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Morpho-physiological Criteria for Drought Tolerance in Sorghum (*Sorghum bicolor*) at Seedling and Post-anthesis Stages

MUHAMMAD AMJAD ALI[1], AMJAD ABBAS†, SHAHID NIAZ‡, M. ZULKIFFAL AND SHIRAZ ALI‡
Wheat Research Institute, Faisalabad, Pakistan
†*Agricultural Biotechnology Research Institute, AARI, Faisalabad, Pakistan*
‡*Barani Agricultural Research Station, Fatehjang, Attock, Pakistan*
[1]Corresponding author's e-mail: amjad.ali2001@gmail.com

ABSTRACT

Ten sorghum genotypes including one check (JS-2002) were evaluated at seedling and post-athesis stages for drought tolerance based on morpho-physiological criteria. The data regarding all morpho-physiological traits such as dry root weight, root length, coleoptile length, root: shoot ratio, flag leaf area, specific flag leaf area, specific flag leaf weight, leaf dry matter, excised leaf weight loss, relative dry weigh, relative water content, residual transpiration, cell membrane stability and grain yield per plant revealed significant ($P>0.01$) differences among the genotypes. Blocking considerably affected specific flag leaf area, specific flag leaf weight, leaf dry matter, relative water content and cell membrane stability. The genotypes H-18 followed by PGRI-191, PGRI-35 and PARC-SS-1 showed better stress tolerance traits. Genotypic coefficient of variation was the highest for excised leaf weight loss followed by grain yield suggesting considerable scope for selection of these traits. High estimates of broad sense heritability and genetic advance for all the characters indicated the most appropriate condition for selection against these traits except for relative dry weight. Correlation analysis revealed that root length, coleoptile length, root: shoot ratio, flag leaf area, leaf dry matter, excised leaf weight loss, residual transpiration cell membrane stability and grain yield might be improved simultaneously and could be exploited as reliable morpho-physiological markers for drought tolerance in sorghum at seedling and reproductive stages.

Key Words: Morpho-physiological criteria; Drought tolerance; Growth stages; Sorghum

INTRODUCTION

Sorghum has a wide range of adaptability and can be grown in wide series of environments. It is mainly grown for food, feed and industrial purposes. Combined with its potential use in the emerging biofuels industry, sorghum is an ideal candidate for a more concerned crop improvement program as agriculture is to push more marginal lands, and food and energy demands might be boosted in the near future. Although sorghum has an ability to cope with many types of stresses, including heat, drought, salinity and flooding (Ejeta & Knoll, 2007) but in arid and semi-arid regions, this crop is usually affected by water stress at the reproductive stage particularly post flowering stage (Tuinstra *et al*., 1997; Kebede *et al*., 2001).

Water stress is a major limitation to crop productivity worldwide and possible global climate change scenarios suggest a future increase in the risk of drought (IPCC 2001, Tahir & Mehdi, 2001). Water stress has diverse effects on yield depending on the development stage at which it occurs (Agboma *et al*., 1997). Incidence of water stress at seedling stage may lead to higher dry root weights, longer roots, coleptiles and higher root: shoot ratios (Zekri, 1991; Matsuura *et al*., 1996; Pace *et al*., 1999; Takele, 2000; Dhanda *et al*., 2004; Kashiwagi *et al*., 2004). Water stress taking place at both pre-flowering and post-flowering stages of development has the most adverse effect on yield during and after anthesis (Tuinstra *et al*., 1997; Kebede *et al*., 2001). Stress during flowering and anthesis lead to the failure of fertilization, because of the impairment of pollen and ovule function (Prasad *et al*., 2008), which in turn results in lower grain yield. Studies of Fischer (1973) revealed that drought conditions prevailing for 5-15 days before ear emergence, reduced grain number by 40% in wheat.

Drought resistance in sorghum is a complex trait influenced by many genes coding for various traits contributing towards drought tolerance (Blum, 1979). Over the past decades plant breeders have focused on some traits that were incorporated to plant survival under drought for instance lower leaf canopy and reduced transpiration (Fischer & Wood, 1979; Karamanos & Papatheohari, 1999), which are not essentially correlated with high yield and led the breeders to evolve cultivars with poor yield under stress condition.

Many studies have been carried out to set selection

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criteria for drought tolerance (Misra *et al*., 2002). Dhanda *et al*. (2004), Khan *et al*. (2004) and Misra (1990 & 1994) reported that drought-adapted plants are often characterized by deep and vigorous root systems. Some focused on flag leaf characters especially leaf water relations due to their considerable interaction with drought tolerance (Aggarwal & Sinha, 1984; Misra & Misra, 1991). A survey of literature revealed that morpho-physiological traits such as flag leaf area (Fischer & Wood, 1979; Karamanos & Papatheohari, 1999), specific leaf weight, leaf dry matter (Aggarwal & Sinha, 1984; Misra, 1995), excised leaf weight loss (Clarke, 1987; McCaig & Romagosa, 1991; Bhutta, 2007), relative dry weight (Wilson *et al*., 1980; Jones *et al*., 1980), relative water content (Fischer & Wood, 1979; Colom &Vazzana, 2003), residual transpiration (Clarke *at al*., 1991; Sabour *et al*., 1997) and cell membrane stability (Premachandra *et al*., 1992; Tripathy *et al*., 2000; Rahman *et al*., 2006) had been widely used as selection parameters contributing towards drought tolerance for various crop plants in addition to grain yield. Moreover, productivity enhancement of crops grown under drought conditions is not an easy task, because of the un-predictable nature of most periods of drought stress prevailing in growing areas and gaps in our knowledge of drought biology (Nelson *et al*., 2007). The difficulty arises from the diverse strategies adopted by plants themselves to combat drought stress depending on the timing, severity and stage of crop growth (Misra, 1990 & 1994; Vinod *et al*., 2006).

The objective of this investigation was to sort out drought tolerant parents, to estimate genetic parameters and character association for some valuable morpho-physiological traits, which have been extensively utilized for screening of water stress tolerant crop plants.

MATERIALS AND METHODS

Plant material. The experiment was carried out at the Barani Agricultural Research Station, Fatehjang (33º34´ N, 72º38´ E), Pakistan during the year 2008. Ten sorghum genotypes/lines G-160, JS-61, H-118, H-18, PARC-SS-1, PGRI-141, PGRI-191, PGRI-29 and PGRI-35 including one approved variety JS-2002 were evaluated for drought tolerance at seedling and post-anthesis stage under rain fed environment.

Seedling traits. Water deficit condition at seedling stage was achieved by watering the plants with quantity of water 50% of normal condition according to Khan *et al*. (2004) with some modifications. Ten seeds per genotype were grown in iron trays (20×20 cm with 10 cm depth) filled with river sand by keeping row to row and plant to plant distance of 5 and 3 cm, respectively. After two weeks data were recorded for root and coleoptile length (cm), dry root weight (g) and root: shoot ratio.

Field experiment. The sorghum genotypes were planted on 2nd of July, 2008 in triplicate Randomized Complete Block Design (RCBD) with experimental plots that comprising of two rows, 4 m long and 30 cm apart. Four soil samples from each replication were taken for soil analysis, which resulted in maximum average water holding capacity of the soil was 35% of soil dry weight and the permanent wilting point was 12%. Plots were treated alike for all the cultural practices and nutrient application from sowing till harvest. Meteorological data regarding minimum and maximum temperature, relative humidity, pan evaporation and monthly rain fall were taken through out the growing season. Patterns of rainfall, temperature, relative humidity and pan evaporation (Fig. 1) showed sufficient period for the crop to be exposed to water stress at booting, anthesis and post-anthesis stages. At post-anthesis stage in both the year flag leaf of the plants were utilized for recording of the data for various physiological parameters.

Morpho-physiological traits related to flag leaf. Flag leaf area (FLA) of 10 randomly selected plants from each replication was obtained during early morning hours when leaves were fully turgid. Flag leaf area was measured in centimeters (cm^2) by using leaf area meter (LI-3000/Lambda Instr. Corp. Lincolin, Nebraska, USA). The leaves were oven dried at 80ºC during 48 h and specific flag leaf area (SFLA) was calculated as a ratio of flag leaf area to the oven dry weight (g) of the leaves. Specific flag leaf weight (SFLW) was determined by the ratio of oven dry weight (g) of the leaves to flag leaf area (cm^2). The specific flag leaf weight (SFLW) was calculated as SFLW = DW/LA. For excised leaf weight loss (ELWL) the leaves were weighed at three stages, viz., immediately after sampling (fresh weight), then dried in an incubator at 28ºC at 50% R.H. for 6 h and then dried again in an oven for 24 h at 70ºC as proposed by Clarke and Townley-Smith (1986). ELWL was calculated from the following formula:

ELWL= [(Fresh weight -Weight after 6 h)/(Fresh weight - Dry weight)] × 100

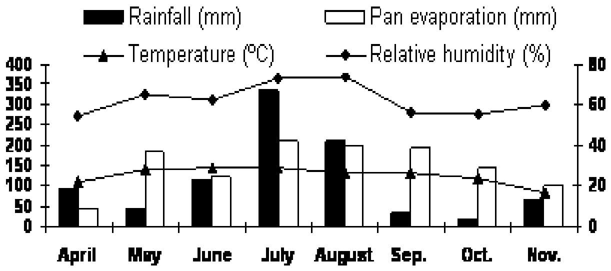
The "residual transpiration" (RT, the rate of water transpired at minimum stomatal aperture in total water limitation) was measured according to Clarke *et al*. (1991) leaves were excised and immediately brought to the laboratory. Then they remained in the darkness for stomatal closure for half an hour under ambient room conditions. They were weighed (W1 in g) after this period and again 180 min later (W2 in g); the leaf area (LA in cm^2) was determined using leaf area meter (LI-3000/Lambda Instr. Corp. Lincolin, Nebraska, USA). Residual transpiration on leaf area basis (g $H_2O/min/cm^2/10^5$) was determined as given below:

$$RT = (W1 – W2)/(LA.180)$$

Relative water content (RWC) was determined for detached leaves using the method of Mata and Lamattina (2001). The relative water content (RWC) was calculated on flag leaf blades from the following equation:

$$RWC (\%) = (FW – DW)/(TW – DW) \times 100$$

Fig. 1. Meteorological data regarding rainfall (mm), temperature (ºC), relative humidity (%) and pan evaporation (mm) during the crop season



The fresh weight (FW) was measured immediately after excision, the full turgid weight (TW) was determined after the rehydration of the leaves placing them in a test tube containing distilled water for 24 h at 4ºC in darkness and the dry weight (DW) after oven drying at 80ºC during 48 h. Leaf dry matter was determined by taking the average of dry weight in RWC and dry weight in ELWL. The relative dry weights of the leaves (RDW) were calculated following using the following formula:

RDW= DW/(TW-DW)

For the measurement of cell membrane stability (CMS), plant material (0.4 g) was washed with double distilled deionized water, placed in tubes with 20 mL of 3 d water and incubated for 2 h at 25°C. Subsequently, the electrical conductivity of the solution (L1) was determined using conductivity meter (Model, 145 A+, Thermo Electron USA). Samples were then autoclaved at 120°C for 20 min and the final conductivity (L2) was measured after equilibration at 25°C. The CMS was the mean percentage of five leaf sample and was calculated as follows:

CMS (%) = [(1-(L1/L2)] × 100

At maturity the heads of ten randomly selected plants were detached from the plants and threshed to determine grain yield per plant (g).

Statistical analysis. The average data recorded for seedling traits and physiological characters were subjected to the analysis of variance according to Steel *et al.* (1996) using MSTATC software to evaluate significant differences among the varieties for seedling parameters. Genetic parameters were obtained as outlined by Johnson *et al.* (1959) and Mahmud and Kramer (1951). Heritability estimates were calculated following the method of Allard (1960). Correlation coefficients were estimated according to Dewey and Lu (1959).

RESULTS AND DISCUSSION

Performance of various sorghum genotypes for morpho-physiological traits. Different genotypes responded differently to the water stress at seedling and post-anthesis stages for various morpho-physiological traits (Table I). For dry root weight, PGRI-191 surpassed all the genotypes followed by H-18 and PGRI-35 however; PGRI- 29 exhibited the least value. Similarly the line H-18 gave best performance for root length and coleoptile length followed by PGRI-191 and both of these lines were at the top for root: shoot ratio. Zekri (1991), Misra (1990, 1993 & 1994), Matsuura *et al.* (1996), Pace *et al.* (1999), Takele (2000), Dhanda *et al.* (2004), Kashiwagi *et al.* (2004) and Khan *et al.* (2004) concluded that these root traits can be reliably utilized for screening of tolerant genotypes in various crops. The results exhibited that the lines H-18 and PGRI-191 showed considerable tolerance against water stress based on seedling traits and can be further exploited in hybridization program. Takele (2000) reported that the water stress significantly affects the root-shoot ratio (R/S) as the decrease in water supply contributes to increase in R/S of seedlings, which also could be an important selection parameter for selection of drought tolerant genotypes (Zekri, 1991; Misra, 1990, 1993 & 1994). Moreover water stress tolerance is also directed by the traits like root thickness, the ability of roots to penetrate compacted soil layers and root depth and mass (Misra, 1990, 1993 & 1994; Pathan *et al.*, 2004). Even though long roots have been proved to be helpful tool for yield under terminal drought, it is imperative to recognize better how root traits contribute to drought tolerance (Kashiwagi *et al*., 2004). Long roots are positively associated with high harvest index (Kashiwagi *et al*., 2004) in chickpea under severe situation of water stress.

Flag leaf area and specific leaf area was the maximum for PARC-SS-1 followed by G-160. Although, flag leaf area has positive correlation with grain yield in many cereal crops but more leaf area might cause more water losses due to more evapotranspiration from the surface. Therefore optimum leaf area is required for carrying out enough photosynthesis to run the essential processes of plant (Khaliq *et al.*, 2008). Similarly, PARC-SS-1 was at the top for leaf dry matter leading to H-18 and H-118, which revealed that these genotypes were well adapted to the water stress conditions at post-anthesis stage providing a well developed source and sink association between leaf and grain yield (Aggarwal & Sinha, 1984; Misra & Misra, 1991, 1995; Misra *et al*., 2002). Evaluation of excise leaf weight loss (ELWL) water loss has shown a good promise for illustrating water stress tolerance (Clarke, 1987; McCaig & Romagosa, 1991; Bhutta, 2007). The data regarding excised leaf weight loss showed that the check variety JS-2002 was the minimum for this parameter followed by H-18 and PGRI-191, respectively. This displayed that these genotypes are less affected by evapo-transpiration losses. Likewise, higher relative dry weight values are supposed to be lead to vigorous accumulation of osmotica resulting in ability of plants to withstand against severe drought conditions (Jones *et al*., 1980). The genotypes, PARC-SS-1, PGRI-29, PGRI-35 and JS-61 had the topper values for relative dry weight suggesting good adaptation for these traits for drought stress.

Table I. Performance of various morpho-physiological traits in sorghum under water stress

	DRW	RL	CL	RL:SL	FLA	SFLA	SFLW	LDM	ELWL	RDW	RWC	RT	CMS	GY
G-160	0.027	4.870	1.557	0.312	104.888	65.445	0.015	0.517	15.297	0.432	46.330	0.012	45.756	24.385
JS-61	0.040	4.851	2.113	0.351	46.509	24.688	0.041	0.434	26.966	0.488	39.387	0.015	56.983	11.787
H-118	0.043	4.087	1.983	0.252	63.544	30.821	0.032	0.549	16.439	0.455	38.495	0.010	56.115	11.550
H-18	0.092	5.306	2.417	0.357	72.834	36.854	0.027	0.586	11.666	0.412	59.711	0.006	58.723	18.693
PARC-SS-1	0.044	4.980	1.432	0.337	107.700	67.530	0.019	0.634	13.671	0.556	38.467	0.007	60.646	26.763
PGRI-141	0.049	3.287	1.513	0.172	58.832	33.905	0.029	0.502	31.691	0.456	39.540	0.015	44.754	9.189
PGRI-191	0.104	4.237	2.410	0.375	60.296	27.307	0.038	0.533	12.060	0.463	38.922	0.009	63.756	12.667
PGRI-29	0.024	2.468	2.020	0.251	42.840	38.408	0.026	0.434	32.156	0.552	36.875	0.011	61.158	9.743
PGRI-35	0.090	3.787	1.663	0.209	48.404	33.930	0.032	0.434	20.142	0.483	42.413	0.010	57.828	12.024
JS-2002 (Check)	0.040	2.877	1.667	0.119	55.388	34.354	0.029	0.521	10.673	0.436	39.707	0.008	49.674	11.710

Where, DRW= Dry root weight (g), RL= Root length (cm), CL= Coleoptile length (cm), RL:SL= Root: shoot ratio, FLA= Flag leaf area (cm), SFLA= Specific flag leaf area, SFLW= Specific flag leaf weigh, LDM= Leaf dry matter (g), ELWL= Excise leaf weight loss (%), RDW= Relative dry weigh, RWC= Relative water content (%), RT= Residual transpiration, CMS= Cell membrane stability (%) and GY= Grain yield per plant (g)

Table II. Analysis of variance for various characters under drought stress

Characters	Replication mean squares	Genotype mean squares	Error mean squares
Dry root weight (g)	0.00001	0.0033**	0.0001
Root length (cm)	0.030	2.77**	0.12
Coleoptile length (cm)	0.007	0.40**	0.01
Root: shoot ratio	0.00004	0.02**	0.00012
Flag leaf area (cm)	25.920	1575.39**	36.45
Specific flag leaf area	72.124**	666.30**	0.31
Specific flag leaf weight	0.00002*	0.0002**	0.00001
Leaf dry matter (g)	0.0633**	0.0136**	0.0001
Excise leaf weight loss (%)	0.9456	206.27**	1.70
Relative dry weigh	0.0039	0.008**	0.002
Relative water content (%)	48.809**	135.34**	1.80
Residual transpiration (g $H_2O/min/cm^2/10^5$)	0.0000002	0.000035**	0.000001
Cell membrane stability (%)	51.573**	129.80**	0.17
Grain yield per plant (g)	3.868	116.20**	11.01

Where, * and **= significant at P>0.05 and P>0.01, respectively

Relative water content (RWC) is a key indicator of the degree of cell and tissue hydration, which is crucial for optimum physiological functioning and growth processes.

Numerous studies have shown that maintenance of a relatively high RWC during mild drought is indicative of drought tolerance (Jamaux *et al*., 1997; Altinkut *et al*., 2001; Colom & Vazzana, 2003). RWC is closely related with cell size and it may closely reflect the balance between water supply to the leaf and transpiration rate (Fischer & Wood, 1979). According to this, H-18 demonstrated the highest RWC followed by G-160 and PGRI-35, which in turn revealed the significance of these genotypes for water stress. Cuticular or residual transpiration is the key scheme of water loss during night time under conducive conditions and during noon under drought conditions. It has been recommended as selection criterion in breeding programs aimed at increasing the drought tolerance in crop plants (Clarke *et al*., 1991; Balota, 1995). The lowest value of residual transpiration was exhibited by H-18 followed by PARC-SS-1, JS-2002 and PGRI-191 revealing considerable scope of these genotypes for contributions towards drought tolerance. Cell membrane stability (CMS) refers to the capability of plant cell tissues to hold electrolytes under drought condition by retaining the cell membrane configuration undamaged (Sullivan, 1971). The CMS has been extensively used as selection criterion against water stress in sorghum (Premachandra *et al*., 1992), rice (Tripathy *et al*., 2000), mustard (Hashem *et al*., 1998), cotton (Ullah *et al*., 2006) and wheat (Rahman *et al*., 2006). In this regard, PGRI-191, PGRI-29, PARC-SS-1 and H-18 showed substantial promise towards drought stress. In addition to good performance of various genotypes for morpho-physiological traits contributing towards drought tolerance in sorghum, most of them revealed lower grain yield per plant. This supported the soundly recognized fact that yield of crop plants in drying soil reduces even in tolerant lines of that crop species (Ashraf & Mehmood, 1996; Tahir & Mehdi, 2001). However, PARC-SS-1 presented the highest value for grain yield per plant followed by G-160 and H-18.

For successful breeding program, presence of substantial amount of variability in the available germplasm is the condition (Ali *et al*., 2008). The genotypes studied showed significant statistical differences for all the parameters (Table II) which suggested that selection might be fruitful for drought tolerance contributing morpho-physiological traits. However, specific flag leaf area, cell membrane stability, leaf dry matter, relative water content, specific flag leaf weight revealed significant involvement on blocking effects. Dhanda *et al*. (2004), Khan *et al*. (2004) and Misra (1990, 1993 & 1994) also found significant variation among seedling traits in wheat, maize and pearl millet, respectively.

Variability parameters for various morpho-physiological traits. Improvement of crop plants against drought stress necessitates the exploration of the possible attributes of drought tolerance along with investigation of the genetic variation of the crops for the traits contributing towards drought tolerance (Misra & Misra, 1991; Misra *et al*., 2002; Dhanda *et al*., 2004). Variability parameters for different morpho-physiological characters were assessed to determine patterns of genetic variation among the genotypes (Table III). Flag leaf area exhibited the highest phenotypic and genotypic variance followed by specific leaf area and

Table III. Estimates of variability parameters among sorghum genotypes for morpho-physiological characters under drought stress

	δ^2g	δ^2p	CVg (%)	CVp (%)	h^2 b.s. (%)	GA	GA (% of the mean)
DRW	0.0011	0.0012	52.0731	54.3692	91.7321	6.4272	10289.0065
RL	0.88	1.00	23.14	24.63	88.25	182.10	4483.91
CL	0.13	0.14	19.20	19.82	93.83	72.08	3837.24
RL:SL	0.015	0.017	31.45	32.41	94.15	17.22	6295.27
FLA	512.98	549.43	34.25	35.45	93.37	4514.82	6827.87
SFLA	222.00	222.31	37.89	37.92	99.86	3071.66	7811.11
SFLW	0.0001	0.0001	26.1108	27.6842	88.9565	1.4624	5080.5191
LDM	0.0045	0.0046	13.0346	13.1250	98.6273	13.7393	2670.5120
ELWL	68.19	69.89	43.29	43.82	97.57	1682.69	8820.95
RDW	0.002	0.004	9.16	13.36	47.04	6.26	1296.60
RWC	44.51	46.32	15.84	16.16	96.11	1349.36	3204.14
RT	0.000011	0.000012	32.90	34.29	92.05	0.67	6511.71
CMS	43.21	43.38	11.84	11.86	99.60	1353.35	2436.75
GY	35.06	46.07	39.87	45.70	76.11	1065.75	7176.24

Where, DRW= Dry root weight (g), RL= Root length (cm), CL= Coleoptile length (cm), RL:SL= Root: shoot ratio, FLA= Flag leaf area (cm), SFLA= Specific flag leaf area, SFLW= Specific flag leaf weigh, LDM= Leaf dry matter (g), ELWL= Excise leaf weight loss (%), RDW= Relative dry weigh, RWC=Relative water content (%), RT=Residual transpiration (g H_2O/min/cm^2/10^5), CMS=Cell membrane stability (%) and GY=Grain yield per plant (g)

Table IV. Simple correlation coefficients among different morpho-physiological characters in sorghum under drought stress

	DRW	RL	CL	RL:SL	FLA	SFLA	SFLW	LDM	ELWL	RDW	RWC	RT	CMS
DRW	1.000												
RL	0.294	1.000											
CL	0.585	-0.005	1.000										
RL:SL	0.454	0.738**	0.545	1.000									
FLA	-0.340	0.718*	-0.399	0.374	1.000								
SFLA	-0.551	0.484	-0.595	0.181	0.897**	1.000							
SFLW	0.725**	-0.189	0.571	0.064	-0.763**	-0.912**	1.000						
LDM	-0.157	0.480	-0.053	0.304	0.741**	0.497	-0.434	1.000					
ELWL	-0.133	-0.425	-0.139	-0.232	-0.499	-0.257	0.196	-0.677*	1.000				
RDW	-0.350	-0.386	-0.358	-0.299	-0.233	0.004	-0.077	-0.559	0.870**	1.000			
RWC	0.305	0.340	0.360	0.337	0.251	0.092	-0.213	0.291	-0.372	-0.435	1.000		
RT	-0.044	0.139	-0.417	0.017	-0.009	0.138	0.001	-0.443	0.760**	0.759**	-0.289	1.000	
CMS	0.448	0.091	0.665*	0.559	-0.187	-0.197	0.345	0.084	-0.148	-0.389	-0.053	-0.351	1.000
GY	-0.188	0.771**	-0.291	0.496	0.947**	0.888**	-0.720**	0.667*	-0.525	-0.354	0.361	-0.032	-0.001

Where, * and **= significant at P>0.05 and P>0.01 respectively, DRW= Dry root weight (g), RL= Root length (cm), CL= Coleoptile length (cm), RL:SL= Root: shoot ratio, FLA= Flag leaf area (cm), SFLA= Specific flag leaf area, SFLW= Specific flag leaf weigh, LDM= Leaf dry matter (g), ELWL= Excise leaf weight loss (%), RDW= Relative dry weigh, RWC= Relative water content (%), RT= Residual transpiration, CMS= Cell membrane stability (%) and GY= Grain yield per plant (g)

excised leaf weight loss. However, dry root weight demonstrated the highest value of phenotypic and genotypic coefficient of variations following excised leaf weight loss and grain yield per plant, which suggested that considerable selection pressure for drought tolerance could be possible. All the morpho-physiological traits displayed high estimates of heritability in broad sense except relative dry weight, however specific flag leaf area and cell membrane stability exhibited the highest heritability. Cell membrane stability also revealed high heritability in wheat (Dhanda *et al*., 2004), however Tripathy *et al*. (2000) in contrast reported low heritability for this trait in rice. High estimates of heritability in narrow sense represents fixable, additive heritable variation, which indicated that response to selection, should be rapid for these characters (Ali *et al*., 2008). Various scientists revealed high heritability for root and shoot length, root-to-shoot ratio and coleoptile length in wheat (Dhanda *et al*., 2004), flag leaf area and its related traits contributing towards drought tolerance in wheat (Ahmed *et al*., 2004), specific leaf area in peanut (Songsri *et al*., 2008), excised leaf weight loss in durum wheat (Clarke & Townley-Smith, 1986). Reliable heritability demonstrated by these morpho-physiological traits will not only points towards the scope of assembling genetic characters imparting stress tolerance but also facilitates us to formulate predictions about the possible progress in this effort. Similarly, most of the characters exhibited high genetic advance being dry root weight at the top followed excised leaf weight loss and specific flag leaf area. The considerable amount of genetic advance indicated high extent of selection gain followed by hybridization for these parameters. Moreover, high estimates of broad sense heritability coupled with high genetic advance indicated additive genetic effects, which provided sufficient scope for selection of most of the characters.

Simple correlation analysis among morpho-physiological parameters. Information regarding character association is of much importance for a plant breeder to ascertain the expected response of other characters when selection is exercised to the character of interest in a breeding program and it is measured by coefficient of correlation (Dabholkar, 1992). The coefficients of correlation among the different morpho-physiological characters (Table IV) showed that root length revealed significant positive association with root: shoot ratio, flag leaf area and grain yield. On the other hand Dhanda *et al*. (2004) reported negative association of root length with root: shoot ratio in wheat under water stress. Likewise dry root weight displayed positive relationship with specific flag leaf weight. Coleoptile length and cell membrane stability showed positive association between each other, both of these parameters are well known criteria against drought stress. The results suggested that root length, root: shoot ratio, flag leaf area, coleoptile length, cell membrane stability and grain yield can be selected simultaneously due to absence of un-wanted relationship and this pointed out that these parameters could be utilized as selection criteria for drought tolerance. In the same way, flag leaf area demonstrated strong positive association with specific flag leaf area, leaf dry matter and grain yield per plant, while negative correlation with specific leaf weight. Khaliq *et al*. (2008) also reported positive association of flag leaf area and grain yield in bread wheat. Correspondingly specific flag leaf area also exhibited strong positive relationship with grain yield, while negative one with specific leaf weight. This suggested that flag leaf area could contribute towards water stress tolerance. Specific leaf weight revealed negative association with grain yield, which supported that high leaf area and lower specific leaf weight, might help in selecting the genotypes with higher grain yields with considerable water stress tolerance.

Leaf dry matter revealed significant positive correlation with grain yield, while negative association with excised leaf weight loss. This was the better relationship with the scope of selection of genotypes with high leaf dry matter, grain yield and lower excised leaf weight loss. Similarly, excised leaf weight loss displayed positive and significant link with relative dry weight and residual transpiration, while considerable but statistically non-significant correlation with grain yield (r= 0.525). Clarke *et al.* (1991) reported significant negative correlation between residual transpiration and grain yield among winter wheat genotypes, which suggested that cuticular transpiration is a major factor explaining the genotypic differences in drought resistance among the studied genotypes. Relative water content was positively associated with relative dry weight, which advocated that selection of genotypes with considerable amount of water and more accumulation of osmotica in the flag leaves could be possible, which in turn will help the plant to cope with drought stress conditions at reproductive stage.

CONCLUSION

Although most of the genotypes performed better than the check variety, the genotypes H-18 followed by PGRI-191, PGRI-35 and PARC-SS-1 proved better for most of the drought tolerance contributing characters. Coefficient of variation was the highest for excised leaf weight loss followed by grain yield, which suggested considerable scope for selection of these traits. High estimates of broad sense heritability and genetic advance for all the characters advocated the most appropriate condition for selection for these traits except for relative dry weight. Correlation analysis revealed that higher root length, coleoptile length, root: shoot ratio, flag leaf area, leaf dry matter, cell membrane stability, grain yield and lower values for specific leaf weigh, excised leaf weight loss, residual transpiration could be improved simultaneously and might be reliable selection criteria for drought tolerance in sorghum at seedling and post-flowering stages.

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