11^{h}	997.29±6.37^{f}	1.26±0.23^{h}	0.93±0.02^{g}	0.30±0.01^{i}
C. judaicum 182	1.00±0.09^{d}	1.01±0.17^{abc}	1.20±0.08^{ab}	972.50±10.01^{e}	1071.70±10.39^{f}	1264.30±14.16^{e}	1.44±0.15^{h}	1.33±0.16^{g}	0.80±0.01^{h}

Data was subjected to Tukey's test. Each value represents mean value ± S.D. Mean values marked with same alphabets are significantly not different. Data pooled for both years (2015-16 and 2016-17) for control, 50% reduction and 75% reduction.

The mechanisms of differential response can be explained via the root-shoot allometric relationships. Genotype PBG 7 and wild accessions exhibited decrease (20.02% and 27.36%) at 50% reduction in root:shoot resulting in the accumulation of photosynthates towards shoot growth, thus being less affected by drought stress (Table 1). In contrast some of the genotypes depicted increased root:shoot ratio thus partitioning its photosynthates towards below ground system for the expansion of root area. Among kabuli genotypes, GNG 2285 exhibited maximum increase of 53.46% and 46.36% at 50 and 75% moisture reduction in comparison to control. Higher root:shoot in turf grass explained the drought tolerance to channelize and expand its roots against water scarcity that ultimately improved the hydraulic status of the former (Karcher *et al.,* 2008).

The root length density (RLD) declined in desi and kabuli chickpea genotypes at 50 and 75% reduction levels. The tolerance level of wild accessions was exhibited in terms of considerable increase of 1.29 and 1.18 folds in *C. judaicum* 185B and *C. judaicum* 182 from 50% to 75% reduction to combat reduction in moisture conditions (Table 3). PBG 7, a desi chickpea check variety, showed lowest decline of 1.06 and 1.15 folds at 50% and 75% moisture reduction, respectively. The tolerance mechanism of this variety against water stress coincided with resistance against Ascochyta blight, wilt and dry root rot (PAU, 2021). Poorter *et al.,* (2012) observed that plants exposed to severe drought stress portray an array of responses *viz*., increase in root mass fraction (root biomass relative to total biomass), root biomass being compensatory, as a drought avoidance strategy.

There was an overall significant decrease in the root length of 4.77 % at 50% reduction and 13.69 % at 75% reduction respectively (Table 1). The drought stress impeded serious effects of 22.79% and 29.88% reduction in root length in GNG 2285 at 50% and 75% water reductions, respectively. On the contrary there were some genotypes that expanded its length to acquire water from the deeper strata. Desi genotype PBG 7 increased root length by 34.04% and 42.54% at 50 and 75% water reduction. Root area expanded on exposure to water deficit conditions by depicting an overall upheaval of 36.21% and 65.73% at 50 and 75% water reduction, respectively (Table 3). Desi genotypes were more efficient in expansion of root horizons in comparison to wild and kabuli accessions. Amongst them, check varieties PDG 4 and PBG 5 indicated maximum root area increase of 49.71 and 43.86% at 50% water reduction and 62.07 and 142.91% at 75% reduction in water in comparison to control.

Kabuli variety HK-10-103 exhibited increase in root area of 66.59% and 71.45% at 50% and 75% water reduction, respectively, in comparison to control. However, the major proportion in increase of root area (52.75%, 78.64%) in the kabuli genotypes was recorded when the moisture content was reduced to 75% from 50% in comparison to control. *C. judaicum* 185B wild accession expanded its root horizons by 17.56 and 38.35% when water was reduced to 50% and then to 75% in comparison to control, respectively. The results are in complete agreement with the response of maize and sunflower cultivars that maintains high carbon assimilation and water use efficiency during the course of drought tolerance by depicting deeper root system (Ghannoum, 2009). Increase in root surface area via root hairs promote contact with soil particles thus compensating for reductions in root elongation in extremely dry soils (Wasson *et al.,* 2012). In *Silene vulgaris* Franco *et al.* (2008) reported that branching of the roots, root surface area and total root length increased under moderate drought stress.

Moisture stress negated the growth of plant by reducing the plant length on exposure to receding moisture conditions. There was an overall decline of 7.83% and 14.30% in plant length thus deciphering the stress conditions (50 and 75% reduction, respectively) in comparison to control (Table 2). Amongst all genotypes, GNG 2285, a kabuli genotype, exhibited 32.70 and 27.77% decline at 50 and 75% moisture reduction amongst all genotypes. However, PBG 7 recorded an upheaval of 14.88 % decline at 50% reduction and further 2.95 % on exposure to 75% reduction in plant length. Ammar *et al.* (2014) reported reduction in plant height in Faba bean on being exposed to drought stress created by different concentrations of PEG in managed and open field conditions. Drought stress in Faba bean suppressed cell elongation due to low turgor pressure (Shao *et al.,* 2008) that caused interruption of water flow from the xylem to the surrounding elongating cells. Drought-induced alteration in the homoeostasis of phytohormones was another reason for growth reduction under water deficit conditions (Farooq *et al.,* 2009).

The number of leaflets is directly proportional to the photosynthetic efficiency of plant. Drought stress alters the capacity by negatively affecting the number of leaves under drought stress. Analysed data shows significant differences at both 50% and 75% moisture reduction levels (Table 2). The decline was evident in genotypes GL 12020 (63.24%), *C. judaicum* 182 (58.36%) and GNG 2285 (55.77%) at 75% water reduction in comparison to control. At 50% water reduction, PBG7 showed significant reduction of 36.99% in comparison to control.

In concordant to our studies, there had been a decline in number of leaves in variants of *Arabidopsis* when exposed to mild stress conditions (Clauw *et al.,* 2015). Emergence of leaves is a genetic phenomenon rather than morphological one. During the onset of stress, several other defence and signalling (ABA) genes get upregulated. The upregulation in the levels of ABA altered the emergence of leaf in *Arabidopsis* (Baerenfaller *et al.,* 2012).

The effect was more pronounced in shoot biomass when levels were reduced from 50 to 75% moisture reduction by declining mean shoot weight by 26.10%. Among kabuli types, GNG 2285 showed maximum reduction of 47.75% at 50% moisture level (Table 2). Stress disturbs the delicate balance of partitioning of photosynthates to below ground system thus reducing the probability of biomass storage and utilizing it in extension to withdraw more water from lower soil strata (Jaleel *et al.,* 2009). Webber *et al.* (2006) reported that common bean and green gram exhibited decrease in root and shoot weight on being exposed to drought stress. Similar responses have also been reported in field and laboratory experiments where decline in biomass compensates for drought avoidance strategies (Herzog *et al.,* 2014, Zang *et al.,* 2014). Drought stress tends to disturb the carbon partitioning and source sink relations that ultimately limit the storage pools in the above and below ground systems. The dynamics are further interfered when the assimilates like sucrose are deviated to form osmolytes for osmolyte adjustment rather than the formation of storage pools thus leading to breakdown of sucrose and overall reduced biomass (Hasibeder *et al.,* 2015).

Shoot dry weight to root length density ratio (SW:RLD) is the relevant trait portraying effectiveness of roots in shoot production. This parameter explores the behavioural changes of partitioning the photosynthates that occur on account of facing stress. There was an overall decrease of 8.29 % and 28.82 % in the ratio at 50 and 75% water reduction over control (Table 3). The maximal decline in ratio was observed in *C. judaicum* 185 (74.82%) and GNG 2285 (37.67%) at 75% reduction in comparison to control. The tolerance of HK-10-103 showed striking results by an increase in ratio by 27.39 % at receding moisture levels. Drought stress immensely affects the shoot weight. So exploring the equation, if the decline in SW kept constant, the ratio mainly depends on the value of RLD. The variation in ratio thus is compensated by alteration in RLD values. The ratio was severely compromised in mini-core chickpea accessions by showing low values of heritability pointing towards the negative influence of soil drying and ultimately water deficit (Kashiwagi *et al.,* 2005).

The tolerance of accessions has an inversely proportional relationship with the MPI that is an indicator of leakiness of membranes. There was significant variation amongst all accessions depicting an overall damage of 56.66 and 84.57% at 50 and 75% reduction respectively in comparison to control (Fig. 2). Certain genotypes were affected very severely thus reporting a damage of 176.4% (PBG 7), 163.78% (PDG 4) and 125.73% (HK-10-103) at 75% moisture reduction in comparison to control. On the contrary, there were several genotypes that were able to maintain homeostasis by being reluctant to any change on exposure to drought conditions. Wild accessions *viz.*, *C. judaicum* 185 and *C. judaicum* 182 effectively managed to show reluctance to damage by having only 11.04 and 18.41% increase in MPI when stress levels were elevated from 50 to 75%. Stress alleviates the damage to membranes, thus disturbing the ionic homeostasis. The maize tolerant cultivar Giza 2 exhibited high concentration of osmolytes *viz.*, proline, glycine betaine, trehalose to nullify the effects of drought stress condition (Moussa and Abdel-Aziz, 2008).

Stress affects viability in terms of respiratory enzymes (dehydrogenases) exhibiting significant differences amongst accessions at receding moisture levels. There had been overall decline of 27.45 and 44.51% in cellular respiration at 50 and 75% moisture reduction (Figure 3). Amongst desi genotypes, PBG 5 showed fragile behaviour by recording 44.02 and 59.42 % decline in dehydrogenase activity at 50 and 75% reduction, respectively. The enzymes remained efficient in GNG 1581 (9.65%) at 50% reduction and at 75% reduction in PDG 4 (20.30%) highlighting their tolerant behaviour of resisting denaturing of dehydrogenases at respective moisture stress levels. Kabuli genotypes in proportion showed lower efficiency of dehydrogenases than desi and wild accessions reporting maximal damage of 56.60% in HK-10-103 at 75% water reduction. Tolerant lines effectively shield dehydrogenases via osmolytes from getting denatured under stress conditions. The cells with active respiratory enzymes will more efficiently produce ATP and eventually explore water by expanding its horizons in deep soil strata. Bent grass cultivar 'Independence' maintained optimal root viability from 0-20 cm of soil depth thus providing better drought tolerance capacity (McCann and Huang, 2008).

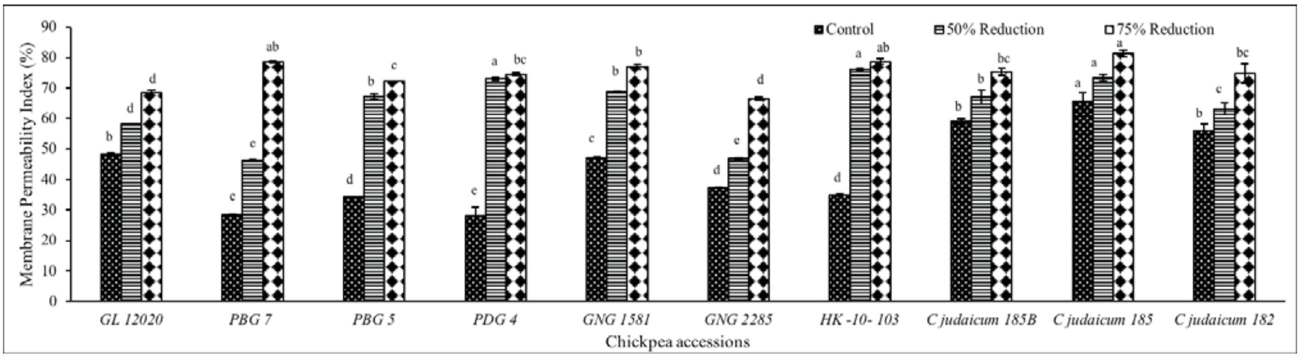

Fig. 2. Membrane permeability index (%) of chickpea accessions under receding moisture conditions. Each bar represents mean value ± S.E. Mean values marked with same alphabets are significantly not different. Data pooled for both years (2015-16 and 2016-17) and for control, 50% reduction and 75% reduction.

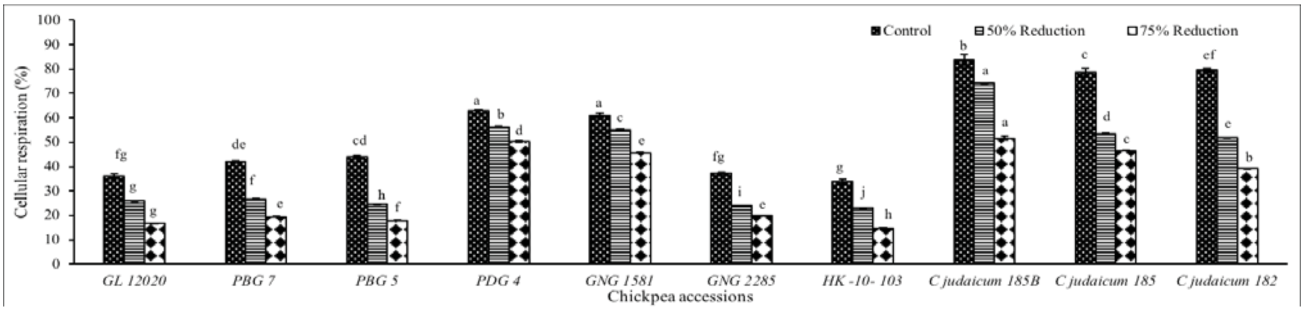

Fig. 3. Cellular respiration (%) of chickpea accessions under receding moisture condition. Each bar represents mean value ± S.E. Mean values marked with same alphabets are significantly not different. Data pooled for both years (2015-16 and 2016-17) and for control, 50% reduction and 75% reduction.

Table 4. Correlation between root indices, morphological parameters and stress indices under receding moisture conditions

	RLD	MPI	CR	RA	SRLD	RW	RL	RSR	SW	PH	NOL
RLD	1.00										
MPI	-0.15	1.00									
CR	-0.38	0.69	1.00								
RA	0.05	-0.37	-0.34	1.00							
SRLD	-0.16	**-0.75***	**-0.74***	**0.61***	1.00						
RW	0.18	-0.59	**-0.69***	**0.88***	**0.81***	1.00					
RL	0.47	-0.34	-0.59	0.11	0.43	0.36	1.00				
RSR	0.28	0.38	0.29	0.41	-0.33	0.18	-0.40	1.00			
SW	0.18	**-0.82***	**-0.88***	0.52	**0.93***	**0.80***	**0.66***	-0.36	1.00		
PH	0.41	-0.49	**-0.72***	0.30	**0.61***	0.56	**0.94***	-0.42	**0.80***	1.00	
NOL	0.24	**-0.79***	**-0.69***	**0.71***	**0.81***	**0.88***	0.37	-0.05	**0.84***	0.59	1.00

*Significant at 0.05 level.

RLD- root length density, MPI- membrane permeability index, CR- cellular respiration, RA-root area, SRLD- shoot weight: root length density, RW- root weight, RL-root length, RSR- root:shoot ratio, SW-shoot weight, PH- plant height, NOL-number of leaves.

Path coefficient and correlation analysis

The tolerance capacity of the desi genotypes is attributed to high root area that contributes directly to root length density (P=0.89) (Table 5). Root area of genotypes positively and strongly correlated with the partitioning of photosynthates i.e. SW:RLD (r=0.61) and root weight (r=0.88) (Table 4). Under receding moisture conditions morphophysiological parameters are tightly linked *viz*., shoot weight that further strongly correlated with plant height (r= 0.80) and number of leaves (r=0.84) and shoot biomass forms an important component to the root length density (P=0.62). The epicenter of moisture deficit tolerance relies strongly on the relative values of root length density, that further is instrumental in maintaining yield stability under terminal drought stress as was evidenced in sorghum (Kashiwagi *et al*, 2005).

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Table 5. Path coefficient analysis depicting the direct effects of membrane permeability index (MPI), CR (cellular respiration), RL (root length), SW (shoot weight), RW (root weight), RSR (root shoot ratio), PH (plant height), NOL (number of leaves) and RA (root area) on root length density (RLD) under receding moisture conditions.

Physiological parameters	RLD
MPI	P=0.68
CR	P=0.27
RL	P=0.17
SW	P=0.62
RW	P=0.62
RSR	P=0.43
PH	P=0.23
NOL	P=0.50
RA	P=0.89

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