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Phenotyping sorghum [*Sorghum bicolor* (L.) Moench] for drought tolerance with special emphasis to root angle

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The study was conducted to characterize early maturing sorghum genotypes under moisture stress and non-stress environments based on root angle. Phenotyping of 23 early maturing sorghum genotypes was carried out under post-flowering moisture stress and non-stressed environment using randomized complete block design (RCBD) in two replications at Werer Agricultural Research Center in 2018 off season. The genotypes were selected based on root angle data that varied from 13.0 to 26.75°. The analysis of variance revealed significant variation among genotypes for most of the traits. Post-flowering drought reduced grain yield by 21% and all the traits showed a reduction in value except flag leaf area. Grain yield showed positive correlations with seedling vigor, grain filling rate, thousand grain weight and panicle weight while negative correlations with number of fertile tiller and panicle exertion for both environments. Root angle revealed positive correlation with grain yield, grain filling rate and thousand grain weight while there was negative phenotypic correlation with panicle exertion in the stressed environment. Therefore, selection for high correlated traits could aid breeding program to develop genotypes with superior yield under both environments flag leaf area, chlorophyll content, harvest index and root angle traits could be used as morphological marker for drought tolerance screening in sorghum since there was positive correlation with yield observed for stressed environment only. The result revealed the importance of intermediate to slightly wider root angle for drought tolerance of early maturing sorghum genotypes by enhancing lateral water absorption of the roots under silty clay soil.

Key words: Correlation, early maturing sorghum, morphological marker, post-flowering drought, root architecture, root traits.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereal crops in the world as well in

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Ethiopia. In Ethiopia sorghum is major staple food and the second preferred grain for making flat bread (Enjera) which is the most common traditional food in the country. East Africa is considered to be the center of origin and diversity for sorghum and Ethiopia is the third largest producer from Africa next to Nigeriya and Sudan (Rakshit et al., 2014; FAOSTAT, 2017). Cultivation of sorghum takes the third larger area under wide agro-ecology of Ethiopia and highly preferred in dry lowlands where drought predominates (Demeke and Marcantonio, 2013; FAOSTAT, 2017). Even if sorghum has the ability to cope with many stresses including heat and moisture, its production highly affected by drought occurred during reproductive stage in arid and semi-arid regions of the world (Ejeta and Knoll, 2007).

Terminal drought is a common phenomenon in Ethiopia especially in southern, southeastern, eastern and northeastern part of the country where sorghum is dominant and the main livelihood of the population (Geremew et al., 2004; Brhane et al., 2006). A severe drought during post anthesis leads to loss of chlorophyll and grain pre-maturation which bring about 55% or more yield loss in sorghum (Assefa et al., 2010).

Drought resistance and drought escape is the two main drought survival strategies (Ludlow and Muchow, 1990). Drought resistance is a complex trait that shows high level of interaction with environment (Cooper et al., 2006). Stay green phenotype is the most common selection criteria for post-flowering drought in plants. However, identification and analysis of a new set of plant traits with sound and positive correlation with yield and drought tolerance is compulsory to feed the ever increasing human population in a Blue revolution (Borrell et al., 2000; Rauf and Sadaqat, 2008; Pennisi, 2008).

Under water limited condition researchers identified root traits that increase the extraction of resources from the soil. Researchers have been working to identify specific root traits targeted for plant improvement under drought and nutrient limitation conditions (Comas et al., 2013; Lynch et al., 2014). Thus, recently much more focus was given to root system architecture and root angle is one of the important root traits in drought tolerance breeding (Mace et al., 2012; Rostamza et al., 2013; Ali et al., 2015).

Mace et al. (2012) indicated an association between the Quantitative Trait Loci (QTL) identified for nodal root angle at the leaf six stage and both yield and the stay green drought response in sorghum. Also, nodal root angle in the seedling stage is associated with subsequent root system architecture and can potentially affect water extraction patterns of mature plants suggesting the trait importance to improve drought tolerance in sorghum. Moreover, root biomass and distribution of matured plant could be predicted through analyzing root angle growth at early stage (Kato et al., 2006; Sanguineti et al., 2007; Manschadi et al., 2008). Incorporation of nodal root angle in a breeding program requires at least a moderately high-throughput platform. However, where there is unavailability of this platform above ground phenotyping and indicating possible association of root angle traits with morphological markers could be an indicator as a screening technique for sorghum improvement in moisture stress area. Since there is no single plant character to identify plants with improved performance under moisture stress condition, phenotyping to rank the contribution of trait towards the desirable plant response in a given environment is crucial. Moreover, earliness and drought tolerance are farmers' preferred trait and a key factor to enhance adoption of improved sorghum varieties in Eastern lowlands of Ethiopia (Mekbib, 2008).

In order to exploit the most from root angle trait in maximizing water uptake under drought condition, it is imperative to be complemented with appropriate shoot characteristics associated with high yield. Ethiopian early maturing sorghum genotypes have never been studied for their response to drought adaptation in relation to root angle and possible association with shoot phenotype. Hence the objectives of this research are to characterize early maturing sorghum genotypes under moisture stress and non-stress environments and to evaluate the effect of root angle for drought tolerance.

MATERIALS AND METHODS

Experimental location

Two experiments (stressed and non-stressed) were conducted at the field of Werer Agricultural Research center in the 2018 off season. The center is located in Eastern Ethiopia Afar region (9°16'8" N, 40° 9'41"E and with altitude of 750 m.a.s.l).

Experimental materials

The experiment was conducted using 23 early maturing sorghum genotypes (Table 1). The genotypes were selected based on their root angle data generated at Jimma University College of Agriculture and Veterinary Medicine greenhouse (Menamo et al., 2017).

Experimental design and management

The experiment was carried out using randomaized complete block design under two moisture regimes (non-stress and stress conditions) and each of individual experiment was replicated twice. Irrigation was applied every eleven days according to the area recommended for sorghum crop; thus the two moisture regimes were achieved by ceasing irrigation at early booting stage before flowering for stressed block to induce post-flowering drought; while non-stressed block received sufficient irrigation until maturity. Fertilizer application and all other agronomic practices were done following the recommendation for the area.

Data collection

Data collected on plot basis

Days to 50% flowering (DF), Days to 75% physiological maturity

Table 1. Early maturing sorghum genotypes with root angle.

Genotype	Root angle (°)	Maintainer	Genotype	Root angle (°)	Maintainer
76T1#23	22.61	M.ARC/EIAR	Emahoye	25.17	P.ARC/EIAR
Birhan	21.66	S.ARC/ARARI	Misikir	15.91	S.ARC/ARARI
B-35	15.81	M.ARC/EIAR	Meko-I	15.56	M.ARC/EIAR
ETSL100674	13.75	M.ARC/EIAR	SC103-14E	16.53	M.ARC/EIAR
Macia	16.24	M.ARC/EIAR	Teshale	13.03	M.ARC/EIAR
A2267-2	17.88	M.ARC/EIAR	Abshir	26	M.ARC/EIAR
Dekeba	26.75	M.ARC/EIAR	ICSV 93046	18.28	M.ARC/EIAR
E36-1	19.04	M.ARC/EIAR	ICSV745	18.22	M.ARC/EIAR
ESH-1	20.09	M.ARC/EIAR	Melkam	17.96	M.ARC/EIAR
ESH-3	17.34	M.ARC/EIAR	Khwangphang	15	M.ARC/EIAR
Girana-1	22.08	S.ARC/ARARI	ICSV700	22.5	M.ARC/EIAR
ICSR14	20.75	M.ARC/EIAR			

M: Melkasa, S: Sirinka, P: Pawe, ARC: Agricultural Research Center, EIAR: Ethiopian Institute of Agricultural Research, ARARI: Amhara Agricultural Research Institute.

(DM), Seedling vigor (SVG), Stay-green (SG), Over all plant aspect (PAS), Drought Score (DRS): under stressed environment, Leaf senescence (LSC), Disease Score (Dis), Grain filling period (GFP), Grain filling rate (GFR): kg ha^{-1} day^{-1}, above ground biomass (AGBM): kg ha^{-1}, Harvest index (HI) in percentage, Thousand grain weight (TGW): in grams at moisture content were adjusted to 12% and Grain yield (YLD) kg ha^{-1}.

Data collected on plant basis

Five randomly selected plants were pre-tagged to collect all the plant basics data in the plot: plant height (PH) in cm, Panicle length (PL) in cm, Panicle weight (PW) in g, Panicle exertion (PEX) in cm, Flag leaf area (FLA) (Stickler et al., 1961), chlorophyll content (SPAD reading) using Chlorophyll Meter SPAD-502 and number of tillers (NT).

Root structures image was taken on both sides of each chamber using Tablet (T-113) by connecting with two digital cameras (CANON SX610 HS) through Wi-Fi. The tablet and camera were connected by camera connect android app. This app helps to take image using Table from camera and controlled the imaging set up and synchronized the imaging of both sides of each root chamber. The images were used to determine the root angle (RA), relative to the vertical plane (Figure 1). RA was taken from the first flush of nodal roots at a distance of 2 cm from the base of the plant (Singh et al., 2011) using *Opengelphoto* software which was designed by the University of Queensland. The observed root angle for each plant was the mean of four observations (left and right of each plant for both sides of the chamber). All the data were collected based on sorghum descriptors (IBPGR/ICRISAT, 1993) and the method adopted by National Sorghum Improvement Program of Ethiopia by using ‘Fieldscorer 4 Android’ software.

Soil samples like soil texture, soil pH, organic carbon, bulk density, water retention at field capacity (FC) and permanent wilting point (PWP) were taken. Moreover soil moisture contents were taken three times at booting stage, grain filling stage and at maturity stage. Six soil samples diagonally from 30 cm depths were collected from each replication to estimate soil moisture content by using gravimetric method as described by Klute (1986). Meteorological data such as minimum and maximum temperature, rainfall, sunshine hours and relative humidity were recorded. Data analysis were carried out using SAS statistical version 9.2 (SAS, 2009) and Minitab version 17.1.0.0 (2013) packages.

RESULTS AND DISCUSSION

Analysis of variance and mean performance of genotypes

Phenological and growth traits

Significant variation among genotypes was observed for flowering and maturity date under both moisture environments (Table 2). Days to flowering ranged from 58 to 68 and 59 to 66 days after emergence (DAE) in non-stressed and stressed environments, respectively with mean value of 62 days for each (data not shown). Days to physiological maturity ranged from 96 to105 DAE in non-stressed and from 95 to 101 DAE in a stress environment. Maturity date was earlier for stressed environment as a result of interaction effect which upshot early maturing genotypes to escape the moisture stress by utilizing the maximum stored water under post-flowering drought (Kadam et al., 2002). Similar findings were reported by El Naim et al. (2012) and Yaqoob et al. (2015) in sorghum.

Growth traits viz seedling vigor, plant height, panicle exertion, plant agronomic aspect, flag leaf area, number of productive tiller and disease reaction revealed highly significant variation among genotypes under both environments (Table 2).

The mean values for plant height were 188.2 cm for non-stressed and 175.5 cm for stressed environments. Therefore, here an average of 7% reduction (%R) was observed due to post-flowering drought (Table 3). Similar observation was made by Khaton et al. (2016) and Menezes et al. (2014) on sorghum. According to Ali et al. (1999) decrease in plant height might be due to the

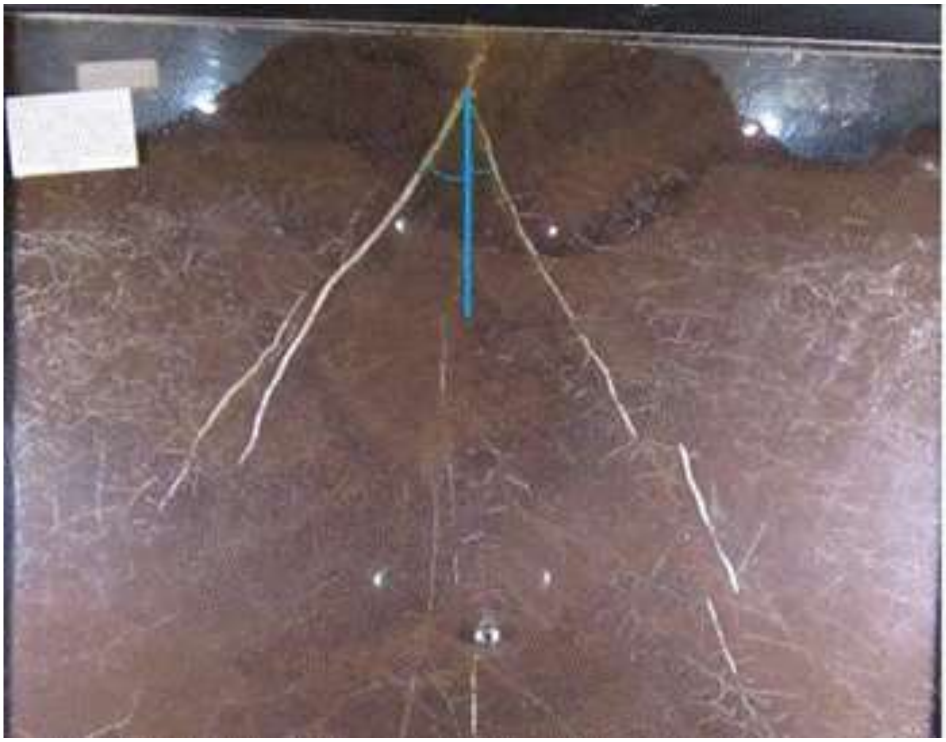

Figure 1. Root angle measuring methods at 5th leaf stage relative to the vertical line.
Source: Menamo et al. 2017.

Table 2. ANOVA and mean squares of traits for sorghum genotypes under non-stressed and stressed environments.

Traits	Mean square					
	Non-stressed			Stressed		
	Geno	Error	CV (%)	Geno	Error	CV (%)
Days to flowering	23.15**	0.81	1.45	9.51**	1.83	2.18
Days to maturity	15.01**	2.23	1.51	7.35**	1.72	1.34
Grain filling period	2.80	1.88	3.73	2.47	2.11	4.07
Seedling vigor	0.44*	0.22	22.59	0.52**	0.11	15.51
Plant height	7199.79**	100.81	5.34	6417.49**	74.47	4.92
Plant aspect	0.74**	0.20	15.27	0.70**	0.18	13.10
Flag leaf area	11021.6**	3727.84	27.42	13686.4**	2315.19	19.14
Panicle exertion	113.77**	1.34	16.56	74.09**	0.81	19.45
Number of tillers	0.52**	0.01	29.54	0.29**	5.93	2.34
Disease	0.06	0.06	11.13	0.54*	0.26	19.61
Grain yield	3234791.84**	298384.07	11.09	2315971.5**	222288.5	12.12
Grain filling rate	2485.69**	307.75	13.06	1841.3**	192.84	12.71
Tausand grain weight	57.82**	2.63	4.43	74.56**	9.81	10.01
Above ground biomass	136216211**	11476375	17.72	72877882**	6213106	15.98
Harvest index	144.70**	28.33	18.48	150.62**	15.74	14.39
Panicle length	36.79**	1.76	4.79	37.37**	3.15	6.69
Panicle weight	1626.34**	257.90	13.94	1282.8**	420.35	19.96
Stay green	0.86*	0.33	21.79	0.87**	0.20	14.62
Lefe scenecence	1.35**	0.46	21.47	2.68**	0.85	21.18
chlorophyll content	33.94	25.41	8.59	43.65*	19.27	9.00
Drought score	-	-	-	0.76*	0.29	17.34
Root angle	29.4**	0.1	1.67	-	-	-

Table 3. Means of yield and other important agronomic traits of sorghum genotypes under non-stressed (NS) and stressed (DS) environments.

Genotype	RA	GYLD		PW		TGW		SG		SPAD		PH	
	-	NS	DS	NS	DS	NS	DS	NS	DS	NS	DS	NS	DS
76T1#23	22.61^{d}	5432.1^{b-g}	4409.8^{b-e}	112.31^{c-g}	96.82^{b-e}	37.58^{ef}	34.00^{a-g}	3.0^{a-c}	2.5^{c-e}	59.36^{ab}	52.83^{b-d}	153.5^{hg}	144.0^{e-g}
Birhan	21.66^{e}	4507.2^{f-h}	4021.8^{b-g}	103.73^{d-g}	98.29^{b-e}	40.35^{a-e}	36.61^{a-d}	2.0^{dc}	3.0^{b-d}	62.38^{ab}	51.08^{b-d}	126.5^{ij}	112.0^{hi}
B-35	15.81^{l}	3602.1^{hi}	3192.4^{f-j}	75.39^{hg}	74.00^{d-f}	34.07^{fg}	35.95^{a-e}	1.3^{d}	1.5^{e}	66.20^{a}	65.23^{a}	108.5^{jk}	97.5^{ij}
ETSL100674	13.75^{n}	3159.2^{i}	2689.0^{h-j}	124.87^{a-f}	114.15^{a-e}	23.39^{h}	15.83^{i}	2.0^{dc}	2.0^{ed}	59.89^{ab}	45.17^{cd}	280.0^{a}	255.0^{a}
Macia	16.24^{kl}	4705.8^{e-h}	3743.6^{c-h}	95.16^{e-g}	95.55^{b-e}	31.15^{g}	30.06^{c-h}	2.5^{b-d}	3.0^{b-d}	58.30^{ab}	51.82^{b-d}	130.0^{ij}	120.5^{h}
A2267-2	17.88^{ji}	5325.2^{b-g}	2613.9^{ij}	120.47^{b-f}	114.44^{a-e}	40.98^{a-e}	29.67^{d-h}	4.0^{a}	4.3^{a}	54.06^{ab}	50.40^{b-d}	270.5^{a}	249.0^{a}
Dekeba	26.75^{a}	5903.1^{a-e}	4833.9^{a-c}	143.11^{a-c}	111.07^{a-e}	33.20^{g}	28.41^{e-h}	2.5^{b-d}	2.5^{c-e}	55.82^{ab}	50.38^{b-d}	134.0^{hi}	129.0^{f-h}
E36-1	19.04^{h}	4449.4^{gh}	3626.8^{d-i}	86.78^{fg}	82.90^{c-f}	31.32^{g}	26.03^{h}	1.5^{a-c}	2.5^{c-e}	61.52^{ab}	58.41^{ab}	135.0^{hi}	125.0^{gh}
ESH-1	20.09^{g}	5809.2^{a-f}	4803.1^{a-c}	121.30^{b-f}	94.42^{b-e}	38.30^{ed}	31.81^{a-h}	2.5^{b-d}	3.0^{b-d}	59.03^{ab}	52.84^{b-d}	177.0^{ef}	169.0^{d}
ESH-3	17.34^{j}	4550.0^{f-h}	3471.5^{e-i}	86.47^{fg}	65.31^{ef}	34.58^{fg}	27.50^{f-h}	2.3^{b-d}	3.0^{b-d}	61.65^{ab}	47.89^{b-d}	167.5^{e-g}	155.0^{de}
Girana-1	22.08^{ed}	6070.8^{a-d}	4730.8^{a-d}	146.20^{a-c}	113.70^{a-e}	42.49^{ab}	38.32^{ab}	3.5^{ab}	3.8^{ab}	55.11^{ab}	42.94^{cd}	234.0^{dc}	227.5^{b}
ICSR14	20.75^{f}	4805.5^{d-h}	4041.6^{b-g}	110.69^{c-g}	100.82^{a-e}	41.87^{a-d}	32.84^{a-h}	3.5^{ab}	4.0^{ab}	55.68^{ab}	50.79^{b-d}	138.5^{hi}	131.5^{f-h}
Emahoye	25.17^{c}	4983.0^{c-g}	4248.5^{b-f}	109.52^{c-g}	101.51^{a-e}	42.23^{a-c}	39.06^{a}	2.5^{b-d}	3.0^{b-d}	51.85^{b}	49.63^{b-d}	237.0^{dc}	208.5^{c}
Misikir	15.91^{kl}	5578.0^{b-g}	4392.7^{b-e}	129.90^{a-e}	127.29^{a-c}	38.50^{c-e}	33.28^{a-h}	3.0^{a-c}	3.5^{a-c}	55.87^{ab}	53.61^{bc}	224.5^{d}	208.5^{c}
Meko-I	15.56^{lm}	6415.2^{ab}	4494.9^{b-e}	121.84^{c-f}	117.78^{a-d}	43.94^{a}	37.60^{a-c}	2.5^{b-d}	3.3^{a-c}	62.93^{ab}	49.31^{b-d}	184.5^{e}	174.0^{d}
SC103-14E	16.53^{k}	2728.4^{i}	2240.8^{j}	75.31^{gh}	66.72^{ef}	31.17^{g}	28.70^{e-h}	2.5^{b-d}	3.0^{b-d}	60.74^{ab}	45.26^{cd}	100.5^{k}	90.0^{j}
Teshale	13.03^{o}	6355.2^{ab}	4690.0^{a-d}	140.73^{a-d}	109.60^{a-e}	37.35^{ef}	31.14^{b-h}	3.0^{ab}	3.8^{ab}	59.11^{ab}	48.80^{b-d}	247.5^{bc}	236.5^{ab}
Abshir	26.00^{b}	4878.4^{c-h}	4514.3^{b-e}	128.54^{a-e}	127.14^{a-c}	39.68^{b-e}	36.92^{a-d}	3.0^{a-c}	3.5^{a-c}	65.11^{a}	52.70^{b-d}	136.5^{hi}	124.5^{gh}
ICSV 93046	18.28^{i}	4486.9^{f-h}	3004.6^{g-j}	121.56^{b-f}	99.64^{a-e}	37.82^{ef}	26.44^{hg}	3.0^{ab}	4.0^{ab}	54.65^{ab}	42.75^{d}	282.5^{a}	253.5^{a}
ICSV745	18.22^{i}	6981.7^{a}	5136.7^{ab}	163.03^{a}	140.63^{ab}	40.14^{a-e}	36.80^{a-d}	3.0^{ab}	3.0^{b-d}	62.52^{ab}	58.07^{ab}	181.0^{e}	171.5^{d}
Melkam	17.96^{ij}	6164.3^{a-c}	5677.3^{a}	137.43^{a-d}	123.13^{a-d}	41.15^{a-e}	34.77^{a-f}	2.0^{dc}	2.5^{c-e}	61.65^{ab}	57.95^{ab}	155.5^{f-h}	146.5^{ef}
Khwangphang	15.00^{m}	1585.8^{j}	911.0^{k}	44.05^{h}	38.82^{f}	25.96^{h}	16.85^{i}	3.0^{ab}	3.0^{b-d}	50.62^{b}	42.31^{d}	260.0^{ab}	253.5^{a}
ICSV700	22.50^{d}	4822.0^{d-h}	3971.9^{c-g}	155.89^{ab}	148.97^{a}	34.20^{fg}	31.09^{b-h}	2.5^{a-c}	3.5^{a-c}	55.58^{ab}	48.28^{b-d}	263.0^{ab}	253.5^{a}
Mean	**19.05**	**4926.02**	**3889.60**	**115.40**	**102.73**	**36.58**	**31.29**	**2.6**	**3.1**	**58.68**	**50.80**	**192.4**	**175.5**
%R	**-**	**18.96**		**10.8**		**14.47**		**17.36**		**13.42**		**6.75**	

Where %R=relative percentage reduction and trait abbreviation as described in materials and methods.

reduction in cell division, cell elongation and cell enlargement caused by the stress factor. Mean minimum value for panicle exertion was 0 for both environments and mean maximum was 37.5 and 27.0 cm for non-stressed and stressed environments, respectively. Mean panicle exertion was 7.0 and 4.62 cm for non-stressed and stressed environments implying 34%R due to post flowering drought (data not shown). The result concurs with the finding of Malala (2010), Sakhi et al. (2014) and Abraha et al. (2015).

The highest mean flag leaf area was observed from genotypes ICSR14 (351.57 cm^2) and Misikir (390.80 cm^2) while genotype Kwangphang was found to be the least (70.14 and 90.30 cm^2) under non-stressed and stressed environments, respectively. The mean value for flag leaf area showed 14% increase under stressed environment in comparison with non-stressed environment. Most of the genotypes showed significant increase in flag leaf area along the stress induction except ETSL100674, A2267-2 and SC103-14E which exhibited susceptible phenotype and poor yield performance under stress. In contrast, the highest increase was observed for the genotype Melkam which is relatively high yielder in both environments. Therefore, higher value for flag leaf area is associated with higher yield under moisture stress and could serve as an indicator for drought tolerance (Ali et al., 2009; Ali et al., 2010). Comparatively, Surwenshi et al. (2007) indicated that tolerant sorghum genotypes had greater leaf area and longer active leaf area duration under post-flowering drought.

Of the twenty-three genotypes tested, half of them exhibited tillering capacity under non-stressed condition whereas under stressed condition, only three genotypes Kwangphang, SC103-14E and A2267-2 tillered and performed poor as well. Tillering was reduced by average of 72% due to the stress and thus low tillering ability could serve as drought adaptive mechanism (Richards et al., 2002; Abraha et al., 2015).

Yield and yield components

The variation for grain yield and yield components were highly significant among twenty three sorghum genotypes on both moisture environments (Table 2). The highest grain yield was recorded for genotypes ICSV745 (6981.7 kg/ha), Meko-1 (6415.2 kg/ha) and Teshale (6355.2 kg/ha) with the mean value of 4926.0 kg/ha for non-stressed environment. Mean yield under stressed environment was 3889.6 kg/ha and genotypes Melkam, ICSV745 and Dekeba revealed 5677.3, 5136.7 and 4833.9 kg/ha, respectively to be good yielder and drought tolerant. The least yield performance under both environments was observed for genotypes Kwaangphang and SC103-14E. The mean grain yield of genotypes was reduced by 21% as stress induced and it is regarded as stress intensity of 0.21. High yield reduction or drought susceptibility was observed for genotypes A2267-2, Kwangphang and ICSV93046. On the other hand, genotypes Abshir, Melkam, Birhan and B-35 which is tolerant showed low yield reduction and less affected by drought. Post-flowering drought highly affected the yield of sorghum and similar findings were reported by Menezes et al. (2014), Khaton et al. (2016), Hamza et al. (2016) and Sory et al. (2017). Yield loss under drought condition could be driven by stomatal conductance and concomitant lowering of photosynthesis rate, smaller active leaf area and higher rates of leaf senescence coupled with altered assimilate partitioning between plant parts and reduction in both grain numbers per panicle and thousand seed weight (DaMatta et al., 2003; Naserian et al., 2007; Prasad et al., 2008).

The mean value was 28.2 and 26.5 cm for panicle length and 115.4 and 102.7 cm for panicle weight under non-stressed and stressed environments, respectively.

The stress induced resulted in an average reduction of 4.6 and 10.8% panicle length and panicle weight, respectively. This result coincided with the findings of Sakhi et al. (2014), Sara, (2015), Khaton et al. (2016) and Hamza et al. (2016) on sorghum moisture stress experiments. Thousand seed weight ranged from 23.4 to 43.9 g with mean value of 36.6 g under non-stress environment while the performance in stressed environment were from 15.8 to 39.1 g with mean of 31.3 g. Thousand seed weight of Meko-1, Emahoy and Girana-1 genotypes affected less by the stress factor. Terminal drought affects sorghum grain weight thereby grain yield and it could be triggered by the lessening in rate and productivity of photosynthesis and altered assimilate partitioning (Khaton et al., 2016; Menezes et al., 2014; DaMatta et al., 2003). Also, Assefa et al. (2010) and Prasad et al. (2008) explained the reduction in thousand seed weight as the main cause for lower grain yield in sorghum under drought condition.

Grain filling rate is expressed as kg ha^{-1} day^{-1} and shows the average weight gain per hectare once genotype achieves within a day throughout the grain-filling period. Under non-stressed environment genotypes Kwangphang and ICSV745 revealed 41.7 and 191.4 kg ha^{-1} day^{-1} to be the lowest and highest, respectively. Genotypes Kwangphang and Melkam were the lowest and the highest by having 25.7 and 153.4 kg ha^{-1} day^{-1}, respectively for the stressed environment. Mean performance was reduced by 19% due to drought stress which disrupts the soil moisture status in turn affected the sink-source balance between plant parts resulting in lower grain filling rate thereby grain yield (Okamura et al., 2018). Moreover, drought is one of the limiting factors of yield by affecting the rate of grain filling and decreased yield per panicle of plants (Rahman and Yoshida, 1985). Aboveground biomass shows the accumulation of photosynthetic product while harvest index indicates the partitioning of assimilates to economical yield or in our case grain yield (Sinclair, 1998). The mean aboveground biomass weight was 19115.9 kg ha^{-1} for non-stressed and 15599.0 kg ha^{-1} for stressed environment. Drought had greater impact on biomass production of sorghum genotypes and this finding is in agreement with Hamza et al. (2016) and Abraha et al. (2015). Also, drought reduced the harvest index of the majority of genotypes and this finding is in conformity with Majid et al. (2010) and Malala. (2010). On the contrary, Deblonde and Ledent (2000) suggested that moderate drought conditions did not influence harvest index.

Traits for drought tolerance evaluation

Significant ($P \leq 0.05$) and highly significant ($P \leq 0.01$) variation were observed among genotypes for stay green trait under non-stressed and stressed environments, respectively. Genotypes B-35, E-36, and Melkam showed higher stay greenness and lower leaf senescence at

Table 4. Genotypic (above diagonal) and phenotypic (below diagonal) correlations of grain yield with other traits under non-stressed environment.

Traits	SVG	YLD	GFR	TGW	AGBM	PEX	NT	PW
SVG		-0.444*	-0.421*	-0.132	-0.244	0.458*	0.38	-0.263
YLD	-0.312*		0.993**	0.729**	0.345	-0.598**	-0.427*	0.789**
GFR	-0.298*	0.988**		0.734**	0.399	-0.611**	-0.41	0.798**
TGW	-0.142	0.698**	0.699**		0.126	-0.417*	-0.327	0.463*
AGBM	-0.221	0.352*	0.404**	0.131		-0.428*	0.077	0.68**
PEX	0.386**	-0.564**	-0.567**	-0.405**	-0.399**		0.492*	-0.649**
NT	0.284	-0.405**	-0.384**	-0.306*	0.063	0.478**		-0.286
PW	-0.219	0.741**	0.753**	0.415**	0.658**	-0.594**	-0.261	

*, ** Significant at 5 and 1% level of probabilities, respectively and traits abbreviation as described in material and methods.

maturity under both environments. On the other hand, genotype A2267-2 found to be senescent type under both environments. The lowest scores (stay greenness) were 1.25 and 1.5 for B-35 genotype under non-stressed and stressed moisture regimes, respectively. The introduced drought brings about 17.4 and 35.6% performance reduction for stay green and leaf senescence traits, respectively.

Genotypes varied significantly for chlorophyll content and drought score for stressed environment only (Table 2). The lowest chlorophyll content (SPAD reading) was recorded by Kwangphang and the highest reading was recorded from B-35 and E-36 (stay green parents) and ICSV745, and Melkam genotypes which revealed drought tolerance according to the current study. The chlorophyll content (SPAD reading) for stressed environment ranged from 42.3 to 65.2 with mean value of 50.8. Also, mean performance was reduced by 13.4% as drought induced. Several authors reported performance reduction of sorghum genotypes for chlorophyll content (SPAD reading), stay greenness, leaf senescence and drought score due to post-flowering drought (Kassahun et al., 2010; Sara, 2015; Abraha et al., 2015; Sory et al., 2017).

According to Smart (1994), moisture stress in plants results in closing of stomata, inhibition of photosynthesis, cell division, wall and protein synthesis; however, chloroplast is the first organelle to break down under drought condition. Lichtenthaler et al. (1998) further describes the damage on chloroplast is less likely to happen in tolerant sorghum genotypes than the susceptible ones due to magnesium in their cells. Stay green genotypes maintain chlorophyll concentration, contribute to longevity of leaves, high relative water content (Razakou et al., 2013), maintenance of greenness and absorption of more nitrogen and delay in chloroplast protein degradation under drought condition (Kamran et al., 2014). However, since drought tolerance is a complex trait controlled by many genes and is dependent on the timing and severity of the stress (Ludlow and Muchow, 1990), leaf chlorophyll content alone does not assure sufficient yield under post-flowering drought condition. Therefore, introgression of these traits to adaptable and high yielding genotypes could have paramount importance for drought tolerance breeding. Accordingly, genotypes B-35, E-36, ICSV745 and Melkam could be utilized as a parent (Table 3). The variability of genotypes for traits related to leaf chlorophyll content was found to be higher for the stressed environment which exhibited an association between chlorophyll content and available soil moisture. Therefore, the testing environment has imperative importance in ease of selection for drought tolerance breeding.

Genotypic and phenotypic correlation of grain yield with other traits in stressed and non-stressed environments

The magnitude of correlation was higher for genotypic correlation than phenotypic correlation in non-stressed environment which describes the heritable association of the characters (Johnson et al., 1955). Grain yield had significant and strong positive genotypic correlation coefficients with grain filling rate, thousand grain weight and panicle weight (Table 4). The positive and significant correlation indicates that simultaneous selection of these traits under non-stressed moisture condition will bring significant yield advantage on sorghum. Correlation analysis showed that grain yield had negative significant correlation with seedling vigor but, as the data scoring was in descending order (1=vigorous; and 5=less vigorous), the association remains positive. Chalachew et al. (2017) reported that grain yield was positively associated with thousand seed weight, biomass yield, and panicle weight in sorghum. Other reports also showed the correlation of yield with thousand seed weight and panicle weight in sorghum (Tesso et al., 2011; Amelework, 2012).

Under stressed environment, phenotypic correlation was found to be higher in magnitude which depicts higher degree of unheritable environmental effect as a result of induced post flowering drought. Grain yield had a positive significant genotypic correlation coefficient with chlorophyll content (SPAD reading), flag leaf area, grain

Table 5. Genotypic (above diagonal) and phenotypic (below diagonal) correlations of grain yield with other traits under stressed environment.

Traits	SVG	YLD	SPAD	FLA	GFR	TGW	HI	PEX	NT	PW	RA
SVG		-0.39	0.01	-0.34	-0.40	0.04	-0.18	0.46*	0.51*	-0.07	-0.04
YLD	-0.36*		0.34*	0.56**	0.99**	0.70**	0.46*	-0.53**	-0.66**	0.61**	0.38*
SPAD	0.05	0.42*		0.45*	0.39	0.43*	0.52*	-0.10	-0.37	0.16	0.03
FLA	-0.27	0.59**	0.26		0.55**	0.35	0.35	-0.49*	-0.50*	0.43*	0.07
GFR	-0.37*	0.99**	0.33*	0.52**		0.68**	0.49*	-0.58**	-0.69**	0.68**	0.40*
TGW	0.001	0.71**	0.37*	0.34*	0.67**		0.52*	-0.33	-0.53**	0.44*	0.43*
HI	-0.19	0.51**	0.39**	0.32*	0.44**	0.47**		-0.08	-0.26	-0.13	0.26
PEX	0.39**	-0.56**	-0.09	-0.44**	-0.55**	-0.31*	-0.07		0.77**	-0.65**	-0.29
NT	0.46**	-0.69**	-0.32*	-0.46**	-0.65**	-0.50**	-0.25	0.76**		-0.58**	-0.26
PW	-0.05	0.67**	0.16	0.31*	0.60**	0.39**	-0.17	-0.58**	-0.50**		0.28
RA	-0.03	0.40**	0.03	0.06	0.38**	0.40**	0.23	-0.29*	-0.26	0.25	

*, ** Significant at 5 and 1% level of probabilities, respectively and traits abbreviation as described in material and methods.

filling rate, thousand grain weight, harvest index, panicle weight and root angle (Table 5).

As these traits have a positive significant correlation with yield, breeding for drought tolerance in sorghum should consider higher value of these traits in developing varieties for moisture stress areas. In agreement with these results previous finding by other workers indicated significant positive correlation of grain yield with chlorophyll content (SPAD reading), thousand grain weight and harvest index by Kumar et al. (2013); thousand grain weight, panicle weight and harvest index by Chalachew et al. (2017) in sorghum. Similarly, Kamran et al. (2014) reported chlorophyll content to have a positive correlation with grain yield. Moreover, Khaliq et al. (2008) in bread wheat and Ali et al. (2009) in sorghum also observed the positive association of flag leaf area and grain yield in moisture stress experiment. This suggests utilization of traits through selection which showed positive correlation with yield could be important if adopted as breeding strategy to increase yield in moisture stress area. More importantly, harvest index, chlorophyll content, root angle and flag leaf area showed significant positive correlation with yield under stressed environment only. Therefore, these traits could be used as morphological marker for screening of drought tolerant sorghum genotypes.

On the other hand, panicle exertion and number of fertile tiller revealed significant negative genotypic and phenotypic correlation with grain yield under both environments. Even if the two traits had a desirable character in sorghum they do have yield penalty by consuming greater assimilates which could be allocated to grain yield. Hence, considering lower value for these traits could bring significant yield advantage on sorghum. Comparable result was reported by Richards et al. (2002) for fertile tiller.

Effect of root angle for drought tolerance

Highly significant variation was observed among sorghum seedlings in root angle (Table 2). Therefore, genotypic variability for root angle trait will give us an opportunity for selection of sorghum tolerant to drought. From the 23 genotypes tested the widest mean root angle was observed for Dekeba and Abshir which revealed 26.75 and 26.0°, respectively and the narrowest was observed from Teshale: 13.0° and ETSL100674: 13.75° with mean and standard deviation of 19.05 and 3.84°, respectively (Table 3).

Positive significant correlation coefficient of root angle with yield and some yield component were observed under stressed environment and no significant association of any trait under non-stressed environment (Table 5). Similar results were reported by Pandey et al. (2015) and Ali et al. (2015). Under stressed condition, significant genotypic and phenotypic correlation were observed between root angle with yield, grain filling rate and thousand grain weight (Table 5). The associations observed were weak (<0.43) for all these traits, therefore, intermediate to slightly wider root angle had a synergic effect on drought tolerance of sorghum under silty clay soil condition. In conformity with this result, Fenta et al. (2014) observed soybean genotype with intermediate root angle was the most drought-tolerant cultivar under irrigated as well drought environments.

Comparably, Mace et al. (2012) indicated a possible association between nodal root angle and sorghum yield in the study of QTL. According to Singh et al. (2012) wide nodal root angle of sorghum could potentially enhance access to water through more horizontal root system and higher root biomass in the upper soil surface that would be advantageous to extract water from inter-row spaces; this contributes to better grain yield. In contrast, Pandey et al. (2015) observed consistence negative correlation of root growth angle with grain yield in managed drought, irrigation and rainfed wheat experiment under sandy loam soil; while no correlation was observed under silt loam soil condition. These could be as a result of soil compaction layer which limits vertical growth of the roots. Moreover, Malamy (2005) observed the variation in the expression of root traits under different soil and rainfall condition.

Early maturing sorghum genotypes had lesser root weight in comparison to late ones because more assimilate is partitioned to shoot growth to escape the stress by completing life cycle (Matthews et al., 1990). Therefore, as the root growth for early maturing sorghum genotypes is limited, its advantage to have it on the upper surfaces means moderate to wider root angle for effective top soil foraging. These suggested that under stressed environment moderate to slightly wider root angle was associated with high yield by increasing the efficiency of the root system in capturing lateral available soil resources. However, the importance of soil textural class should be kept in mind in exploiting root angle trait for drought adaptation.

Conclusion

The variation observed among sorghum genotypes in most of the traits gives opportunity for further improvement by selection and hybridization. Post-flowering drought reduces grain yield and the values for the most of the traits. The goal of the study is to characterize and establish possible selection criteria helpful for screening of sorghum for drought prune environments. Flag leaf area, SPAD, harvest index and root angle traits could be used as morphological marker for sorghum breeding program for moisture stress. The result pointed out the importance of root angle under drought condition and also, the contribution of intermediate to slightly wider root angle for enhanced grain yield under silty clay soil. Genotypes B-35, E36, Melkam and ICSV745 showed better performance in stay green and SPAD chlorophyll reading which is good indicators of drought tolerance traits and could be utilized as a parent. As per the result, genotype ICSV745 utilized maximum soil moisture to give better yield under optimum as well drought environments. In addition, for drought prone environments varieties Melkam and Dekeba are good yielders as well drought tolerant.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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