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Genetic Variability and Diversity of *Sorghum* Landraces Collected from Uttar Pradesh, India

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Ninety-nine sorghum landraces collected from Uttar Pradesh were evaluated during *kharif* 2008 and 2009 for 22 agro-morphological traits using minimal descriptors developed by NBPGR. Analysis of variance showed significant differences among genotypes for 22 traits. Large variation among genotypes was found for the traits *viz.,* days to 50% flowering (66-87 days), leaf length (62.1-101.5 cm), leaf width (5.0-9.0 cm), number of leaves/ plant (9-16), plant height (215.1-383.0 cm), ear head length (10.1-34.3 cm), ear head width (3.7-9.5 cm), 100-seed weight (1.7-3.5 g), days to maturity (103-126 days), stem fresh weight/5plants (1063-3200 g) and stem dry weight/5plants (569-2038 g). Selections can be made for traits *viz*., days to flowering, leaf length, leaf orientation, days to maturity, plant height and grain luster governed by additive gene action.

Key Words: Diversity, Genetic variability, Landraces, Sorghum, Uttar Pradesh

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a non-native species for which India is a secondary centre of diversity (Singh, 2002). The Indian Council of Agricultural Research (ICAR) promoted programmers/projects independently or in collaboration with USIAD, on germplasm collection, evaluation and utilization of sorghum during 1963-1964. The first major effort on the collection of sorghum genetic diversity was made under the auspices of Rockefeller Foundation and ICAR, and a total of 16,138 collections were assembled during 1970 (Rockefeller Foundation, 1970). Sorghum is grown during rainy and post-rainy seasons in semi-arid regions of the country on the marginal lands. Crop is well adapted to drought-prone regions with poor soil as compared to other cereal crops. In India, sorghum is mainly grown in Maharashtra, Karnataka and Andhra Pradesh during rabi (post-rainy) and in Madhya Pradesh, Rajasthan, Uttar Pradesh, Uttarakhand, Gujarat and Tamil Nadu during kharif (rainy) seasons. Sorghum is classified into five basic races *viz., bicolor*, *guinea*, *caudatum*, *kafir* and *durra*, which are further classified into ten intermediate races namely *durra-caudatum, durra-guinea, durra-kafir, durra-bicolor, caudatum- guinea, caudatum-kafir, caudatum-bicolor, guinea-kafir, guinea-bicolor,* and *kafir-bicolor* (Harlan and de Wet, 1972).

Uttar Pradesh is the home of traditional crops as well as large number of traditional/local sorghum varieties. The collection of cultivated types includes landraces from various environments where they are adapted and grown. These are all annual cultigens. Several landraces were found resistant and used to grow under severe stress condition. Collection of such genotypes from the field together with recorded data provides information for further evaluation. High temperature and low water availability during the reproductive phase of rabi sorghum are the major limitations for a healthy crop growth and thus only the adaptive and selective varieties can be grown under such environments. Loss of genetic variability leading to genetic erosion has led to greater emphasis on germplasm collection and characterization for present and future plant breeding programmes (Prasanna, 2010). The present study was undertaken to explore the genetic and environmental variability in sorghum landraces collected from different agro-ecological regions of Uttar Pradesh.

Materials and Methods

Ninety-nine sorghum landraces collected from 11 districts, 25 talukes and 54 villages of Uttar Pradesh were evaluated during kharif (rainy) season. The germplasm collection represented some basic and intermediate races of sorghum *viz*., *bicolor* (2), *durra* (44), *durra-bicolor* (5), *durra-caudatum* (42), *guinea* (2) and *guinea-caudatum* (4) (Table 1). These accessions were evaluated during kharif 2008 and 2009 seasons at Directorate of Sorghum Research, Hyderabad.

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Table 1. List of accessions collected from Uttar Pradesh with racial classification

S. No.	Accession number	Indigenous collection number	Race	Village	Taluk	District
1	ES 1	IC 333346	Durra	Kalyanpur	Kanpur	Kanpur
2	ES 3	IC 333348	Durra	Kalyanpur	Kanpur	Kanpur
3	ES 4	IC 333349	Durra	Kalyanpur	Kanpur	Kanpur
4	ES 5	IC 333350	Bicolor	Kalyanpur	Kanpur	Kanpur
5	ES 6	IC 333351	Durra	Kalyanpur	Kanpur	Kanpur
6	ES 7	IC 333352	Durra	Ruma	Kanpur	Kanpur
7	ES 8	IC 333353	Durra	Ruma	Kanpur	Kanpur
8	ES 9	IC 333354	Durra	Kalyanpur	Kanpur	Kanpur
9	ES 10	IC 333355	Durra	Gowdiya	Kanpur Nagar	Fatehpur
10	ES 11	IC 333356	Durra	Badagarh	Kanpur Nagar	Fatehpur
11	ES 12	IC 333357	Durra	Pajithpur	Kanpur Nagar	Fatehpur
12	ES 13	IC 333358	Durra	Pajithpur	Kanpur Nagar	Fatehpur
13	ES 14	IC 333359	Durra	Fatehpur	Fatehpur	Fatehpur
14	ES 15	IC 333360	Bicolor	Bilanda	Allahabad	Fatehpur
15	ES 16	IC 333361	Durra	Mayaramakapurva	Hairamva	Fatehpur
16	ES 17	IC 333362	Durra	Ganbath Sakhiya	Allahabad	Kaushambi
17	ES 18	IC 333363	Durra	Ganbath Sakhiya	Allahabad	Kaushambi
18	ES 19	IC 333364	Durra	Keshavapur	Allahabad	Kaushambi
19	ES 20	IC 333365	Durra	Keshavapur	Allahabad	Kaushambi
20	ES 21	IC 333366	Durra	Suratjung	Allahabad	Kaushambi
21	ES 22	IC 333367	Durra	Suratjung	Allahabad	Kaushambi
22	ES 23	IC 333368	Durra	Suratjung	Allahabad	Kaushambi
23	ES 24	IC 333369	Durra	Sikantharpur Vajaga	Allahabad	Allahabad
24	ES 25	IC 333370	Durra	Pannoie	Allahabad	Allahabad
25	ES 26	IC 333371	Durra	Bagadpur	Bhulpur	Allahabad
26	ES 27	IC 333372	Guinea	Bagadpur	Bhulpur	Allahabad
27	ES 28	IC 333373	Durra	Vashiki	Bhulpur	Allahabad
28	E 16	IC 333374	Durra	Bodeganj	Allahabad	Allahabad
29	E 17	IC 333375	Durra	Gowganya	Allahabad	Allahabad
30	E 18	IC 333376	Durra	Gowganya	Allahabad	Allahabad
31	E 19	IC 333377	Durra	Gowganya	Allahabad	Allahabad
32	E 20	IC 333378	Durra	Suratpur	Allahabad	Allahabad
33	E 21	IC 333379	Durra	Murka	Mau	Banda
34	E 22	IC 333380	Durra	Katya Mau	Mau	Banda
35	E 23	IC 333381	Durra	Akiri	Mau	Banda
36	E 24	IC 333382	Durra	Akiri	Mau	Banda
37	E 25	IC 333383	Durra	Devanda	Ramnagar	Chitrakut
38	E 26	IC 333384	Durra	Devanda	Ramnagar	Chitrakut
39	E 27	IC 333385	Durra	Lepura	Ramnagar	Chitrakut
40	E 28	IC 333386	Durra	Lepura	Ramnagar	Chitrakut
41	E 29	IC 333387	Durra	Rawli	Narayani	Chitrakut
42	E 30	IC 333388	Durra	Rawli	Narayani	Chitrakut
43	E 31	IC 333389	Durra	Rajputh Nagar	Choti Badokar	Chitrakut
44	E 32	IC 333390	Durra	Mahokar	Bargarh	Banda
45	E 33	IC 333391	Durra-bicolor	Mahokar	Bargarh	Banda
46	E 34	IC 333392	Durra	Pasangi	Bargarh	Banda
47	E 35	IC 333393	Durra-bicolor	Pasangi	Bargarh	Banda
48	E 36	IC 333394	Durra	Jaseipur	Tindwari	Banda
49	E 37	IC 333395	Durra	Jaseipur	Tindwari	Banda
50	E 38	IC 333396	Durra	Jawarpur	Tindwari	Banda
51	E 39	IC 333397	Durra	Indrapurva	Banda	Banda
52	E 40	IC 333398	Durra	Indrapurva	Banda	Banda

Contd.....

Table 1. Contd.....

S. No.	Accession number	Indigenous collection number	Race	Village	Taluk	District
53	E 41	IC 333399	Durra	Raipura	Kaveregi	Mahoba
54	E 42	IC 333400	Durra	Suba	Kulphakad	Mahoba
55	E 43	IC 333401	Durra	Kulphakad	Kulphakad	Mahoba
56	E 44	IC 333402	Durra	Sankara	Kulphakad	Mahoba
57	E 45	IC 333403	Durra	Panwari	Panwari	Mahoba
58	E 46	IC 333404	Durra	Ital	Gohand	Hamirpur
59	E 47	IC 333405	Durra	Beena	Gohand	Hamirpur
60	E 48	IC 333406	Durra	Chunahut	Gohand	Hamirpur
61	E 49	IC 333407	Durra	Chunahut	Gohand	Hamirpur
62	E 50	IC 333408	Durra	Rahak	Gohand	Hamirpur
63	E 51	IC 333409	Durra	Devgunpur	Panwari	Mahoba
64	E 52	IC 333410	Durra	Devgunpur	Panwari	Mahoba
65	E 53	IC 333411	Durra	Dhavapur	Mauranipur	Jhansi
66	E 54	IC 333412	Durra	Chakkara	Mauranipur	Jhansi
67	E 55	IC 333413	Durra-bicolor	Chakkara	Mauranipur	Jhansi
68	E 56	IC 333414	Durra	Chakkara	Mauranipur	Jhansi
69	E 57	IC 333415	Durra-bicolor	Bamhauri	Mauranipur	Jhansi
70	E 58	IC 333416	Durra	Bamhauri	Mauranipur	Jhansi
71	E 59	IC 333417	Durra-bicolor	Mauranipur	Mauranipur	Jhansi
72	E 60	IC 333418	Durra-bicolor	Mauranipur	Mauranipur	Jhansi
73	E 61	IC 333419	Caudatum	Mauranipur	Mauranipur	Jhansi
74	E 62	IC 333420	Caudatum	Mauranipur	Mauranipur	Jhansi
75	E 63	IC 333421	Durra	Mauranipur	Mauranipur	Jhansi
76	E 64	IC 333422	Caudatum	Mauranipur	Mauranipur	Jhansi
77	E 65	IC 333423	Caudatum	Mauranipur	Mauranipur	Jhansi
78	E 66	IC 333424	Durra	Mauranipur	Mauranipur	Jhansi
79	E 67	IC 333425	Durra	Mauranipur	Mauranipur	Jhansi
80	E 68	IC 333426	Caudatum	Pallara	Baghera	Jhansi
81	E 69	IC 333427	Caudatum	Pallara	Baghera	Jhansi
82	E 70	IC 333428	Caudatum	Pallara	Baghera	Jhansi
83	E 71	IC 333429	Durra	Orai	Orai	Jalaun
84	E 72	IC 333430	Durra	Chamari	Orai	Jalaun
85	E 73	IC 333431	Durra-bicolor	Ata	Kalpi	Jalaun
86	E 74	IC 333432	Durra-bicolor	Ata	Kalpi	Jalaun
87	E 75	IC 333433	Durra-bicolor	Ata	Kalpi	Jalaun
88	E 76	IC 333434	Durra	Ata	Kalpi	Jalaun
89	E 77	IC 333435	Durra	Ata	Kalpi	Jalaun
90	E 78	IC 333436	Durra	Bimbiraya	Kalpi	Jalaun
91	E 79	IC 333437	Durra	Itora	Kalpi	Jalaun
92	E 80	IC 333438	Durra	Chowra	Amrovdhar	Kanpur Dehat
93	E 81	IC 333439	Durra	Chowra	Amrovdhar	Kanpur Dehat
94	E 82	IC 333440	Durra	Hosemau	Bhagnipur	Kanpur Dehat
95	E 83	IC 333441	Durra	Hosemau	Bhagnipur	Kanpur Dehat
96	E 84	IC 333442	Durra	Chatteni	Bhagnipur	Kanpur Dehat
97	E 85	IC 333443	Durra	Chatteni	Bhagnipur	Kanpur Dehat
98	E 86	IC 333444	Durra	Mohamedpur	Malasa	Kanpur Dehat
99	E 87	IC 333445	Durra-bicolor	Mohamedpur	Malasa	Kanpur Dehat

The experimental field is located at 17° 19' 28.5" N latitude and 78° 24' 13.4" E longitudes at an altitude of 524 m MSL (mean above sea level). The seed material was sown in augmented block design with two replications. Each genotype was sown in three rows, 5 m long at 45 × 15 cm apart. The data were recorded in each genotype on 22 agro-morphological traits following the minimal descriptors developed by National Bureau of Plant Genetic Resources (NBPGR) (Mahajan *et al.*, 2000). Five plants in each accession were selected for data recording of

qualitative and quantitative traits. The seedling vigour was recorded in 14-day-old seedlings. The midrib colour was recorded in one-month-old seedlings. The data on days to 50% flowering (days) was recorded during the panicle emergence stage. The leaf orientation, leaf length (cm) and leaf width (cm) were measured during the physiological maturity stage. The number of leaves, plant height (cm), ear head length (cm) and ear head width (cm) were measured during the physiological maturity stage. The fresh and dry weights (g/5 plant) of stem were measured after harvesting. The 100-seed weight was recorded after threshing. The shape and compactness of ear head were recorded during the maturity stage. The glume colour, glume coverage, presence of awns, grain color, size and lustre were recorded after harvesting stage. For qualitative and quantitative traits data on average of five plants of each genotype were computed for statistical analyses.

Analysis of variance (ANOVA) was carried out assuming season effects as random and cultivar effects as fixed. The homogeneity of error variance was established (Gomez and Gomez, 1984). Co-efficient of variation (CV %), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and heritability in broad-sense (h^2) were calculated (Burton and De Vabe, 1953, Singh and Chaudhary, 1985) including expected genetic advance (Johnson *et al.*, 1955). The data were subjected to multivariate analysis (Mahalanobis, 1949) and the genotypes were further grouped into different clusters based on Ward's minimum variance method (Hair *et al.*, 1987) and principal component analysis (Rao, 1952). Genotypes were grouped on the basis of minimum generalized distance using Tocher's method (Rao, 1964). All the data analysis was performed using Indostat (2004).

Results and Discussion

Genetic Variability

Analysis of variance revealed significant differences among genotypes for all the 22 traits (Table 2). There was large variation among genotypes for the traits, days to 50% flowering, leaf length, leaf width, number of leaves/plant, plant height, ear head length, ear head width, 100-seed weight, days to maturity, stem fresh weight/5plants and stem dry weight/5plants (Table 2). Significant GxE interaction for leaf length and leaf width of the plant was observed.

Significant differences among the genotypes for all

Table 2. Genetic variability, heritability and genetic advance for different traits in sorghum germplasm

Character	Mean	CV	CD 5%	Range	Variance geno-typical	Variance pheno-typical	ECV	GCV	PCV	(%) h2 (broad sense)	Genetic advance % of mean (5%)
Days to 50% flowering (no.)	79.16	6.40	7.05	66.00-87.00	8.67	34.36	6.40	3.72	7.41	25.00	3.85
Leaf length (cm)	87.85	8.27	10.11	62.10-101.50	19.29	72.08	8.27	5.00	9.66	27.00	5.33
Leaf width (cm)	7.08	12.62	1.24	5.00-9.00	0.21	1.01	12.62	6.44	14.17	21.00	6.04
Number of leaves	13.13	10.82	1.98	9.00-16.00	0.68	2.70	10.82	6.26	12.51	25.00	6.46
Plant height (cm)	318.88	7.55	33.52	215.10-383.00	894.95	1475.09	7.55	9.38	12.04	61.00	15.05
Ear head length (cm)	19.00	14.48	3.83	10.10-34.30	17.46	25.04	14.48	21.99	26.33	70.00	37.83
Ear head width (cm)	5.85	14.71	1.20	3.70-9.50	0.65	1.39	14.72	13.77	20.15	47.00	19.37
100-seed weight (g)	2.53	14.07	0.50	1.70-3.50	0.10	0.23	14.07	12.59	18.89	45.00	17.30
Days to maturity (no.)	115.98	3.66	5.91	103.00-126.00	9.09	27.11	3.66	2.60	4.49	34.00	3.10
Stem fresh weight (g/5plants)	2093.90	30.30	883.02	1063.00-3200.00	69624.83	472249.30	30.30	12.60	32.82	15.00	9.97
Stem dry weight (g/5plants)	1165.61	38.36	622.30	569-2038	41602.61	241570.70	38.36	17.50	42.17	17.00	14.96
Vigour	2.67	0.00	–	2.00-3.00	0.22	0.22	0.00	17.77	17.77	100.00	36.60
Leaf orientation	1.17	0.00	–	1.00-2.00	0.14	0.14	0.00	32.35	32.35	100.00	66.64
Midrib colour	1.10	0.00	–	1.00-2.00	0.09	0.09	0.00	27.51	27.51	100.00	56.67
Ear head shape	3.67	0.00	–	2.00-7.00	1.53	1.53	0.00	33.74	33.74	100.00	69.51
Ear head compactness	1.86	0.00	–	1.00-3.00	0.31	0.31	0.00	29.78	29.78	100.00	61.35
Glume colour	4.00	0.00	–	2.00-10.00	6.39	6.39	0.00	63.19	63.19	100.00	130.16
Glume covering	2.09	0.00	–	1.00-4.00	0.47	0.47	0.00	32.83	32.83	100.00	67.63
Awns	0.82	0.00	–	0.00-1.00	0.15	0.15	0.00	47.38	47.38	100.00	97.60
Grain size	6.37	0.00	–	3.00-9.00	1.44	1.44	0.00	18.83	18.83	100.00	38.79
Grain colour	2.65	0.00	–	1.00-10.00	4.84	4.84	0.00	83.16	83.16	100.00	171.30
Grain luster	0.24	0.00	–	0.00-1.00	0.19	0.19	0.00	177.68	177.68	100.00	366.01

the characters indicated adequate genetic variability in the experimental material. The genetic constants for the characters revealed that the magnitude of phenotypic co-efficient of variation (PCV) was higher than the corresponding genotypic co-efficient of variation (GCV) indicating impact of environmental factors on their expression. Narrow difference between PCV and GCV suggested their relative resistance to environmental fluctuations. In the present study, the PCV and GCV were higher for days to 50% flowering, leaf length, leaf width, number of leaves, plant height, ear head length, ear head width, 100-seed weight, days to maturity, stem fresh weight, stem dry weight, vigour, leaf orientation, midrib colour, ear head shape, ear head compactness, glume colour and glume covering (Table 2). High amount of GCV and PCV suggested greater scope for selection of superior genotypes for these traits. While lower degree or equal GCV and PCV for presence of awns, grain size, grain colour, and grain luster indicated that improvement for such traits might be achieved only up to some extent and these traits cannot be influenced by the environment as they are very stable traits. Utilization of these stable traits for creating variability among the genotypes is possible. High GCV and PCV values were observed for grain luster as also reported earlier (Warkad *et al.*, 2008; Elangovan *et al.*, 2013). Equal GCV and PCV were observed in sorghum for plant height up to base of flag leaf, stigma length, plant total height and panicle length (Reddy *et al.*, 2009). High GCV and PCV values were recorded for grain luster.

The determination of the heritable portions is not based on the estimation of the GCV and PCV, alone. The estimation of heritability along with the coefficient of variability would mean the amount of advance expected. Burton (Burton, 1952) also suggested that GCV and heritability estimate would give better information about the efficiency of the selection. The heritability (%) ranged from 15% (stem fresh weight) to 100% (vigour, leaf orientation, midrib colour, ear head shape, ear head compactness, glume colour, glume covering, presence of awns, grain size, grain colour and grain luster). The utility of heritability is increased when it is used to estimate genetic advance (Johnson *et al.*, 1955). The genetic advance has an edge over heritability as a guiding factor to breeders in selection programme. High heritability coupled with high genetic advance and GCV was noticed for grain luster, grain colour, glume colour, presence of awns, ear head shape, glume covering and leaf orientation.

Genetic Diversity

Ninety-nine sorghum landraces tested for two years during the *kharif* season were grouped into 16 clusters based on D^2 values (Table 5). The distribution pattern indicated that the maximum number of genotypes were included in cluster I with 54 genotypes, followed by cluster II having 23 genotypes, cluster V and IX having four genotypes each and cluster XII having three genotypes. A total of 11 clusters have only one genotype *i.e.*, cluster III – E 83, IV – E 55, VI – E 37, VII – ES 9, VIII – E 27, X – E 87, XII – ES 22, XIII – E 24, XIV – E 43, XV – ES 5 and XVI – E 25. The cluster distance was ranging from 817.00 to 1401.19 within the clusters and 398.78 to 12709.03 between clusters (Table 6). The inter-cluster distances were higher than intra-cluster distances, which indicated wide genetic diversity among the accessions of different groups than those of same cluster. The least intra-cluster distance of 817 was found among the accessions. Cluster I showed lack of variation among the accessions.

The diversity among the present set of material was also supported by the appreciable amount of variation among cluster means for different characters (Table 3). The cluster which is diverse from other clusters was found to have different mean values for number of leaves, ear head length, 100-seed weight, days to maturity, stem fresh weight, stem dry weight, glume colour and grain colour. Cluster IV was diverse from other clusters due to different cluster mean values for days to 50% flowering, leaf length, leaf orientation, days to maturity and plant height comparable results have been reported by Reddy *et al.* (2009) and Elangovan *et al.* (2014). Genetic diversity is generally associated with geographical diversity but the former is not necessarily directly related to geographical distribution (Ganesamuthy *et al.*, 2010; Elangovan *et al.*, 2012). Principal component analysis gives supplementary information on the usefulness of the characters for the definition of the groups (Table 4). The first three principal vectors contribute to 73% of the variance. The first vector, which accounts for 46% variance, the important characters responsible for genetic divergence in the major axis of differentiation was glume covering, vigour, ear head compactness. In the second vector (17.6% of variation), the important characters responsible for genetic divergence were awns, grain size, luster and vigour. Exploitation of genetic

Table 3. Cluster mean values for different contributing characters

S. No.	Variable	PC I	PC II	PC III	PC IV	PC V	PC VI	PC VII	PC VIII	PC IX	PC X	PC XI	PC XII	PC XIII	PC XV	PC XV	PC XVI
1	Days to 50% flowering (no.)	79.75	79.03	79.25	86.50	76.69	82.00	77.25	79.50	74.44	79.25	72.75	81.17	79.25	80.25	66.00	82.00
2	Leaf length (cm)	89.20	85.18	92.60	82.60	83.29	91.25	91.33	89.70	88.69	101.48	85.58	87.45	81.53	85.85	79.18	89.83
3	Leaf width (cm)	7.18	6.97	7.33	6.55	6.81	7.68	7.68	6.50	6.89	7.55	6.20	7.26	7.20	7.35	5.95	6.18
4	Number of leaves (no.)	13.28	12.97	13.50	15.75	12.56	14.25	12.75	12.75	11.69	12.25	13.75	13.33	13.75	12.50	11.25	15.00
5	Plant height (cm)	318.01	316.74	371.63	273.80	314.09	329.60	383.00	286.5	318.50	311.63	360.13	323.46	314.13	346.63	314.75	319.38
6	Ear head length (cm)	17.85	19.29	21.63	22.13	24.64	18.83	19.03	15.93	25.51	17.85	27.83	15.19	12.63	22.78	34.28	14.45
7	Ear head width (cm)	5.93	5.96	5.75	5.68	6.20	5.88	4.50	4.73	4.79	6.40	5.80	5.84	5.80	6.00	4.15	5.63
8	100-seed weight (g)	2.58	2.52	1.80	1.83	2.14	1.95	3.13	2.90	2.18	2.90	2.08	3.01	3.03	2.13	2.33	2.95
9	Days to maturity (no.)	116.53	115.50	112.75	121.30	114.63	115.30	113.25	115.00	115.13	113.25	110.25	116.00	118.75	118.75	109.50	118.25
10	Stem fresh weight (g/5plants)	2112.89	2045.82	2187.50	2588.00	1933.40	2050.00	2525.00	2362.50	1831.25	2250.00	1575.00	2162.50	2325.00	1987.50	1762.50	2987.50
11	Stem dry weight (g/5plants)	1166.34	1143.48	1481.25	1550.00	978.13	1288.00	1750.00	1318.80	942.19	1175.00	706.25	1258.30	1662.50	1050.00	768.75	1906.30
12	Vigour	2.72	2.65	3.00	2.75	2.75	2.00	3.00	3.00	2.75	3.00	3.00	2.00	2.00	2.00	2.00	2.00
13	Leaf orientation	1.17	1.09	1.00	2.00	1.00	2.00	1.00	1.00	1.25	1.00	1.00	1.33	2.00	2.00	1.00	1.00
14	Midrib colour	1.03	1.13	1.00	1.00	1.25	1.00	2.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	Ear head shape	3.43	3.35	4.00	4.00	6.25	4.00	4.00	2.00	5.50	2.00	7.00	3.33	3.00	4.00	7.00	2.00
16	Ear head compactness	1.77	1.75	2.00	2.00	2.75	2.00	2.00	1.00	3.00	1.00	3.00	1.67	1.00	2.00	3.00	1.00
17	Glume colour	2.32	7.25	2.00	2.00	4.00	2.00	2.00	2.00	6.75	9.00	2.00	2.67	9.00	7.00	6.00	10.00
18	Glume covering	2.07	2.04	4.00	3.00	1.50	2.00	2.00	1.00	2.06	1.00	4.00	2.33	1.00	4.00	4.00	1.00
19	Awns	0.85	0.91	1.00	1.00	0.50	1.00	0.00	1.00	0.06	1.00	1.00	1.00	1.00	1.00	0.00	1.00
20	Grain size	6.41	6.57	5.00	3.00	6.00	3.00	9.00	9.00	5.00	9.00	5.00	7.00	7.00	5.00	5.00	9.00
21	Grain colour	2.20	2.26	1.00	1.00	1.00	1.00	3.00	1.00	7.75	3.00	1.00	9.67	2.50	1.00	1.00	10.00
22	Grain luster	0.22	0.13	0.00	0.00	0.75	0.00	1.00	0.00	0.44	0.00	0.00	0.67	1.00	0.00	0.00	0.25

Table 4. Matrix of principal components of 22 variables for 99 sorghum germplasm

S. No.	Variable	PC I	PC II	PC III	PC IV	PC V	PC VI
1	Days to 50% flowering (no.)	0.004	0.021	0.005	0.003	0.015	0.013
2	Leaf length (cm)	0.009	0.016	–0.006	–0.005	–0.014	0.023
3	Leaf width (cm)	0.005	0.014	0.001	0.001	0.002	0.002
4	Number of leaves (no.)	0.004	0.007	0.012	–0.001	0.019	0.007
5	Plant height (cm)	0.001	–0.019	0.008	–0.006	–0.057	–0.018
6	Ear head length (cm)	–0.007	–0.074	0.023	–0.064	–0.005	0.022
7	Ear head width (cm)	0.002	0.022	0.015	0.004	0.011	–0.012
8	100-seed weight (g)	–0.001	0.035	–0.028	0.020	–0.050	0.023
9	Days to maturity (days)	0.000	0.005	0.000	0.001	–0.022	0.002
10	Stem fresh weight (g/5plants)	–0.001	0.017	–0.010	0.013	0.011	–0.015
11	Stem dry weight (g/5plants)	–0.003	0.012	–0.009	0.018	–0.003	–0.006
12	Vigour	0.028	0.046	0.129	–0.064	–0.575	–0.592
13	Leaf orientation	0.005	–0.061	–0.084	0.049	0.254	–0.410
14	Midrib colour	–0.046	–0.110	–0.152	–0.087	–0.072	–0.145
15	Ear head shape	0.013	–0.455	–0.018	–0.550	–0.067	0.120
16	Ear head compactness	0.018	–0.447	–0.013	–0.435	–0.125	0.104
17	Glume colour	–0.988	–0.077	0.117	0.032	–0.002	–0.036
18	Glume covering	0.072	–0.462	0.203	0.596	–0.345	0.048
19	Awns	–0.042	0.413	0.069	–0.268	0.117	–0.146
20	Grain size	–0.064	0.411	–0.099	–0.114	–0.632	0.444
21	Grain colour	–0.098	–0.091	–0.900	0.182	–0.031	0.056
22	Grain luster	0.005	0.022	–0.269	–0.122	–0.198	–0.455
	Root	51346.61	19512.96	10034.02	8801.46	5644.06	4085.98
	% Var. Exp.	46.469	17.659	9.081	7.965	5.108	3.698
	Cum. Var. Exp.	46.469	64.128	73.209	81.174	86.282	89.980

Table 5. Grouping of genotypes into different clusters

Cluster	Genotype
I	ES 19 (IC 333364), ES 21 (IC 333366), E 63 (IC 333421), E 19 (IC 333377), E 81 (IC 333439), ES 17 (IC 333362), E 75 (IC 333433), E 82 (IC 333440), E 85 (IC 333443), E 49 (IC 333407), E 79 (IC 333437), E 76 (IC 333434), E 58 (IC 333416), ES 28 (IC 333373), E 30 (IC 333387), ES 6 (IC 333351), E 57 (IC 333416), E 22 (IC 333380), E 20 (IC 333378), E 21 (IC 333379), ES 7 (IC 333352), ES 10 (IC 333355), E 16 (IC 333374), E 71 (IC 333429), E 51 (IC 333409), E 50 (IC 333408), E 48 (IC 333406), E 18 (IC 333378), E 26 (IC 333384), ES 8 (IC 333353), E 68 (IC 333424), E 44 (IC 333402), E 40 (IC 333398), E 34 (IC 333393), E 17 (IC 333375), E 45 (IC 333403), E 77 (IC 333435), ES 25 (IC 333370), E 23 (IC 333368), ES 13 (IC 333358), E 78 (IC 333436), E 36 (IC 333395), ES 26 (IC 333371), ES 24 (IC 333369), E 56 (IC 333414), ES 20 (IC 333365), E 29 (IC 333374), E 38 (IC 333397), ES 16 (IC 333361), E 31 (IC 333390), E 73 (IC 333431), E 80 (IC 333438), E 41 (IC 333386), ES 15 (IC 333360)
II	E 69 (IC 333427), ES 1 (IC 333346), E 54 (IC 333413), E 32 (IC 333390), E 67 (IC 333425), E 66 (IC 333424), E 46 (IC 333405), E 35 (IC 333393), E 42 (IC 333400), E 52 (IC 333410), ES 14 (IC 333359), E 72 (IC 333430), E 74 (IC 333432), E 84 (IC 333442), E 60 (IC 333418), ES 11 (IC 333356), ES 27 (IC 333372), E 53 (IC 333412), E 86 (IC 333444), ES 4 (IC 333349), E 59 (IC 333418), E 33 (IC 333392), E 64 (IC 33423)
III	E 83 (IC 333441)
IV	E 55 (IC 333414)
V	ES 3 (IC 333348), ES 18 (IC 333363), E 47 (IC 333405), ES 23 (IC 333368)
VI	E 37 (IC 333395)
VII	ES 9 (IC 333357)
VIII	E 27 (IC 333385)
IX	E 61 (IC 333420), E 65 (IC 333424), E 62 (IC 333421), E 70 (IC 333429)
X	E 87 (IC 333445)
XI	ES 22 (IC 333367)
XII	E 39 (IC 333397), ES 12 (IC 333360), E 28 (IC 333386)
XIII	E 24 (IC 333382)
XIV	E 43 (IC 333402)
XV	ES 5 (IC 333353)
XVI	E 25 (IC 333383)

Table 6. Average intra- (bold) and inter-cluster distances for 99 genotypes of sorghum (Tocher method)

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
I	**817.00**	2846.12	1555.41	1425.34	1936.30	1330.89	1340.08	1423.21	3977.76	5064.00	2543.25	2064.90	4976.10	3511.69	4406.25	7549.68
II		**981.09**	3972.42	3859.05	2711.63	3703.11	3638.01	3587.54	2572.03	1630.20	4987.40	3809.47	1660.12	1930.63	3670.01	3290.69
III			**0.00**	721.11	2815.41	1685.06	2195.58	3741.93	4497.32	7882.89	699.64	3279.26	7730.60	2458.78	2486.08	10938.91
IV				**0.00**	2463.59	398.78	2871.36	3580.60	4240.45	7736.25	1419.78	3220.17	6649.04	2651.05	3364.38	10663.76
V					**1401.19**	2206.76	2184.27	3257.71	2863.48	5136.13	2501.00	3568.46	4563.86	3540.19	3271.46	7655.66
VI						**0.00**	3049.15	2965.68	4379.18	7087.19	2415.61	2983.56	5689.37	3299.09	4324.90	9698.86
VII							**0.00**	1691.45	3959.84	5658.79	2977.85	2210.52	5902.30	4599.82	4690.29	8018.26
VIII								**0.00**	6466.07	4070.95	5520.89	3065.99	4863.82	6071.07	8014.61	7056.13
IX									**1048.46**	4704.18	4297.89	3497.81	4150.79	2904.56	2909.14	4926.10
X										**0.00**	9659.97	5701.11	888.71	4521.88	7614.88	1299.28
XI											**0.00**	4353.52	9251.08	3170.61	1785.53	12709.03
XII												**1001.73**	5324.75	4604.14	5721.18	5676.32
XIII													**0.00**	3607.00	6837.14	1787.32
XIV														**0.00**	1283.19	6397.81
XV															**0.00**	9655.20
XVI																**0.00**

resources within and among these contrasting pools of diversity may provide a different source of germplasm with combination traits for utilization in the sorghum improvement programme.

Local cultivars or landraces are used by farmers and breeders selected for varietal improvement prgrammes. Owing to several reasons. (*i*) grain superiority, (*ii*) The improved varieties/versions do not provide anything percept visual appeal and quality and (*iii*) improved versions have as restricted adaptation as the original landraces and hence, are less suitable for wide adaptations. Sorghum germplasm collections of Uttar Pradesh represent greater genetic diversity as the crop has been grown traditionally under varied agro-climatic conditions for centuries and has adapted to the environmental conditions. These landraces with rare and useful alleles could serve as potential donors for yield enhancement and also for developing varieties to withstand biotic and abiotic stresses in the semi-arid tropical regions.

To conclude, the sorghum genotypes used for evaluation study had wide range of variation for agro-morphological characters. There is greater scope for improvement for specific characters. Highest genetic variability is likely to be created when the crosses are made between selected genotypes from different clusters than those made within a cluster. Selection for the trait *viz.*, glume colour, awns, grain colour and grain luster are governed by the non-additive gene effects and can used for developing distinct variety.

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