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Assessment of genetic diversity in sorghum (*Sorghum bicolor* (L.) Moench) for reactions to *Striga hermonthica* (Del.) Benth.

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Abstract

Striga is the largest biological barrier to sorghum production in several sorghum growing areas in Africa and Asia. Field experiments were conducted to assess the diversity of 49 sorghum genotypes for their reaction to *Striga hermonthica* and grouped them. Different multivariate analysis, including principal component and cluster analysis, were made on 15 (for *Striga*-infested) and 6 (for non-infested) yield, yield attributes and *Striga* resistance/tolerance parameters. The result showed that the first four and three PCs explained 77 and 73 % of the total variation under *Striga* infested and non-infested conditions, respectively. Emerged *Striga* counts at 17 and 20 weeks after planting, *Striga* severity , *Striga* vigor, area under *Striga* number progress curve and area under *Striga* severity progress curve were the most important traits in the first PC. However, grain yield and dry weight had strong association and were loaded on the second PC. Scatter plot of PC1 and PC2 revealed sufficient diversity among genotypes and separated them with those field resistant and tolerant to *Striga* from the susceptible ones. The Ward's minimum variance cluster analysis grouped the 49 sorghum genotypes in to four and three distinct clusters under *Striga* infested and non-infested conditions, respectively. Under *Striga* infested condition, most members of cluster I and III showed adequate degree of *Striga* resistance and tolerance, while cluster II and IV exhibited susceptibility to *Striga*. From these observations, it could be suggested that rich genetic sources of resistance and tolerance are available in a range of landrace, which could be utilized for future breeding and germplasm conservation programs aimed at improving *Striga* resistance and tolerance in sorghum.

Keywords: Genotypes; Non-infested; Sorghum; *Striga hermonthica*; *Striga*-infested.
Abbreviations: ASNPC_ area under *Striga* number progress curve; ASVPC_ area under *Striga* severity progress curve; DSE_days to *Striga* emergence; DSF_days to sorghum flowering; GY_ grain yield; IBPGR_institute of biodiversity and plant genetic resources; ICRISAT_international crop research institute for semi-arid tropics; IITA_international institute of tropical agriculture; PAL_ panicle length; PH_ plant height; PCA_ principal component analysis; SDW_*sorghum biomass dry weight*; SC_*Striga* emergence count; SH_*Striga* height; SSEV_ *Striga* severity; SV_ *Striga* vigor; STW_*Striga* weight; TIL_tillering; WAP_weeks after planting.

Introduction

Sorghum is an important cereal crop globally next to maize, wheat rice and barely. Over 80% of the sorghum production comes from Africa and Asia (FAO, 2010). In Ethiopia, sorghum is the principal food crop for people living in marginal areas where erratic rainfall, high temperatures, poor soil fertility and *Striga* infestation are major production problems. The parasitic weed (*Striga hermonthica*) infestation is gravely limiting sorghum production in Africa in general and in Ethiopia in particular. In Africa the weed has infested about 50 million hectares of crop lands which has negatively affected nearly 300 million people (Ejeta, 2007). The yield loss accounted to *Striga* infestation is immense, reaching up to 65% on average. In countries like Ethiopia and Sudan the damage is worse, reaching up to 100% yield loss, especially when it comes to drone prone (Ejeta et al., 2002). According to Reda and Parker (1994), in some areas in Ethiopia because of heavy infestation it is common to get farmers who have either abandoned their land or switched to other less important crops. Different researchers (Bayu et al., 2001; Omanya et al., 2004; Rodenburg et al., 2005) have reported variability in sorghum responses to *Striga* infestation. Some sorghum genotypes support significantly fewer *Striga* plants and give higher grain yield than others. Some other genotypes show smaller yield reductions than others under the same level of infestation. Some are highly susceptible and would not give yield at all. The presence of this wide range of variability in *Striga* resistance and tolerance traits among sorghum genotypes suggests an opportunity to develop high yielding and resistant/tolerant genotypes through hybridization.

Though there is no single effective method to control *Striga*, developing *Striga* resistant and tolerant genotypes is the most promising, practical, and cost effective approach to reduce the debilitating effects of *Striga* in small holding farming systems in Africa (Ejeta and Butler, 1993).

Therefore, assessing the availability of variability in the existing gene pool should be the first step to begin developing integrated *Striga* management technologies. Despite the fact that Ethiopia is the center of sorghum diversity, no or little efforts has been made to study variability in the genetic pool to *Striga* resistance and tolerance. Hence, the present study was conducted to assess sorghum genetic diversity to *Striga* hermonthica resistance and tolerance.

Results

Principal component analysis

Under *Striga* infested conditions, the mean squares among sorghum genotypes were significant for all traits except panicle length, *Striga* vigor score, ASVPC and *Striga* height in 2010 and panicle length, plant height and tillering in 2011. In the combined years, there were significant variations for all tested traits except *sorghum biomass dry weight* under non-infested conditions indicating large genotypic variation (Table 2). The large genotypic variation in yield, yield attributes, *Striga* resistance and tolerance traits of sorghum genotypes reveals the usefulness of multivariate analysis to describe genetic diversity for their reactions to *Striga hermonthica*. From 15 (*Striga* infested) and 6 (non-infested) principal component that were set, four and three were found to have Eigen values > 1, under *Striga*-infested and non-infested conditions, respectively. These PCs contributed 77 and 73% of the total variability among genotypes under *Striga*- infested and non-infested conditions, respectively (Tables 3 and 4). Under *Striga* infested conditions, the first principal component (PC1) alone explained 45% of the total variation, mainly due to variation in *Striga* related traits: *Striga* emergence counts at 17 and 20 weeks after planting (WAP), SSEV, ASVPC, ASNPC and STW. Characters which contributed more to the second principal component (PC2) accounted for 13% of the total variation and were dominated by grain yield (GY), *sorghum biomass dry weight* (SDW), *Striga* vigor (SV), and *Striga* height (SH). The third principal component (PC3) with 10% of the variance was composed of plant height (PH), tillering (TIL), and panicle length (PAL) with positive loading in the axis. Days to sorghum flowering (DSF) were loaded on the 4^{th} principal component (PC4) (Table 3). Under non-infested conditions, PH, PAL TIL and DSF were loaded on PC1 with 32% of the total varation. GY and SDW were loaded on PC2 (24%). (Table 4).

Cluster analysis

The traits loaded on the axes were employed to group the genotypes in to closely related clusters using Ward's minimum variance cluster method. Based on yield, yield attributes, *Striga* resistance and tolerance traits, 49 sorghum genotypes were grouped in to 4 clusters under artificially *Striga* infested (Fig. 3) and 3 clusters under non-infested conditions (Fig. 4) which showed remarkable correspondence with the PCA. Under *Striga* infestation, cluster I comprised of 21 genotypes (Fig. 3). The genotypes were GY ranged from 864 kg ha^{-1} for Afesso to 2099 kg ha^{-1} for Mankebar and the cluster had mean GY of 1316 Kg ha^{-1} (Table 5). The genotypes in the cluster generally had mean *Striga* counts (12.5 *Striga* plot^{-1}) at 20 WAP and they had wide ranges (1266) and variances (132485) in GY. The genotypes Mankebar, Wogerie and Degalit were members of this cluster and outstanding in terms of GY but with moderate emerged *Striga* counts suggesting that tolerant to *Striga*. Cluster II was composed of 8 genotypes. These genotypes were generally low yielding, with GY below the average yield of the study (1228 Kg ha^{-1}). Moreover, these genotypes had mean emerged *Striga* counts (14.8 *Striga* plot^{-1}) at 20 WAP. This cluster contained Cherkit, Keyehele, Achero, Mayite and Mokakie which had low GY and high number of emerged *Striga* counts. However, the highest yielding genotype, Mera is also a member of this cluster indicating that it is tolerant to *Striga*. Cluster III was represented by 15 genotypes. This cluster contained resistant checks (Brhan and Gobiye) and the promising genotypes like Nechmashila I, Woftel, Tetron, Zegerie, Wolegie and Eyssa. The cluster had high mean GY (1574 Kg ha^{-1}) with a large cluster variance (261787) and a wide range (1291). Cluster IV contained 5 genotypes. This cluster contained the lowest yielding local susceptible checks, Wencho (395 Kg ha^{-1}) and Gabiso (457 Kg ha^{-1}), which had the highest emerged *Striga* counts, Gabiso (46.7 *Striga* plot^{-1}). However, this cluster contained the highest yielding genotypes, Zengada (2272 Kg ha^{-1}) with its moderate *Striga* counts (25.7 *Striga* plot^{-1}) indicating that it is tolerant to *Striga*. The genotypes in the cluster had the lowest mean GY (994 Kg ha^{-1}) with the highest mean SC (29.4 *Striga* plot $^{-1}$) . The variance (599466) and range (1877) in GY for the genotypes with in this cluster was quite large (Table 5). Under non-infested condition, 25 sorghum genotypes were grouped in cluster I (Fig. 4). The genotypes in this cluster recorded low GY (1984 Kg ha^{-1}) and tillering capacity (Table 5). Similarly, the cluster contained genotypes with GY below the trial mean (2266 Kg ha^{-1}). The 14 genotypes in Cluster II had a mean GY of 2304 Kg ha^{-1} with a range of 1994 Kg ha^{-1} to 3870 Kg ha-1 (Table 5). The 10 genotypes in cluster III had a mean GY of 2919 Kg ha^{-1} with a range of 1463 - 3333 Kg ha^{-1}. The outstanding genotypes in terms of GY came from this cluster and were Mankebar, Zengada, Eyssa, Woftel, and the resistant checks (Gobiye and Brhan) are members. The cluster means, minimum and maximum values, ranges and variances estimated for the various character are presented in Table 5 which indicates considerable differences between different clusters. For example, eleven of the genotypes assigned to cluster I were common, while 3 and 6 were common in cluster II and III, respectively under both *Striga* infested and non-infested conditions. Moreover, the genotypes were assigned to four and three major clusters under *Striga* infested and non-infested conditions, respectively. A close examination of the genotypes in the different clusters showed 21,8,15, and 5 genotypes were classified in to cluster I,II,III and IV respectively, under *Striga* infested conditions while 25,14, and 10 genotypes were placed in cluster I,II and III respectively, under non-infested conditions.

Scatter plot

Scatter plot was prepared according to the PC1 and PC2 (Fig. 2). These PC1 and PC2 contained GY, SDW and basic *Striga* resistance indices which accounts for more than 58 % of the total variation in the set of data than all other traits. Results of scatter plot supported the results of cluster analysis and genotypes were distributed in two sides of scatter plot (Fig. 2). The genotypes of cluster I and III were settled on left side (*Striga* resistant and tolerant) and the genotypes of cluster II and IV on right side of the plot (*Striga* susceptible) (Fig. 2). Starting from the positive to the negative values of PC1 (cluster IV to cluster III), these genotypes indicated a gradual

Table 1. Entry (identification), Status, Place of collection and Origin of sorghum genotypes.

Entry (identification)	Status	Place of collection	Origin
1 (Afesso)	Landrace	Shoa	Ethiopia
2 (Nechumera), 3 (Yekersolatie),	Landrace	Wollo	Ethiopia
4 (Brhan)	Variety	SARC	USA
5 (Jamyo), 6 (Gedido), 7 (Tegelie)	Landrace	Wollo	Ethiopia
8 (Cherkit)	Landrace	Shoa	Ethiopia
9 (Mera)	Landrace	Wollo	Ethiopia
10 (Zolie)	Landrace	Gonder	Ethiopia
11 (Gobiye)	Variety	SARC	USA
12 (Keyehele)	Landrace	Wollo	Ethiopia
13 (Tewzalie)	Landrace	Gonder	Ethiopia
14 (Keymashila)	Landrace	Wollo	Ethiopia
15 (Mankebar), 16 (Gemelie)	Landrace	Gojam	Ethiopia
17 (Keyhumera)	Landrace	Wollo	Ethiopia
18 (Nechtenkish)	Landrace	Gojam	Ethiopia
19 (Keyguagurti)	Landrace	Wollo	Ethiopia
20 (Wogerie)	Landrace	Gojam	Ethiopia
21 (Tetron)	Landrace	Gonder	Sudan
22 (Nechmashila I), 23 (Woftel), 24 (Mako), 25 (Mokakie), 26 (Bobie), 27 (Gobie)	Landrace	Gojam	Ethiopia
28 (Lili), 29 (Bulie), 30 (Kucho), 31(Eyssa)	Landrace	Gonder	Ethiopia
32 (Nechshegurti)	Landrace	Wollo	Ethiopia
33 (Kuchbyie), 34 (Temego),	Landrace	Gojam	Ethiopia
35 (Degalit)	Landrace	Wollo	Ethiopia
36 (Wolegie), 37 (Arero), 38 (Amoratie)	Landrace	Gojam	Ethiopia
39 (IS9302)	Variety	MARC	ICRISAT, India
40 (Gabiso), 41 (Achero), 42 (Fincho) 43 (Nechmashila II), 44 (Zegerie), 45(Zengada),46 (Gambilo), 47 (Wencho)	Landrace	Gojam	Ethiopia
48 (Abola)	Landrace	Wollo	Ethiopia
49 (Mayite)	Landrace	Shoa	Ethiopia

ICRISAT = International Crops Research Institute for the Semi-Arid Tropics, MARC =Melkassa Agricultural Research Center, SARC = Sirinka Agricultural Research Center.

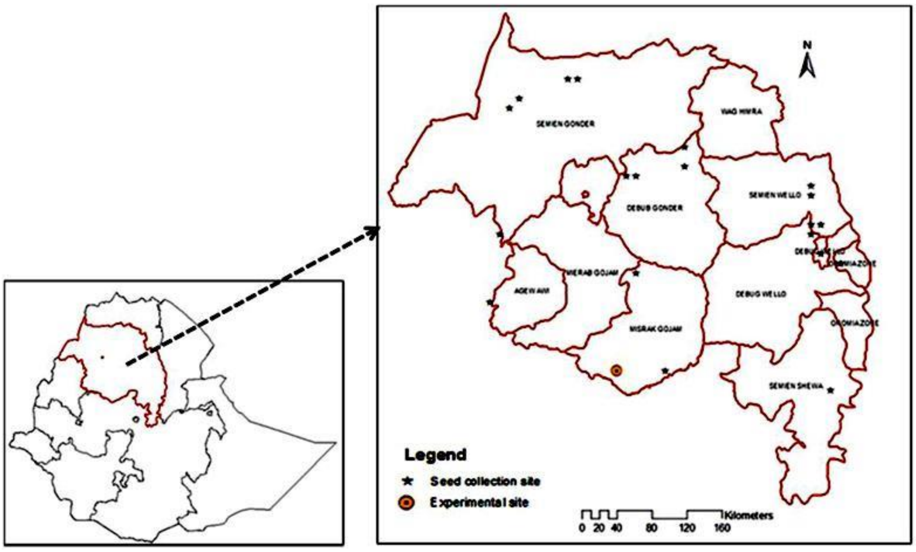

Fig 1. Map and position of the experimental field and seed collection sites at Amhara National Regional State, Ethiopia.

increase in GY and yield attributes with a decrease in *Striga* related traits.

Discussion

The primary objective of this study was to group 49 sorghum genotypes on the basis of yield, yield attributes, *Striga* resistance and tolerance traits. Analysis of variance was performed for the aforementioned traits to confirm the existence of variability among sorghum genotypes. The mean squares among sorghum genotypes were highly significant for almost all traits indicating large genotypic variation. Hence, the first step for achieving grouping of sorghum genotypes was well satisfied. PCA is important to observe the interrelationship in the whole set of data that explains the largest proportion of the variance which could be exploited to execute a breeding program aimed at improving *Striga* resistance and tolerance. As Chatfied and Collins (1980) stated, components with an eigenvalue of less than 1 should be eliminated so that fewer components are dealt with. Furthermore, Hair et al. (1998) suggested that eigenvalues greater than one are considered significant and component loadings greater than ± 0.3 were considered to be meaningful. In the present study, the PCA analysis divided the total variance in to 15 (*Striga* -infested) and 6 (non-infested) PCs out of which the first four and three PCs contributing substantial amount of diversity among the genotypes under artificially *Striga*-infested and non-infested conditions, respectively. The first PC was mainly due to variation in *Striga* resistant indices like emerged *Striga* counts at 17 and 20 weeks after planting, *Striga* severity, area under *Striga* number progress curve, area under *Striga* severity progress curve, and *Striga* weight but had negative loadings of yield and yield attributes like grain yield, sorghum biomass dry weight, plant height and panicle length. Menkir (2006) and Badu-Apraku (2007) reported that variation of maize genotypes in the first PC was due *Striga* related traits under *Striga*- infested conditions. In contrast to our result, Badu-Apraku et al. (2006) reported that variation in PC1 was mainly due yield related traits in maize under *Striga* infested conditions. As shown in Fig. 2, *Striga* count, area under *Striga* severity progress curve, area under *Striga* number progress curve, grain yield and sorghum biomass dry weight were the main contributors of diversity in the PC1 and PC2 which accounts for more than 58 % of the total variation in the set of data than all other traits. These two PCs were the most appropriate to use in the preliminary grouping of the 49 sorghum genotypes evaluated under *Striga* -infested conditions and clearly separated the sorghum genotypes with field resistance to *Striga* from the susceptible ones. Badu-Apraku et al. (2006) showed that 51% of the total variation was explained by the first two PCs in evaluating maize inbred lines. Grouping of sorghum genotypes under both infested and non-infested conditions based on yield, yield attributes and *Striga* related traits are highly desirable in sorghum breeding for designing guide lines for use in developing *Striga* resistance and tolerance varieties. We employed the Ward's minimum variance cluster methods for grouping of genotypes under both *Striga*- infested and non-infested conditions. The cluster analysis showed considerable amount of diversity for sorghum genotypes under *Striga* infested conditions. The genotypes in I and III (Nechmashila I, Woftel, Wolegie, Eyssa, Tetron, Zegerie) cluster were characterized by higher GY with low and moderate emerged *Striga* counts. This revealed that this group of genotypes could be exploited for improvement in *Striga* resistance and tolerance. Provided that a uniformly infested field is available, low emerged *Striga* counts combined with higher GY has been considered reliable selection criterion for resistance screening in the field (Haussmann et al., 2000; Badu Apraku & Akinwale, 2011). Kim (1994) and Ast et al. (2000) reported that selection of landraces based on higher GY with moderate emerged *Striga* counts have been considered important parameters in evaluating genotypes for *Striga* tolerance. On the other hand, the genotypes in cluster II and IV were characterized by low grain yield with high emerged *Striga* counts suggesting susceptibility to *Striga*. However, Rodenburg and Bastiaans (2011) showed that resistance or tolerance alone is neither complete nor everlasting however, each reaction types by itself is useful and can be combined in the same host-plant through breeding. Hence, a variety with high resistance and low tolerance or high tolerance but low resistance , while not recommendable for direct use by farmers, can provide useful genetic material for breeding purpose. The results of this study also revealed that grouping of genotypes based on Ward's minimum variance cluster analysis under *Striga*-infested condition was different from that under non-infested conditions. This implies the need for evaluating genotypes in contrasting environments to identify those with a consistent response to the environment under study. Similar findings were reported by Menkir et al. (2003) and Badu-Apraku et al. (2005) for selected maize inbred lines evaluated in stressed and free environment.

Materials and Methods

Description of the study area

The field experiments were conducted in Bassoliben district (Chemoga gorge), Eastern Gojam zone, north western part of Ethiopia. The area is very hot spot to *Striga*. The experimental field was situated at 10.1055' N latitude, 37.602'E longitude, at an altitude of 2010 m above sea level. It is characterized by a monomodal, long, and dependable rainy season occurring from May to October with an average of 180 days of growing season (MOA, 2010). The study site received an average rainfall of 104 and 95 mm during the sorghum production seasons (June to November) of 2010 and 2011, respectively, while the temperature of the area averaged 26 and 27 ^{0}C during the same period of each experimental year. The soil type is Sandy clay with 1.68 % organic matter, 14 mg P/Kg , and pH of 6.25.

Plant materials

Forty- nine sorghum genotypes which includes two standard resistant checks, one standard susceptible check, 2 local susceptible checks and 44 local landraces that were claimed by farmers as resistance and tolerance to *Striga* were used for the study (Table 1). The local landraces were collected in 2009 where 138 panicles of 46 local sorghum landraces (3 panicles/landrace) growing in 5.5 hectares were collected from 22 villages located between 726m-2010m above sea level. The standard resistant and susceptible checks were obtained from Sirinka and Melkassa Agricultural Research Centers in Ethiopia, respectively.

Source of infestation

Striga hermonthica seeds used for this study were obtained from Pawe Agricultural Research Center, Ethiopia harvested

Table 2. Mean squares from the ANOVA for grain yield, yield attributes and *Striga* resistance and tolerance indices of 49 sorghum genotypes evaluated under artificial *Striga* -infested and non-infested conditions in Ethiopia, in 2010, 2011 and 2010 - 2011 years.

Source of varation	DF	Grain yield (Kg/ha)	Sorghum biomass dry weight (Kg/ha)	Plant height (cm)	Number of Tillers	Panicle length (cm)	*Striga* emergence count at 17 weeks after planting	*Striga* emergence count at 20 weeks after planting	*Striga* vigor score (1-9)	Area under *Striga* severity progress curve	Area under *Striga* number progress curve	*Striga* height (cm)	*Striga* weight (g)
2010													
Striga infested environment													
Genotype (G)	48	660756***	75894923***	0.37***	1.80***	58.2ns	0.32**	0.27***	0.09ns	0.69ns	0.38***	0.31ns	0.23**
Replication (R)	2	74776ns	54677925**	0.03ns	2.40*	83.4ns	0.64*	0.26ns	0.07ns	0.91ns	0.40ns	0.87ns	0.09ns
Error	96	72631	10928896	0.16	0.54	40.6	0.16	0.13	0.09	0.23	0.18	0.30	0.13
CV		23	33	26	34	27	48	38	48	19	20	45	73
Striga free environment													
G	48	1056008***	97736624ns	0.27***	1.82***	48.7*	-	-	-	-	-	-	-
R	2	3439131***	410501616**	0.01ns	2.39*	11.5ns	-	-	-	-	-	-	-
Error	96	404698	66806868	0.08	0.54	31.5	-	-	-	-	-	-	-
CV		31	41	18	20	28	-	-	-	-	-	-	-
2011													
Striga infested environment													
G	48	604404***	85423075***	0.12ns	1.53ns	49.8ns	0.33**	0.32***	0.14***	0.69***	0.39**	0.45*	0.63*
R	2	187338ns	125613701**	0.31ns	9.57**	69.5ns	0.67*	0.33ns	0.08ns	0.89ns	0.64ns	0.61ns	0.46ns
Error	96	86390	17182429	0.11	1.19	37.5	0.16	0.15	0.06	0.23	0.21	0.26	0.38
CV		22	28	18	47	25	48	43	36	19	23	40	53
Striga free environment													
G	48	938578***	41570440ns	0.17*	1.52ns	66.4*	-	-	-	-	-	-	-
R	2	725652ns	36719615ns	0.32ns	9.57**	53.9ns	-	-	-	-	-	-	-
Error	96	248657	33303070	0.10	1.19	38.4	-	-	-	-	-	-	-
CV		23	28	17	28	24	-	-	-	-	-	-	-
2010 - 2011													
Striga infested environments													
G	48	1181995***	150151109***	0.24**	1.85**	65.59**	0.65***	0.59***	0.15***	0.62***	0.75***	0.46**	0.80**
Year (Y)	1	1666476***	1909412373***	5.79***	3.06ns	198.34*	0.002ns	0.06ns	0.04ns	48.9***	0.32ns	0.19ns	33.28***
G xY	48	83167ns	11164432ns	0.24**	1.49*	42.09ns	0.004ns	0.01ns	0.08ns	0.27*	0.02ns	0.29ns	0.06ns
Error	194	79603	14002661	0.13	0.97	39.69	0.16	0.14	0.07	0.22	0.19	0.28	0.25
CV		23	30	22	44	26	48	40	42	22	21	43	60
Striga free environments													
G	48	1679373***	62221692ns	0.29***	1.85**	67.14**	-	-	-	-	-	-	-
Y	1	1591307*	8690577ns	6.01***	3.06ns	3066.5***	-	-	-	-	-	-	-
G x Y	48	315214ns	77085526*	0.15*	1.49*	48.03ns	-	-	-	-	-	-	-
Error	194	331396	50635970	0.09	0.97	34.84	-	-	-	-	-	-	-
CV		27	35	18	26	26	-	-	-	-	-	-	-

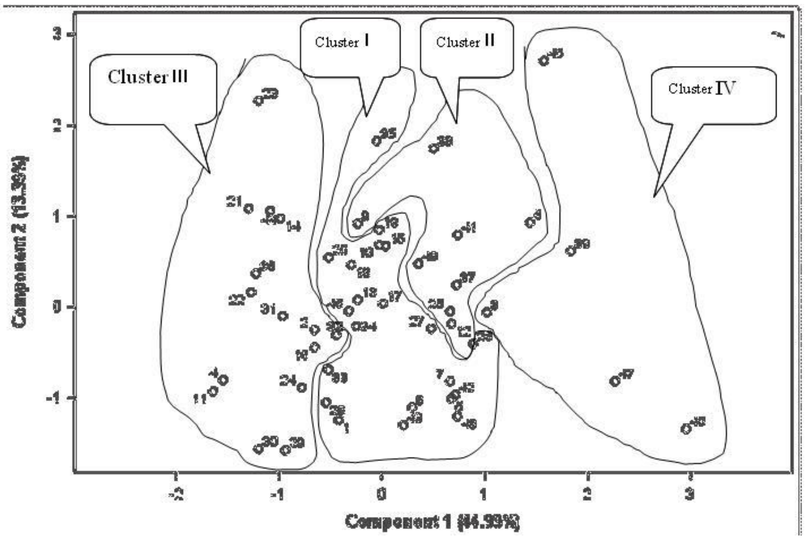

Fig 2. Scatter plots of PC1 and PC2 scores of sorghum genotypes evaluated under *Striga* -infestation at Chemoga gorge, in Eastern Gojjam zone, Ethiopia in 2010 and 2011 years. Refer table 1 for names of entry numbers.

Table 3. Eigen vectors of the first four principal component axes (PC1, PC2, PC3, and PC4) of 49 sorghum genotypes evaluated under Striga-infested conditions at Chemoga gorge, in Eastern Gojjam zone, Ethiopia in 2010 and 2011 years.

Characters	PC1	PC2	PC3	PC4
Striga emergence count at 17 WAP	**0.36**	-0.11	0.09	0.17
Striga emergence count at 20 WAP	**0.36**	-0.14	0.07	0.19
Days to Striga emergence	-0.22	-0.11	**-0.37**	0.18
Striga height	0.20	**0.51**	-0.23	-0.21
Striga vigor score	0.18	**0.48**	-0.24	**-0.35**
Striga severity	**0.36**	0.09	-0.04	0.14
Area under Striga number progress curve	**0.32**	0.13	-0.18	0.12
Area under Striga severity progress curve	**0.35**	-0.15	0.05	0.19
Striga dry weight	**0.33**	-0.01	0.13	0.17
Days to sorghum flowering	0.15	0.14	**0.47**	**-0.42**
Number of tillers	-0.15	0.23	**0.42**	0.02
Plant height	0.16	-0.04	**0.36**	0.00
Panicle length	-0.18	-0.04	**0.32**	-0.11
Sorghum biomass dry weight	-0.15	**0.43**	0.23	**0.44**
Grain yield	-0.17	**0.39**	0.04	**0.51**
Eigen values	6.75	2.01	1.44	1.29
Proportion	0.45	0.13	0.10	0.09
Cumulative	0.45	0.58	0.68	0.77

Only eigenvectors with values equal to or greater than 0.3 are bolded.

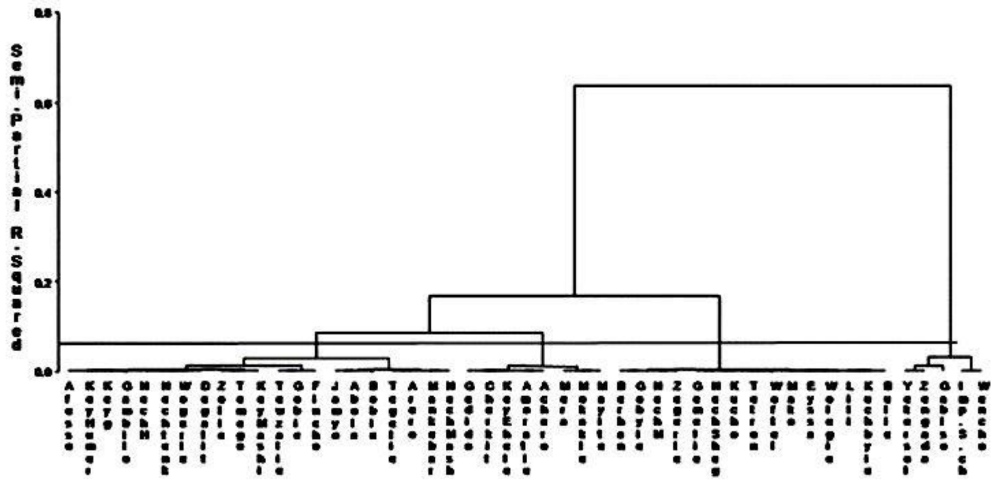

Fig 3. Dendrogram of 49 sorghum genotypes for 15 quantitative traits recorded using the first four principal components under Striga infestation at Chemoga gorge, in Eastern Gojjam zone, Ethiopia in 2010 and 2011 years.

Table 4. Eigen vectors of the first three principal component axes (PC1, PC2, and PC3) of 49 sorghum genotypes evaluated under *Striga*-free conditions at Chemoga gorge, in Eastern Gojjam zone, Ethiopia in 2010 and 2011 years.

Characters	PC1	PC2	PC3
Days to sorghum flowering	**0.31**	**-0.32**	**0.58**
Number of tillers	**0.38**	**0.43**	-0.23
Plant height	**0.60**	0.05	0.18
Panicle length	**0.58**	0.06	-0.04
Sorghum biomass dry weight	-0.23	**0.35**	**0.76**
Grain yield	-0.07	**0.76**	0.01
Eigen values	1.94	1.40	1.03
Proportion	0.32	0.24	0.17
Cumulative	0.32	0.56	0.73

Only eigenvectors with values equal to or greater than 0.3 are bolded.

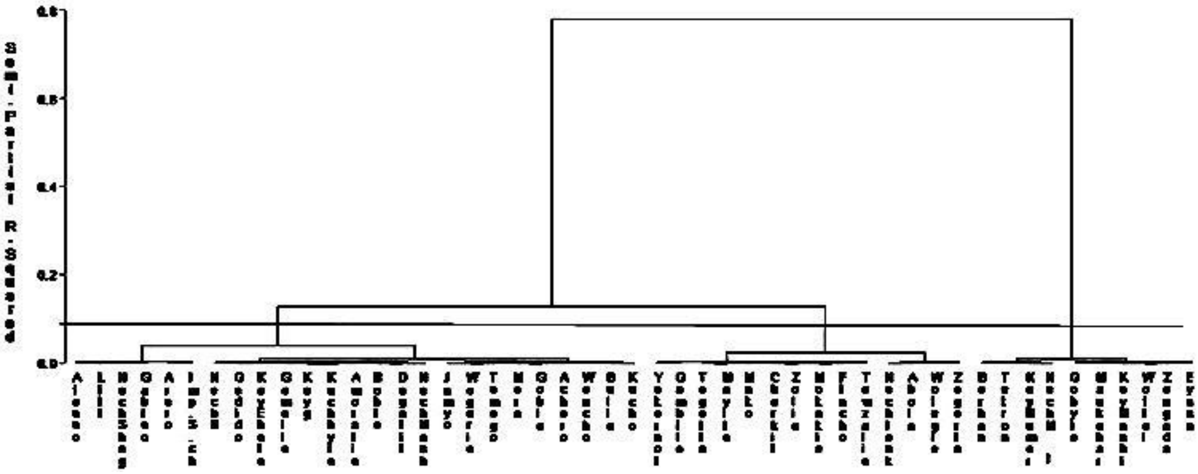

Fig 4. Dendrogram of 49 sorghum genotypes for 15 quantitative traits recorded using the first three principal components under *Striga* free conditions at Chemoga gorge, in Eastern Gojjam zone, Ethiopia in 2010 and 2011 years.

from plants that parasitized sorghum in the year 2009. The experimental field was planted sorghum consecutively for five years prior to 2010, and no *Striga* was found in the study site. This confirms no original *Striga hermonthica* seeds that could influence the result. The 2011 planting was made in different parts of the field to avoid residual effects from previous crop, *Striga* seed and even fertilizer application. Following the *Striga* infestation method developed by IITA (IITA, 1997) about 20 mg of *Striga* seeds (≈ 4000 viable *Striga* seeds) were placed on 5-10 cm horizon in each planting hole two weeks before sorghum planting to allow preconditioning of *Striga* seeds.

Field experiments

The field experiment was conducted in the 2010 and 2011 main cropping seasons. The experiment was laid in a 7x7 lattice design with three replications for each of *Striga*-infested and non-infested conditions using SAS version 9.2 (SAS, 2002). Planting of sorghum was done on May 16, 2010 and May 20, 2011 in adjacent artificially *Striga*- infested and non-infested conditions. Care was taken to put the experiment on *Striga* free farmers field by assessing the history of the field. To allow preconditioning of *Striga* seeds in each planting hole about 20 mg of *Striga* seeds (≈ 4000 viable seeds) (IITA, 1997) were placed at 5-10 cm soil depth two weeks before sorghum planting following . At each planting hole five sorghum seeds were planted at 3 cm soil depth and thinned to one plant per hill three weeks later. Each plot consisted of 0.6m long three rows and separated from the neighboring plots by one empty row. Rows and hills were spaced 0.75 m and 0.15 m, respectively. Half of the nitrogen fertilizer at the rate of 60 kg N ha^{-1} was applied at sowing and the remaining half at four weeks after planting. Weeds other than *Striga* were removed by hand weeding as required.

Data collection and statistical analysis

Data were collected on plant and plot basis for yield, yield attributes, *Striga* resistance and tolerance traits using Sorghum Descriptors (IBPGR/ICRISAT, 1993). Emerged *Striga* plants were recorded in the three rows of infested plots at 17 and 20 WAP (weeks after planting). Days to *Striga* emergence were recorded as the number of days from sowing date to the days on which a *Striga* plants emerged from the plot. *Striga* height (cm) was measured on five randomly taken plants as a distance from the soil surface to the tip of the shoots in each plot during harvesting. At the same time, *Striga* weight (g/plot) was measured in each plot after dried to constant weight in oven. *Striga* vigor was rated based on the scale from 1 to 9 depending on height and number of branches. *Striga* severity was calculated by multiplying emerged *Striga* count with *Striga* vigor.

Table 5. Comparison of means, minimum and maximum values, ranges and variances of different clusters derived from 15 quantitative characters of 49 sorghum genotypes evaluated under *Striga*–infested (I) and *Striga*–free (NI) conditions at Chemoga gorge, Ethiopia in 2010 and 2011 years.

Cluster no.	No. of genotypes grouped		No. of genotypes common in each cluster	Descriptive statistics	Grain yield (Kg/ha)		Sorghum biomass dry weight (Kg/ha)		Panicle length (cm)		Plant height (m)		Days to sorghum flowering (days)		Number of tillers (No.)		*Striga* emergence count		Days to *Striga* emergence (days)	*Striga* height (cm)	*Striga* vigore score (1-9)	*Striga* severity (No.)	Area under *Striga* severity progress curve (No.)	Area under *Striga* number progress curve (No.)	*Striga* weight (g/plot)
	I	NI			I	NI	I	NI	I	NI	I	NI	I	NI	I	NI	17 WAP	20 WAP							
1	21	25	11	Mean	1269	1984	11887	20011	21.3	25.7	1.6	1.8	132.6	136.1	2.1	3.7	11.3	12.5	126.0	33.1	4.9	54.6	401.2	211.9	20.3
				Minimum	833	1136	6563	14953	18.0	21.2	1.3	1.6	114.0	105.0	1.3	2.8	2.7	3.3	119.0	14.8	3.0	20.2	192.5	58.3	1.9
				Maximum	2099	3506	22963	24575	24.8	31.4	1.9	2.0	147.0	147.0	3.3	5.2	24.3	26.0	150.0	61.8	7.8	121.8	551.2	446.0	42.2
				Range	1266	2370	22963	9622	6.8	10.2	0.6	0.4	33.0	42.0	2.0	2.4	21.7	22.7	31.0	47.0	4.8	101.7	358.8	387.7	40.2
				Variance	132485	323199	15177780	8128132	3.7	8.3	0.02	0.02	60.5	145.9	0.2	0.3	45.4	53.6	109.8	119.3	1.9	605.2	11984	15379	155.5
2	8	14	3	Mean	1228	2304	10502	19127	22.6	23.7	1.6	1.8	139.5	138.9	2.3	3.8	12.8	14.8	119.9	41.8	5.8	88.5	796.8	242.7	31.2
				Minimum	938	1994	5254	13936	17.7	20.2	1.4	1.5	132.0	95.0	1.7	3.2	7.3	7.8	119.0.0	20.8	3.5	53.7	574.6	137.1	10.2
				Maximum	1907	3870	13649	22756	27.7	27.8	1.8	2.3	147.0	147.0	3.0	5.0	21.3	21.3	126.0	62.2	7.5	132.3	979.7	337.3	84.3
				Range	969	1876	8395	8820	10.0	7.6	0.4	0.8	15.0	52.0	1.3	1.8	14.0	13.5	7.0	41.3	4.0	78.7	405.1	200.2	74.1
				Variance	147844	224622	8311776	7588625	10.4	6.5	0.03	0.04	42.9	168.7	0.3	0.4	21.6	21.5	6.1	212.7	1.9	822.5	15775	5508	589.4
3	15	10	6	Mean	1574	2919	14414	22877	21.9	25.5	1.5	1.7	130.1	122.2	2.6	3.9	3.6	4.4	132.7	20.2	3.1	13.2	118.8	75.4	5.6
				Minimum	870	1463	8128	19077	14.8	21.2	1.2	1.3	98.0	85.0	1.8	3.3	1.0	1.5	119.0	3.20	1.0	1.5	23.3	26.2	0.7
				Maximum	2161	3333	21422	30743	28.5	31.3	2.0	2.2	147.0	141.0	3.7	4.7	8.0	9.7	150.0	42.8	5.8	39.8	259.6	151.2	22.2
				Range	1291	1870	13294	11666	13.7	10.1	0.8	0.9	49.0	56.0	1.8	1.4	7.0	8.2	31.0	39.70	4.8	38.3	236.3	125.0	21.5
				Variance	261787	275915	21691357	11884045	15.1	16.7	0.1	0.1	210.6	664.2	0.4	0.3	4.9	6.3	166.4	112.6	2.0	85.7	3725.0	1546.0	49.1
4	5	0	0	Mean	993.8	-	10938	-	21.2	-	1.8	-	138.4	-	1.9	-	24.4	29.4	119.0	46.70	5.9	171.7	1575.0	473.1	54.6
				Minimum	395	-	4568	-	18.7	-	1.5	-	114.0	-	1.5	-	15.0	17.2	119.0	33.80	4.5	120.2	1257.0	294.3	20.2
				Maximum	2272	-	27605	-	23.5	-	2.2	-	147.0	-	2.7	-	33.0	46.7	119.0	65.20	7.2	219.3	1834.0	762.7	82.5
				Range	1877	-	23037	-	4.8	-	0.7	-	33.0	-	1.2	-	18.0	29.5	0.0	31.30	2.7	99.2	577.6	468.3	62.3
				Variance	599466	-	90275082	-	3.2	-	0.1	-	204.8	-	0.2	-	43.8	115.7	0.0	207.0	1.2	1368	82963	30295	756.0

area under *Striga* number progress curve and area under *Striga* severity progress curve were recorded for 5consecutative times at 7 days interval starting from *Striga* emergence until sorghum harvesting. Before undertaking a series of multivariate analysis, the data were standardized to a mean of zero and a variance of unity to avoid differences in scales used for recording data on different characters (Sneath &Sokal, 1973). PCA was performed using the PRINCOMP procedure of the SAS version 9.2 (SAS, 2002) on the average values for each trait to identify the group of traits that accounted for most of the variance in the data. First two PCs were plotted against each other to find out the patterns of variability among genotypes using SAS statistical package. Hierarchical cluster analysis was performed using Ward's minimum variance methods (Ward, 1963) SAS version 9.2 (SAS, 2002).

Conclusion

In the present study, the multivariate analysis revealed the presence of high level of diversity for several yield, yield attributes, *Striga* resistance and tolerant traits evaluated among sorghum genotypes, suggested considerable prospects for improvement in resistance and tolerance to *Striga*. The PCA summarized most of the diversity among genotypes in to 4 components with GY, SDW and basic *Striga* resistance traits being the main contributors towards diversity in PC1 and PC2. Likewise, clustering of *Striga* resistant and tolerant genotypes proposed the use of some members of these clusters as parents to build up populations for selection of transgressive segregants against *Striga* stress in subsequent generations and for the development of quantitative trait loci (QTLs) related to *Striga* resistance and tolerance. In this study, several promising landraces (Nechmashila I, Woftel, Wolegie, Eyssa, Tetron, Zegerie, Mankebar, Mera and Zengada) that combined high grain yield with low or moderate emerged *Striga* plants were identified. The existence of these wide genetic sources of resistance and tolerance in a range of landraces would be important for cultivar development towards *Striga* resistance and tolerance breeding work.

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