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ARTICLE

Evaluation of Sorghum (*Sorghum bicolor*) Landraces for Drought Tolerance Using Morphological and Yield Characters under Rainfed Conditions of Sub Region Hagaz, Eritrea

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ABSTRACT

Sorghum is an important food crop in Eritrea where it is widely grown in the mid and low lands, of semi-arid regions. Eritrea being the center of origin of sorghum, a large variability exist in its landraces being grown by the farmers since generations. In order to improve the productivity of sorghum under moisture stress conditions, it is imperative to evaluate these landraces for drought tolerant characteristics and their use for further crop improvement programmes. Therefore, a field study was conducted in a randomized complete block design with three replications to estimate the extent of genetic variability of 20 sorghum genotypes for moisture stress tolerance using various morphological, phenological, yield and yield related parameters under rainfed conditions at Hagaz Research Station. Significant difference was observed for almost all the characters in the individual analysis of variance suggesting that these sorghum accessions were highly variable. Accessions EG 537, EG 1257, EG 849, EG 791, EG 783 and EG 813 showed promising results for post flowering drought tolerance, grain yield and stay green traits. Higher PCV and GCV were also obtained in parameters like plant height, leaf area, biomass, peduncle exertion, panicle length, and grain yield and panicle weight. The genotypes also exhibited varying degrees of heritability estimates. Characters such as plant height, panicle length, days to flowering and maturity showed higher heritability. Cluster analysis revealed that sorghum landraces were grouped on the basis of their morphological traits and geographical sites. 77.3% of the total variation of sorghum landraces was contributed by the first four principal components analysis having Eigen value > 1. Overall, the current study confirmed that EG 537, EG 849, EG 1257, EG 791, and EG 813 are drought tolerant sorghum landraces during post flowering stage.

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1. Introduction

Sorghum [*Sorghum bicolor (L.)* Moench] ranks fifth worldwide after wheat, rice, maize, and barley [1]. The crop is produced for grain which is used for food, and stalks used for fodder and building materials in developing countries. In developed countries, grain or sweet stem of sorghum is used primarily as animal feed, making sugar, syrup, and molasses [2]. This crop is widely adaptable to several types of stresses, though its production has been limited to water- and heat-stresses within subtropics and tropical regions of the world [3,4].

Sorghum is an important food crop in Eritrea where it is widely grown in the mid lands, low lands and semi-arid regions of Eritrea [5]. Eritrea is a center of origin and diversity for sorghum which exists a large number of variability. As a result, a large number of sorghum germplasm accessions have been collected by the Eritrean Genetic Resource Center, in the National Agricultural Research Institute (NARI) since 1993. Even though most of the sorghum accessions collected, they have not been characterized and evaluated using morphological, biochemical and DNA molecular markers [5].

The local landraces have been grown for generations in Eritrea and have exhibited useful characters to adapt under drought conditions. Farmers prefer these landraces due to their ability to produce some yield under low rain fall conditions in a situation when modern cultivars fail.

In addition sorghum productivity in Eritrea is less than 1 t/ha^{-1} which is below the average global production [6]. This low productivity of sorghum is due to moisture stress, *Striga* weed and poor understanding and exploitation on the potentials of the genetic diversity in the country. Post-flowering drought stress is the most important factor that severely reduces the yield. Therefore, the present investigation was carried out to evaluate the sorghum land races for drought tolerance using morphological and yield characters.

2. Materials and Methods

The experiment was conducted under rainfed condition at Hagaz Research Station which is located in Anseba region, about 25 kilometers South West of Keren town, at an altitude of 860 meters means above sea level. The area receives a mean annual rainfall ranging from 300 mm to 400 mm. It is characterized by hot and dry climate where minimum and maximum temperature ranges from 24 °C and 42 °C, respectively. It has a sandy soil with fair amount of clay and silt [7].

The germplasm used in this field study comprised of 20 sorghum genotypes including 11 accessions selected from Zoba Gash Barka, 5 from Zoba Anseba and 3 from Zoba Debub. Among the 20 genotypes, 19 are landraces and one genotype B-35 was an improved cultivar obtained from International Crop Research Institute for Arid and Semi-Arid Tropics (ICRISAT) (Table 1). These genotypes were tested in randomised complete block design with three replications during summer, 2017. All the genotypes were sown on 7th July at a plant to plant and row to row spacing of 20 cm and 75 cm, respectively with uniform fertilizer and agronomic practices.

Table 1. Sorghum genotypes used in this study along with their local names and area of origin

No	Accession Number	Local name	Area of collection
1	EG 849	Hugurtay	Gash Barka
2	EG 786	Embulbul	Gash Barka
3	EG 526	Wedi-Aker	Gash Barka
4	EG 469	TsedaBazenay	Gash Barka
5	EG 537	Anseba	Debub
6	EG1224	Muhagen	Gash Barka
7	H-35-1	TsedaMeshala	Debub
8	EG 836	Hugurtay	Anseba
9	EG 711	Embulbul	Anseba
10	EG 1257	Gedem hamam	Gash Barka
11	B-35	B-35	ICRISAT
12	EG 783	Aklomay	Gash Barka
13	EG 791	Koro-Kora	Gash Barka
14	EG 787	Duruta	Gash Barka
15	EG 782	Tseda Hele	Debub
16	EG 789	Ajebsidu	Gash Barka
17	EG 806	Hariray	Gash Barka
18	EG 481	Wedi Susa	Anseba
19	EG 813	Wedi-Ferej	Anseba
20	EG 797	Wedi Aker Short	Anseba

Note: Except B-35 which is an improved type from ICRISAT others are Land races and H-35-1 failed.

In this study various morphological, phenolgical, yield and yield related traits that contribute for drought tolerance assessment were included. The data recorded included plant height, leaf area, panicle orientation, time to 50% flowering, days to maturity, root length, flag leaf area, peduncle exertion, panicle length and width. After harvesting each of the land races depending upon their time of maturity (70-90 days), the root zone of randomly selected plants was given sufficient water to soften the soil. Thereafter, roots were manually pulled and the length of primary roots was measured with the help of measuring scale. Over all agronomic scores were taken based on a scale of 1 to 5 where 5 = most desirable and 1 = least desirable.

Other characters such as grain yield, 1000 grain weight, harvest Index and stay-green scores at maturity based on visual ratings [8] were assessed. Stay green was evaluated on 1 to 5 scale basis where 1 = < 10% leaves stay green and 5 = > 75% leaves stay green which are most desirable based on the proportion of leaf area of normal sized leaves that had greenness and dried leaves. The rate of stay green determines the maintenance of quality flowers and seed set [9].

Data collected on the various morphological traits were analysed using the GENSTAT 14 Statistical software, Carl Pearson correlation matrix, Principal component analysis (PCA), Cluster analysis was also done using the UPGMA system. Dendrograms were constructed using the SAHN Soft Ware Program.

Analysis of Genetic, and Genotypic Variability, Genotypic and phenotypic coefficient of variation and broad sense heritability were estimated using the formulas illustrated below.

i. Genotypic variance, GV= MSg-MSe/r where MSg = mean square of genotypes, M Se = mean square of error, and r = number of replications.

ii. Phenotypic variance, PV= GV+ MSe where GV = genotypic variance and MSe = mean square of error.

iii. Phenotypic coefficient of variation, $PCV = \sqrt{\ }(PV)/\ \bar{x} *$ 100 where PV = phenotypic variance and x^{-} = mean of the character.

iv. Genotypic coefficient of variation, $GCV = \sqrt{\ }\ \bar{x} *100$ where GV = genotypic variance and $\bar{x}$ = mean of the character.

v. Heritability (broad sense heritability), $H = \sqrt{GV}/PV$ = where GV and PV are genotypic and phenotypic variances respectively.

3. Results and Discussion

3.1 Morphological and Phenological Parameters

The data on various morphological parameters like plant height, leaf area, agronomic score, root length, stay green, flag leaf area and phenological parameters like days to flowering and days to maturity evaluated in the study have been presented in Table 2 and discussed here below.

Plant height*:* A critical perusal of the data in Table 2 reveal that the plant height of different sorghum landraces ranged from 107.4 cm to 277.3 cm. While landraces EG 836 and EG 813 produced significantly taller plants of height 277.3 cm and 258.4 cm, respectively, the improved variety B-35 and landrace EG 797 produced significantly dwarfed plants of 107.4 cm and 128.9 cm height, respectively. The remaining land races produced plants of medium height ranging from 207.4 cm to 246.5 cm. This is in conformity with Nouri, R. A. H. [10], who reported that there was significant variation among the sorghum landraces in plant height.

Leaf area: The leaf area of different landraces ranged from 259.9 cm^2 to 433.1 cm^2 (Table 2). Among the tested landraces EG 791, EG 836, EG 782, EG 537, EG 849 and improved variety B-35 produced significantly higher leaf area resulting in higher transpiring and photosynthetic surface area than remaining landraces. This is in agreement with Khaliq, I., et al. [11], who reported that although, leaf area has positive correlation with grain yield in many cereal crops but larger leaf area might cause more water losses due to more evapo-transpiration from the surface. Mortlock, M.Y. and Hammer, G.L. [12] reported that plants having larger leaf area transpire more water than plants with smaller leaf area.

Agronomic score: There were statistically significant differences in overall agronomic scoring among the sorghum landraces (Table 2). Significantly higher (4.3-5.0) agronomic score was recorded by accessions EG 526, EG 469, EG 1224, EG 791, EG 849, EG 789, EG 806, EG 813, EG 797 and EG 787. Whereas lower score (3-3.7) was recorded by accessions EG 836, B35, EG-782 and EG 786 (Table 2). This was in disagreement with Tesfamichael, A., et al. [13], who reported that EG 791, EG 711, EG 783, EG 836, EG 782 were among the varieties scored higher agronomic score because of comparatively favourable gene environment interaction obtained under mid hill conditions of Hamelmalo experiencing comparatively less drought stress in off season.

Root length: There was significant difference among the sorghum landraces in root length which ranged from 38.0 cm to 47.23 cm (Table 2.). Among the land races, EG 789 (47.23 cm), EG 1257 (43.7 cm) and EG 469 (40.1 cm) being statistically at par produced significantly longer roots to extract water from deeper layers for drought tolerance. On the other hand land races EG 786, EG 723 and EG 711 produced significantly shorter roots (24.9 cm ~ 27.8 cm.) making the plants susceptible to moisture stress. This study showed that roots are the first plant parts that are affected by moisture stress and express their response in the leaf surface. This is in agreement with Xiong L., et al. [14] and Khodarahmpour, Z. [15], who reported that roots are the place where plants first encounter water stress which senses and responds to the stress condition. According to the researchers [16,17], root length is an important trait for drought tolerance response in crop varieties especially if the variety/landraces has a longer root growth it has the ability for resistance to drought and produce higher yield.

Stay green: There was statistically significant difference among the sorghum landraces for stay green with the values ranging from 2.67-5.0 (Table 2). Except landraces EG 786, EG 711, EG 782 and EG 481 all other land races under study were superior in stay green character. This study confirmed that a variety/landrace with better stay green behavior plays a significant role in post flowering drought stress by avoiding leaf senescence during grain filling stage. This is in agreement with the report of Kouressy, M. [18], who confirmed that further increase in yield can be achieved through increasing the sink capacity by improving the assimilate availability through early expression of stay-green traits and delaying leaf senescence.

Flag leaf area: There was statistically significant difference among the sorghum landraces in flag leaf area (Table 2). Landraces that scored higher flag leaf area were EG 789, B-35, EG 1224, EG 836, EG 537, EG 782 with the value of 216.0 cm^2, 193.7 cm^2, 176.7 cm^2, 164.1 cm^2, 159.8 cm^2, and 156.6 cm^2, respectively. Whereas landraces EG 786, EG 787, EG 813, EG 783 and EG 711 produced lower (73.0 cm^2 ~ 110.5 cm^2) flag leaf area helping them to transpire less water for better drought tolerance. The current study confirmed that crops with optimum flag leaf area have less transpiring surface than crops with wider flag leaf area. This is in agreement with Tsuji, W., et al. [19], who reported that although, flag leaf area has positive correlation with grain yield in many cereal crops but more flag leaf area might cause more water losses due to more evapotranspiration from the surface and that drought tolerance in sorghum is associated with its smaller flag leaf area. Khaliq, I., et al. [11] also reported optimum leaf area is required for carrying out adequate amount of photosynthesis to run the essential processes of plant growth. Furthermore, Karamanos, A. J. and Papatheohari, A. Y. [20] reported that, traits like reduced leaf area and prolonged stomata closure, decrease water loss, which results in reduced dry matter production and reduced final yield.

Reported [21] that in flag leaf photosynthetic activity had important role in rice grain yield. It is also reported [22] that the top three leaves especially flag leaf contributes most to grain yield and greater carbohydrate translocation from vegetative plant parts to the spikelets. So flag leaf has an important role in rice yield by increasing grain weight by 41 to 43 percent.

Days to flowering: There was significant difference among the sorghum landraces for days to 50% flowering. The current experiment confirmed that sorghum landraces took less number of days (< 63 days in average) to flowering due to stress condition (Table 2). However, B-35, EG 836, EG 782, EG 813 being at par took significantly more (67-70) number of days to 50 percent flowering over remaining land races. This is in agreement with Nouri, R. A. H. [10], who reported that stressed plants significantly took fewer days to reach 50% flowering compared to plants grown at normal condition.

Days to maturity: There was statistically significant difference among the sorghum landraces for days to maturity. The current study confirmed that early and medium maturing varieties gave better grain yield in comparison with late maturing ones. This is in agreement with Nouri, R. A. H. [10], who reported that stressed plants took significantly less days to reach milking and maturity stages compared to late matured plants. It was observed that early maturity had an obvious advantage in grain yield and harvest index under drought conditions because late flowered plants deplete more moisture before the critical periods. Therefore they are not suitable to be cultivated in low rain fall areas.

3.2 Yield and Yield Related Parameters

The data on grain yield, biomass yield, harvest index and yield related parameters like panicle length, panicle width, panicle weight and thousand grain weight have been presented in Table 3 and discussed here below.

Panicle length: There was a significant difference among the sorghum landraces in panicle length. Landraces with significantly higher panicle length (22.2 cm ~ 23.7 cm) were EG 789, EG 791 and B-35. Whereas, the landraces with lower panicle length (8.4 cm ~ 10.2 cm) were EG 786, EG 836, EG 782 and EG 783 and EG 481 (Table 3). The period of stress might have stimulated stressed plants to hasten the development of their root system and consequently accelerates head development. These results were in agreement with the findings of Younesi, O and Moradi, A. [23] but in contradiction to the finding of Tesfamichael, A., et al. [13], who reported that EG 469 (28 cm) scored highest and EG 836 (9 cm) scored the lowest panicle length due to gene environment interaction. The present study was conducted at a location having comparatively more drought stress with higher maximum and minimum temperature and lower rainfall than the location of Hamelmalo where Tesfamichael, A., et al. [13] conducted his study in off season.

Panicle width: There was significant difference among the sorghum landraces for panicle width. Sorghum landraces with higher panicle width were, EG 836, EG 782, EG 849, EG 813, EG 537, and EG 789, values ranging from 14.10 cm to 22.7 cm. This result is in disagreement with Tesfamichael, A., Githiri, S.M., Kasili, R., Woldeamlak, A. and Nyende, A.B., who reported that EG 889, EG 797, and EG 469 were among the landraces that scored higher panicle width when grown under comparatively less drought prone environment of Hamelmalo having comparatively lower temperatures and higher rainfall.

Table 2. Mean performance of sorghum landraces for morphological and phenological parameters.

S.N.	LR	PH	LA	FLA	RL	STG	AS	DF	DM
1	EG 849	207.6	373.3	149.0	35.6	4.67	4.7	61	89
2	EG 786	219.8	259.9	73.0	24.9	2.67	3.7	65	87
3	EG526	176.8	313.9	125.8	33.4	4.67	5.0	62	90
4	EG 469	237.7	339.5	142.4	40.1	5.00	5.0	64	91
5	EG 537	246.5	381.2	159.8	38.3	4.33	4.0	63	89
6	EG1224	229.9	348.9	176.7	31.1	5.00	5.0	63	90
7	EG 836	277.3	431.9	164.1	37.6	5.00	3.0	69	93
8	EG 711	232.0	313.1	100.2	27.8	3.00	4.0	60	87
9	EG 1257	234.2	350.2	141.4	43.7	4.33	4.7	65	90
10	B-35	107.4	420.0	193.7	38.4	4.33	3.3	70	98
11	EG783	242.0	349.5	109.8	26.7	4.00	4.3	49	70
12	EG 791	239.3	433.1	142.1	37.2	5.00	5.0	65	89
13	EG 787	239.9	335.3	106.5	29.9	4.33	5.0	63	96
14	EG 782	226.1	386.0	156.6	34.1	3.33	3.7	68	91
15	EG 789	227.1	403.2	216.0	47.2	5.00	4.3	64	93
16	EG 806	207.4	308.4	115.2	28.8	4.33	4.7	59	86
17	EG 481	229.3	307.7	123.5	26.9	3.00	4.0	54	76
18	EG 813	258.4	379.3	110.5	38.0	4.00	4.3	67	90
19	EG 797	128.9	378.9	148.9	31.9	4.33	4.7	63	87
	Mean	219.	336.1	139.7	34.3	4.23	4.3	62.9	86.6
	LSD (5%)	30.2	80.1	59.4	12.2	1.52	0.9	4.00	21.8
	CV (%)	6.3	10.3	21.9	17.7	16.2	8.0	2.4	10
	P.value	<0.001	0.013	0.04	0.03	0.04	<0.001	<0.001	0.04

Note: LR= Landraces PH=Plant height (cm); LA=Leaf area (cm^2); FLA= Flag leaf area (cm^2) RL= Root length (cm); STG= Stay green (1-5 scale); AS= agronomic score, (1-5 score); DF: Days to flowering, DM: Days to Maturity, LSD = Least significant difference; CV (%) = Coefficient of Variation.

Panicle weight: There was no significant difference among the sorghum landraces for panicle weight but numerically EG 1257 with minimum and EG 526 showed maximum value in panicle weight with 30.0 grams ~ 52.8 grams, respectively. The decreased panicle weight was due to reduced grain size and potential grain number under water stress. These results are in agreement with Bakheit, B. R. [24] and Ahmed, S. H. [25] and who found that moisture stress reduced the mean grain yield per plant and panicle weight per plant during flowering and grain filling period. Furthermore Balko, L. G. [26] reported that water stress during growth stage three usually reduces the seed weight and becomes smaller in size.

Thousand grain weight: Thousand grain weight showed statistically significant difference among the sorghum landraces. Landraces with higher thousand grain weight were, EG 791, EG 789, EG 806, EG 849, EG 836 and EG 787 with values ranging from 15 grams to 28.33 grams per 1000 seed weight (Table 3). This might be due to better capability of these genotypes to tolerate drought stress by maintaining higher water content, which helped in prolonging their grain filling period by translocation of photosynthates from the source (foliage) to the sink (grains) for longer period.

Grain yield: Grain yield showed a significant difference among the sorghum landraces (Table 3). Land races EG 1257, EG 537, EG 849, EG 791, EG 813 and EG 789 being statistically at par resulted in significantly higher grain yield. The study confirmed that moisture stress during post flowering stage affected the yield potential of the sorghum landraces evaluated in the study area. This was in agreement with Sheoran, I.S. et al. [27], who reported such yield reduction due to drought stress in wheat and rice. Blum, A. [28] also reported drought escape by shortening the life cycle of the crops at the expense of the yield potential of the crop in drought prone areas. Yield potential obtained under stress serves as important criteria in the selection for drought tolerance in varieties or landraces. Rehman, S., et al. [29] reported that yield potential of the landrace is the principal selection index used commonly under drought stress conditions.

Biomass yield: There was significant difference among the sorghum landraces in biomass yield which ranged from 5670 kg/ha to 7530 kg/ha. The current experiment showed that landraces having longer duration recorded higher biomass than early maturing ones. This is in agreement with Blum, A. [30], who reported that the genotypes with longer growth duration produced more stover and total biomass with a lesser amount of grains per panicle and per unit area, as compared with genotypes of shorter growth duration.

Harvest index: There was no significant difference among the sorghum landraces for harvest index but numerically EG 783 recorded higher harvest index and EG 469 with minimum harvest index values ranging from 13.6% to 32.83% respectively. This non-significance is due to the reduced yield and increased biomass that leads to lower harvest index. This is in contradiction with results of Blum, A. [30] ,who reported that harvest index varied extensively among the genotypes due to moisture stress.

Overall the results related to superior landraces could be discussed using the major yield contributing parameters.

The superior landrace EG 537 was characterized by early maturity, stay green, higher panicle width and higher grain yield, EG 849 characterized by early flowering and maturity, stay green, higher panicle width and grain yield, EG 1257 by longer root length and higher grain yield, EG 791 was characterized by higher leaf area, stay green, higher thousand seed weight and grain yield, EG 783 was characterized by early flowering and maturity, higher harvest index and grain yield, EG 813 was characterized by higher root length, panicle weight, panicle width and higher grain weight as compared to the rest of the landraces. In general their superiority is based on grain yield obtained at harvest and are listed in the conclusion part for further breeding and research.

Table 3. Mean performance of sorghum landraces for yield and yield related parameters .

S.No.	LR	PL (cm)	PWTH (cm)	PWT (g)	THGWT (g)	GY (t/ha)	BM (t/ha))	HI (%)
1	EG849 849	9.9	21.8	37.7	25.7	17.0	65.0	25.8
2	EG786 cm^2 786	8.4	14.1	34.7	20.7	9.4	43.0	22.3
3	EG526	16.8	15.5	52.8	21.0	8.9	38.3	23.3
4	EG469	20.6	15.4	36.1	18.7	10.1	73.4	13.6
5	EG537 537	14.2	20.9	40.2	21.3	18.3	75.3	24.6
6	EG12244	20.5	16.3	44.4	24.7	11.3	40.9	27.9
7	EG836 836	9.8	22.3	38.6	25.0	6.8	44.7	14.9
8	EG711 711	14.0	16.2	35.8	23.3	11.0	49.5	23.2
9	EG1257 1257	19.1	19.0	30.0	21.7	18.2	69.3	26.4
10	B-35	22.2	14.2	41.1	18.5	6.4	32.1	20.2
11	EG783	10.2	16.3	45.0	20.7	14.3	50.9	32.8
12	EG791 791	22.6	18.1	40.8	28.3	16.0	64.3	25.1
13	EG787 787	9.8	19.5	40.8	25.0	12.4	56.7	21.9
14	EG782 782	12.1	22.2	45.6	22.3	11.0	43.1	24.3
15	EG789 789	23.7	19.9	50.4	26.0	12.8	52.9	24.9
16	EG806 806	10.9	17.8	46.4	26.0	10.7	39.3	27.1
17	EG481 481	9.9	14.3	42.1	19.7	9.3	45.3	20.5
18	EG813 813	15.4	21.2	50.2	16.7	12.9	47.0	27.3
19	EG797 797	17.4	14.1	42.8	15.0	7.2	29.3	23.5
	Mean	15.1	17.87	42.3	22.11	11.80	50.5	23.62
	LSD (5%)	2.7	5.12	NS	5.12	5.63	25.6	NS
	CV (%)	6.8	2.6	22.9	7.0	14.0	17.2	21.5
	P.value	<0.001	0.006	0.06	<0.001	<0.001	0.002	0.26

Note: LR= Landraces; GY=Grain yield (Q/ha); BM=Biomass (Q/ha); PL=Panicle length (cm); PWTH=Panicle width (cm); PS=Panicle size (cm^2); PWT=Panicle weight (g); HI=Harvest Index (%); THSWT=Thousand grain weight (g); LSD=Least significant difference; CV (%) =Coefficient of Variation.

3.4 Correlation Analysis of Selected Morphological Traits

Plant height had significant and positive correlation with grain yield, biomass and non-significant positive correlation with harvest index. This means that landraces having tall and medium plant height had both higher grain yield and biomass. This is in agreement with Mohammadi, M., et al. [31], who reported that a positive correlation between plant height and grain yield normally exist due to increased translocation of the stored dry matter from the stem reserves.

Stay green also showed a positive correlation with grain yield, biomass and agronomic score but it was negatively correlated with harvest index which implies that landraces with better agronomic and stay green trait produced significantly more yield as compared with those landraces with poor agronomic performance and senescence leaves. This is in agreement with Tesfamichael, A., et al. [13], who reported that stay-green had a positive association with grain yield and with overall agronomic score implying that genotypes with high stay green and good agronomic performance gave high grain yield.

3.5 Assessment of Heritability, Phenotypic and Genotypic Coefficients of Variations

Studying phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is useful for comparing the relative variability of the landraces taking into account different traits.

Generally, the GCV were lower in magnitude than the PCV (Table 5). High GCV and PCV were also observed for some characters. This reveals that the genotypes have a broad genetic base as well as good potential in responding positively to selection. High heritability estimates were observed in some characters such as plant height, panicle length, days to flowering and maturity and these characters are expected to respond positively to selection. This result is in conformity with Tesfamichael, A., et al. [13], who reported that highest heritability was recorded in days to flowering, days to maturity, panicle length and overall agronomic score. Eckebil, J.P., [32] also confirmed that characters like number of nodes per plant, panicle length, and early number of leaves per plant, plant height, days flowering and days to maturity would respond positively to selection due to higher values related to broad sense heritability.

3.6 Principal Component Analysis of Various Morphological Traits

Principal component (PC) analysis showed that the first four, out of the 7 PCs explained majority of the total variation. Eigen value is mathematical value of a parameter with non-zero value under a given condition. These four PCs with Eigen value ≥1 (Table 5.) contributed 77.3% of the total variability amongst the sorghum landraces assessed for various morphological traits (Table 5). The

Table 4. Simple correlation analysis among morphological traits recorded under drought stress condition

	PH	LA	AGS	STG	PEX	DFL	DM	GY	BM	HI	TSWT	PWT	RL	FLA
PH	1													
LA	–0.03	1												
AGS	–0.01	–0.23	1											
STG	0.01	0.57*	0.42	1										
PEX	–0.04	0.24	0.62**	0.65**	1									
DFL	–0.14	0.47*	–0.30	0.23	0.24	1								
DM	–0.24	0.43	–0.09	0.42	0.39	0.90**	1							
GY	0.45*	0.11	0.37	0.15	0.21	–0.22	–0.15	1						
BM	0.55*	0.10	0.30	0.26	0.34	–0.08	0.01	0.79**	1					
HI	0.03	–0.08	0.30	–0.09	–0.08	–0.45	–0.43	0.54*	0.05	1				
TSWT	0.41	0.16	0.16	0.33	0.09	–0.02	0.14	0.36	0.29	0.14	1			
PWT	–0.14	0.13	0.14	0.20	–0.02	–0.11	–0.05	–0.21	–0.46*	0.33	–0.04	1		
RL	0.05	0.66**	0.02	0.62**	0.61**	0.54*	0.61**	0.30	0.43*	–0.18	0.08	0.01	1	
FLA	–0.24	0.73**	–0.13	0.61**	0.39	0.39	0.51*	–0.02	0.01	–0.13	0.16	0.20	0.71**	1

Note:* Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed) PH= Plant height, LA= Leaf area AGS= Agronomic sore, STG= Stay green, PEX= Peduncle exsertion, DF= Days to flowering, DM= Days to maturity, GY= Grain yield, BM= Biomass, HI= Harvest index, TSWT= Thousand seed weight, PS= Panicle size, PWT= Panicle weight, RL= Root length, FLA= Flag leaf area remaining 3 components contributed only 15.8% towards the total morphological diversity for this set of sorghum landraces. The PC I contributed maximum towards the variability (34.3%) followed by PC II (20.7%), PC III (13%) and PC IV (9.3%). The most important characters in PC I was due to variations among the sorghum landraces mainly for days to maturity, flag leaf area, peduncle exertion, panicle length, root length and stay green. Similarly PC II was related to diversity among sorghum landraces due to specific biomass, grain yield, days to 50% flowering, and plant height. The PC III was explained mainly by variation among genotypes resulting from harvest index, panicle weight and biomass.

3.7 Cluster Analysis

The percentage similarity between accessions ranged from 0.7 to 0. 98 (Figure 1). The phenotypic dendrogram showed that the accessions could be grouped into three main clusters (I, II and III). The result of the component analysis obtained in this study was similar to those of studies [13,33,34] on various agro-morphological traits in sorghum. Moreover, the principal components analysis also showed that the variation in the germplasm materials cannot be explained on the basis of very few characters.

In order of diminishing importance, the explanation of greater proportion of the entire phenotypic diversity has involved major traits dealing with panicle width, panicle weight and peduncle exertion), as well as leaf traits like stay-green, flag leaf area and leaf area; yield related traits like grain weight and biomass and plant phenology traits plant height, days to flowering and maturity. This is in conformity with Ayana, A. and Bekele, E. [35], who described the importance of all these traits in contributing towards the overall diversity of the sorghum germplasm. These results on the effect of environment on yield components of sorghum are in conformity with those of William, W.T. et al. [36].

Morphological cluster analysis confirmed the presence of variation among genotypes. Besides, sorghum landraces indicated in cluster ‘I’ are also known for their drought tolerance and high yielding ability. These sorghum landraces were clustered together mainly based on the geographical sites (region), morphological and pedigree relationship. Likewise studies [37-39] detect clustering of sorghum accessions based on their collection site and pedigree relationship. Teshome, A., et al. [40] evaluated 117 sorghum accessions from North Shewa and South Welo regions of Ethiopia using 14 morphological traits and reported on the extensive variation of the accessions based on geographical locations**.**

Table 5. Estimates of means, genotypic and phenotypic variation, genotypic and phenotypic coefficients of variation and heritability for major morphological parameters.

Traits	Mean	δ^2p	δ^2g	PCV (%)	GCV (%)	h^2_{BS} (%)
Plant height	219.3	1921.0	1599.0	295.8	270.0	83.0
Leaf area	361.0	3431.0	1089.0	308.2	173.4	32.0
Number of leaves	12.2	2.4	0.8	44.4	25.6	33.0
Stay green	4.2	1.6	0.8	62.0	44.0	50.0
Agronomic score	4.3	0.5	0.3	34.1	26.4	60.0
Days to flowering	62.9	29.3	23.5	68.0	61.0	80.0
Days to maturity	88.3	45.3	33.1	71.4	61.0	73.0
Panicle width	17.8	14.9	5.3	91.0	54.0	35.0
Peduncle exertion	38.4	66.1	42.1	131.0	104.4	64.0
Panicle length	15.1	28.1	25.4	136.0	129.6	91.0
Panicle weight	919.0	101294.0	21880.0	1049.8	487.8	22.0
Grain yield	11.8	21.0	9.4	133.0	88.9	44.0
Biomass	50.5	296.9	125.1	242.2	157.2	42.0
Harvest index	24.7	58.2	4.8	153.0	44.0	8.2
Root length	34.3	73.6	18.9	146.3	74.2	26.0

Note: δ^2p = phenotypic variation, δ^2g = genotypic variation, GCV (%) = Genotypic coefficient variance, PCV (%) = Phenotypic coefficient variance and h^2_{BS} (%) = Heritability in broad-sense.

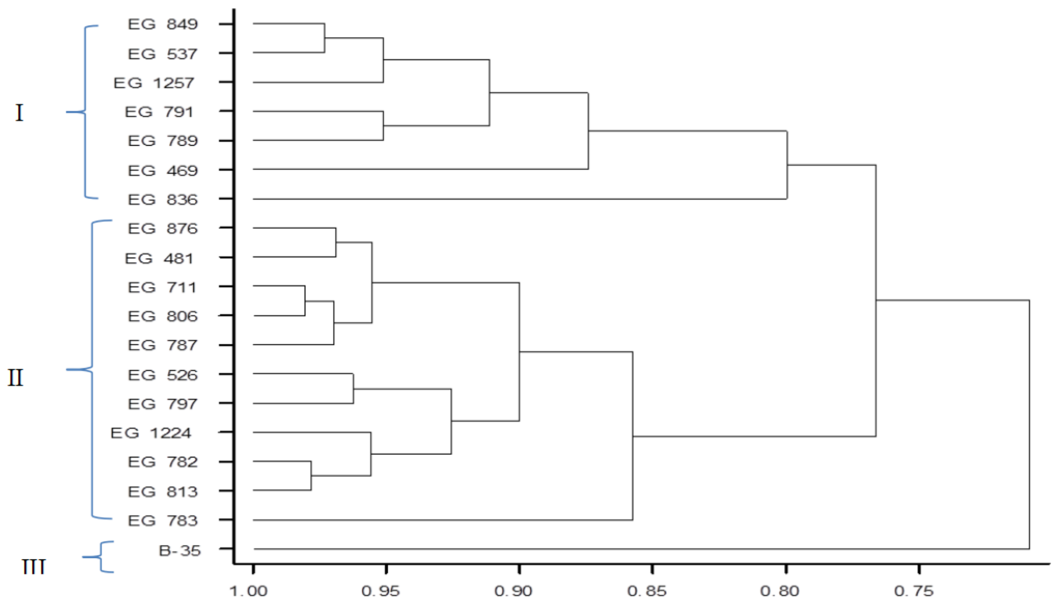

Figure 1. Genetic similarity among sorghum landraces

4. Conclusions

It can be concluded from the study that based upon grain yield and stay green characters, EG 537, EG 849, EG 1257, EG 791, EG 783 and EG 813 were the superior land races for cultivation under semi-arid conditions of Hagaz and its vicinity. The superior sorghum landraces with longer root length responding to post flowering drought tolerance were EG 789, EG 1257; EG 469, B-35, EG 537, and EG 813 with values ranging from 38 cm to 47.23 cm. High GCV and PCV observed for some characters revealed that the sorghum landraces had a broad genetic base as well as good potential responding positively to selection. High heritability estimates were observed in some characters such as plant height, panicle length, days to flowering and maturity. Having the minimum threshold Eigen of one, out of seven principal components (PCs), the first four principal components (PCs) accounted for a cumulative of about 77.3% of the whole phenotypic diversity observed among the sorghum landraces. The result of the dendogram demonstrated variation of landraces based on morphological traits and the region or place where the landraces have been collected are a valuable source for sorghum improvement programs particularly the three geographical regions mainly Gash Barka, Anseba and Debub and different parts of Eritrea as a whole.

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Conflict of Interest

There is no conflict of interest.

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