American Journal of Plant Sciences, 2020, 11, 1618-1631
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

The MET Analysis of Yield Performance of Advanced Sorghum [*Sorghum Bicolor* (L.) Moench] Lines under Moisture Stress Areas Using Spatial Analysis

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How to cite this paper: Wagaw, K., Seyoum, A., Tadesse, T., Gebreyohannes, A., Nega, A. and Tadesse, D. (2020) The MET Analysis of Yield Performance of Advanced Sorghum [*Sorghum Bicolor* (L.) Moench] Lines under Moisture Stress Areas Using Spatial Analysis. *American Journal of Plant Sciences*, **11**, 1618-1631.
https://doi.org/10.4236/ajps.2020.1110117

Received: October 21, 2019
Accepted: October 25, 2020
Published: October 28, 2020

Abstract

Sorghum is one of the most widely cultivated cereal crops in Ethiopia which is grown for food and feed uses. It's far an indigenous crop that's grown in incredibly diverse environments of getting diverse water strain, soil fertility, and temperature situations. Trait of sorghum varieties tolerant to drought and producing desirable grain yield at the same time as addressing the biomass requirement is one of the techniques within the sorghum breeding program to the dry lowland surroundings so one can feed the growing population in Ethiopia. A total of 126 superior early maturing sorghum elite lines had been evaluated through along with recently released popular trendy check Melkam and Argiti to estimate the grain yield and stability of overall performance throughout the testing environments. Based on the overall performance of grain yield, flowering time, plant height, and the stability of grain yield genotype ETSC14501-2-2 and 14MWLSDT7196 become top ranked followed by genotype 14MWLSDT7176, 14MWLSDT7241 and 13MWF6#6037 which could be a capability candidate for production to the target environments. The varieties had better grain yield performance and stability across the environment, which may be used as capacity parental lines for genetic improvement in the sorghum improvement program. Finally based on the presented result on early maturing variety ETSC14501-2-2 with the pedigree of Redswazi/Meko-1 identified and registered for variety verification across locations on stations and on farms to confirm the stability and preference by farmers with their own farming practices.

Keywords

Heritability, Stability, META, Elite Lines, Correlation, Spatial Analysis

1. Introduction

Sorghum is a food and feed cereal crop adapted to warm and drought prone areas and it is a staple food crop for 500 million of the world's poorest people. Its African-domesticated small diploid genome and phenotypic diversity make it an ideal C_4 grass model as a complement to C_3 rice [1]. It is an extremely productive, dry-resistant C_4 grass which grown mostly for grain, forage, sugar and biomass cultivation [2]. It has a chromosome of $2n = 20$ and a ~800 Mb genome size [1] [3]. Sorghum is predominantly self-pollinated short-day crop with the degree of cross-pollination reaching up to 30%, depending on the nature of panicles. It is an indigenous crop of Ethiopia mostly cultivated with low rainfall areas, low soil fertility and high temperature conditions in extremely varied settings. In Ethiopia, sorghum develops from lowland regions that receive reduced rainfall and have elevated altitude temperatures characterized by low temperatures and greater rainfall levels [4]. Sorghum is the world's fifth largest cereal crop and third largest dry land crop in Ethiopia cultivated by 6 million smallholder farmers in over 1.9 million hectares of soil with 25% area coverage from cereal crops and sorghum contributed 17% of cereal production (Maize, Teff and Wheat) which is about 51.7 M quintals of production [5].

Globally, sorghum is an important source of animal feed and forage, an emerging biofuel crop and model for C_4 grasses particularly genetically complex sugarcane. The full exploitation of sorghum's potential requires an understanding of genetic diversity at the gene level and needs to create genetic diversity to get important variety which could have high yield and preference by end users specially farmers and commercial sectors.

Improvement of high yielding and stable performing sorghum varieties is the key riding element to interact the farmers and personal seed sectors and commercialize sorghum in Ethiopia [6]. In Ethiopia, sorghum breeding has been mostly restricted to germplasm characterization using phenotypic traits and exotic sorghum hybrid parental lines. There is also an increment in developing elite lines from the local available sorghum lines. Research on sorghum variety development targeted the dry lowland sorghum growing areas is currently hosting ample amount of elite lines developed from national sorghum research program through successive pedigree crossing program and now a time there are many varietal experiments which have being planned and executed to evaluate their grain yield performance and stability in the areas where sorghum is grown mainly. One of the best strategies to cope up the limiting factor for sorghum production can be tackled by developing offspring from the genpool which is found locally where the business will be done.

Because of the inherent capacity to adapt the limited moisture available and serve the farming community for multi purposes, sorghum is the dominant cereal crop in the dry lowland area. Hence, the national program has given more emphasis and much has been exerted to generate varieties for the dry lowland areas. Using of genetic variability is the most important tool in plant breeding, and this must be generalized by phenotypic expression. The issues of the phenotypic variation depend largely on the environment where it grown [7]. This variation is further complicated by the fact that not all genotypes respond in similar ways to the change in environment and season. If the performance of genotypes is different in different environments, then GEI becomes a major challenge to crop betterment. Genotype by environment interaction is the variation, coming up from the lack of agreement between the genetic and non-genetic effects in multi-location experiments. So, the national sorghum research program in Ethiopia is developing and evaluating over thousands elite lines across Ethiopia dry lowland areas over years. So, in order to confirm the developed inbred lines, whether they are adapted and good performing lines or not, varietal experiment across environments over location and year need to be planned and executed. Hence, in 2017 (60 advanced lines) and 2018 (90 advanced lines) over 126 with 24 common elite lines including recently released popular varieties as standard check were evaluated as of national variety trial over six locations and two years which make 10 environments in order to evaluate their performance and stability across sorghum growing areas.

2. Materials and Methods

The field testing was conducted during the main cropping season of at six locations (Kobo, Mieso, Shiraro, Erer, Mehoni and Shewarobit) which are representing the moisture stressed lowland areas of Ethiopia located in the altitude range of 1179 - 1574 m.a.s.l, where sorghum is predominantly grown by small holder farmers (**Table 1**).

2.1. Genetic Materials

A total of 126 (90 in 2018 and 60 in 2017 with 24 intersection genotypes which were advanced from 2017 to 2018 national variety trial) candidate sorghum inbred lines including popular recently released variety (Melkam and Argiti) as a standard check were evaluated over 6 dry lowland sorghum growing areas of Ethiopia which make ten environments (**Table 1**). The advanced lines were developed through pedigree crossing method at Melkassa agricultural research

Table 1. Testing location description.

Location	Longitude	Latitude	Altitude (m.a.s.l)	Soil type	Rain fall (mm)	Minimum T˚C	Maximum T˚C
Kobo	39˚38'E	12˚09'N	1513	Vertisol	678	14.8	32
Miesso	39˚21'E	8˚30'N	1470	Vertisol	571	16	31
Shiraro	39˚9'E	14˚6'N	1179	Vertisol	615	20.4	34
Shewarobit	39˚93'E	10˚35'N	1500	Vertisol	713	17.7	33
Mehoni	39˚68'E	12˚51'N	1574	Vertisol	300 - 750	18	25
Erer	42˚15'E	9˚10'N	1297	Vertisol	778	17	37

Source: Center profile assessed from each center.

center and advanced through successive evaluation and selection for their grain yield performance and stability under moisture stressed sorghum growing areas of Ethiopia. All the advanced lines were evaluated for their yield, biomass content, over all agronomic performance and other farmers' attributes.

2.2. Statistical Design

The experiment was conducted at Mieso, Shiraro, Shewarobit, Kobo, Erer and Mehoni in 2017 and 2018 cropping seasons. Row column Design was used to laid out the advanced lines with two replications in a row column arrangement to minimize the special variability (trends) in estimating the genetic value. Each plot contained two rows of 5 m length separated by 0.75 m. At all locations sowing was done in between last week of June to first week of July when enough rain was received. Plantation was done manually by drilling along the farrow, and population was adjusted by thinning considering 0.20 m as spacing between plants. NPS fertilizer was applied at planting time with the rate of 100 kg/ha and Urea was side dressed when the plant reached at knee height at 50 kg/ha basis. Weeding was conducted at least three times during the growing period in each of the test sites depending on the level of weed infestation in the experimental plot.

The following agronomic traits were collected and analyzed to identify stable and superior hybrids compared the standard check variety and hybrid.

2.2.1. Days to 50% Flowering (DTF)

The time between days to emergence to 50% of the plants in a plot reached half-bloom stage.

2.2.2. Plant Height (PHT)

The length from the base of the plant to the tip of the panicle in cm.

2.2.3. Grain Yield per Plot (GY)

Grain yield in kilogram of plants from the three rows and adjusted to 13% moisture level and converted to $qt \cdot ha^{-1}$.

2.2.4. Days to Physiological Maturity (DTM)

The number of days from emergence to the stage when 90% of the plants in a plot reached at physiological maturity, *i.e.*, the stage at which when the panicle lose their pigmentation and begin to dry.

2.2.5. Plant Aspect (PAS)

Over all agronomic desirability score (drought tolerance, earliness, head exertion and compactness, grain size and shape, thresh ability, disease and insect resistance, etc.) was scored using 1 - 5 score where 1 = excellent and 5 = poor.

2.3. Statistical Analysis

The concurrence of genotypes and populations between testing sites was used to check as of the trial series could be analyzed as a single META as of each trial consisting similar test entries, which is the current best practice method for analyzing field trials for plant breeding programs [8]. The MET for sorghum advanced lines included 126 candidate lines including recently released varieties as standard check and executed in six sites of ten environments over two years. Spatial effects were fitted to each trial and then a variance structure was created to produce correlations between trials (environmental) in a factor analytic (FA) framework [8]. Heritability (repeatability) estimates on a line mean basis were calculated for the different environments (trials) groups according to the method proposed by [9].

For each analyzed trait, the genotype × environment (G × E) interactions were considered. These interactions were created by considering a pair-wise correlation matrix for the correlations of each pair of trials. The analysis results in a genetic variance for each trial along with a set of loadings that represent FA frameworks that can be used to recreate the correlation matrix [8]. Although the agronomic traits were measured as usual measurement and score, we are confident that the values satisfy an assumption of normality. The genetic correlations between the trials at the ten environmental trials were identified, with a mean genetic correlation between the trials. Lack of correlation between sites was associated with heterogeneity of variation rather than reranking. These results indicated that there was little G × E interaction for the agronomic trait. In contrast, the genetic correlations between trials for grain yield were indicated.

The model used for analysis is spatial mixed model for MET and can then be written as

$$\begin{aligned} y &= X_{\tau} + Z_{u} + e \\ &= X_{\tau} + Z_{0}u_{0} + Z_{g}u_{g} + e \end{aligned}$$

The fixed effect τ includes environmental main effects and trial specific effects for extraneous field variation (Gilmour *et al.*, 1997), u_g is variety effects at each environment with associated design matrix $Z_g^{(nxmp)}$ and u_0 comprise an additional random effect with design matrix Z_0, and variance matrix G_0.

3. Result and Discussion

The range of genotypic BLUPs for grain yield over the ten trials varied from 0.38 (ETSC14547-7-1) t/ha at MS18SG2N02 to 6.53 (14MWLSDT7196) t/ha at KB18SG2N02 while the overall average grain yield is ranged from 3.23 (14MWLSDT7196) t/ha to 2.28 (14MWLSDT7325) t/ha (**Table 2**). The correlations between testing environments for grain yield performance of testing genotypes in respect to testing environments ranged from 0.85 (SR18SG2N02 and ER17SG2N02) and −0.96 (SR18SG2N02 and MH18SG2N02). Correlations of ~−1 (SR18SG2N02 and MH18SG2N02) indicate that the performance of the genotypes at that specific testing environment falls in opposite direction, implying that the highest performing genotypes in one environment were the lowest performing genotypes in the other environment. Correlation of ~+1 (SR18SG2N02 and ER17SG2N02) is an indication of perfect similarity between the environments,

Table 2. BLUPs for the tested elite lines in each environment and over locations.

Genotype	Grain yield performance at each testing site and year											DTF Mean	PHT mean	PAS mean
	ER17 SG2N02	KB17 SG2N02	KB18 SG2N02	MH18 SG2N02	MS17 SG2N02	MS18 SG2N02	SH17 SG2N02	SH18 SG2N02	SR17 SG2N02	SR18 SG2N02	GY mean			
ETSC14501-2-2	1.98	3.15	6.91	2.76	2.18	2.68	3.66	2.38	3.92	3.15	3.31	74.47	221.07	2.1
14MWLSDT7196	1.21	5.03	6.53	2.28	1.35	1.98	4.16	1.78	5.30	2.68	3.23	74.83	177.95	2.9
14MWLSDT7176	1.18	5.00	5.39	2.20	1.63	0.61	4.55	1.49	5.79	2.76	3.06	75.02	190.74	3.4
14MWLSDT7241	1.46	3.87	5.90	2.04	1.41	1.72	4.04	1.56	5.44	2.80	3.02	77.10	193.51	3.2
13MWF6#6037	1.59	4.62	3.33	1.95	1.40	2.47	4.50	1.54	5.62	2.87	2.99	75.63	182.03	3.3
14MWLSDT7060	1.23	3.43	5.30	2.03	1.32	2.46	4.24	1.52	5.08	2.80	2.94	76.01	176.30	3.4
ETSC14325-4-1	0.99	3.51	6.28	2.17	1.14	2.17	3.88	1.95	4.36	2.68	2.91	74.85	229.51	2.7
ETSC14020-1-1	0.92	3.36	6.15	2.18	1.08	2.62	3.77	2.10	4.07	2.66	2.89	76.87	190.46	2.5
14MWLSDT7040	1.30	3.77	4.60	2.03	1.28	2.18	4.09	1.56	5.21	2.79	2.88	74.46	190.49	3.1
Pipeline2	1.52	3.32	4.01	1.91	1.46	2.10	4.46	1.59	5.49	2.88	2.87	74.10	197.83	3.4
ETSC14149-6-3	1.21	3.46	5.44	2.05	1.20	2.28	3.92	1.71	4.70	2.76	2.87	74.74	201.13	3.2
14MWLSDT7332	1.95	3.34	5.02	1.75	1.35	1.57	4.02	1.14	5.54	2.97	2.87	76.91	182.59	3.4
14MWLSDT7033	1.29	3.84	5.02	1.96	1.15	1.49	4.19	1.27	5.55	2.85	2.86	76.36	184.08	3.8
ETSC14486-1-2	0.93	3.61	5.54	2.22	1.14	2.18	3.91	2.01	4.34	2.65	2.85	73.03	216.25	3.0
ETSC14209-2-2	0.96	3.57	5.92	2.19	1.15	1.75	3.90	2.02	4.36	2.67	2.85	75.38	174.14	3.3
ETSC14307-2-1	1.01	3.47	5.68	2.15	1.14	2.13	3.86	1.99	4.36	2.69	2.85	73.24	181.53	2.3
ETSC14109-2-1	1.04	3.46	5.88	2.13	1.15	1.89	3.86	1.97	4.40	2.70	2.85	73.03	215.62	3.1
ETSC14501-2-2	0.96	3.15	6.06	2.12	1.05	2.68	3.66	2.18	3.92	2.68	2.85/3.57	74.47	221.07	2.1
2005MI5093	0.97	3.23	5.40	2.16	1.16	2.42	3.65	2.10	4.56	2.68	2.83	74.55	197.82	3.2
ETSC14209-5-3	1.17	3.31	5.54	2.05	1.15	2.03	3.82	1.87	4.48	2.75	2.82	74.45	182.81	2.8
ETSC14483-3-1	0.79	3.64	5.77	2.29	1.11	1.74	3.88	2.23	4.12	2.60	2.82	74.53	218.85	2.9
ETSC14124-4-3	1.32	2.91	4.95	1.90	1.11	3.35	3.65	1.76	4.33	2.81	2.81	75.82	178.67	3.3
Melkam	1.65	3.84	5.05	1.86	0.74	2.01	3.77	1.36	4.94	2.88	2.81	76.22	157.91	3.4
ETSC14225-4-2	1.06	3.16	5.50	2.07	1.08	2.61	3.70	2.05	4.12	2.71	2.81	75.59	190.57	2.4
14MWLSDT7400	0.89	3.76	4.85	2.13	1.39	1.81	3.86	1.85	4.81	2.72	2.81	72.77	182.99	3.6
14MWLSDT7238	1.95	3.72	3.49	1.70	1.44	1.44	4.13	0.93	6.16	3.03	2.80	77.42	174.28	3.4
ETSC14116-2-1	1.13	3.66	5.38	2.13	1.22	1.20	4.01	1.78	4.76	2.72	2.80	73.99	178.00	3.0
ETSC14018-3-3	1.61	3.19	4.39	1.80	1.27	2.42	3.91	1.29	5.17	2.92	2.80	78.18	185.90	2.8
14MWLSDT7202	0.90	3.54	5.35	2.16	1.17	2.15	3.89	2.02	4.05	2.67	2.79	74.41	194.32	3.5
14MWLSDT7413	1.14	3.83	4.44	2.02	1.22	1.86	3.70	1.76	5.14	2.79	2.79	73.42	177.28	3.9
ETSC14151-3-2	1.25	3.25	4.73	1.99	1.17	2.57	3.82	1.75	4.57	2.78	2.79	72.85	217.51	3.7
ETSC14524-3-1	1.25	3.22	4.72	1.99	1.16	2.66	3.80	1.73	4.54	2.78	2.79	78.23	183.47	3.1
12MW6146	0.94	3.67	5.32	2.15	1.02	2.16	3.74	2.03	4.10	2.68	2.78	76.32	159.26	4.1
2401	1.10	2.99	4.56	2.00	1.25	2.56	3.96	1.71	4.78	2.78	2.77	72.40	180.69	3.6
ETSC14117-3-1	1.14	3.25	5.01	2.05	1.13	2.29	3.78	1.93	4.35	2.74	2.77	71.82	212.99	2.9

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14MWLSDT7201	1.82	3.37	3.47	1.73	1.40	1.44	4.32	1.22	5.86	2.99	2.76	76.19	188.84	3.8
90MW5319	1.07	3.47	4.19	2.02	0.97	2.06	4.20	1.78	5.04	2.78	2.76	72.52	191.00	3.7
ETSC14487-1-2	1.21	3.19	5.20	2.01	1.14	1.96	3.77	1.91	4.42	2.77	2.76	73.14	205.70	3.0
14MWLSDT7234	1.84	3.72	2.83	1.75	1.44	1.47	4.43	1.17	5.93	2.99	2.76	75.80	172.86	2.9
ETSC14019-4-1	1.38	3.25	4.86	1.93	1.21	1.78	3.86	1.64	4.80	2.83	2.75	74.53	183.45	3.1
ETSC14113-9-1	1.19	3.35	4.91	2.04	1.17	1.84	3.85	1.85	4.55	2.75	2.75	71.59	216.59	2.9
2523	0.78	3.53	5.39	2.16	1.29	2.22	3.43	2.09	3.96	2.66	2.75	71.59	162.04	4.1
ETSC14231-5-1	1.24	3.13	4.80	1.98	1.13	2.43	3.74	1.84	4.42	2.78	2.75	76.11	181.92	2.5
ETSC14123-4-2	0.98	3.06	5.38	2.10	1.03	2.56	3.61	2.22	3.86	2.68	2.75	74.83	192.30	2.6
ETSC14221-9-2	1.04	3.13	5.46	2.08	1.07	2.13	3.68	2.14	4.05	2.71	2.75	73.35	193.96	2.8
12MW6440	1.50	3.54	4.39	1.89	1.18	1.85	3.72	1.62	4.92	2.86	2.75	76.62	184.25	3.8
ETSC14203-5-3	1.08	3.46	5.11	2.12	1.16	1.55	3.87	1.96	4.46	2.71	2.75	74.16	212.52	3.7
14MWLSDT7207	1.40	3.45	4.65	1.96	1.32	1.96	3.82	1.75	4.35	2.80	2.75	76.11	189.37	3.2
ETSC14427-3-1	1.35	3.14	4.42	1.92	1.17	2.47	3.79	1.69	4.64	2.82	2.74	71.40	185.45	2.6
ETSC14217-10-3	1.24	3.45	4.74	2.03	1.21	1.52	3.92	1.75	4.74	2.77	2.74	75.29	180.88	3.6
Argiti	1.40	2.95	4.57	1.87	1.14	2.63	3.70	1.73	4.53	2.85	2.73	77.32	192.21	3.0
ETSC14236-7-2	1.16	2.91	4.47	1.98	1.05	3.41	3.59	1.98	4.04	2.75	2.73	73.91	198.21	2.9
ETSC14225-2-1	1.14	3.35	5.12	2.07	1.15	1.55	3.83	1.93	4.46	2.73	2.73	78.29	172.37	4.0
ETSC14284-2-2	1.58	3.10	4.63	1.80	1.24	1.70	3.85	1.48	5.02	2.91	2.73	76.71	134.52	3.3
2005MI5057	1.96	3.27	3.73	1.70	1.24	1.71	3.98	1.33	5.42	2.98	2.73	74.26	201.82	3.0
ETSC14206-6-3	1.45	2.90	4.21	1.83	1.15	2.95	3.68	1.67	4.56	2.86	2.73	76.22	182.43	3.1
2294	0.52	3.37	6.01	2.31	0.86	2.51	3.62	2.44	3.00	2.54	2.72	69.96	173.09	4.2
12MW6251	1.80	3.31	3.13	1.73	1.37	1.20	4.45	1.13	5.99	3.00	2.71	77.41	201.54	3.6
2001MS7036	0.97	3.14	5.00	2.05	1.10	2.10	3.67	1.93	4.40	2.74	2.71	72.76	199.01	4.5
ETSC14203-5-1	1.22	3.23	4.93	2.01	1.15	1.60	3.79	1.90	4.49	2.77	2.71	74.96	207.66	2.6
2003MW6053	0.76	3.14	5.36	2.14	0.99	2.25	3.61	2.12	3.96	2.67	2.70	73.89	179.72	3.4
12MW6420	1.43	3.13	4.57	1.92	1.01	1.97	3.97	1.75	4.41	2.82	2.70	78.51	153.41	3.9
ETSC14224-1-1	1.36	3.00	4.24	1.90	1.14	2.52	3.71	1.76	4.51	2.83	2.70	77.59	207.17	3.4
14MWLSDT7395	0.80	2.82	5.13	2.09	1.02	2.14	3.84	1.98	4.43	2.71	2.69	72.92	170.29	4.2
05MW6026	1.53	3.05	4.24	1.84	1.26	1.83	3.87	1.58	4.87	2.88	2.69	73.91	188.87	3.0
ETSC14230-3-4	1.00	2.95	4.95	2.07	1.01	2.66	3.56	2.24	3.79	2.69	2.69	76.21	193.24	3.8
99MW4047	0.96	2.91	4.97	2.04	1.08	2.10	3.81	1.92	4.39	2.74	2.69	75.90	154.33	4.2
ETSC14547-7-1	1.46	3.36	5.06	1.90	1.26	0.38	3.95	1.61	5.07	2.86	2.69	71.19	173.57	3.0
ETSC14194-3-1	1.57	3.07	4.20	1.80	1.23	1.84	3.82	1.48	4.97	2.90	2.69	74.69	175.59	3.3
ETSC14121-4-2	1.18	3.22	4.27	2.03	1.13	2.20	3.77	1.93	4.39	2.75	2.69	74.69	185.08	2.7
14MWLSDT7193	1.34	3.40	3.63	1.80	1.21	2.23	3.85	1.48	5.03	2.91	2.69	72.69	171.40	4.0
ETSC14534-5-2	1.33	3.28	5.13	1.96	1.20	0.78	3.86	1.79	4.73	2.81	2.69	77.47	193.19	3.4
ETSC14115-9-1	1.50	2.95	4.23	1.82	1.18	2.27	3.73	1.62	4.70	2.88	2.69	76.99	205.11	3.3

Continued

14MWLSDT7364	1.91	3.20	4.25	1.73	1.68	0.53	4.22	1.19	5.15	2.99	2.68	77.46	186.75	3.6
ETSC14196-1-2	1.68	3.30	4.08	1.78	1.32	1.02	3.99	1.31	5.41	2.94	2.68	74.77	155.01	3.4
ETSC14019-1-1	1.31	2.94	4.27	1.91	1.11	2.61	3.66	1.85	4.36	2.81	2.68	76.87	211.19	2.9
ETSC14112-7-1	1.51	3.02	4.33	1.82	1.20	1.88	3.77	1.60	4.81	2.89	2.68	72.70	194.76	2.6
ETSC14146-2	1.01	2.95	4.92	2.07	1.01	2.56	3.56	2.26	3.80	2.70	2.68	72.44	186.06	3.4
ETSC14154-4-1	1.63	2.98	3.94	1.75	1.23	2.13	3.79	1.43	4.99	2.93	2.68	77.23	153.32	4.1
ETSC14223-6-1	1.32	3.24	4.43	1.96	1.19	1.57	3.83	1.76	4.68	2.81	2.68	77.53	153.44	3.1
14MWLSDT7157	1.60	3.00	4.20	1.82	1.50	1.87	3.76	1.60	4.49	2.89	2.67	76.59	198.86	3.2
14MWLSDT7421	1.50	2.78	4.16	1.81	1.34	1.83	3.85	1.57	4.91	2.89	2.66	75.93	203.17	3.4
ETSC14530-3-1	1.84	3.13	4.17	1.67	1.34	0.80	3.95	1.19	5.53	3.01	2.66	78.24	193.80	4.0
ETSC14202-6-2	1.85	3.05	3.57	1.65	1.32	1.60	3.90	1.15	5.46	3.01	2.66	76.95	156.84	2.6
14MWLSDT7036	0.98	3.08	5.34	2.11	0.95	2.34	3.68	2.19	3.22	2.66	2.66	76.61	189.69	3.6
2004MW6197	1.01	2.62	4.87	2.00	0.99	2.10	3.92	1.91	4.37	2.76	2.65	76.36	174.66	4.3
14MWLSDT7042	1.65	3.12	4.33	1.84	1.09	1.97	3.78	1.71	4.16	2.86	2.65	76.16	191.77	3.1
ETSC14181-5-4	1.01	2.88	5.08	2.05	1.00	2.20	3.53	2.31	3.74	2.70	2.65	76.70	185.33	3.1
ETSC14179-1-2	1.37	2.94	4.46	1.88	1.13	1.89	3.68	1.83	4.46	2.83	2.65	73.92	205.76	3.4
ETSC14154-8-1	2.15	3.17	3.12	1.52	1.44	0.96	4.07	0.75	6.13	3.12	2.64	78.27	172.51	3.3
ETSC14525-4-1	1.70	3.05	3.99	1.73	1.27	1.27	3.86	1.38	5.18	2.95	2.64	77.23	175.66	3.8
ETSC14236-8-1	1.20	3.05	4.86	1.99	1.10	1.45	3.68	2.05	4.26	2.77	2.64	74.32	177.34	2.7
ETSC14531-2-2	1.71	2.97	3.91	1.71	1.25	1.50	3.81	1.39	5.12	2.96	2.63	78.29	212.55	3.2
ETSC14228-2-1	2.33	2.57	2.59	1.33	1.36	2.55	3.80	0.69	5.86	3.20	2.63	78.45	189.17	4.1
2005MI5069	1.47	2.43	4.18	1.81	1.06	1.87	4.04	1.61	4.86	2.89	2.62	77.25	186.32	3.8
12MW6243	1.16	3.05	4.87	1.98	1.03	2.21	3.38	2.00	3.78	2.75	2.62	76.56	142.70	3.6
ETSC14556-8-1	1.77	3.03	3.67	1.69	1.29	1.26	3.87	1.33	5.29	2.98	2.62	79.32	179.96	3.5
14MWLSDT7291	1.76	2.60	3.69	1.67	1.34	1.73	3.69	1.40	5.19	2.98	2.61	75.32	214.32	4.2
14MWLSDT7209	1.92	3.01	3.57	1.62	1.38	1.74	3.28	1.40	5.06	3.00	2.60	77.70	194.56	3.5
ETSC14317-1-2	1.46	3.19	4.06	1.88	1.22	0.78	3.85	1.69	4.90	2.86	2.59	73.25	183.98	2.8
14MWLSDT7324	1.67	2.61	3.87	1.71	1.27	1.83	3.60	1.52	4.85	2.94	2.59	78.12	216.34	2.8
12MW6302	1.88	2.66	3.64	1.64	1.31	1.77	3.59	1.43	4.87	2.99	2.58	77.27	156.85	3.8
ETSC14528-6-1	1.75	2.78	3.25	1.66	1.22	1.98	3.72	1.41	5.00	2.98	2.57	77.11	200.19	3.5
ETSC14437-1-1	1.48	2.53	3.59	1.75	1.07	2.86	3.48	1.82	4.24	2.88	2.57	75.61	188.26	3.8
ETSC14406-3-1	1.40	3.14	4.05	1.90	1.19	0.62	3.81	1.82	4.73	2.84	2.55	70.97	191.16	3.8
04MW6043	2.35	2.95	2.90	1.42	1.39	1.56	3.13	1.14	5.53	3.13	2.55	77.83	197.84	3.8
04MW6079	2.01	2.46	3.14	1.56	1.09	1.49	4.12	1.24	5.28	3.05	2.54	77.90	175.43	3.4
14MWLSDT7311	1.77	2.31	3.62	1.63	1.19	1.78	3.64	1.44	5.07	2.99	2.54	76.80	218.29	3.3
2003MW6038	1.23	2.46	4.54	1.87	0.95	2.15	3.42	1.90	4.05	2.81	2.54	75.32	188.98	3.9
ETSC14017-1-1	1.89	2.86	3.04	1.60	1.29	1.25	3.81	1.25	5.34	3.03	2.54	78.68	169.88	4.0
13MWF6#6077	1.30	2.50	4.44	1.84	0.93	2.13	3.33	1.87	4.11	2.83	2.53	77.53	146.22	3.5

Continued

14MWLSDT7410	1.39	2.35	4.39	1.82	1.07	2.13	3.47	1.86	3.83	2.84	2.52	77.58	193.93	3.7
14MWLSDT7402	1.29	2.51	4.79	1.92	0.97	2.33	3.41	2.09	3.04	2.76	2.51	75.64	225.95	3.3
ETSC14124-8-3	1.39	2.58	3.34	1.81	1.05	2.49	3.49	1.98	4.13	2.85	2.51	78.19	210.46	3.6
ETSC14397-6-1	1.70	2.96	3.48	1.72	1.24	0.57	3.80	1.54	5.08	2.95	2.50	79.17	180.55	3.9
2005MI5064	2.17	1.98	2.97	1.44	1.41	1.58	3.74	1.17	5.41	3.11	2.50	77.40	190.88	3.6
14MWLSDT7310	2.03	2.33	3.33	1.53	1.05	1.75	3.48	1.37	5.04	3.04	2.50	77.21	213.10	3.2
14MWLSDT7191	1.20	2.43	4.67	1.88	0.87	2.29	3.16	2.04	3.53	2.78	2.49	78.89	179.97	4.2
12MW6444	2.11	1.94	3.04	1.46	1.34	1.63	3.68	1.22	5.30	3.10	2.48	77.24	196.31	3.2
14MWLSDT7322	2.02	1.84	3.10	1.46	1.14	1.69	3.56	1.28	5.31	3.08	2.45	77.94	217.37	3.2
ETSC14435-3-3	2.20	2.75	2.22	1.43	1.36	0.65	3.86	0.98	5.79	3.15	2.44	78.43	143.70	4.5
ETSC14015-2-2	1.79	2.63	2.55	1.61	1.20	1.52	3.65	1.50	4.92	3.00	2.44	78.83	172.63	3.9
12MW6471	2.32	2.50	2.97	1.41	1.06	1.74	3.04	1.30	4.92	3.10	2.44	78.83	201.24	3.5
ETSC14204-4-1	2.09	2.56	2.02	1.45	1.28	0.91	3.71	1.21	5.40	3.11	2.37	79.32	157.58	4.3
14MWLSDT7115	1.94	1.57	3.23	1.47	1.05	1.85	3.38	1.44	4.74	3.05	2.37	78.21	196.90	4.1
ETSC14143-4-2	2.08	2.30	1.69	1.41	1.22	1.58	3.56	1.30	5.12	3.11	2.34	79.97	198.94	4.2
14MWLSDT7325	1.74	2.04	1.83	1.49	1.21	2.10	3.24	1.30	4.79	3.05	2.28	79.73	210.53	3.6
Grand mean	1.43	3.10	4.40	1.88	1.19	1.90	3.79	1.67	4.73	2.85	2.69	75.78	187.64	3.39
Max	2.35	5.03	6.53	2.31	1.68	3.41	4.55	2.44	6.16	3.20	3.23	79.97	229.51	4.50
Min	0.52	1.57	1.69	1.33	0.74	0.38	3.04	0.69	3.00	2.54	2.28	69.96	134.52	2.25

ER17SG2N02 = Erer 2017, KB17SG2N02 = Kobo 2017, KB18SG2N02 = Kobo 2018, MH18SG2N02 = Mehoni 2018, MS17SG2N02 = Miesso 2017, MS18SG2N02 = Miesso 2018, SH17SG2N02 = Shiraro 2017, SH18SG2N02 = Shiraro 2018, SR17SG2N02 = Shewarobit 2017, SR18SG2N02 = Shewarobit 2018.

hence selection of best genotypes in one environment is the same as selection for another environment (**Figures 1(a)-(c)**).

This study identified the relative genetic merits of different advanced lines where trials are correlated with the corresponding environments and year of the experiments. When trials are correlated (similar response of genotypes at testing environment) selecting best lines in a given environment is the same as selecting best material in another environment. Most of the trials except SR18SG2N02 were strongly positively correlated for plant height which is the most important trait for biomass improvement to get good genotype for forage and feeding purpose (**Figure 1(b)**). selecting bets line for forage from one of the corelated environments is the same as selecting from the other site. Then, information from multiple environment can be combined to improve genetic gains. In this case, META can help the breeder to understand the broad and specific adaptation of genotypes over a range of target environments. The associated heritability of grain yield is varying from 61.15 (MS17SG2N02) and 98.02 (MS18SG2N02) % and averaging 79.56% (**Table 3** and **Figure 2**). Similar finding was reported for malt barley experiment across environments and over season following similar fashion of this study [10].

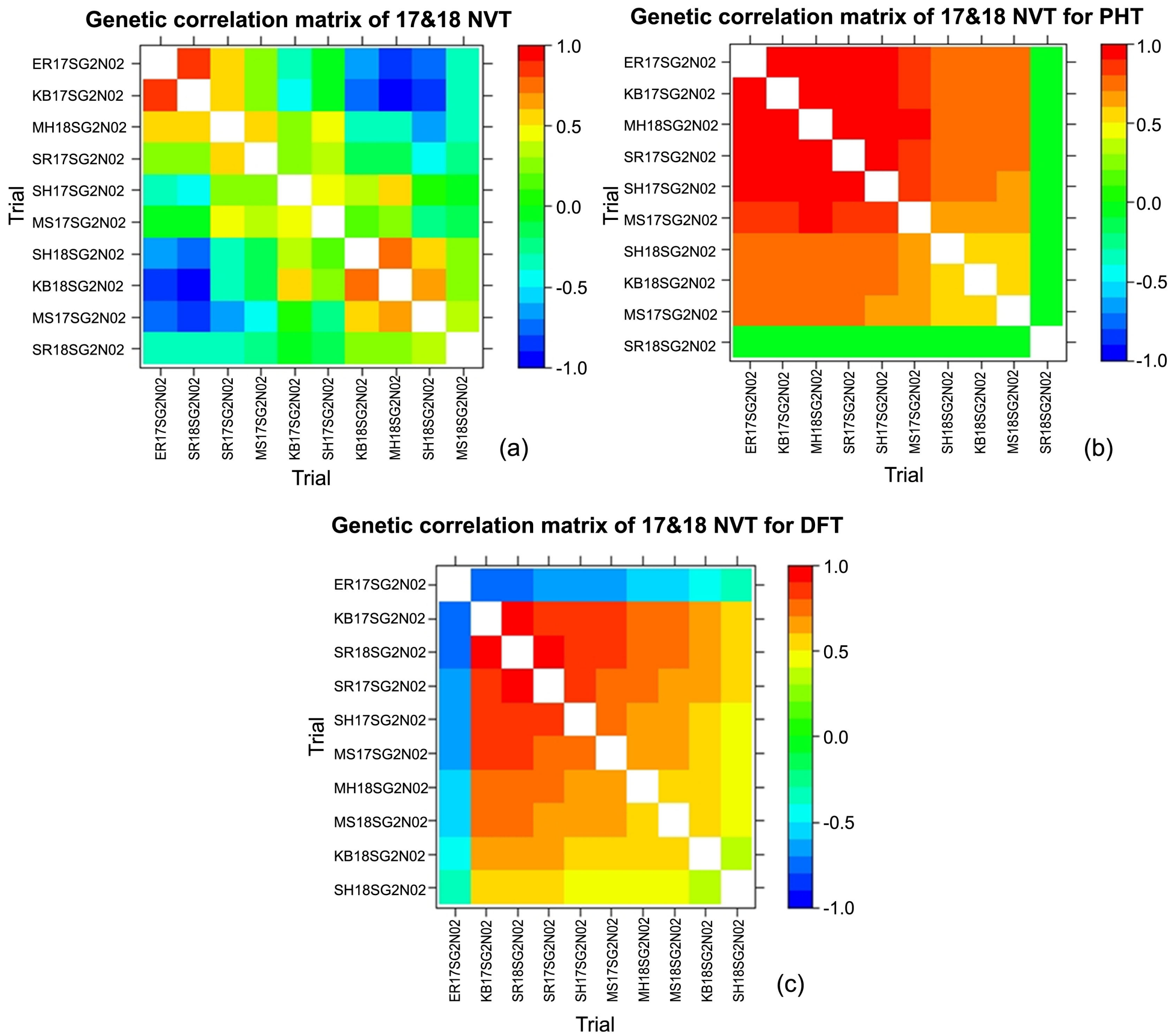

Figure 1. Genetic correlation for grain yield (a), plant height (b) and DTF (c) across environments.

Table 3. Over all mean and heritability performance for yield, days to flowering & plant height of the lines at each of trials.

Trial	Grain yield				Days to flowering				Plant height			
	Mean	Genetic σ	Error σ	H_2	Mean	Genetic σ	Error σ	H_2	Mean	Genetic σ	Error σ	H2
ER17SG2N02	1.47	0.248	0.33	74.58	74.9	0.5	19.1	47.1	150.7	342.8	420.2	92.0
KB17SG2N02	3.11	0.609	0.797	79.13	86.7	15.9	13.6	90.5	188.9	718.7	148.5	97.2
KB18SG2N02	4.44	1.452	1.05	76.56	77.8	18.5	10.7	84.7	212.5	1363.7	295.1	93.3
MH18SG2N02	1.9	0.079	0.901	62.58	79.4	5.1	71.1	53.0	148.2	62.6	491.4	86.5
MS17SG2N02	1.27	0.063	0.582	61.15	77.7	6.6	8.9	83.3	151.6	360.8	308.8	88.0
MS18SG2N02	1.87	0.437	0.009	98.02	71.4	12.4	7.1	86.9	186.4	454.8	288.3	92.4
SH17SG2N02	3.8	0.173	0.222	73.45	70.1	11.7	3.9	92.2	218.6	492.4	609.4	90.0
SH18SG2N02	1.63	0.173	0.262	75.85	73.7	17.6	0.9	96.3	177.6	562.0	179.7	91.3
SR17SG2N02	4.81	0.715	1.42	70.12	72.3	13.9	5.8	91.1	219.9	1062.0	100.3	97.9
SR18SG2N02	2.86	0.029	0.84	68.78	73.5	0.0	5.0	33.1	216.8	69.3	1152.5	16.7

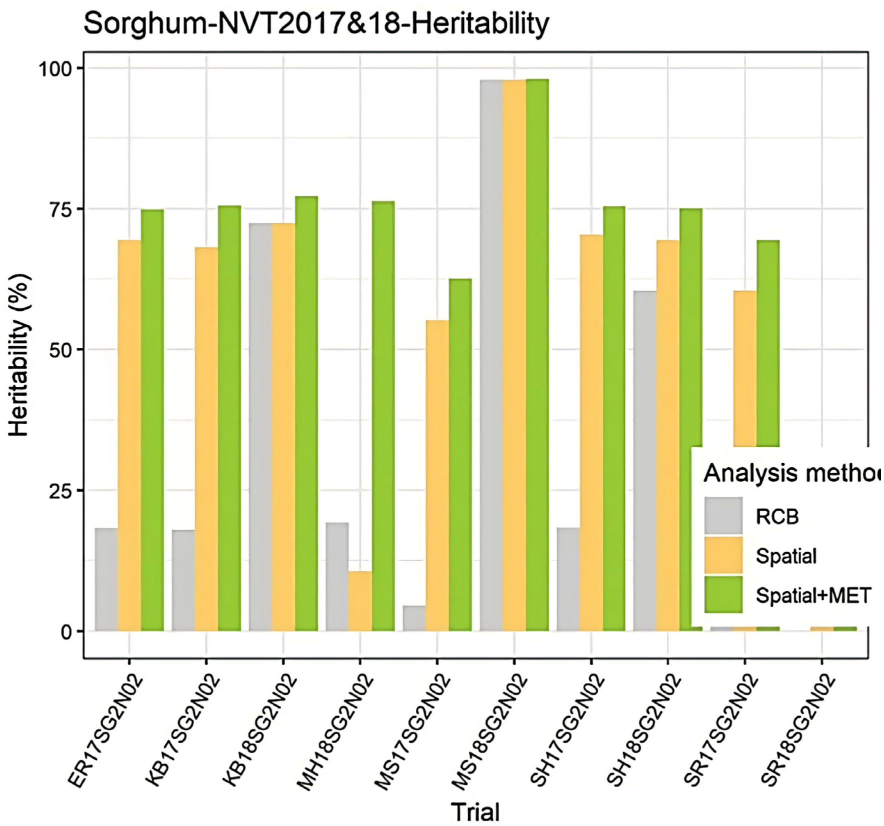

Figure 2. Heritability of grain yield for the advanced lines with their respected testing environments computed using different analytical models.

Heritability for days to flowering and plan height also shows a better repeatability ranged from 33.1% to 96.3% with an average of 64.7% of reputability over all testing environments and this indicates that days to flowering is one of the traits that are highly heritable from parent to progenies (Table 3). Similarly plant height is one of the most preferred traits that research needs to excavate more parallel to improving grain yield. Because there is no compromising the biomass component for the farmers which is the best input for animal feed and forage in Ethiopia and other like areas specially where an agrarian life is mostly depended on mixed farming system like animal husbandry and cropping is main components of their life time for sustainability. So, based on this experiment output plant height (the main component for biomass production in sorghum) is found highly heritable trait (Table 3) and those all trail environments are highly correlated ranged from +1 to 0 which indicate that the genotypes were evaluated in ideal testing environments and selection made for a given environment could be compliment for another location (Figure 1) for plant height. So, based on the heritability result for plant height is ranged from 16.7% to 97.9% with an overall mean of 57.3% across testing environments. This indicates that taking more samples to measure plant height may not give significant (varied) result deviate from the result obtained from single observation (sample).

Based on overall agronomic preference (PAS) and other agronomic traits

(PHT, GY and DTF) ETSC14501-2-2 and 14MWLSDT7196 were found better over the rest genotypes and standard checks followed by 14MWLSDT7176, 14MWLSDT7241 and 13MWF6#6037. These lines were found ideal for crossing parents in population improvement related activities. Based on the grain yield and overall agronomic performance (PAS) including plant height to know the biomass contribution and days to flowering to estimate its earliness, the days taken for maturity, ETSC14501-2-2 is presented for variety verification trial at sorghum growing dry lowland areas of Ethiopia to be verified for end users in 2019 cropping year.

Graphical explanation of the MET biplot data is commonly used to explain genotype by environment interactions. In **Figure 3**, the concepts of which genotype won and where is illustrated. Plots show that the environment with the longest line from the center measures the discriminativeness of that environment when compared with others. For example, SR17SG2N02, KB18SG2N02 and KB17SG2N02 were among the most discriminative environments. This means these environments had considerable contributions in discriminating genetic variations. On the other hand, environments with less distances from the center were those stable environments, hence they explained less genetic variations. In additions, when a specific genotype is close to a given environment, it indicates that the genotype is the winner for that specific environment. That means that genotype is the best performer for that trial. This statement is supported by (**Figure 4**) which stated that the clustering of testing trials in respect to testing location and year based on the grain yield performance of the advanced test lines.

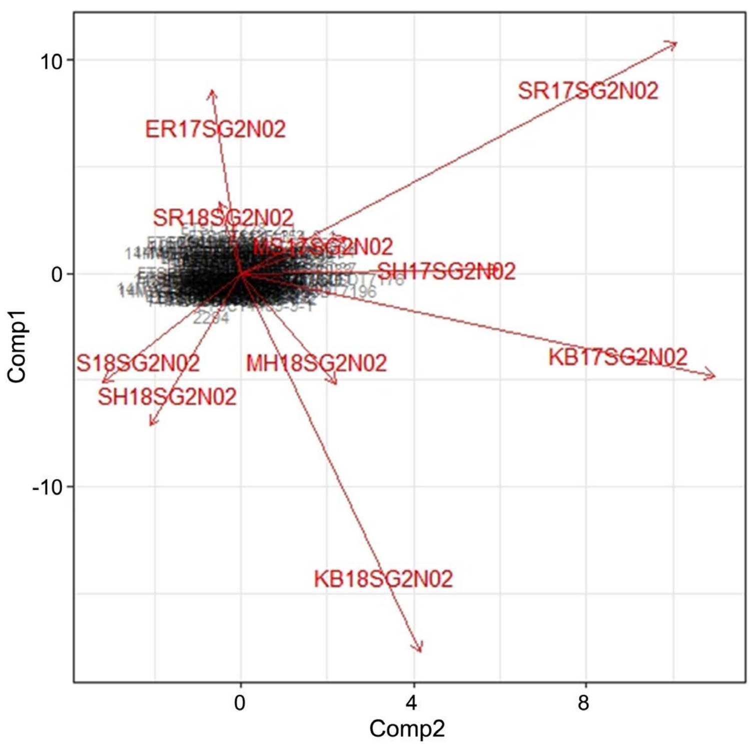

Figure 3. G × E biplot of the advanced lines.

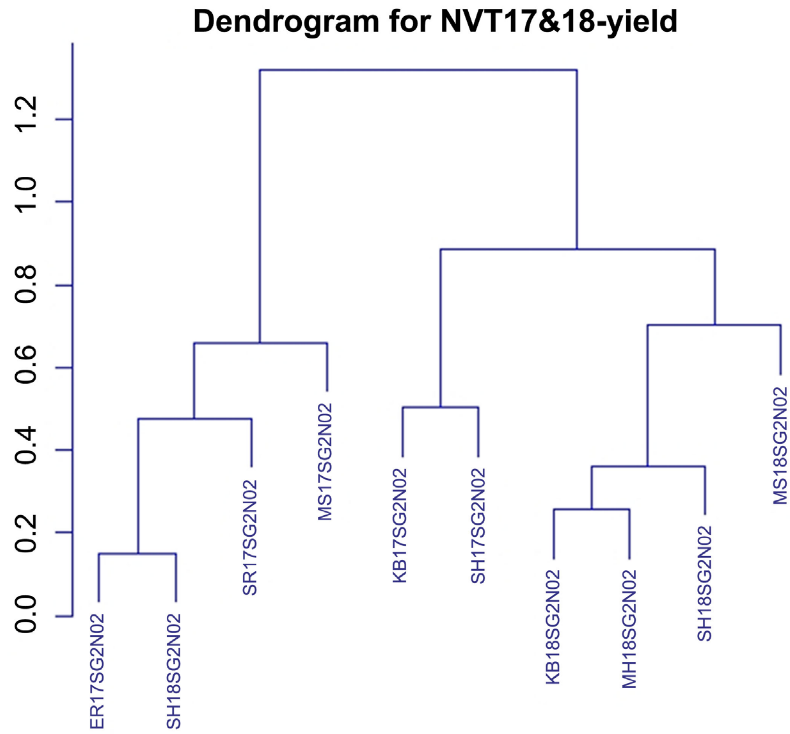

Figure 4. Clustering of testing environments (trials).

4. Conclusions

The national sorghum research program developed promising elite lines and evaluated at sorghum growing areas. Following this a total of 126 advanced lines at national variety trial were evaluated at six testing locations over two cropping years 2017 and 2018 which make ten testing environments. Based on the combined analysis of the data ETSC14501-2-2, 14MWLSDT7196, 14MWLSDT7176, 14MWLSDT7241 and 13MWF6#6037 were found the top ranked lines which their grain yield potential was predicted to 3.31, 3.2, 3.1, 3.0 and 3.0 t/ha respectively. The trial was strongly and negatively correlated from +1 (SR18SG2N02 and ER17SG2N02) which were found in the same cluster group to −1, (SR18SG2N02 and MH18SG2N02) which were laid in different clusters and this correlation helped to identify the best genotype from where it grew well.

One of the most important things which help the breeder to advance the best genotype from where it was adopted for a given trait is heritability which is the best indicator to know how much that given trait is inherited from parents to filial. From the presented analysis, heritability for grain yield is found in between of 61.15% for MS17SG2N02 and for MS18SG2N02 is 98.02%. So, the highest heritability was recorded for Miesso in 2018 trial while the comparable low heritability was recorded for Miesso in 2017 trial. Based on the overall agronomic data analysis result ETSC14501-2-2 with pedigree of Redswazi/Meko-1 is presented for variety verification committee to be released for farmers and commercial seed producers after getting farmer preference evaluation on their farm land with their own farming practices for dry lowland sorghum growing areas of Ethiopia.

Acknowledgements

Thanks to Ethiopian Institutes of Agricultural Research (EIAR) especially National Sorghum research program who developed and evaluated these lines nationally.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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