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RESEARCH ARTICLE

Genetic Diversity of Sorghum (*Sorghum bicolor* (L) Moench) for Agronomic Traits and Shoot Fly Tolerance and Suitability for Winter Season

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Genetic diversity analysis of sorghum germplasm could provide useful information on selection of parental lines and diversifying the genetic base in winter sorghum wherein yield improvement has been marginal. An experiment was conducted on 4000 germplasm lines belonging to 28 countries of origin in augmented design in two winter sorghum growing regions of Maharashtra. Observations were recorded on yield parameters and traits governing shoot fly tolerance. Promising germplasm lines were identified for individual agronomic traits and shoot fly tolerance. The lines from Rwanda, Burundi and Kenya had more grain yield and the lines from India were tolerant to shoot fly. Though grain yield per plant was more variable among all the traits, the PCA analysis revealed that the panicle length, panicle width and shoot fly dead heart % contributed maximum towards divergence. A hierarchical cluster resulted in 11 clusters of originating countries with the accessions from Yemen, Gambia, Somalia, Mozambique, China and India clustering individually. Grain yield was positively associated with shoot fly resistance indicating possibility of co-evolution.

Key Words: Sorghum, Genetic Diversity, Grain yield, Shoot fly

Introduction

Sorghum is an important staple cereal for people residing in the semi-arid tropics of the world. It occupies fifth place after wheat, rice, maize and barley as one of the widely grown cereal (Sinha and Kumaravadivel, 2016). The sorghums grown in winter season (*rabi* or post-rainy season) assume importance in lieu of food, fodder and nutritional security especially in the Indian subcontinent. Across India, around 3 million tonnes of sorghum grain is produced from 5.7 million ha during the *rabi* season. The *rabi* cropping season follows the hot, wet rainy season (*kharif*) and is characterized by limited rainfall, cooler average temperature and shorter days, resulting in lower potential crop evapo-transpiration (Kholova *et al.,* 2013). The grain productivity of post-rainy season sorghum in India is very low as much of the cultivated area is under landraces that are poor in grain yield. For the past 30 years, several programs in India attempted to improve varieties and/or hybrid parents through pedigree breeding approach without much success (Sanjana Reddy *et al.,* 2009). M 35-1, a landrace selection developed in 1937 still dominates the post-rainy season sorghum areas in India (Sanjana Reddy *et al.,* 2012). Of 150 insect pests that attack sorghum, sorghum shoot fly, *Atherigona soccata* (Diptera: Muscidae) is a serious pest that causes a loss of 80–90% of grain, and 68% of fodder yield in India (Kahate *et al.,* 2014). Improvement of *rabi* sorghum productivity has a great impact on socio-economic status of the sorghum growing regions in India. Hence, there is an urgent need to identify and introgress new genetic diversity for developing improved lines with higher grain and fodder yields and tolerance to shoot fly.

Knowledge of genetic diversity of a crop usually helps the breeder in choosing desirable parents for the breeding program. The more diverse genotypes or accessions can be crossed to produce superior recombinants with high yield and resistance to abiotic and biotic stresses. Quantitative traits were reported as useful tool for preliminary evaluation of genetic diversity (Sinha and Kumaravadivel, 2016). In the present study, an attempt has been made to determine the extent of diversity among the 4000 sorghum accessions for yield traits and tolerance to shoot fly.

Materials and Methods

Plant Material

The plant material consisted 4000 accessions obtained from Indian Institute of Millets Research (IIMR)

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genebank, India. Among these, India is the major source of germplasm with 1494 accessions followed by Zimbabwe with 405 accessions and Uganda with 270 accessions (Table 1) in the current set of germplasm lines studied.

Experiment

The plant material was multiplied during 2012 *rabi* season at IIMR, Hyderabad, Telangana and evaluated at Mahatma Phule Krishi Vidyapeeth, Rahuri and Marathwada Agricultural University, Parbhani, Maharashtra during *rabi* 2013. The 4000 germplasm lines were evaluated in augmented design along with five checks viz., IS 18551 (shoot fly tolerant line), DJ 6514 (shoot fly susceptible line), CSV 8R, CSV 22, CSV 29R (high yielding varieties with *rabi* adaptation released at

Table 1. Variability parameters of sorghum germplasm lines evaluated at Parbhani and Rahuri during *rabi* 2013

Sl. No.	Region of origin	No. Acc.	Days to 50% flowering				Plant height (cm)				Panicle length (cm)				Panicle width (cm)			
			Mean	Range	SD	CV (%)	Mean	Range	SD	CV (%)	Mean	Range	SD	CV (%)	Mean	Range	SD	CV (%)
1	Benin	64	84	64-105	9.5	11.3	180	74-269	39.7	22.12	**25.7**	7.5-45.1	8.7	33.9	3.7	1.7-8.5	1.2	31.0
2	Burkina Faso	118	83	56-102	10.2	12.4	169	79-268	40.1	23.82	23.6	9.9-37.6	6.2	26.3	3.5	1.0-5.6	0.9	26.1
3	Burundi	44	88	68-108	9.0	10.2	164	78-230	29.1	17.74	18.5	12.7-31.4	3.8	20.5	3.7	1.7-6.4	1.1	29.5
4	Cameroon	80	**77**	56-103	10.5	13.6	**146**	62-229	35	23.92	18.1	6.8-34.7	6.5	36.1	3.6	2.0-5.6	0.8	22.9
5	China	12	80	67-93	8.4	10.6	147	90-181	26	17.64	17.8	10.1-28.7	5.5	31.2	**4.0**	1.8-6.2	1.3	31.5
6	Ethiopia	107	85	62-105	10.5	12.4	171	88-260	33.1	19.31	22.2	7.5-38.3	6.1	27.7	**4.0**	1.4-6.7	1.0	24.9
7	Gambia	15	88	70-102	8.1	9.2	166	104-241	34.7	20.87	**25.8**	15.9-35.9	6.7	26.1	3.7	1.4-5.1	1.1	28.9
8	Ghana	23	82	69-93	7.6	9.3	178	122-240	29.2	16.38	24.7	17.1-45.0	6.9	28.1	3.5	2.0-6.2	1.0	27.4
9	Hungary	20	**77**	57-91	7.9	10.2	147	90-192	29.8	20.24	20.7	13.8-39.4	6.6	31.8	3.7	1.7-5.5	1.0	26.7
10	India	1494	**77**	53-105	9.0	11.6	169	80-269	29.4	17.44	17.7	5.8-49.4	5.7	32.2	**4.1**	1.5-10.5	1.0	24.4
11	Kenya	59	82	63-103	9.3	11.4	156	82-223	32.5	20.87	20.2	10.1-37.4	5.4	26.6	3.8	2.0-5.9	0.9	24.0
12	Lesotho	123	81	57-103	9.1	11.2	**146**	82-225	27.3	18.73	19.9	9.3-37.6	5.1	25.5	3.8	1.5-7.3	1.0	25.8
13	Malawi	19	85	63-103	10.0	11.7	**190**	139-243	27.9	14.63	**27.7**	11.5-38.5	7.7	27.9	3.8	2.0-6.3	0.9	22.6
14	Mali	81	82	59-104	9.6	11.7	180	82-255	36.6	20.4	24.8	8.0-38.8	7.4	29.6	3.7	1.2-6.2	1.1	28.9
15	Mozam-bique	13	93	74-105	8.4	9.0	175	110-236	37.7	21.52	25.9	16.3-32.8	5.4	20.8	3.7	1.2-6.6	1.3	36.0
16	Nigeria	82	80	58-102	9.9	12.4	166	82-277	40.8	24.64	21.4	7.7-37.8	6.9	32.3	3.7	2.3-7.1	0.8	22.6
17	Rwanda	32	88	73-102	8.4	9.6	171	100-236	37.1	21.73	18.9	13.0-27.2	3.8	20.1	3.8	1.8-5.8	1.0	26.4
18	Somalia	12	**75**	64-88	8.1	10.8	157	117-216	27.2	17.34	15.4	6.6-34.6	8.7	56.3	3.2	2.0-5.4	1.0	31.9
19	South Africa	147	83	57-106	9.1	11.0	151	74-240	33.0	21.89	21.9	8.1-36.9	5.1	23.1	3.5	1.0-5.8	0.8	23.5
20	Sudan	142	82	56-104	9.6	11.6	162	82-270	31.6	19.54	21.2	7.0-40.1	6.3	29.6	3.5	1.0-5.7	0.9	26.5
21	Swaziland	80	86	62-105	8.9	10.3	153	87-236	30.0	19.57	22.2	8.8-33.4	4.7	21.3	3.4	1.2-6.5	0.9	26.6
22	Tanzania	132	86	65-106	9.5	11.0	176	105-273	34.4	19.57	21.9	9.0-46.1	6.6	29.9	3.9	1.0-6.7	1.2	29.8
23	Togo	78	80	60-101	9.7	12.2	175	88-259	40.5	23.15	23.2	8.1-37.6	7.3	31.7	3.6	1.4-6.7	0.9	24.3
24	Uganda	270	82	60-114	9.6	11.8	165	89-254	32.0	19.35	19.2	7.2-37.2	6.4	33.6	3.8	1.6-6.9	1.0	25.6
25	USA	129	79	59-96	7.9	9.9	154	79-242	35.3	22.88	20.1	6.3-35.7	5.5	27.5	3.7	1.0-6.7	0.9	25.3
26	Yemen, Republic of	102	84	58-104	10.8	12.9	166	69-262	32.0	19.26	17.7	7.0-35.1	5.2	29.3	3.7	1.0-6.5	1.2	31.3
27	Zambia	117	83	61-110	10.8	13.1	156	82-246	32.7	20.97	21.1	8.5-38.1	5.7	27.1	3.7	1.5-6.7	1.0	27.6
28	Zimbabwe	405	84	56-108	10.6	12.7	161	74-277	36.3	22.56	21.5	8.5-45.1	6.1	28.5	3.6	1.0-6.5	0.9	26.0
	Total	4000	81	53-114	10.0	12.4	165	62-277	33.43	20.28	19.9	5.8-49.4	6.4	32.1	3.9	1.0-10.5	1.0	26.4

1Leaf glossiness evaluated visually on a 1–5 scale (1 = highly glossy, and 5 = non-glossy) at fifth leaf stage national level). The material was sown in 20 blocks with 200 entries in each block. The checks were randomised in each block. The experimental site at Rahuri is located at an altitude of 657m above mean sea level with latitude of 19.24°N and longitude of 74.39°E. The experimental site at Parbhani is located at an altitude of 357m above mean sea level with latitude of 19.25°N and longitude of 74.80°E. Both the locations receive a rainfall of 260-280 mm during crop growth period. Each accession at each location was raised in a single row of 2 meters length by adopting a spacing of 60cm × 15cm. All the recommended crop production packages were followed to raise a healthy crop. Observations were recorded on days to 50% flowering, plant height (m), panicle length (cm), panicle width (cm), grain yield per plant (g), glossy score (on a 1 to 5 scale where 1= more glossy and 5= less glossy) and the shoot fly infestation as per cent dead hearts at 28 days after emergence (Sharma and Nwanze, 1997). The mean values were utilized for statistical analysis to assess the genetic diversity among the accessions.

Statistical Analysis

The data was analyzed using augmented design for both the locations. The adjusted values were pooled and the mean, range and variances were calculated for the seven traits. Instead of standardisation of variables for cluster analysis, correlation matrix was used since correlations are themselves standardized. The mean values were used to perform principal component analysis (PCA) on Genstat 12 release (VSN International, 2010). The genotypes were grouped along their country of origin. Euclidean measure of genetic distance was used for estimating genetic distance among accessions (Mohammadi and Prasanna, 2003) and the hierarchial cluster analysis was performed based on the origin to group the country of origin. Phenotypic correlations were estimated among all quantitative characters and their significance was tested (Snedecor and Cochran, 1980).

Results and Discussion

Mean Performance

Agronomic traits: In sorghum, flowering is considered as a crucial event as it plays a key role in adaptation and geographical distribution of this crop (Mauro-Herrera *et al.,* 2013). The days to 50% flowering in the 4000 germplasm lines evaluated in the study ranged from 53 to 114 days (Mean: 81 days, SD: 10) (Table 1). The early (<55 days) and the late (>108 days) flowering lines are given in Table 2. The high yielding checks flowered in 76 to 84 days. Sorghum responds to the flowering time by two mechansims; firstly the sensitivity or insensitivity of genotypes to photoperiod and secondly, the inheritance of early or late flowering characteristic (Shehzad *et al*., 2014). On an average, the germplasm lines from Somalia, India, Hungary and Cameroon were early (75-77 days) while the lines from Mozambique were late (93 days). The lines from Cameroon were most variable (CV: 13.6) followed by Zambia (CV: 13.1) and Yemen (CV: 12.9) for flowering time. With a shorter daylength in the post-rainy season, all the accessions, including those from tropical African countries, flowered in a relatively shorter time as has been earlier reported by Appa Rao *et al.* (1996). As sorghum has been postulated to have originated in the north east quadrant of Africa (Doggett, 1988) and was transported to India only about 3000 years ago, it is a short day plant (Appa Rao *et al.*, 1996). The plant height ranged from 62 to 277 cm (Mean: 165 cm, SD: 33.4). The dwarf (<0.75 m) and the tall (>270 cm) lines are given in Table 2. The high yielding checks had a plant height of 169 to 208 cm. From the country means, it can be seen that lines from Cameroon, Hungary, China and Lesotho are dwarf (<147 cm) while those from Malawi were tall (190 cm). The lines from Nigeria were most variable (CV: 24.6) followed by Cameroon (CV: 23.9) and Burkina Faso (CV: 23.8). Panicle length and width are important components which contribute to yield. Panicle length is a stable character which is a characteristic feature of a particular race (Doggett 1988, Harlan 1992). The panicle length ranged from 5.8 to 49.4 cm (Mean: 19.9 cm, SD: 6.4). The 13 lines had a panicle length above 40 cm while the high yielding checks had a panicle length of 18.3 to 20.6 cm (Table 2). The lines from Malawi had a greater mean panicle length of 27.7 cm followed by Gambia (25.8 cm) and Benin (25.7 cm). The lines from Somalia were most variable (CV: 56.3) followed by Cameroon (CV: 36.1) and Benin (CV: 33.9) for panicle length. The panicle width ranged from 1 to 10.5cm (Mean: 3.9 cm, SD: 1.0). The 13 lines with stouter panicles (>7 cm) are given in Table 2. The high yielding checks had a panicle width of 4.4 to 5.2 cm. The lines from India, China and Ethiopia had greater panicle width (4.0 to 4.1 cm). The lines from Mozambique were more variable (CV: 36)

Table 2. Promising germplasm lines identified for yield parameters and shoot fly tolerance in sorghum germplasm lines evaluated at Parbhani and Rahuri during *rabi* 2013

Trait	Description	Value	Promising Germplasm Lines	Best Check
Days to 50% flowering	Early	<55 days	IS 480, EC 524565, IS 1385	C3: 76 days
	Late	>108 days	EC 483654, EC 483741, EC 524852, EC 524853	
Plant height (cm)	Tall	>270 cm	IC 290960, IS 1648, IS 1651, IS 1936, IS 2070, EC 524626	C4: 208 cm
	Dwarf	<75 cm	IC 253668, IS 1879, IS 2648, EC 533462, EC 524675	
Panicle length (cm)	Greater	>40 cm	EC 483888, IS 2154, EC 483502, EC 524644, EC 483887, IS 3735, EC 483656, IS 1961, IS 1976, IS 2137, IS 2434, EC 483857, EC 483862	C4: 20.6 cm, C5: 20.6 cm
Panicle width (cm)	Wider	>7 cm	EC 483117, EC 483213, IS 249, IS 323, EC 483255, IC - 253562, IS 1071, IS 1175, IS 1742, IS 1789, IS 1791, IS 1802, EC 524654	C4: 5.2 cm
Grain yield per plant (g)	Higher	>100 g	EC 483105, EC 483116, EC 483271, EC 483279, IS 585, IS 1119, IS 2168, IS 2343, IS 2597, EC 484181, IS 3366, EC 524799, EC 489763	C4: 57 g
Glossy score	More glossy	Score 1	IS 94, IS 222, IC 484370, IC 289482	C1: 1.9
Shoot fly dead hearts	Less	<15%	EC 483116, IS 182, EC 483203, EC 524490, EC 483226, IS 291, IC 291008, IS 1441	C1: 24%

1 Leaf glossiness evaluated visually on a 1–5 scale (1 = highly glossy, and 5 = non-glossy) at fifth leaf stage
C1: IS 18551, C2: DJ 6514, C3: CSV 8R, C4: CSV 22, C5: CSV 29R

followed by Somalia, Yemen and Benin (31.0 to 31.9). The grain yield per plant ranged from 4 to 144 g. The lines, EC 483105, EC 483116, EC 483271, EC 483279, IS 585, IS 1119, IS 2168, IS 2343, IS 2597, EC 484181, IS 3366, EC 524799, EC 489763 had more than 100 g/plant while the high yielding checks had 39 to 57 g/plant (Table 2). The lines from Rwanda, Burundi and Kenya had more average grain yield per plant (40.3 to 42.4 g). The lines from Gambia, Yemen and Ethiopia were more variable (51.4 to 55.4) (Table 1). Earlier workers identified greater diversity in the germplasm collections made from eastern parts of Ethiopia (Geleta and Labuschagne, 2005), Eritrea (Ghebru *et al.,* 2002), in the varieties collected from Burkina Faso (Barro-Kondombo *et al.,* 2010, Kondombo *et al.,* 2016) and in local landraces in Cameroon (Barnaud *et al.,* 2007).

Shoot fly tolerance traits: Host plant resistance (HPR) is one of the most economic and practical means for controlling shoot fly damage because it does not involve any extra cost to the farmers or require application skills in pest control techniques (Sharma, 1985). Although several improved varieties and hybrids have been developed and released, the yield gains at farmers' level are minimal (Sharma *et al.,* 2003). Therefore, there is a need to combine shoot fly resistance with high grain yield to increase the productivity of this crop. In the current study, the glossy score among the 4000 germplasm lines ranged from 1 to 5 (Mean: 3.1, SD: 0.7). Leaf glossiness has been reported to be associated with resistance to sorghum shoot fly (Agrawal and Abraham, 1985). There is negative correlation between glossiness with oviposition and deadhearts (Kamatar and Salimath, 2003). The intensity of leaf glossiness at the seedling stage is positively associated with the level of resistance to shoot fly (Sharma *et al.,* 1997). The lines IS 94, IS 222, IC 484370 and IC 289482 had a glossy score of 1 while the resistant check, IS 18551 had a score of 1.9 and the susceptible check, DJ 6514 had a score of 3.2 (Table 2). The lines from India and China has less mean glossy score of 2.8. The lines from China, Gambia, Rwanda and India were more variable (CV: 23.8 to 24.8) (Table 1). The shootfly infestation in terms of dead heart ranged from 8 to 100%. The lines, EC 483116, IS 182, EC 483203, EC 524490, EC 483226, IS 291, IC 291008, IS 1441 had less than 15% dead hearts while IS 18551 had 24%, DJ 6514 had 79% and the high yielding checks recorded 31-34% dead hearts (Table 2). The lines belonging to India had less mean dead heart % of 53 and more variable as well (CV: 29.5). The reason for less dead heart % in Indian lines might be due to local adaptation of the lines favouring resistance. Also, the majority of the resistance sources for shoot fly, stem borer and striga were found to originate from India (Appa Rao *et al.,* 1996). Among all the traits, grain yield per plant was more variable followed by panicle length.

Diversity Analysis

Principal Component Analysis (PCA) carried out using data of seven traits captured 81.5% of total variation from the first two principal components (PCs) (Table 3). The first principal component (PC) alone explained 68.5% of the total variation, mainly due to variation

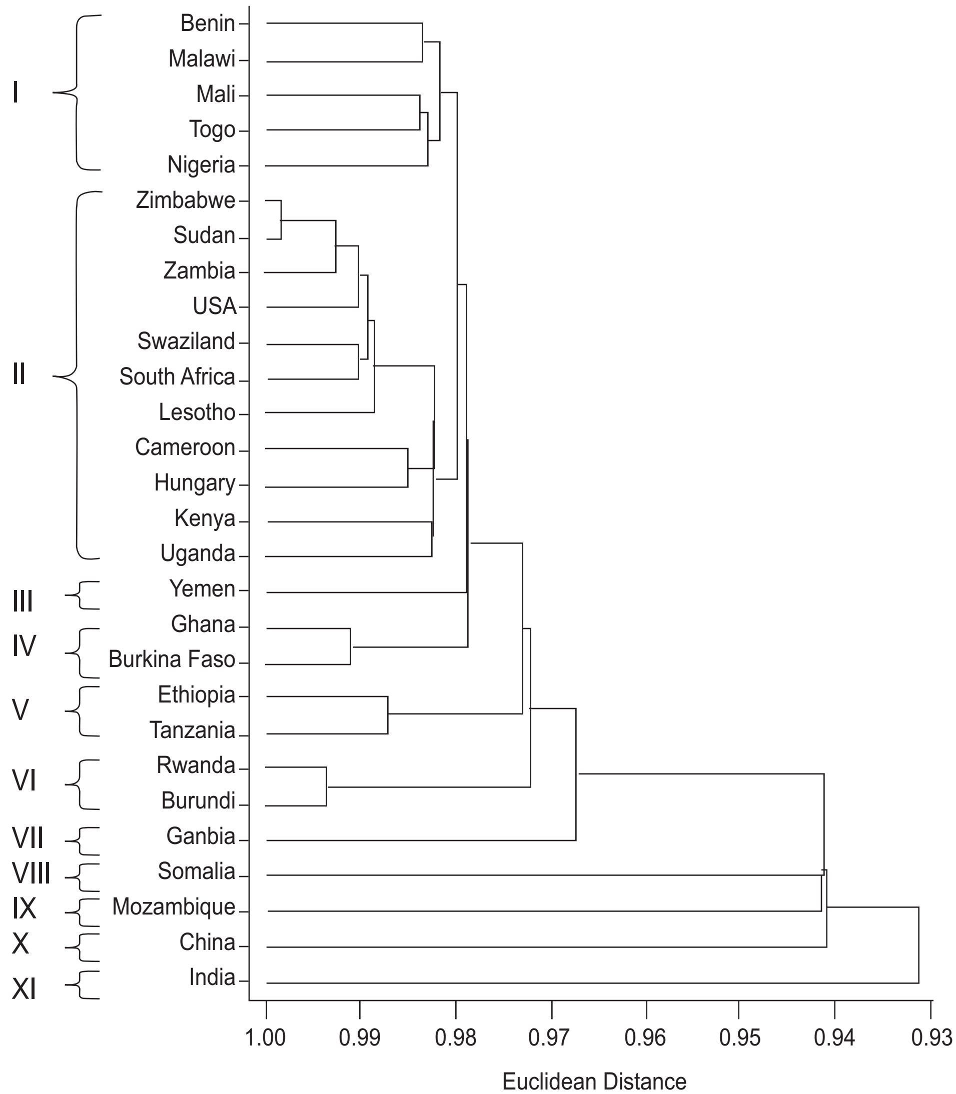

Fig. 1. Dendrogram generated by cluster analysis showing the relationships among the 28 regions of origin of 4000 sorghum accessions

Table 4. Characteristic means of 11 similarity cluster groups of origins of sorghum accessions

Cluster No.	Region of origin	No. of Acc	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle width (cm)	Grain yield per plant (g)	Glossy score	Shoot fly dead hearts (%)
1	Benin, Malawi, Mali, Nigeria, Togo	324	82	178	25	4	34	3.2	63
2	Cameroon, Hungary, Kenya, Lesotho, South Africa, Sudan, Swaziland, Uganda, USA, Zambia, Zimbabwe	1572	81	154	21	4	36	3.2	64
3	Yemen, Republic of	102	84	166	18	3.7	36	3.3	68
4	Burkina Faso, Ghana	141	82	173	24	4	31	3.4	69
5	Ethiopia, Tanzania	239	86	173	22	4	39	3.3	64
6	Burundi, Rwanda	76	88	167	19	4	42	3.2	64
7	Gambia	15	88	166	26	3.7	30	3.5	65
8	Somalia	12	75	157	15	3.2	37	3.1	63
9	Mozambique	13	93	175	26	3.7	31	3.6	75
10	China	12	80	147	18	4.0	40	2.8	64
11	India	1494	77	169	18	4.1	39	2.8	53

Table 3. Principal component analysis for yield parameters and shoot fly tolerance in sorghum germplasm lines evaluated at Parbhani and Rahuri, 2013 *rabi* season

	PC I	PCII
Eigen value	0.35	0.67
% total variance	68.5	13.0
Cumulative variance %	68.5	81.49
Factor loading by various traits		
Days to 50% flowering	0.00	-0.01
Plant height	-0.01	0.03
Panicle length	**0.11**	0.02
Panicle width	-0.34	0.11
Grain yield per plant	0.02	-0.02
Glossy score	0.03	0.04
Shoot fly dead heart (%)	**0.27**	-0.04

in panicle length, shoot fly infestation as percent dead heart and the panicle width with negative loading. Panicle width contributed more to the second PC and accounted for 12.99 % of the total variation. The PCA analysis revealed that the panicle length, panicle width and shoot fly dead heart % contributed maximum towards divergence.

Depending on the divergence between clusters, emphasis is given for deciding the parents for hybridization (Rohman *et al.,* 2004). A hierarchical cluster resulted in 11 clusters of originating countries (Fig. 1 and Table 4). Cluster 1 consisted of accessions from five countries, cluster 2 from 11, cluster 4, 5, 6 from two each while the accessions from Yemen, Gambia, Somalia, Mozambique, China and India clustered individually. Cluster 1 had accessions with greater plant height while the second cluster had those with dwarf height. Cluster 6 grouped the accessions with greater grain yield per plant while cluster 7 for those having greater panicle length. Cluster 8 grouped the accessions with early flowering while cluster 9 for those having greater panicle length. Cluster 10 had the accessions with more panicle width, grain yield per plant and lesser glossy score. Cluster 10 had accessions from India which were the source for early flowering, more panicle width, grain yield per plant and shoot fly tolerance traits (less glossy score and less dead hearts%). Ramu *et al.* (2013) found that guineas from India and Western Africa formed two distinct clusters.

Correlations

The lines with more dead hearts (shoot fly susceptibility) was associated with delay in flowering, shorter plant height, greater panicle length, less panicle width and less grain yield. Grain yield was positively associated with shoot fly resistance (less glossy score and less dead hearts%), late flowering, greater plant height and more panicle width (Table 5). High positive and significant correlation of panicle weight with grain yield was reported by earlier researchers (Bakheit, 1989; Senthil and Palanisamy, 1995)

Conclusions

This study supports that quantitative traits are useful for preliminary evaluation of genetic diversity. The principle component analysis and hierarchical cluster analysis grouped the sorghum accessions under 11 clusters with six countries including India clustering individually. The Indian accessions were distinct from others and hence can be combined with the lines from other countries for generating diversity for yield traits. However, the lines from India were better tolerant to shoot fly than the countries from other clusters. Hence incorporation of stable resistance into elite genetic background will minimize the use of toxic chemicals leading to environmentally friendly and sustainable sorghum production in the semi-arid tropics. The germplasm lines identified superior for individual traits can be utilised in breeding program for generating diversity. Correlation studies clearly showed that the grain yield and shoot

Table 5. Correlation among yield parameters and shoot fly tolerant traits in sorghum germplasm lines evaluated at Parbhani and Rahuri during *rabi* 2013

Trait	Glossy score	Shoot fly dead hearts %	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle width (cm)
Shoot fly dead hearts (%)	0.43**	1.00				
Days to 50% flowering	0.25**	0.27**	1.00			
Plant height	-0.13**	-0.12**	0.02	1.00		
Panicle length (cm)	0.15**	0.18**	0.19**	0.35**	1.00	
Panicle width (cm)	-0.21**	-0.19**	-0.10*	0.19**	0.04	1.00
Grain yield/ panicle (g)	-0.13**	-0.20**	0.11**	0.12**	-0.06	0.18**

* and **, Significant at 5% and 1% probability levels, respectively

fly resistance are positively associated paving way for simultaneous selection.

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