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Genotypic variation for traits associated with dry matter remobilization in grain sorghum (*Sorghum bicolor* L. Moench) genotypes under drought stress conditions

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ABSTRACT

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This study was conducted to evaluate traits that have an effect on yield, and genetic variation for these traits, including dry matter accumulation, remobilization, and traits associated with them, in 10 grain sorghum genotypes obtained from the National Plant Gene Bank of Iran under moisture stress conditions. Field trials were carried out in the 2008 cropping season using split-plot arrangements in a randomized complete block design with three replications at Torogh Agricultural Research Station of the Agricultural and Natural Resource Research Center of Khorasan Razavi Province, Mashhad, Iran. Trials were conducted separately under three water regimes: normal conditions and two water deficit levels at the vegetative and reproductive stages. Genotypes were assigned to main plots and two levels of photosynthetic status, normal and disturbed current photosynthesis, by applying potassium iodide after anthesis, in sub-plots. Results revealed significant genetic variation for traits related to dry matter remobilization (amounts of remobilized dry matter [ARDM], remobilization efficiency [REE] and remobilization percentage [REP]) among sorghum genotypes under moisture stress and well-watered conditions. Cluster analysis using the Ward method grouped sorghum genotypes differently under different irrigation conditions. There were no differences between grouping of genotypes treated with potassium iodide (disturbed current photosynthesis) and grouping under normal current photosynthesis as well as in the drought stress environment at the vegetative stage. Results also showed that genotype 04-12 had the highest REE and REP under the three irrigation regimes. Therefore, these traits could be used to improve grain yield and yield stability in sorghum breeding programs.

Keywords: current photosynthesis, dry matter accumulation, remobilization efficiency, reproductive stage, vegetative stage

INTRODUCTION

Evaluation of genetic variation has a significant impact on the strategies of breeding and genetic resource conservation programs. Indirect estimates of similarity based on morphological information and traits have been widely used in many crops such as sorghum (Ayana and Bekele, 1999). Morphological variation cannot reveal the reliability of genetic variation because of the interactions among genotype and environment and other genetic factors controlling heritability and agronomic traits.

Cluster analysis is one of several mathematically based genotype grouping methods. Characterization and cluster analysis help breeders to avoid duplicating population sampling (Sharma and Hore, 1993). Although heritability of traits such as grain yield is low in moisture stressed environments, identifying physiological traits that have an effect on yield under these conditions and adapting these traits to moisture stress conditions are important in breeding for yield stability (Beheshti, 1997; Ehdaie *et al.*, 2008; Smith and Frederison, 2000).

Optimizing conditions to support grain-filling by stem reserves is an important goal in breeding cereals that are grown in abiotic stress prone environments, especially moisture stress during grain-filling (Blum, 1996; Blum *et al.*, 1983, 1989; Bonnet and Incoll, 1992; Kiniry and Tishler, 1992;). When assimilates are produced, they are translocated through whole parts of the plant and form various compounds. Some of these assimilates form structural compounds such as cellulose and hemicellulose that are non-transmittable and make up the structure of the plant.

At certain stages of plant development, more photosynthates are synthesized than are required for growth and development. These extra synthesized products are converted into stored compounds. In subsequent stages, these stored compounds are remobilized towards active centers such as seed

(Ehdaie *et al.*, 2006; Beheshti and Behboodi Fard, 2010; Blum, 1996). Research results have shown that in cereals such as wheat and barley, 15 to 20 days after flowering, net assimilates are more than the developing seeds and soluble carbohydrates accumulate in stems and leaf sheaths and are estimated to be about 2 tons per hectare in the crops (Ehdaie *et al.*, 2008; Royo and Blanco, 1998).

With aging and increased shadowing in the crop canopy and with decreasing absorption of net assimilation, these stored assimilates are translocated to the developing seed. Accumulation and translocation of stored photosynthates helps to stabilize grain growth rate during most of the grain-filling period and has an effect on stem dry weight variability after flowering, when the stem stops growing (Ehdaie, 2006).

When cereals are affected by severe post-anthesis moisture stress, grain growth depends significantly on reserve growth sources (Royo and Blanco, 1998). Moisture limitation during grain-filling increases the dependence on assimilates stored before anthesis in sorghum and corn (Kiniry and Tishler, 1992). The relationship between drought resistance and remobilization to grain of assimilates stored before anthesis is still unknown. Environmental and genetic factors affect accumulation of stem reserves and their remobilization for grain-filling. This is completely dependent on growth conditions before anthesis. Stem total non-structural carbohydrate (TCN) during anthesis varied between 50-350 g kg^{-1} dry matter in different studies (Blum, 1996).

The rate of carbon fixation depends on water regime and nutrient availability, and some synthesized assimilates are stored under optimal growth conditions. If plants are affected by moisture stress during stem elongation, the carbon fixation rate and the rate of stem storage will decrease. For example, in wheat under drought stress, the rate of water-soluble carbohydrate remobilization to the developing grain was 641 mg kg^{-1} and 1047 mg kg^{-1} under unstressed conditions (Davidson and Chevalier, 1992). This indicated that the remobilization rate of soluble carbohydrates from stem reserves under drought stress was lower than under normal conditions. In addition, compared with irrigated conditions, under non-irrigated conditions only half of stem water-soluble carbohydrates were available for remobilization during grain-filling (Davidson and Chevalier, 1992).

Stem storage potential, as an important source, is determined by stem length and weight density. Stem weight density is calculated from the proportion of stem dry weight to stem length, because storage capacity and its availability for remobilization may vary by plant height (Davidson and Chevalier, 1992). In wheat it has been shown that assimilates are mainly stored in the lower part of the peduncle enclosed by the flag leaf sheath, and in the penultimate internodes (Wardlaw and Willenbrink. 1994). Differences in dry matter storage and remobilization under different experimental conditions were greater in the penultimate internodes than in the lower internodes (Bonnett and Incoll, 1992).

The culm's anatomical aspects for storing assimilates have not been completely identified. Ghodsi 2004 reported that in wheat, in addition to early maturity and high grain number m^{-2}, peduncle length is one of the important traits of drought tolerant genotypes in the temperate areas of Iran. They concluded that due to their higher capacity to store and remobilize assimilates, tolerant wheat genotypes are better adapted to terminal drought conditions.

Dwarfing genes Rht_1 and Rht_2, in wheat have reduced plant height by 21%; hence, the capacity for culm storage also decreased by 35% and 39%, respectively. Although the relative advantages of tall genotypes under favorable agricultural conditions have been reported, the advantage of tall genotypes in reserve storage was not expressed as greater mobilization to the ear (Blum *et al.*, 1989). Under favorable grain-filling conditions, only about 20% of grain yield was contributed by stem reserves (Blum *et al.*, 1997). In barley, it was observed that the rate of stem reserves in seed yield was greater in tall genotypes than in dwarf ones, but the yield was same in both (Daniels and Alcock, 1982; Bonnett and Incoll, 1992).

Evaluation of tall and dwarf isogenic lines showed that under drought stress conditions and using photosynthesis disrupting chemicals (without considering year, treatment and genotypes), plants with higher stem weight lost more stem reserve storage at the onset of grain-filling (Blum *et al.*, 1989). Thus, stem weight reduction as a percentage of grain weight per panicle was greater when stem weight was heavier (Blum *et al.*, 1983). Compared with favorable conditions, the effect of photosynthesis disturbing chemicals on plant height and number of grains per panicle was not significant. Panicle grain weight was decreased by this treatment due to the reduction in grain weight. Panicle grain weight was reduced under drought stress only in dwarf genotypes (Blum *et al.*, 1983).

Variation in stem dry weight clearly reflected the variation in the rate of stem water-soluble carbohydrate (WSC) remobilization. The relative reduction in grain weight in each panicle caused by the chemical treatment was greater in dwarf (51%) than tall genotypes (38%) when compared with favorable conditions (Blum *et al.*, 1983). However, stem weight reduction under stress conditions was higher, however, it could not be entirely accounted for costs of maintenance respiration. Therefore, high stem reserve storage at the beginning of grain-filling was constantly utilized for grain-filling under stress conditions that reduce the photosynthesis source (Blum *et al.*, 1983).

It is concluded that comprehensive studies on grouping sorghum genotypes based on traits associated with dry matter remobilization are not available. This study was carried out to evaluate the genetic variation and relationship between photosynthate assimilation and remobilization in sorghum genotypes to be used in breeding programs targeting moisture stressed environments.

MATERIALS AND METHODS

This study was carried out in three separate field trials that included favorable conditions (without water deficiency) and two stress conditions (moisture stress during the vegetative and reproductive stages) at Torogh Research Station of Mashhad (Agricultural and Natural Resources Research Center of Khorasan Razavi Province) in the 2008 cropping season. Torogh Research Station (36° 13′11″ N, 59° 38′ 19″ E; altitude: 1029 masl; average annual precipitation: 241 mm) is located 5 km south of Mashhad. Average absolute maximum and minimum temperatures are 43.4°C and 27.8°C, respectively. Average temperatures in the warm and cool seasons are 24.5°C and -4 °C, respectively.

Each trial was carried out as a split-plot in a randomized complete block design with three replications. Main plots consisted of 10 sorghum genotypes and two photosynthesis treatments including disturbed (leaves and chlorophyll organs desiccated using potassium iodide) and non-disturbed current photosynthesis were randomly assigned to sub-plots. Disturbed current photosynthesis was simulated following Blum *et al.* (1983). The chemical desiccant (potassium iodide 0.4% WV^{-1}) was sprayed on the canopy (whole plant) 10 days after anthesis to coincide with the end of the lag phase and beginning of linear grain growth (rapid grain-filling). This allowed us to study the role of reserve dry matter remobilization in grain-filling.

Ten selected grain sorghum accessions (designated accession numbers: 04-34, 04-43, 04-101, 04-9, 04-8, 04-4, 04-3,04-2, 04-12, 04-122) were obtained from the National Plant Gene Bank of Iran. The accessions had either dual purpose growth type or grain type, and all of them had a single panicle and no tillers. Moisture stress was applied at two stages: the vegetative stage (from four-leaf to beginning of flowering) and the reproductive stage (from beginning of flowering to hard dough stage). Irrigation was applied during the other growth periods.

The experimental plots were fallow during the previous cropping season. Seedbeds were prepared in April by light plowing followed by disking and leveling. The recommended fertilizer rate was applied prior to sowing based on soil tests. Urea, ammonium phosphate and potassium sulfate were broadcast and incorporated into the soil at rates of 50, 250, and 200 kg ha^{-1}, respectively. Urea fertilizer (50 kg ha^{-1}) was top-dressed at the 6-leaf stage and at panicle initiation beside the crop stands 5 cm below the soil surface.

Sowing was carried out on 28 April and furrow irrigation was applied using hydrofix tubes. Each genotype was sown in four rows, 6 m in length, with 62.5 cm row spacing. Plants were thinned at the 4-leaf stage to a density of 16.5 plants m^{-2}. Plots were hand-weeded throughout the growing season. Irrigation intervals in the non-stressed environment were regular (i.e., 7-9 days during the vegetative stage, 6-7 days during the flowering stage and thereafter, until physiological maturity); irrigation was applied following normal practice.

Morphological and physiological traits were measured and recorded during the growth period on five randomly selected plants tagged from each plot. The above-ground dry matter was determined for plant parts (Beheshti and Behboodi-Fard, 2010). The following equations were used to determine the amount of remobilized dry matter in above-ground plant parts (Papakosta and Gagianas, 1991; Arduini *et al.*, 2006):

$ARDM$ (g $plant^{-1}$) = $DMSHT_{Ant}$ (g $plant^{-1}$) – $DMSHT_{(Mat)}$ (g $plant^{-1}$);

REE (%) = (ARDM (g $plant^{-1}$) / $DMSHT_{Ant}$ (g $plant^{-1}$)) × 100;

REP (%) = (ARDM (g $plant^{-1}$) / GY (g $plant^{-1}$)) × 100,

where ARDM is the amount of remobilized dry matter; $DMSHT_{Ant}$ is above-ground dry matter of plant parts at anthesis; $DMSHT_{Mat}$ is the above-ground dry matter of plant parts at maturity, REE is the remobilization efficiency; REP is the remobilization percentage; and GY is grain yield.

Data were analyzed using SPSS software Version 15.0 (2006), and means were compared using Duncan's multiple-range test. Cluster analysis was used to assess similarity of genotypes and group them based on traits associated with remobilization using the Euclidean distance method. The best genotypes were identified by a mean difference of clusters for each trait from a total mean of those traits in each cluster.

RESULTS AND DISCUSSIONS

The analysis of variance of data from each environment showed that genotypes were significantly (P<0.01) different for all traits (Table 1), which suggests there is variation among genotypes.

The analysis of variance also showed that photosynthetic status had a significant effect on 100-grain weight and remobilization efficiency and percentage in the three environments. Disturbance of photosynthesis after anthesis caused a significant reduction in grain yield and assimilate remobilization to grain as a sink.

Genotype similarity and grouping were assessed by cluster analysis based on data assembled for all traits in a 5-unit distance scale; the results are shown in the dendrograms in Figs. 1-6.

Cluster analysis clustered the test genotypes in three separate groups in the favorable environment (Fig. 1). Cluster analysis of traits related to remobilization under drought stress at the reproductive stage also classified genotypes in three separate groups (Fig. 3). Grouping of genotypes in this environment (drought stress at the reproductive stage) changed slowly with disturbance of current photosynthesis. In this situation, two genotypes (04-9 and 04-34) were assigned to cluster 1 (Fig. 4).

Cluster analysis of traits related to remobilization in the drought stress environments clustered genotypes in two separate groups at the vegetative stage with normal current photosynthesis (Fig. 5). There was no difference between grouping genotypes treated with potassium iodide (disturbed current photosynthesis) and grouping under normal current photosynthesis, and genotypes had a similar grouping in the drought stress environment at the vegetative stage (Fig. 6).

The analysis of variance showed there was significant genetic variation for dry matter accumulation and partitioning among sorghum genotypes under both moisture stressed and well-watered conditions (Table 1). Drought stress in both stress environments (vegetative and reproductive stages) significantly reduced grain yield as compared to normal conditions (Tables 2-6). It has been reported that grain yield decreased in sorghum genotypes that experienced moisture stress at the reproductive stage, as compared to normal conditions, but the rate of dry matter translocation and remobilization efficiency and percentage increased (Blum, 1996; Yang *et al.*, 2007; Beheshti and Behboodi Fard, 2010). When drought occurs during anthesis, it drastically reduces grain yield and its components (Araus *et al.*, 2002; Blum *et al.*, 1983, 1997, 1989; Papakosta and Gagianas, 1991; Seghatoleslami *et al.*, 2008; Yadav and Bhatnagar, 2001; Beheshti and Behboodi Fard, 2010).

Genotypes 04-2, 04-3, 04-4, 04-8, 04-9, 04-122 and 04-101 were grouped in cluster 1 and had a higher mean remobilization percentage (REP) and higher remobilization efficiency (REE) as compared to the grand mean of all genotypes. But for other traits such as grain yield, biological yield, amount of remobilization of dry matter (ARDM), their mean was lower than the grand mean. Despite their low grain and biological yield, these genotypes can be used as parents in sorghum breeding programs for desirable attributes associated with dry matter remobilization (Table 2). Genotypes 04-34 and 04-43 were classified in cluster 2 and had a higher mean for all traits (except remobilization efficiency), than the grand mean; their ARDM was also greater than the grand mean. However, the ARDM was lower than biological yield, indicating that these genotypes allocated more dry matter to the grain (Table 2). Cluster 3 consisted of genotype 04-12, which had a lower mean than the grand mean for remobilization efficiency and 100-grain weight; however, in this genotype, other traits were greater than the grand mean (Table 2). When comparing trait deviation from the grand mean for this genotype, we concluded that its higher grain yield was due to the higher number of grains per plant in comparison to the total grand mean (Table 2).

With the application of potassium iodide and disturbance of current photosynthesis after anthesis, few changes occurred in genotype grouping, and genotypes grouped in two clusters (Fig. 2). Genotypes 04-12 and 04-43 had higher values for all traits than the grand mean, except for REE and stem dry weight at harvest, indicating that these genotypes had higher grain yield when current photosynthesis was disturbed during grain-filling (Table 3).

Three separate clusters were formed under drought stress at the reproductive stage were (Fig. 3). Cluster 1 included genotypes 04-2, 04-3, 04-4, 04-101 and 04-8 and had higher values for remobilization percentage, remobilization efficiency and grain yield than the grand mean, and lower for other traits. These genotypes had similar grain yield potential under favorable conditions (Table 4). Genotypes 04-34, 04-122, 04-43 and 04-9 were classified in cluster 2, which had lower values than the grand mean for remobilization percentage and

Table 1. Analysis of variance of plant characteristics of grain sorghum genotypes under normal conditions and under drought stress a

MS (under normal conditions)

S.O.V.	df	Leaf dry weight at maturity	Panicle weight at maturity	Grain yield	ARDM	REE
Replication	2	14.417^{ns}	17.801^{ns}	1.582^{ns}	8.135^{ns}	1.747^{ns}
Genotype (G)	9	857.182**	6364.224**	3749.755**	159.947**	44.118**
Error a	18	8.117	52.893	17.103	13.640	2.152
Photosynthesis status (PS)	1	56.629**	6796.833**	6796.833**	705.551**	301.863**
G× PS	9	0.767^{ns}	638.243**	638.243**	14.492**	12.931**
Error b	20	1.052	10.170	10.170	1.935	1.043

MS (drought stress at the vegetative stage)

S.O.V.	df	Leaf dry weight at maturity	Panicle weight at maturity	Grain yield	ARDM	REE
Replication	2	5.592^{ns}	119.807^{ns}	3.766^{ns}	17.055^{ns}	3.670^{ns}
Genotype (G)	9	688.384**	4346.125**	2072.781**	151.850**	59.580**
Error a	18	4.746	44.018	19.618	11.812	5.873
Photosynthesis status (PS)	1	36.255**	4196.553**	4196.554**	591.702**	269.240**
G× PS	9	1.452**	237.781**	237.781**	18.143*	6.066^{ns}
Error b	20	0.353	8.574	8.574	6.522	7.777

MS (drought stress at the reproductive stage)

S.O.V.	df	Leaf dry weight at maturity	Panicle weight at maturity	Grain yield	ARDM	REE
Replication	2	15.967^{ns}	5.774^{ns}	0.214^{ns}	2.362^{ns}	1.851^{ns}
Genotype (G)	9	560.567**	1939.897**	1229.718**	236.421**	232.809**
Error a	18	17.904	34.767	6.132	3.031	4.838
Photosynthesis status (PS)	1	42.825**	1337.082**	1337.082**	331.115**	351.626**
G× PS	9	2.633**	31585.000**	31.585**	21.799**	5.926**
Error b	20	0.522	1.892	1.892	0.882	1.875

Table 2. Mean and deviation (%) from the grand mean for different traits of sorghum genotypes based on clus

Cluster	Genotype	Stem dry weight at maturity(g)	Leaf dry weight at maturity(g)	Panicle weight (g)	Grain yield (g plant^{-1})	ARDM (g)	REE%	REP %	100-grain weight (g)	No. seed plant^{-1}
1	04-101,04-8,04-4,04-3,04-9,04-122	68.59	21.06	81.29	57.89	6.12	5.58	11.22	2.94	1341.00
		-0.49	-0.22	-0.18	-0.22	-0.23	0.11	-0.02	-0.01	-0.58
2	04-43, 04-34	198.68	35.83	144.92	117.59	12.89	4.50	12.21	3.12	5610.00
		0.49	0.33	0.45	0.59	0.61	-0.10	0.07	0.05	0.75
3	04-12	457.30	50.55	137.34	98.92	11.36	2.04	11.57	2.83	11431.00
		2.43	0.87	0.38	0.34	0.42	-0.59	0.01	-0.04	2.57
		133.48	26.96	99.62	73.93	8	5.01	11.45	2.97	3204

Table 3. Mean and deviation (%) from the grand mean for different traits of sorghum genotypes based on clus

Cluster	Genotype	Stem dry weight at maturity(g)	Leaf dry weight at maturity(g)	Panicle weight (g)	Grain yield (g plant^{-1})	ARDM (g)	REE%	REP %	100-grain weight (g)	No. seed plant^{-1}
1	04-122,04-9,04-34,04-101,04-8,04-4,04-3									
		74.20	21.62	68.24	43.97	12.50	10.22	29.47	2.52	1294.0
		-0.42	-0.13	-0.12	-0.16	-0.18	0.07	-0.003	-0.10	-0.55
		46.01	38.60	118.70	87.33	26.07	6.57	29.96	2.65	9494.0
	04-12, 04-43	1.69	0.54	0.51	0.65	0.75	0.30	0.01	0.04	2.23
2										
		128.56	25.02	87.34	52.65	14.86	9.5	29.57	2.55	2934

Table 4. Mean and deviation (%) from the grand mean for different traits of sorghum genotypes based on clus

Cluster	Genotype	Stem dry weight at maturity(g)	Leaf dry weight at maturity(g)	Panicle weight (g)	Grain yield (g plant^{-1})	ARDM (g)	REE%	REP %	100-grain weight (g)	No. seed plant^{-1}	
1	04-101, 04-8, 04-4, 04-3	52.87	15.26	51.63	32.88	6.90	7.71	20.90	2.82	741.20	Mo
		-0.56	-0.30	-0.33	-0.38	-0.27	0.13	0.11	0.03	-0.49	De
2	04-122, 04-43, 04-34, 04-9	123.57	23.97	103.02	75.08	11.51	6.82	15.64	2.70	1816.00	Mo
		0.03	0.10	0.34	0.42	0.22	0.00	-0.17	-0.01	0.26	De
3	04-12	441.25	45.54	100.46	63.44	14.00	2.62	22.10	2.40	3488.00	Mo
		2.68	1.09	0.30	0.20	0.48	-0.62	0.17	-0.12	1.41	De
		119.99	21.77	77.08	52.82	9.46	6.85	18.92	2.73	1445.91	Gr

Table 5. Mean and deviation (%) from the grand mean for different traits of sorghum genotypes based on cluster gr

Cluster	Genotype	Stem dry weight at maturity(g)	Leaf dry weight at maturity(g)	Panicle weight (g)	Grain yield (g plant^{-1})	ARDM (g)	REE%	REP %	100-grain weight (g)	
1	04-9,04-34,04-101,04-8,04-4,04-3,04-2	59.24	17.23	48.02	28.50	13.02	12.71	46.89	2.39	7
		-0.48	-0.14	-0.20	-0.20	-0.18	0.11	0.02	0.02	
2	04-122, 04-43	150.81	19.86	88.14	53.68	21.77	10.20	40.68	2.35	1
		0.31	-0.01	0.46	0.49	0.36	-0.11	-0.11	0.00	
3	04-12	434.25	41.81	88.78	51.76	24.74	4.61	47.71	2.00	3
		2.77	1.06	0.47	0.44	0.55	-0.59	0.04	-0.14	
		115.06	20.22	60.13	35.86	15.95	11.37	45.74	2.34	1

Table 6. Mean and deviation (%) from the grand mean for different traits of sorghum genotypes based on cluster gr

Cluster	Genotype	Stem dry weight at maturity(g)	Leaf dry weight at maturity(g)	Panicle weight (g)	Grain yield (g plant^{-1})	ARDM (g)	REE%	REP %	100-grain weight (g)	No. seed plant^{-1}
1	04-34,04-43,04-101,04-9,04-8,04-4,04-3,04-2	48.33	14.74	35.25	23.95	4.98	8.03	21.81	2.53	622.
		-0.28	-0.17	-0.18	-0.21	-0.28	-0.06	-0.03	0.00	-0.
2	04-12, 04-122	141.55	29.47	73.63	56.40	14.75	10.52	22.99	2.46	2461.
		1.11	0.67	0.72	0.85	1.13	0.23	0.11	-0.02	1.
		66.97	17.69	42.93	30.44	6.94	8.53	22.4	2.51	989.

grain yield, and higher for other traits (Table 4). Genotype 04-12 was alone in cluster 3 and had higher values than the grand mean for all traits, except REE and 100-grain weight, indicating that in this genotype the proportion of ARDM to shoot weight at anthesis was lower than the rate of ARDM remobilization to the grains as sinks (Table 4).

Grouping of genotypes in disturbed current photosynthesis and drought stress at the reproductive stage changed slightly. Under these conditions, two genotypes (04-9 and 04-34) were grouped together in cluster 1 (Fig. 4). Under drought stress at the reproductive stage and disturbed current photosynthesis conditions, genotype 04-12 had the best REP and ARDM (Table 5).

Genotypes were clustered in two separate groups under drought stress at the vegetative stage and normal current photosynthesis (Fig. 5). Cluster 1 included genotypes 04-2, 04-4, 04-8, 04-9, 04-101, 04-43, 04-34. Their 100-grain weight was similar to the grand mean, but other traits were lower. Cluster 2 included genotypes 04-122 and 04-12, which had higher values than the grand mean for all traits, except 100-grain weight. The highest grain yield in these genotypes may be associated with their higher REP and higher number of grains per plant under drought stress at the vegetative stage. These genotypes also had higher biological yield and REE than the other genotypes (Table 6). There were no differences between the grouping of genotypes under disturbed current photosynthesis and normal current photosynthesis conditions (Fig. 6).

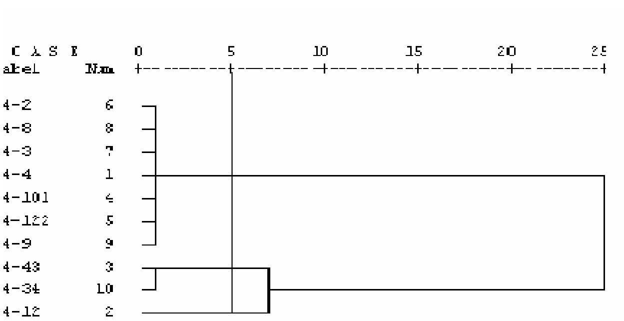

Fig. 1. Dendrogram for traits associated with assimilate remobilization in 10 grain sorghum genotypes under normal conditions.

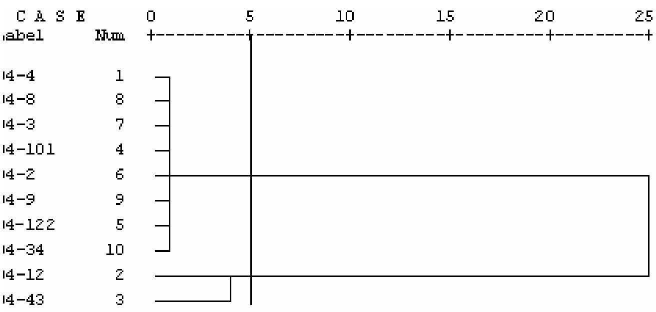

Fig. 2. Dendrogram for traits associated with assimilate remobilization in 10 grain sorghum genotypes under normal conditions and disturbed current photosynthesis.

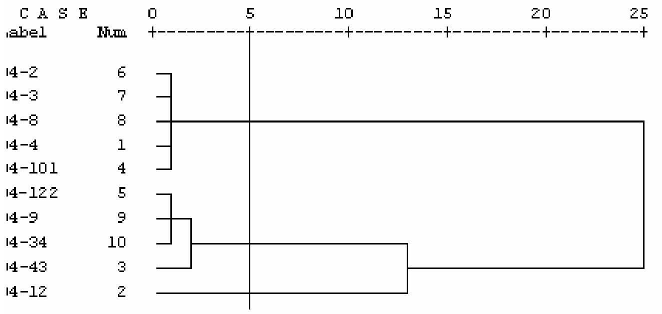

Fig. 3. Dendrogram for traits associated with assimilate remobilization in 10 grain sorghum genotypes under drought stress at the reproductive growth stage.

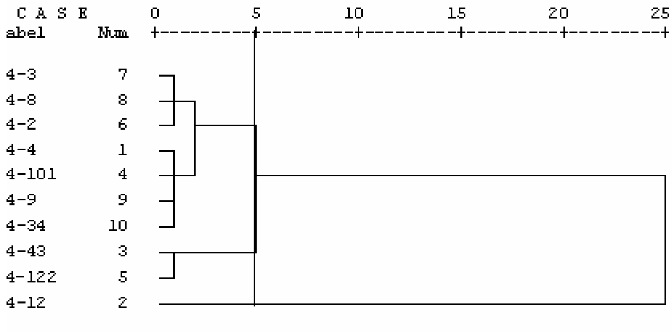

Fig. 4. Denderogram for traits associated with assimilate remobilization in 10 grain sorghum genotypes under drought stress at the reproductive growth stage and disturbed current photosynthesis.

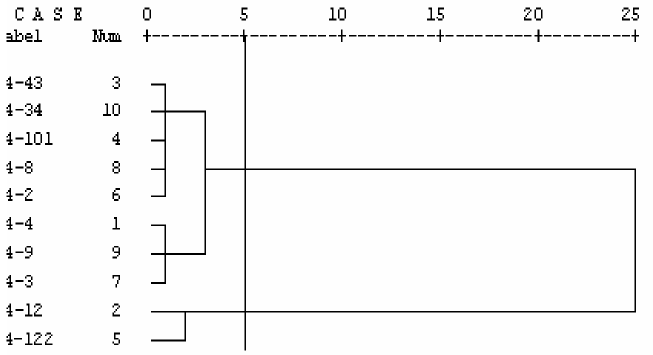

Fig. 5. Dendrogram for traits associated with assimilate remobilization in 10 grain sorghum genotypes under drought stress at the vegetative growth stage.

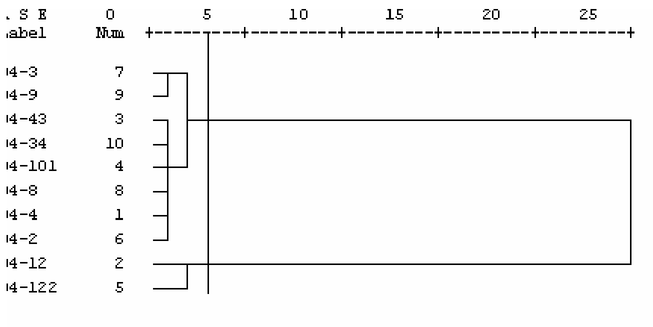

Fig. 6. Dendrogram for traits associated with assimilate remobilization in 10 grain sorghum genotypes under drought stress at the vegetative growth stage and disturbed current photosynthesis.

CONCLUSION

Results of this study show there is significant genetic variation for dry matter accumulation and partitioning among sorghum genotypes under both moisture stress and well-watered conditions. Cluster analysis of each of the three environments indicated that genotype 04-12 had higher grain yield under both normal and drought stress conditions and two photosynthesis conditions, as well as higher ARDM, REE and REP. Sorghum breeding programs could therefore use this genotype to incorporate desirable traits for improving grain yield and stability, particularly for environments prone to drought stress.

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