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CORRELATED RESPONSE OF VARIOUS MORPHO-PHYSIOLOGICAL CHARACTERS WITH GRAIN YIELD IN SORGHUM LANDRACES AT DIFFERENT GROWTH PHASES

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ABSTRACT

Seventeen sorghum landraces were exploited to establish morpho-physiological criteria for drought tolerance and higher grain yield in sorghum at seedling and post flowering stages under rainfed conditions at Barani Agricultural Research Station, Fatehjang, Pakistan during the years 2007 and 2008. Meteorological data of both the years revealed considerable water stress at post-flowering stage. The data were recorded for fresh root and shoot weights (g), dry root and shoot weights (g), root length (cm), shoot length (cm), coleoptile length (cm) and root shoot ratio at seedling stage. At post-flowering stage data on flag leaf area (cm), specific flag leaf area, specific flag leaf weight, leaf dry matter (g), excised leaf weight loss (%), relative dry weight, relative water contents (%), residual transpiration (g $H_2O/min/cm^2/10^5$), cell membrane stability (%) and grain yield per plant (g) were recorded. Analysis of variance revealed significant genetic differences among the landraces for all the traits. Correlation and path coefficient analysis demonstrated that fresh root shoot weights, dry shoot weight and root: shoot ratio were important selection criteria for drought tolerance as well as higher grain yield at seedling stage. Similarly, higher flag leaf area, leaf dry matter, relative water contents and cell membrane stability along with lower values of specific flag leaf weigh, excise leaf weight loss and residual transpiration could be exploited as morpho-physiological markers for drought tolerance and higher grain yield at late growth stage. The studies revealed many important correlations among the characters which can be exploited to execute a breeding programme aimed at the development of drought tolerant sorghum cultivars.

Key words: *Sorghum bicolor* L., morpho-physiological markers, seedling, post-flowering, drought tolerance.

INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is grown for food, feed and industrial purposes. It is considered more tolerant to many stresses, including heat, drought, salinity and flooding as compared to other cereal crops (Ejeta and Knoll, 2007), however, the crop grown in rainfed area is influenced by water stress at the reproductive stage (Kebede *et al*., 2001). Water stress has emerged as one of the most severe stresses faced by the sustainable crop productivity all over the world (Tahir and Mehdi, 2001). Water stress diversely affects various developmental stages and ultimately affects the yield (Agboma *et al*. 1997). Water stress at different growth stages causes various physiological changes in the plants. For example, water stress at seedling stage might lead to higher dry root weights, longer roots, coleoptiles and higher root shoot ratios (Takele, 2000; Dhanda *et al*., 2004; Kashiwagi *et al*., 2004). Similarly, drought conditions both pre-flowering and post-flowering stages have the most adverse effect on yield during and after anthesis (Kebede *et al*., 2001). Post-flowering water stress might lead to the failure of fertilization because of the impairment of pollen and ovule function resulting in declined grain yield.

Many studies have been carried out to set selection criteria for drought tolerance. Dhanda *et al*. (2004) and Khan *et al*. (2004) reported that drought-adapted plants are often characterized by deep and vigorous root systems. Some other scientists focused on morpho-physiological flag leaf related characters especially leaf water relations and their considerable interaction with drought tolerance (Agarwal and Sinha, 1984). The review of literature showed that flag leaf area (Karamanos and Papatheohari, 1999), specific leaf weight, leaf dry matter (Agarwal and Sinha, 1984), excised leaf weight loss (McCaig and Romagosa 1991; Bhutta, 2007), relative dry weight (Jones *et al*., 1980), relative water content (Fischer and Wood, 1979; Colom and Vazzana, 2003), residual transpiration (Clarke *et al*., 1991; Sabour *et al*., 1997) and cell membrane stability (Premachandra *et al*., 1989) had been widely exploited as reliable morph-physiological markers contributing towards drought tolerance for various crop plants including sorghum (Ali *et al*., 2009b, 2009c and 2011).

The success for breeding under stress condition is limited (Hollington and Steele, 2007) but an identification and analysis of plant traits with sound and positive association with drought tolerance and high productivity under drought is necessary (Richards, 2004; Rauf and Sadaqat, 2008). For this purpose the exploitation of correlation and path analysis could be helpful in determining these associations. Correlation coefficients in general show associations among independent characteristics and the degree of linear relation between these characteristics. It is not sufficient to describe this relationship when the causal association among characteristics is needed (Toker and Cagirgan, 2004). Path analysis is used to know causes. In other words path analysis is used to determine the amount of direct and indirect effect of the causal components on the effect component (Ali *et al*., 2009a, Anwar *et al*. 2009).

The local landraces (LLRs) are more tolerant to various abiotic stresses as compared to modern varieties (Brush, 1999). Ali *et al*. (2009c) did the diversity analysis of same group of landraces and suggested that these morpho-physiological traits could be efficiently used as selection criteria for drought tolerance in sorghum at different growth stages. But they did not give information about the correlated response of different traits between each other and with grain yield from these landraces.

In this study local landraces of sorghum were utilized which were collected from farmer's field, cultivated for so many years by the farmers. The objective of this research was to assess correlated response of seedling and physiological traits among them as well as with grain yield and to develop possible selection criteria for sorghum under natural incidence of water stress.

MATERIALS AND METHODS

Plant material: The experiment was conducted at the Barani Agricultural Research Station, Fatehjang (33º34′ N, 72º38′ E) Pakistan during the years 2007 and 2008. Seventeen sorghum genotypes/local land races viz., FJSS-1, FJSS-2, FJSS-3, FJSS-4, FJSS-5, FJSS-6, FJSS-7, FJSS-8, FJSS-9, FJSS-10, FJSS-11, FJSS-15, FJSS-16, FJSS-17, FJSS-20, FJSS-21 and one approved variety Chakwal sorghum (developed at Barani Agricultural Research Institute, Chakwal, Pakistan) were evaluated for drought tolerance at seedling and post flowering stage under rainfed conditions and the average of the two year data was taken. The local landraces were collected during the year 2001 from farmer fields and some of them were acquired from gene bank facilities of Plant Germplasm Recourses Institute (PGRI), Islamabad. Pure lines were developed by inbreeding for five consecutive years.

Seedling traits: Water deficit condition at seedling stage was created by watering the plants with 50% of normal condition (Khan *et al*. 2004). 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, coleoptile and shoot length (cm), fresh root and shoot weight (g), dry root and shoot weight (g) and root shoot ratio.

Field experiment: The sorghum genotypes were planted on second week of July during 2007 and first week of July during 2008 in a triplicate Randomized Complete Block Design (RCBD) with experimental plots comprising of two rows, 4m long and 30cm apart. Four soil samples from each replication were taken for soil analysis. The soil analysis showed maximum average water holding capacity of the soil as 35% and the permanent wilting point as 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 (mm), temperature (ºC), relative humidity (%) and pan evaporation (mm) showed sufficient period for the crop to be exposed to water stress at booting, anthesis and post-anthesis stages (Fig. 1). At post-anthesis stage in both the years flag leaf of the plants were utilized for recording of the data for various physiological parameters.

Morph-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 80 ºC for 48 hours 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 28 ºC at 50% relative humidity for 6 h, and then dried again in an oven for 24 h at 70 ºC 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. Residual transpiration on leaf area basis (g $H_2O/min/cm^2/10^5$) was determined as given below:

RT = (W1 – W2)/ (LA after 180 min.)

Relative water contents (RWC) was determined for detached leaves using the method of Mata and Lamattina (2001) using the following equation:

RWC (%) = (FW – DW)/(TW – DW) × 100

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 hours at 4ºC in darkness, and the dry weight (DW) after oven drying at 80ºC during 48 hours. 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 double distilled deionized water and incubated for 2 hours 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 of the data: The average data recorded for seedling traits and physiological characters during 2007 and 2008 were subjected to the analysis of variance according to Steel *et al*. (1996) using MSTATC software (MSTAT-C development Team, 1989). Genotypic and phenotypic correlations were computed following Kwon and Torrie (1964). Path coefficients were estimated according to Dewey and Lu (1959), where grain yield per plant was kept as resultant variable and other contributing characters as causal variables.

RESULTS

The basic statistics displayed considerable range for various parameters at both early and late growth stages (Table 1). Analysis of variance expressed significant differences among the parents for all the traits (Table 2) which indicated a wide range of variability among the parents for the parameters under consideration.

Genotypic correlations were generally higher than the phenotypic correlations for most of the traits (Table 3 and 5). Significant correlations among various seedling traits were observed (Table 3). Fresh root weight showed positive and significant correlation with dry shoot weight (rp=0.528 and rg=0.676) and grain yield (rp=0.484 and rg=0.634) at both phenotypic and genotypic levels. Fresh shoot weight revealed highly significant association with dry shoot weight both phenotypically and genotypically (rp=0.603 and rg=0.820). Many scientists have utilized dry root weight as a selection criterion for drought tolerance but in these studies, this parameter displayed non-significant association with all the seedling traits. Dry root weight couldn't demonstrate significant relationship with any of the seedling trait. However, longer roots resulted in higher root: shoot ratio as a highly significant relationship between the two was observed (rp=0.885 and rg=0.968). Positive correlation was detected between shoot length of the seedlings and grain yield per plant (rg=0.583) only at the genotypic level.

Similarly, path analysis revealed that FRW (0.657), DSW (0.803) and RL (1.046) exerted positive direct effects on grain yield per plant, while other parameters exercised negative direct effects on grain yield (Table 4). Root shoot ratio (-1.132) exercised maximum negative effects. Among the indirect effects of various traits on grain yield per plant, FRW demonstrated positive indirect effects through DSW, RL and root shoot ratio. Although FSW exerted negative direct weight on grain yield, it revealed considerable positive indirect influence on grain yield through all the traits except RL and CL. Similarly, DRW exerted positive indirect influence on grain yield through all the traits except root shoot ratio, in addition to considerable positive direct effect of DSW on grain yield it also exerted negative indirect effects on grain yield through most of the seedling parameters except FRW and SL. Root length which had the highest direct effect on grain yield also displayed the highest negative indirect effect through root shoot ratio. Positive indirect effects were exhibited by shoot length through all parameters except root shoot ratio which exerted negative indirect effect on grain yield per plant. Root shoot ratio which demonstrated the highest negative direct influence on grain yield also displayed the maximum indirect effect through root length on grain yield. Coleoptile length presented positive indirect effect on the grain yield via FRW, DSW, RL and SL.

Estimates of correlation coefficients among the physiological traits (Table 5) explained that area of the flag leaf blade was positively and significantly associated with leaf dry matter (rp=0.512 and rg=0.789) and grain yield (rp=0.759 and rg=0.807) while FLA revealed significantly negative association with SFLW (rp=-0.838 and rg=-0.866) and ELWL (rp=0.614 and rg=0.680) at both phenotypic and genotypic levels. Specific flag leaf weight was negatively and significantly correlated with SFLA (rp=-0.666 and rg=-0.717) and grain yield (rp= -

0.541 and rg= -0.626) at both phenotypic and genotypic levels, while it showed significant negative relationship with LDM (rg= -0.567) only at genotypic level. Conversely, SFLW was positively and significantly associated with ELWL at both levels (rp=0.657 and rg=0.763). LDM showed significant and negative

Table 1: Basic statistics for various morpho-physiological traits in sorghum under limited moisture

Traits	*Mean± S.E*	*Minimum*	*Maximum*	*Range (Max. – Mini.)*	*Std. Deviation*
FRW	0.33±0.03	0.22	0.62	0.40	0.10
FSW	3.69±0.24	1.92	5.78	3.86	1.00
DRW	0.05±0.01	0.01	0.12	0.11	0.04
DSW	0.58±0.03	0.31	0.91	0.60	0.14
RL	3.23±0.18	1.64	4.88	3.24	0.76
CL	1.79±0.09	1.28	2.76	1.48	0.36
SL	18.16±0.41	14.70	21.10	6.40	1.71
R/S	0.18±0.01	0.11	0.27	0.16	0.04
FLA	81.05±5.21	47.73	121.28	73.55	21.49
SFLA	42.05±3.70	17.63	70.96	53.34	15.27
SFLW	0.037±0.004	0.01	0.07	0.06	0.02
LDM	2.87±0.07	2.20	3.24	1.04	0.29
ELWL	19.04±2.54	9.55	44.44	34.89	10.47
RDW	0.45±0.02	0.25	0.53	0.28	0.06
RWC	65.67±2.74	44.00	87.03	43.03	11.30
RT	0.008±0.001	0.004	0.015	0.011	0.003
CMS	68.9±1.59	56.95	75.38	18.43	6.56
GY	16.38±1.59	7.05	25.96	18.91	6.56

Where, FRW= Fresh root weight (g), FSW= Fresh shoot weight (g), DRW= Dry root weight (g), DSW= Dry shoot weight (g), RL= Root length (cm), SL= Shoot length (cm), CL= Coleoptile length (cm), R/S= Root shoot ratio, FLA= Flag leaf area (cm^2), SFLA= Specific flag leaf area (ratio), SFLW= Specific flag leaf weigh (ratio), LDM= Leaf dry matter (g), ELWL= Excise leaf weight loss (%), RDW= Relative dry weigh (ratio), 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 2: Analysis of variance for some characters in sorghum under drought at various growth stages

Characters	*Replication mean squares (df=2)*	*Genotype mean squares (df=16)*	*Error mean squares (df=32)*
Fresh root weight (g)	0.0009	0.0326**	0.0042
Fresh shoot weight (g)	0.4571	2.9698**	0.3309
Dry root weight (g)	0.00007	0.0046**	0.0002
Dry shoot weight (g)	0.0006	0.0590**	0.0033
Root length (cm)	0.1895**	1.6770**	0.0816
Coleoptile length (cm)	0.0516**	0.3852**	0.0540
Shoot length (cm)	10.3662	8.5679**	3.0826
Root: shoot ratio	0.00006	0.0048**	0.0004
Flag leaf area (cm)	11.09**	1400.18**	0.08
Specific flag leaf area (ratio)	19.75	697.29**	17.48
Specific flag leaf weight(ratio)	0.000005	0.001**	0.000008
Leaf dry matter (g)	0.109	0.236**	0.074
Excise leaf weight loss (%)	40.411	325.108**	21.994
Relative dry weigh (ratio)	0.000006	0.011**	0.001
Relative water content (%)	7.657	386.255**	21.627
Residual transpiration (g $H_2O/min/cm^2/10^5$)	0.000004**	0.00001**	0.000002
Cell membrane stability (%)	31.96849**	127.6123**	13.97217
Grain yield per plant (g)	17.78186**	129.4711**	5.486554

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

Table 3: Coefficients of phenotypic (upper diagonal) and genotypic (lower diagonal) correlation among seedling parameters under limited moisture

Traits	FRW (g)	FSW (g)	DRW (g)	DSW (g)	RL (cm)	SL (cm)	R/S ratio	CL (cm)	GY (g)
FRW	1	0.375	0.042	0.528*	0.063	0.027	0.049	0.130	0.484*
FSW	0.375	1	-0.202	0.603*	-0.221	-0.185	-0.086	0.224	0.020
DRW	0.047	-0.237	1	0.085	0.209	-0.248	0.331	0.282	-0.137
DSW	0.676**	0.820**	0.042	1	0.072	0.063	0.104	0.210	0.263
RL	0.039	-0.252	0.204	0.066	1	0.288	0.885**	0.201	0.008
SL	0.324	-0.197	-0.359	0.335	0.358	1	-0.167	-0.286	0.291
R/S	-0.054	-0.161	0.346	0.037	0.968**	0.122	1	0.389	-0.130
CL	0.123	0.264	0.313	0.268	0.261	-0.066	0.357	1	-0.236
GY	0.634**	0.076	-0.135	0.260	0.018	0.583*	-0.174	-0.228	1

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

FRW= fresh root weight (g), FSW= Fresh shoot weight (g), DRW= Dry root weight (g), DSW= Dry shoot weight (g), RL= Root length (cm), SL= Shoot length, (cm), CL= Coleoptile length (cm), R/S= Root: shoot ratio and GY=Grain yield (g)

Table 4: Direct (bold) and indirect effects of various seedling traits on grain yield under moisture stress conditions

Traits	FRW (g)	FSW (g)	DRW (g)	DSW (g)	RL (cm)	SL (cm)	R/S ratio	CL (cm)	rg with GY
FRW	**0.657**	-0.508	-0.014	0.055	0.041	-0.159	0.061	-0.003	0.634**
FSW	0.328	**-1.021**	0.100	0.659	-0.263	0.096	0.183	-0.006	0.076
DRW	0.021	0.242	**-0.423**	0.034	0.214	0.176	-0.392	0.007	-0.13
DSW	0.457	-0.837	-0.17	**0.803**	0.069	-0.164	-0.042	-0.007	0.260
RL	0.026	0.257	-0.086	0.053	**1.046**	-0.176	-1.096	-0.006	0.018
SL	0.213	0.201	0.151	0.269	0.375	**-0.490**	-0.139	0.001	0.583*
R/S	-0.035	0.165	-0.146	0.029	1.013	-0.060	**-1.132**	-0.008	-0.174
CL	0.081	-0.270	-0.132	0.215	0.273	0.032	-0.404	**-0.024**	-0.228

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

Where FRW= fresh root weight (g), FSW= Fresh shoot weight (g), DRW= Dry root weight (g), DSW= Dry shoot weight (g), RL= Root length (cm), SL= Shoot length, (cm), CL= Coleoptile length (cm), RL: SL= Root: shoot ratio and GY=Grain yield (g)

Table 5: Coefficients of phenotypic (upper diagonal) and genotypic (lower diagonal) correlation among leaf related traits under limited moisture at reproductive stage

Traits	*FLA*	*SFLW*	*SFLA*	*LDM*	*ELWL*	*RDW*	*RWC*	*RT*	*CMS*	*GY*
FLA	1	-0.838**	0.414	0.512*	-0.614**	-0.062	-0.087	-0.057	-0.283	0.759**
SFLW	-0.866**	1	-0.666**	-0.366	0.657**	0.077	0.183	0.081	0.341	-0.541*
SFLA	0.429	-0.717**	1	0.024	-0.391	0.076	-0.074	-0.037	-0.046	0.149
LDM	0.789**	-0.567*	0.079	1	-0.594*	-0.312	-0.087	-0.034	-0.105	0.457
ELWL	-0.680**	0.763**	-0.451	-0.870**	1	0.168	0.193	0.313	0.256	-0.430
RDW	-0.070	0.090	0.103	-0.414	0.204	1	0.141	0.046	0.193	-0.171
RWC	-0.097	0.216	-0.109	0.006	0.215	0.155	1	0.253	0.474	-0.062
RT	-0.080	0.058	-0.063	-0.724**	0.658**	0.134	0.344	1	-0.096	0.006
CMS	-0.334	0.403	-0.093	-0.042	0.308	0.113	0.532*	-0.038	1	-0.100
GY	0.807**	-0.626**	0.165	0.660**	-0.508*	-0.132	-0.068	-0.020	-0.132	1

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

FLA= Flag leaf area (cm), SFLW= Specific flag leaf weigh (ratio), SFLA= Specific flag leaf area (ratio), LDM= Leaf dry matter (g), ELWL= Excise leaf weight loss (%), RDW= Relative dry weigh (ratio), 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 6: Direct (bold) and indirect effects of various morph-physiological parameters under moisture stress at reproductive stage

Traits	*FLA*	*SFLW*	*SFLA*	*LDM*	*ELWL*	*RDW*	*RWC*	*RT*	*CMS*	*rg with GY*
FLA	**-0.277**	2.074	-0.304	0.504	-1.224	-0.007	-0.019	0.060	0.0005	0.807**
SFLW	0.239	**-2.393**	0.508	-0.362	1.373	0.009	0.043	-0.043	-0.0006	-0.626**
SFLA	-0.118	1.717	**-0.708**	0.050	-0.812	0.011	-0.022	0.048	0.001	0.165
LDM	-0.218	1.359	-0.056	**0.638**	-1.565	-0.044	0.001	0.544	0.0001	0.660**
ELWL	0.188	-1.827	0.319	-0.555	**1.798**	0.021	0.042	-0.495	-0.0005	-0.507*
RDW	0.019	-0.216	-0.073	-0.264	0.367	**0.105**	0.031	-0.101	-0.0002	-0.132
RWC	0.027	-0.518	0.077	0.004	0.386	0.016	**0.199**	-0.259	0.0009	-0.068
RT	0.022	-0.139	0.045	-0.462	1.184	0.014	0.068	**-0.752**	0.0001	-0.019
CMS	0.092	-0.964	0.066	-0.027	0.553	0.012	0.108	0.030	**-0.002**	0.132

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

FLA= Flag leaf area (cm), SFLW= Specific flag leaf weigh (ratio), SFLA= Specific flag leaf area (ratio), LDM= Leaf dry matter (g), ELWL= Excise leaf weight loss (%), RDW= Relative dry weigh (ratio), 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)

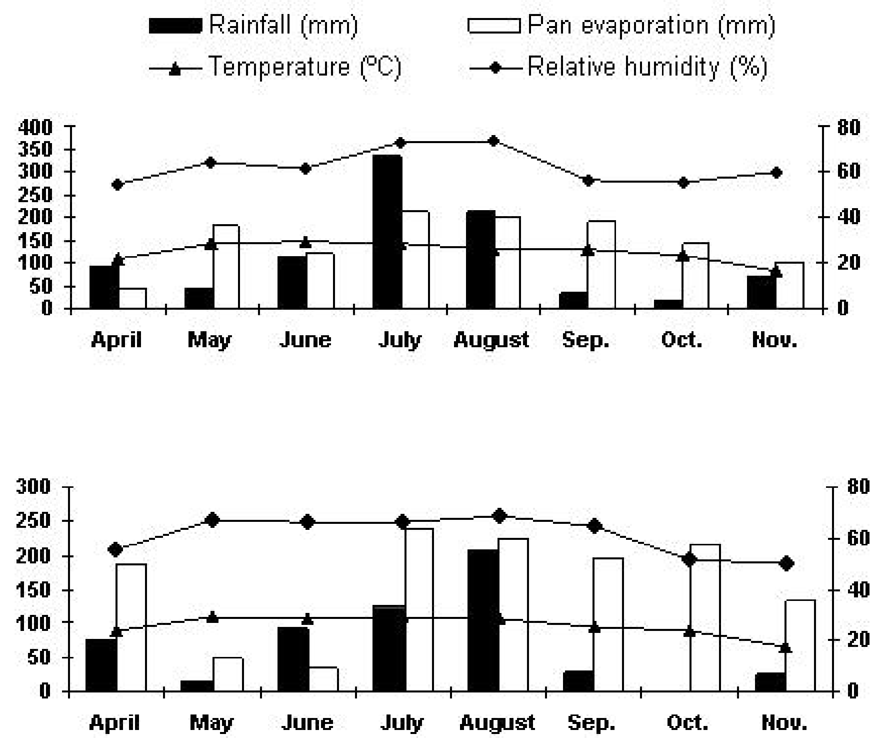

Fig. 1: Meteorological data regarding rainfall (mm), temperature (oC), relative humidity (%) and pan evaporation (mm) during 2007 (upper and 2008 (lower)

correlation with ELWL at both levels (rp=0.594 and rg=0.870) and with residual transpiration (RT) only at genotypic level (rg=-0.724). However, LDM was positively and significantly correlated with grain yield (rg=0.660). The character ELWL demonstrated significantly positive relationship with RT (rg=0.658) and negative association with grain yield (rg=-0.508) only at genotypic level. There was significant and positive genotypic correlation (rg=0.532) between relative water content (RWC) and cell membrane stability (CMS). There were also some important correlations between root characters and leaf traits (data not shown). The RL showed negative association with CMS (r=-0.479). However, CL demonstrated negative correlation with LDM (r=-0.526), while positive one with RDW (r=0.487) and RT (r=0.562). Similarly, SL revealed positive correlation with FLA (r=0.503) and negative relationship with SFLW (r=-0.478).

Path coefficient analysis of physiological traits with grain yield as dependent variable demonstrated that LDM, ELWL, RDW and RWC had positive direct effects on grain yield with the highest value displayed by ELWL (1.798) (Table 6). On the other hand, FLA, SFLW, SFLA, RT and CMS exerted negative direct influence on grain yield among which SFLW exhibited the greatest negative effect (-2.393). Among the indirect effects FLA positioned the highest indirect effect (2.074) on grain yield SFLW and considerable negative effect via ELWL. Specific flag leaf weight which laid the highest negative direct influence and had negative association with grain yield revealed substantial positive indirect effect on grain yield by means of ELWL and SFLA. The parameters SFLA and LDM expressed significant positive indirect effects through SFLW and negative indirect influence via ELWL on grain yield. In addition to the maximum direct influence of ELWL on grain yield, it conditioned the highest indirect negative impact on grain yield through SFLW (-1.827). RDW exerted a small positive indirect effect on grain yield via ELWL. Similarly, RWC explained sizeable postive indirect influence through SFLW and negative effect via ELWL on grain yield. In contrast to the negative direct effect of RT on grain yield, it exposed significant positive indirect influence by means of ELWL. Cell membrane stability (CMS) displayed negative indirect effects on grain yield via SFLW. However, it exerted positive indirect influences on grain yield through most of the traits. The results demonstrated that in addition to maximum negative and positive direct effects exercised by SFLW and ELWL respectively on grain yield, these parameters also affected the yield indirectly through various physiological characters. These parameters might be effective in selection of traits that would guide us towards the objective of higher yield as direct selection for a highly variable and complex trait like grain yield would be ineffective.

DISCUSSION

The grain yield, a major selection criterion against drought stress is a complex character as it is determined by several physiological, biochemical and metabolic plant processes whose genetics and associations are largely vague. Correlation analysis suggested that simultaneous improvement could be possible for DSW, FSW and FRW due to positive correlation between these traits. The character FRW showed significant genotypic correlation with grain yield revealing its importance for selecting the genotypes with drought tolerance and higher yields. RL and R/S ratio was positively associated which was supported by the results of Ali *et al*. (2009b; 2011) in contrary to the results of Dhanda *et al*. (2004) who revealed positive association of root length with shoot length and coleoptile length while negative correlation with R/S ratio in wheat under water stress. SL was also an indicator of higher yields in sorghum landraces. Similarly, the direct and indirect effects of various seedling traits based on genotypic correlations revealed direct involvement of RL, SL and FRW in determining the grain yield per plant amongst the sorghum landraces.

Although, R/S ratio demonstrated the highest direct effect on grain yield, it indirectly contributed to grain yield through RL. FLA showed strong positive correlation with grain yield which indicated selection of both these characters simultaneously and these results were in accordance with those of Ali *et al*. (2009a) for these landrace. On the other hand, Ali *et al*. (2011) in a completely different experiment including this group of landrace demonstrated a non-significant negative correlation. Interestingly more FLA resulted in lower SFLW and ELWL and higher LDM and grain yield per plant. Likewise, more SFLW resulted in lower LDM, SFLA and grain yield while higher ELWL which suggested that one should be careful while selecting the genotypes with high SFLW and high grain yield in sorghum. LDM revealed simultaneous selection with lower ELWL and RT and higher grain yield. Positive association of ELWL with grain yield and negative relationship with RT demonstrated right track for plant breeder to selected high yielding sorghum genotypes with lower values of RT and ELWL.

Similarly, simultaneous selection could be possible for CMS and RWC due to their significantly positive correlation. Farooq and Azam (2002) also found positive correlation of CMS and RWC in wheat under salinity and drought conditions. According to Dhanda and Sethi (2002), ELWL revealed positive association with CMS while CMS negative correlation with RWC in wheat whereas grain yield showed negative relationship with ELWL and CMS, whereas positive correlation with RWC.

Path coefficient analysis is one of biometrical techniques which has been consistently exploited to quantify the associations of different yield attributes and also their direct and indirect effects on grain yield using genotypic correlation values (Bhutta, 2007). Besides a negative correlation of SFLW with grain yield, it also imposed the highest negative direct influence on grain yield. However, ELWL directly and positively affected grain yield to the highest extent. The results of (Bhutta, 2007) working on wheat under drought were conflicting who found that ELWL exerted maximum negative direct effect on grain yield per plant in wheat. Negative association of ELWL with grain yield and positive direct influence suggested the use of a restricted simultaneous selection model is to be followed i.e., restrictions are to nullify the undesirable indirect effects in order to make use of direct effect (Singh and Kakar, 1977). Similarly, if the genotypic correlation is almost equal to the direct effect of any causal factor, then correlation explains the true relationship and direct selection through this trait will be effective (Singh and Chaudhary, 1985). In this study, FRW and LDM displayed similar behavior towards grain yield. However, if the association is positive, but the direct influence is negative or negligible, the indirect effects seem to be the cause of correlation. In such situations, the indirect causal effects are to be considered simultaneously for selection (Singh and Chaudhary, 1985). Here the SL and FLA showed synonymous conditions, where there was positive correlation but negative direct effect but FLA exerted the highest positive indirect effect on grain yield through SFLW. Hence, this positive correlation among FLA and grain yield was the function the highest positive indirect effect via SFLW on grain yield, so selection for this effect could be considered simultaneously. Ali *et al*. (2009b; 2011) reported partially similar findings for sorghum under drought stress but with different sets of genotypes.

CONCLUSION

The correlation and path analysis revealed almost parallel results for interrelationships among various parameters. Correlation and path analysis concluded that FRW, FSW, DSW, RL, SL and R/S ratio could be the reliable and potential selection criteria among the seedling traits while high FLA, LDM, RWC, CMS and lower SFLW, ELWL and RT could be reliable morpho-physiological markers for drought tolerance in case of other flag leaf related parameters at late growth stages. Most of the traits indicated that the genotypes were a significant genetic source for the water stress tolerance.

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