Range Mgmt. & Agroforestry 38 (2) : 199-207, 2017
ISSN 0971-2070

Assessment of morphological diversity among the dual purpose sorghum landraces collected from tribal districts of northern Maharashtra

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Received: 31st December, 2016 Accepted: 6th May, 2017

Abstract
Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important climate resilient crops in the world. A total of 36 sorghum landraces were collected under national exploration programme from rainfed areas of Dhule, Nandurbar and adjoining areas of northern Maharashtra during 2015-16. These accessions were assessed for morphological diversity based on five quantitative and twelve qualitative traits. High variability was observed for most of the characters. Thirty-six accessions were also categorized into six different basic as well as hybrid races of sorghum on the basis of five fundamental spikelet types. High 100 seed weight was recorded in IC 618609 (3.12g) followed by IC 618658 (2.92 g). Total ear head weight varied from 9.23 (IC 618606) to 556.5g (IC 618648) with mean weight of 88.08g. Significant correlation (0.763, P<0.01) was observed among ear head length and ear head weight followed by ear head width and 100 seed weight (0.482, P< 0.05). Diversity analysis using Euclidean distances and Principal Component Analysis (PCA) classified the accessions into three major clusters. In PCA, first two components explained more than 99% of variation in the population. Shannon Diversity Index (SDI) indicated high variability for glume colour (2.05), ear head shape (1.56), grain colour (1.54), glume covering (1.27), ear head compactness and colour of vitreous albumen (1.25). The unique accessions identified in this study will provide excellent opportunities to improve sorghum for ear head weight, ear head length and various grain characteristics. This will further boost up sorghum utilization in developing more climate resilient cultivars.

Keywords: Climate resilient, Diversity, Fodder purpose, Grain traits, Races, Tribal areas

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] occupies fifth position among the most important cereal crops world wide after wheat, rice, maize and barley (Sinha and Kumaravadivel, 2016). It serves as a staple food for more than 500 million people in 30 countries located in arid and semi-arid geographies of the world (Rakshit *et al.*, 2012b; Sivaraj *et al.* 2016). It is a very important crop when compared with other staple cereals because of well known capabilities to tolerate abiotic stresses (Ejeta and Knoll, 2007). In India, it is grown during rainy and post rainy seasons in semi-arid regions of Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Rajasthan, Uttar Pradesh, Gujarat and Tamil Nadu. In rainy season it was grown on about 2.89 million hectares produced 3.05 million tons of grains and in post rainy season the values were 4.88 million hectares with production of 4.18 million tons (Rakshit *et al.*, 2012a, 2014). Sorghum grain has very diversified uses where rainy season sorghum is predominantly used as feed in poultry and base material for alcohol production in distilleries, while post-rainy sorghum is of very prime quality and is used as a food and for making processed food products. (Kleih *et al.,* 2007; Audilakshmi *et al.*, 2007; Patil *et al.,* 2014; Ganapathy *et al*., 2012, 2016). Sorghum fodder has great value in rainfed farming system. Due to its early maturity, drought and salt tolerant attributes makes it fit for arid regions where it supplies high value fodder to overcome the fodder shortages. It supplies highly palatable and nutritionally superior fodder as animal feed resource which has huge demand specifically in lean periods of the year (winter and summer season). In lean season, it has a share of about 60 per cent of the total dry weight of fodder of dairy animals (Elangovan *et al.,* 2013b; Jain and Patel, 2013). Over the last three decades, role of sorghum as an important constituent in animal fodder have increased manifolds (Tonapi *et al.*, 2011). Recently its utilization has increased as raw material for extracting starch, fibre (lignocelluloses), biofuels and even material of fine quality writing and printing paper as well as corrugated and solid particle board (Hallgren *et al.,* 1992;

Rajwanshi and Nimbkar, 2015).

National Bureau of Plant Genetic Resources (NBPGR) played an important role to represent the inter and intra-specific reservoir of potentially useful genetic material. Landraces or farmer varieties are important for developing any variety or hybrid and to obtain high yielding varieties. Sorghum landraces are under cultivation in Maharashtra by different tribal communities of Dhule and Nandurbar district since ancient times. Landraces are the major avenues for deploying genes to improve the nutritional quality, yield potential and tolerance to various biotic and abiotic stresses. Tribal populations in these regions are still growing the landraces considering their importance for resistance to diseases, pest and tolerance to various abiotic stresses. They are mainly valued for superior nutrient content thereby providing nutritional security to tribal communities. Primarily, these are the populations cultivated and maintained by the farmers through method of selection over the years (Elangovan *et al.,* 2009). Sorghum diversity / variability is under severe threat due to loss of habitats, industrial development and large area of cultivation are converted into adoption of cash crops *viz.,* soybean, mung bean, safflower, pigeon pea, *Bt*- cotton etc. As sorghum is the staple crop or known as poor man's food to many tribal communities in this region, the genetic diversity/ variability needs to be collected for conservation and utilization for future crop improvement programmes. In the present study, traditional cultivars i.e. local landraces or farmer's variety of sorghum were collected and assessed for morphological diversity.

Diversity analysis using morphological traits have been carried out in many crop species and such traits are being deployed to perform DUS (Distinctness, Uniformity and Stability) tests in sorghum cultivars (Reddy *et al.,* 2009; Joshi *et al.,* 2009). These are developed as per the guidelines from the Protection of Plant Varieties and Farmers' Rights Act (PPV & FRA) of India. Here we have used descriptors defined by Indian Institute of Millets Research, Hyderabad and PPV & FRA of India. Descriptors only for ear head and seed characters were used to identify promising accessions for these traits.

Materials and Methods

A total of 36 accessions of sorghum germplasm were collected from Dhule, Nandurbar and adjoining areas under national exploration programme of NBPGR, New Delhi under mission code E20150025Z09. This exploration was undertaken in collaboration with Indian Institute of Millets Research, Hyderabad. The source of the material was from farmer's field with random sample method. Sample type was individual plant.

***Collection sites and accessions*:** The Dhule and Nandurbar districts of West Khandesh zone situated in Tapi river basin in the North West of Maharashtra and are predominantly inhabited by tribal population. Nadurbar district was formed after bifurcation of Dhule district and now major tribal population is concentrated in this new district. Forest cover is about one fifth of the total area of the district located on Sahyadri and Satpura ranges. The farming in this area is mainly depends on the South-West monsoon rains which provides about 88% of the total rainfall received. These areas experience hot and dry climate with about 600 mm average rainfall. The areas explored were located between 20^{o} 35' 73 to 21^{o} 49' 58 N latitude and 73^{o} 35' 23 to 76^{o} 43' 48 E longitude. Geographical coordinates of the collection sites of sorghum germplasm were recorded using Garmin 12 hand held Global Positioning System (GPS). Local landraces or farmer's variety of sorghum were collected from 24 villages of those tribal areas/regions. The collected 36 accessions were from Buldana (08), Jalgaon (07), Dhule (10) and Nandurbar (11).

***Observations recorded*:** The collected germplasm was specifically assessed for ear head characteristics and seed traits. Five quantitative traits were recorded *viz.,* ear head length, ear head width, weight of ear head and 100 seed weight (g). For qualitative data, ear head shape, ear head compactness, glume colour, glume covering, grain colour, grain luster, grain, grain size, shape dorsal view, grain shape profile view, size of mark of germ, texture of endosperm, colour of vitreous albumen were observed.

***Statistical analysis*:** The data were analysed using Paleontological Statistics Software Package for Education and Data Analysis (PAST) (Hammer *et al.,* 2001) software (Ver. 3.14) freely available at www.folk.uio.no/ohammer/past/.

Results and Discussion

***Nature and extent of diversity collected*:** During the exploration, a total of 36 accessions were collected. The cultivated sorghums are classified into five basic races and fifteen intermediate races based on the inflorescence characteristics (Harlan and de Wet, 1972). The rainy season sorghums are predominantly represented by *caudatum*, *kafir* and *bicolo*r races, while post-rainy cultivars are mostly from *durra* race. Significant variability was observed among the accessions for the races. Six different races comprising *Durra-Caudatum* (14), *Durra* (8), *Guinea-Caudatum* (06), *Bicolor* (6), *Guinea-Bicolor* (01) and *Durra-Bicolor* (01) were recorded among the landraces collected (Table 1). High variability was recorded in plant height where very tall (550-570 cm), medium (200-300 cm), dwarf (100-150 cm) accessions were collected from farmer's fields. Accessions *viz.,* IC0618595, IC0618598, IC0618607, IC0618609, IC0618--612, IC0618613, IC0618621, IC0618635, IC0618648, IC0618649, IC0618658 and IC0618677 were very tall with average height of about 515 cm. These exhibited very high biomass and excellent quality fodder which were preferred by cattle (information provided by farmers). Ear head length varied from 10.84 (War Gunduni, Dhule) to 56.1 cm (Wadnear village, Buldana), whereas ear head weight varied from 9.23 (Muktha nagar village of Jalgaon) to 556.5g (Dhamnod village of Nandurbar). 100 seed weight was recorded from 1.65 (Khamgaon, Buldana) to 2.92g (Somawal village, Nandurbar).

Table 1. Passport data of 36 Sorghum landraces collected from Dhule, Nandurbar and adjoining districts of Maharashtra

IC Number	Village	Block	Dist.*	Latitude	Longitude	Vern. name
IC 618595	Tanoda	Khamgaon	BD	20°39'56	76°43'48	Deshi Jowar
IC 618596	Tanoda	Khamgaon	BD	20°39'56	76°43'48	Deshi Jowar
IC 618598	Sutla	Khamgaon	BD	20°44'07	76°32'43	Deshi Jowar
IC 618599	Wadnear	Nandura	BD	20°50'10	76°19'59	Hari Gadual
IC 618600	Wadnear	Nandura	BD	20°50'10	76°19'59	Deshi Jowar
IC 618601	Wadnear	Nandura	BD	20°50'10	76°19'59	Deshi Jowar
IC 618602	Wadnear	Nandura	BD	20°50'10	76°19'59	Deshi Jowar
IC 618603	Dhannora	Nandura	BD	20°50'43	76°18'27	Deshi Jowar
IC 618606	Mukthanagar	Mukthainagar	JL	21°00'53	75°56'30	Jowar
IC 618607	Varddgaon	Mukthainagar	JL	21°00'51	75°56'21	Chikkini
IC 618608	Dadwen Varddgaon	Mukthainagar	JL	21°00'51	75°56'21	Chikkini
IC 618609	Rhueawal	Bhusawal	JL	21°01'50	75°43'13	Chikkini
IC 618610	Erandol	Erandol	JL	20°55'45	75°20'05	Deshi Jowar
IC 618611	Erandol	Erandol	JL	20°55'45	75°20'05	Deshi Jowar
IC 618612	Erandol	Erandol	JL	20°54'35	75°17'24	Deshi Jowar
IC 618613	Mukuti	Dhule	DL	20°51'57	74°57'36	Deshi Jowar
IC 618616	War Gunduni	Dhule	DL	20°54'09	74°42'26	Jowar
IC 618617	War Gunduni	Dhule	DL	20°54'09	74°40'33	Jowar
IC 618621	Masti	Sakri	DL	20°57'37	74°11'02	Jaubri
IC 618622	Masti	Sakri	DL	20°57'37	74°11'02	Jwari
IC 618635	Lahangadwan	Nawapur	NB	21°14'04	73°58'42	Jowar
IC 618643	Nagrar	Nawapur	NB	21°18'43	74°06'34	Jowar
IC 618648	Kalamba	Nandurbar	NB	21°24'44	74°17'38	Chikkini
IC 618649	Dhamnod	Nandurbar	NB	21°24'44	74°17'38	Jowar
ESD 76	Lonkheda	Nandurbar	NB	21°26'09	74°14'12	Chikkini
IC 618658	Somawala	Taloda	NB	21°31'12	74°07'47	Jowar/ madi
IC 618659	Somawala	Taloda	NB	21°31'12	74°07'47	Jowar
IC 618661	Modurpada/ Medwad	Taloda	NB	21°33'63	74°05'91	Jowar
IC 618662	Gangapur	Akkalkuwa	NB	21°35'35	74°01'06	Jowar
IC 618677	Talawadi	Dhadgaon	NB	21°48'68	74°15'93	Jowari
IC 618688	Mohid	Shahada	NB	21°29'44	74°29'51	Jowari
IC 618690	Bhampur	Dhule	DL	21°24'75	74°46'36	Chikkini
IC 618691	Sirpur	Sirpur	DL	21°36'13	74°83'33	Chikkini
IC 618694	Gorne Phata	Shindkheda	DL	21°04'41	74°04'20	Chikkini
IC 618695	Gorne Phata	Shindkheda	DL	21°09'57	74°21'70	Chikkini
IC 618697	Songir Phata	Dhule	DL	21°04'46	74°47'20	Jowari

*District: Buldana- BD, Jalgaon-JL, Dhule- DL, Nandurbar-NB

Table 2. Mean performance and spectrum of variability for ear head characters in 36 sorghum landraces

IC number	E_HD_LT	E_HD_WD	PR_BR	100 SW	EH_WT
IC 618595	40.74	5.26	41.40	1.92	62.66
IC 618596	40.68	6.04	43.20	1.79	65.43
IC 618598	31.36	5.66	32.28	1.65	42.85
IC 618599	40.80	5.08	37.40	1.90	41.40
IC 618600	33.66	5.22	37.20	1.98	41.71
IC 618601	56.10	6.05	47.00	1.92	109.02
IC 618602	41.35	4.70	35.50	2.27	39.57
IC 618603	14.20	6.62	30.20	2.05	27.87
IC 618606	24.32	3.24	21.20	1.74	9.23
IC 618607	28.47	6.17	48.00	1.97	70.52
IC 618608	29.20	5.17	43.67	2.72	56.76
IC 618609	22.05	6.35	50.50	3.12	75.51
IC 618610	19.84	4.96	36.60	1.93	41.40
IC 618611	27.10	7.43	91.33	2.50	146.68
IC 618612	22.35	7.40	70.50	2.40	111.02
IC 618613	19.04	5.52	39.60	2.11	62.15
IC 618616	13.90	4.84	46.80	1.80	29.86
IC 618617	10.84	3.40	17.00	1.98	12.08
IC 618621	18.53	6.00	38.00	2.23	58.07
IC 618622	20.13	6.57	54.67	2.18	49.42
IC 618635	26.60	6.16	35.40	1.86	56.55
IC 618643	22.15	7.90	74.00	2.48	128.15
IC 618648	15.93	6.97	47.00	2.17	556.5
IC 618649	22.70	8.43	49.33	2.19	84.89
ESD 76	13.26	5.02	33.40	1.75	43.41
IC 618658	20.28	5.74	41.40	2.92	59.81
IC 618659	21.00	5.18	44.75	2.84	502.68
IC 618661	26.30	7.73	86.33	1.74	148.64
IC 618662	19.30	4.20	23.60	2.29	24.84
IC 618677	27.18	6.84	45.60	2.66	76.78
IC 618688	17.55	5.95	38.25	1.86	47.53
IC 618690	25.07	8.50	54.67	2.03	112.87
IC 618691	17.47	7.33	48.21	2.90	118.46
IC 618694	13.74	3.52	23.80	1.95	20.47
IC 618695	16.96	3.32	21.40	2.38	15.10
IC 618697	14.42	2.98	21.40	2.72	21.26
Range	10.84-56.10	2.98-8.50	17.0-91.33	1.65-3.12	9.23-556.5
Mean	24.29	5.76	43.07	2.19	88.08
SE	1.64	0.24	2.80	0.06	19.14
CV (%)	40.70	25.22	39.03	17.83	130.43

E_HD_LT = Ear head length (cm); E_HD_WD = Ear head width (cm); PR_BR = Number of primary branches in inflorescence; 100_ SW = 100 seed weight; EH_WT = Ear head weight (g)

Table 3. Correlation among different ear head characters

	E_HD_LT	E_HD_WD	PR_BR	100_SW	EH_WT
E_HD_LT		0.430	0.288	0.237	0.763
E_HD_WD			1.58E-08	0.482	0.053
PR_BR				0.319	0.048
100_ SW					0.146
EH_WT					

E_HD_LT = Ear head length (cm); E_HD_WD = Ear head width (cm); PR_BR = Number of primary branches in inflorescence; 100_ SW = 100 seed weight (g); EH_WT = Ear head weight (g)

***Analysis of variance and mean performance of landraces*:** The one-way analysis of variance indicated significant variation (P<0.05) for the ear head characters studied. Ear head weight exhibited highest variation followed by ear head length and primary branches in inflorescence. There was little variation observed for 100 seed weight (Table 2). The mean for ear head length was 56.10 cm and accessions, IC618600 recorded highest length of 56.10 cm followed by IC618602 (41.35 cm). Lowest length was observed in IC618617 (10.84 cm). Maximum ear head width was observed in IC 618649 (8.43 cm) whereas minimum width was recorded in IC 618697 (2.98 cm). Number of primary branches in inflorescence varied from 17.0 (IC 618617) to 91.33 (IC 618611) with a mean of 43.07. Highest 100 seed weight was recorded in IC 618609 (3.12 g) followed by IC 618658 (2.92 g). Total ear head weight varied from 9.23 g (IC 618606) to 556.5 g (IC 618648) with mean weight of 88.08 g (Table 2). For twelve qualitative traits high variability was also observed for most of the characters in collected landraces in earlier exploration programmes (Elangovan *et al.,* 2007*,* 2009; Pandravada *et al.,* 2013; Kannababu *et al.,* 2015; Sivaraj *et al.,* 2016).

***Correlation studies*:** Correlation coefficient provides the type of associations between any two traits which is useful to know the probable effect among the traits. Correlation coefficients were worked out among all the ear head characteristics (Table 3). Highest and significant correlation (0.763, P< 0.05) was observed among ear head length and ear head weight followed by ear head width and 100 seed weight (0.482, P< 0.05). Ear head length recorded positive correlation with all the characters studied. In earlier studies, significant positive correlations were reported among majority of the traits in sorghum (Ayana and Bekele, 2000; Elangovan *et al.,* 2007, Elangovan *et al.,* 2009*,* 2013a; Gomashe *et al.,* 2012; Sinha and Kumaravadivel, 2016).

***Diversity analysis based on Euclidean distances*:** Diversity analysis among 36 accessions of sorghum was carried out using UPGMA clustering based on the Euclidean distances. Estimates of Euclidean distances among genotypes derived from five quantitative ear head traits were used to construct a dendrogram showing scattered distribution of landraces into different groups (Fig 1). Total 36 accessions were grouped into three major clusters. Cluster I consisted of highest number of accessions *i.e* 27 followed by cluster II (7 accessions) and the cluster III with only two genotypes. The cluster I was further divided into three sub clusters (a, b and c) with 11, 9 and 7 accessions, respectively. Morphological traits were used to classify the landraces into different clusters in earlier reports where Umakanth *et al.* (2003) used these traits to segregate 41 *rabi* sorghum landraces. Rajrajan and Ganesamurthy (2014) assessed the one hundred sorghum accessions for various morphological and physiological traits. Sinha and Kumaravadivel (2016) classified forty sorghum accessions in six clusters consisting of different sorghum types collected from Tamil Nadu.

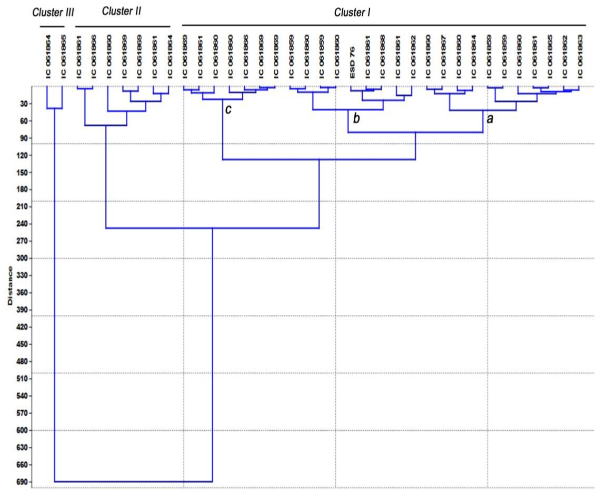

Fig 1. Dendrogram showing clustering of 36 sorghum landraces based on ear head traits

***Diversity based on qualitative traits*:** Visual scores were noted using standard descriptors as per the DUS guidelines and instead of major state of expression of all, the twelve qualitative traits were characterized (Table 4). High variability was observed for various ear head and seed traits (Rakshit *et al.,* 2012b; Joshi *et al.,* 2015). Glume colour (red, reddish orange, purple, bold purple glume, yellow green, chalkish white), glume covering (25-100 per cent), seed colour and seed size (brown, red bold, reddish brown bold seed, white seed, white bold seed and small seed). The Shannon Diversity Index (SDI) is one of the informative statistics indices used for characterizing the species diversity in the population. It gives insight into the diversity present in the material based on the qualitative data. Shannon Diversity Index was calculated for the traits and it indicated high variability for traits like glume colour (2.05), ear head shape (1.56), grain colour (1.54), glume covering (1.27), ear head compactness and colour of vitreous albumen (1.25) (Table 4).

Table 4. Variability for 12 qualitative characters in 36 sorghum landraces

Descriptors	Descriptor state	Frequency	Per cent	SDI
Ear head shape	Round	1	2.78	
	Oblong	6	16.67	
	Ovate	7	19.44	1.56
	Elliptical	13	36.11	
	Cylindrical	2	5.56	
	Broom corn	7	19.44	
Ear compactness	Compact	16	44.44	
	Semi- compact	13	36.11	
	Loose	3	8.33	1.26
	Very loose	2	5.56	
	Broom corn	2	5.56	
Glume colour	White	2	5.56	
	Straw	7	19.44	
	Light brown	2	5.56	2.06
	Brown	3	8.33	
	Reddish brown	7	19.44	
	Light red	1	2.77	
	Black	4	11.11	
	Partially straw and brown tan	10	27.78	
Glume covering	One fourth grain uncover	14	38.89	
	Half grain uncover	11	30.56	
	Three fourth grain uncover	3	8.33	1.27
	Grain fully covered	8	22.22	
Grain colour	White	4	11.11	
	Chalky white	4	11.11	
	Creamy straw	6	16.67	1.55
	Light brown	6	16.67	
	Brown	1	2.77	
	Reddish brown	15	41.67	
Grain lustre	Non lustrous	14	38.89	
	Lustrous	22	61.11	
Grain size	Small	3	8.33	0.67
	Medium	27	75.00	
	Bold	6	16.67	0.72
Grain shape dorsal view	Narrow elliptic	3	8.33	
	Elliptic	20	55.56	
	Circular	13	36.11	0.90
Grain shape profile view	Elliptic	26	72.22	
	Circular	10	27.78	
Size of mark of germ	Medium	18	50.00	0.59
	Large	16	44.44	
	Very large	2	5.56	0.87
Texture of endosperm	75% corneous	2	5.56	
	50% corneous	12	33.33	
	25 % corneous	20	55.55	1.01
	Non corneous	2	5.56	
Colour of vitreous albumen	Grayed yellow	12	33.33	
	Grayed orange	11	30.56	
	Grayed purple	11	30.56	1.25
	Nil	11	5.55	

***Principal component analysis*:** Principal Component Analysis (PCA) is a multivariate statistical technique where complex data sets can be interpreted and explored graphically which is simple to derive valid conclusions (Everitt and Dunn, 1992; Basilevsky, 1994). In PCA major objective is to reduce the dimensionality of the data and find out minimum required components to explain maximum variation of the total. It was evident from the correlation matrix that variables were highly correlated as most of the values were greater than 0.3 (Table 3). Eigen values are the variances of the principal components. In the Eigen values of the correlation matrix, the first and second principal components explained more than 99% of the variance and the remaining components had meagre variance of about 0.66%. The first principal component accounted for the maximum proportion (97.41%) of the total variability. Scree plot graphs the Eigen values against the component number. In the present study, first four points upto elbow point determined the principal components and the remaining Eigen values of the successive components accounted for smaller and smaller amounts of the total variance (Fig 2). PCA also confirmed the cluster analysis obtained through Euclidean distances and clearly depicted the inclusion of the highly diverse genotypes into different clusters (Fig 3) (Grenier *et al.,* 2004; Geleta and Labuschagne, 2005; Sinha and Kumaravadivel, 2016).

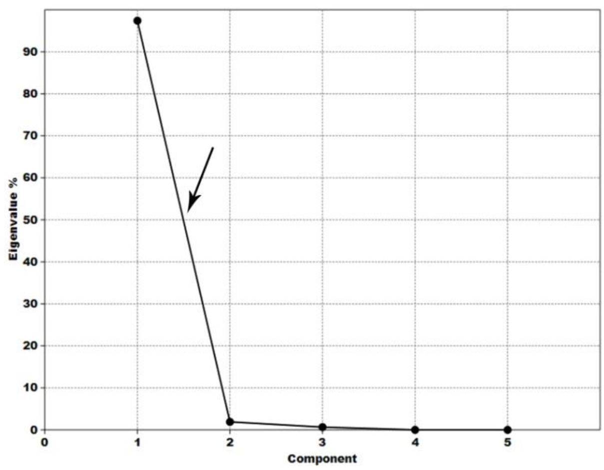

Fig 2. Scree plot depicting the contribution of components towards total variability

Conclusion

The unique accessions identified in this study will provide excellent opportunities to improve sorghum for earhead weight, earhead length and various grain characteristics. The tall landraces identified can be a valuable source to deploy genes related to plant height and high biomass in sorghum. This will further boost up sorghum utilization in developing more climate resilient cultivars and base material for production of second generation biofuels, paper and pressed fibre boards.

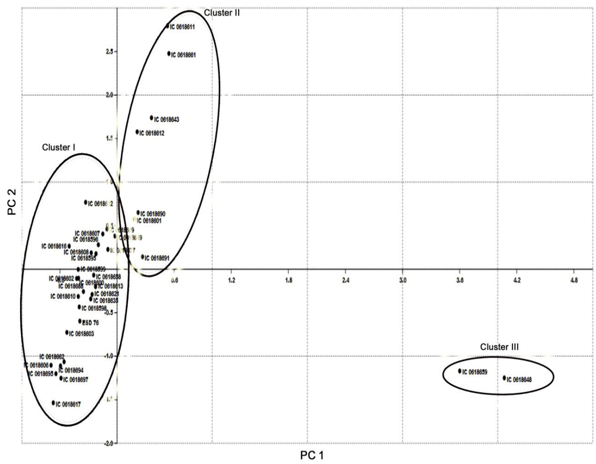

Fig 3. Clustering pattern of sorghum landraces for the first two principal components

Acknowledgment

The authors are thankful to the Director, ICAR-NBPGR, New Delhi and Heads, Germplasm Evaluation Division and Germplasm Exploration Division ICAR-NBPGR, New Delhi for providing facilities and help.

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