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Research Article

Assessment of variability in sorghum [*Sorghum bicolor* (L.) Moench] germplasm for agro-morphological traits

Elangovan Maruthamuthu[1*], Karnam Venkatesh[1], Amasiddha Bellundagi [1], Sushil Pandey[2] and Chitra Devi Pandey[2]

[1]ICAR-Indian Institute of Millets Research (IIMR), Hyderabad 500030, Telangana, India
[2]ICAR-National Bureau of Plant Genetic Resources (NBPGR), New Delhi 110012, India
***E-Mail:** elangovan@millets.res.in

Abstract
Sorghum [Sorghum bicolor (L.) Moench] is an important staple food crop of the semi-arid tropics. Phenotypic characterization of conserved gene bank accessions is necessary for their effective utilization for crop improvement. In this study, a total of 2834 accessions of sorghum were characterized during 2018-19 and the data were subjected to ANOVA, Pearson's correlation analysis, and Shannon's diversity index analysis. Shannon diversity index calculated indicated ear head shape to be the most diverse (H'=1.36). Several trait-specific accessions for early flowering (EC0524806, 57 days), high yield (IC0355254, 245.3 g/plan) etc. were identified. Pearson correlation analysis indicated that grain yield was positively influenced by the traits like ear head width (r=0.14), plant height (r=0.1), number of basal tillers (r= 0.07), and 100seed weight (r= 0.09). The trait-specific germplasm accessions identified in the study could be used as trait-specific donors by breeders for sorghum crop improvement.

Keywords: Sorghum, Shannon Diversity, Correlation

INTRODUCTION

Sorghum is an important cereal crop of the semi-arid tropics which is typically known to have soil moisture stress conditions. Sorghum is cultivated and consumed as a staple food in more than 100 countries in the world. The major sorghum producing countries are India, Nigeria, Mexico, the USA, Argentina and Ethiopia. Globally sorghum is cultivated over an area of 40.25 million ha with a production of around 58.7 million tonnes with the productivity of 1485 kg/ ha (FAO Stat, 2020). India with a total area of 5.50 m. ha. (both rainy and post rainy season) produced 4.71 m.t. of sorghum during 2020 (DES, 2020) and is the fifth largest producer in the world. Sorghum is mainly grown and used as food, and fodder in Africa, Asia and Central America. The high brix content sorghum (Sweet sorghum) is used as an alternative source for ethanol production, beer, alcohol, syrup, bakery items, industrial starch, etc. (Umakanth *et al*., 2012).

The recent changes evident in the climatic patterns in the form of increased frequency of severe drought and flooding events due to climate change are causing crop losses among the input intensive crops such as rice and wheat (Sharma *et al*., 2015; Mamrutha *et al*., 2019). Cultivation of resilient and hardy crops is one of the alternative measures recommended to avoid crop losses caused by climate change. Sorghum is one of the drought hardy crops which can withstand extreme environmental changes. Sorghum has diverse populations and species rich ecosystem and has greater potential to adapt to climate change. The improvement of any crop and for any trait depends on the availability of genetically diverse trait specific germplasm and its utilization in the breeding program. The genetic resources (germplasms and landraces) are the best sources to maintain the wide genetic diversity, incorporate variability (new alleles) and be helpful in the sustainable crop improvement strategies. Conservation and utilization of germplasm resources are of utmost importance as cultivation of input responsive improved cultivars has replaced traditional landraces among several other factors (Upadhyaya *et al.,* 2009).

The international and national gene banks had large collections and conservations of germplasm as well as the wide genetic diversity in different crops including sorghum. In recent years, a decline curve observed for international efforts to collect and conserve plant genetic resources (Food & Nations, 2010). There is a need for critical assessment of the collection of germplasm, identifying gaps and launching germplasm collection missions in unexplored and under explored areas. This is important to enrich the genetic variability further and enhance the efficiency of the crop improvement program. International Crops Research Institute for Semi-Arid Tropics (ICRISAT) Hyderabad, India, conserves more than 39000 sorghum accessions from 90 plus countries including > 6200 countries from South Asia (Upadhyaya *et al.,* 2015). The National Gene bank at ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR) New Delhi, India conserves 4.3 lakh germplasm of all crop plants and horticulture crops as well. ICAR-Indian Institute of Millets Research (IIMR), Hyderabad India is also involved in collection and conservation of millets germplasm (>53000) including sorghum, pearl millet and other six small millets, in which sorghum crop tops the table with >33000 germplasm accessions (ICAR-IIMR, 2021). The states Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Madhya Pradesh and Uttar Pradesh are major sorghum cultivating areas. ICAR-IIMR-Hyderabad is one of the National Active Germplasm Sites (NAGS) with the collection and augmentation of sorghum, pearl millet and small millets, which includes >33000 accessions of sorghum and ~20000 accessions of other millets. The present study aimed at characterizing the Indigenous and exotic sorghum germplasm for qualitative and quantitative traits and identifying trait specific germplasm lines for its use in crop breeding programs.

MATERIALS AND METHODS

A total of 4312 accessions of sorghum germplasm representing 22 countries obtained under the Consortium Research Platform on Agrobiodiversity (CRP-AB) on Sorghum were used for agro-morphological traits characterization during 2018-19. In which, data of 2,834 accessions were used for analysis and the rest of them did not germinate or could not collect the complete phenotypic data are not included in the analysis part and they are multiplied for characterization in near future. The 2,834 accessions included 2,122 accessions of indigenous origin and 440 accessions of exotic collections. There were 272 accessions with unknown origin (country) which did not have any associated passport data (**Fig. 1**). Among the 2,122 indigenous accessions studied, 726 were of unknown origin (state). The characterization was done at experimental fields of ICAR-Indian Institute of Millets Research (IIMR) Hyderabad with the geographical coordinate of 17.3207°N latitude, 78.3959°E longitude and 476.5 meters above MSL. The experiment was conducted in augmented block design along with two checks CSV 29R and M35-1 which were repeated after every 100 accessions. The plot size maintained was 1 m row length and 60 cm distance between each row. The distance between the plants was maintained at 10 cm after two weeks of thinning. Fertilizers were applied at the rate of 80 kg/ha N and 40 kg/ha P_2O_5 during crop growth and all necessary package of practice were followed to maintain good crop stand. Regular irrigation was given to maintain sufficient moisture and the crop was protected from weeds, pests and diseases.

The accessions were characterized for nine quantitative traits during crop growth duration **(Table 1).** The days to 50% flowering were observed on the visual basis in the plot when 50% of the plants showed anthesis and calculated as the number of days for flowering from the date of sowing. The other traits were the total number of leaves, leaf length (cm), leaf width (cm) measured at dough stage ear head length (cm), ear head width (cm), plant height (cm) measured at the maturity stage, grain yield (g/plant) and 100-seed weight measured after harvesting

Table1. List of Quantitative traits and measurement units

Organ	Trait	Abbreviation	Unit
Phenology	Days to 50% flowering	DAYS_FLW	days
	Number of basal tillers	BASAL_TILLERS	numbers
Plant	Plant height	PLANT_HT	cm
	Leaf blade length	LEAF_BLD_LEN	cm
Leaf	Leaf blade width	LEAF_BLD_WID	cm
	Ear head length	EAR_HEAD_LEN	cm
Flower	Ear head width	EAR_HEAD_WID	cm
	100 seed weight	100_SD_WT	g
Seed	Grain yield per plant	GRN_YLD_PLN	g

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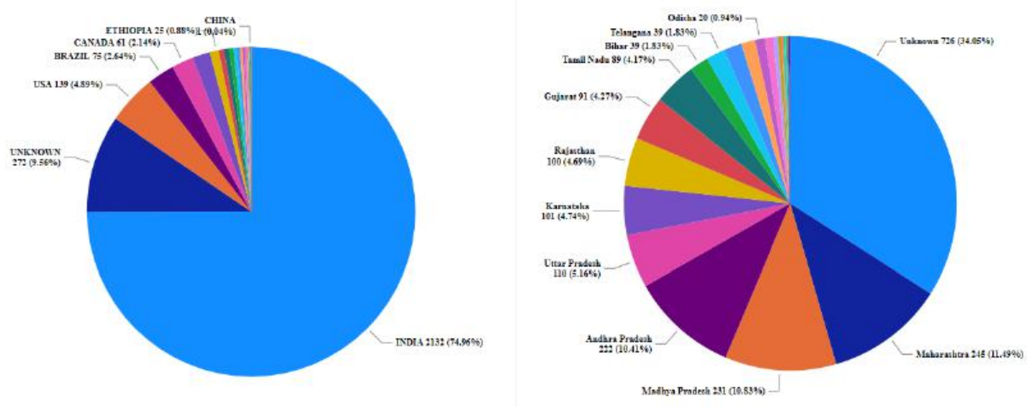


Fig. 1. Global and Indian distribution of 2834 sorghum accessions characterized in the study

and threshing of the genotypes. The observations were collected from three representative plants.

Analysis of variance (ANOVA) was carried out using the Agricola package of R (version 3.4.2). Pearson's correlation coefficient (r) was used to indicate the relationship among traits studied. The Shannon–Weaver index (H′) takes care of both the abundance and evenness of trait classes in the accessions. A low value of H′ indicated a lack of genetic diversity in the collection and a high value of H′ indicated ample genetic diversity in the collections. H' was used to calculate the genetic diversity index of each trait:

$$H = -\sum[(pi) \times \ln(pi)]$$

where 'n' is the number of phenotypic classes for a trait, and 'pi' is the genotypic frequency or the proportion of the total number of entries in the i^{th} class.

RESULTS AND DISCUSSION

ANOVA revealed significant variation (p=<0.001) among the accessions for all the nine quantitative traits studied (**Table 2**).

The genetic diversity in the form of germplasm resources is the basic prerequisite for any crop improvement programme. An ample amount of diversity for all the studied nine quantitative traits was observed among the 2834 accessions (**Fig. 2**). The accession EC0580797 (177 days) recorded the longest days to 50 % flowering while EC0524806 was the earliest in flowering which took just 57 days for 50% flowering. In the grain yield per plant, IC0355254 (245.3 g/ plant) produced a higher grain yield per plant while IC0584535 accession with 1.03 g /plant yielded the lowest. IC0392132 recorded the higher 100 seed weight of 6.7 g and on the contrary, EC0515218 had the lowest 100 seed weight of 0.26 g. It was observed that the longer ear head of 50.13 cm in IC0417763, while the accession, IC0541862 had the smallest ear head of 4.73 cm. The accession, IC0392146 with 360.3 cm was the tallest and on the other hand, accession EC0542209 was the dwarf statured (41.67 cm). Several earlier studies have identified sources of wider agronomically superior, biotic and abiotic stress resistance, mineral content superiority through systematic characterization of germplasm resources (Elangovan *et al.,* 2009; Subbarayudu *et al.,* 2011; Hariprasanna *et al.,* 2014; Jain *et al.*, 2019; Elangovan *et al.*, 2012; Ganesamurthy,

Table 2. Analysis of variance for quantitative traits of 2834 accessions of sorghum germplasm

Trait	Replication	Accessions
df	2	2833
BASAL_TILLERS	<0.001	<0.001
LEAF_BLD_LEN	<0.014	<0.001
LEAF_BLD_WID	<0.001	<0.001
PLANT_HT	<0.001	<0.001
EAR_HEAD_LEN	<0.001	<0.001
EAR_HEAD_WID	<0.001	<0.001
GRN_YLD_PLN	<0.473	<0.001
100_SD_WT	<0.001	<0.001

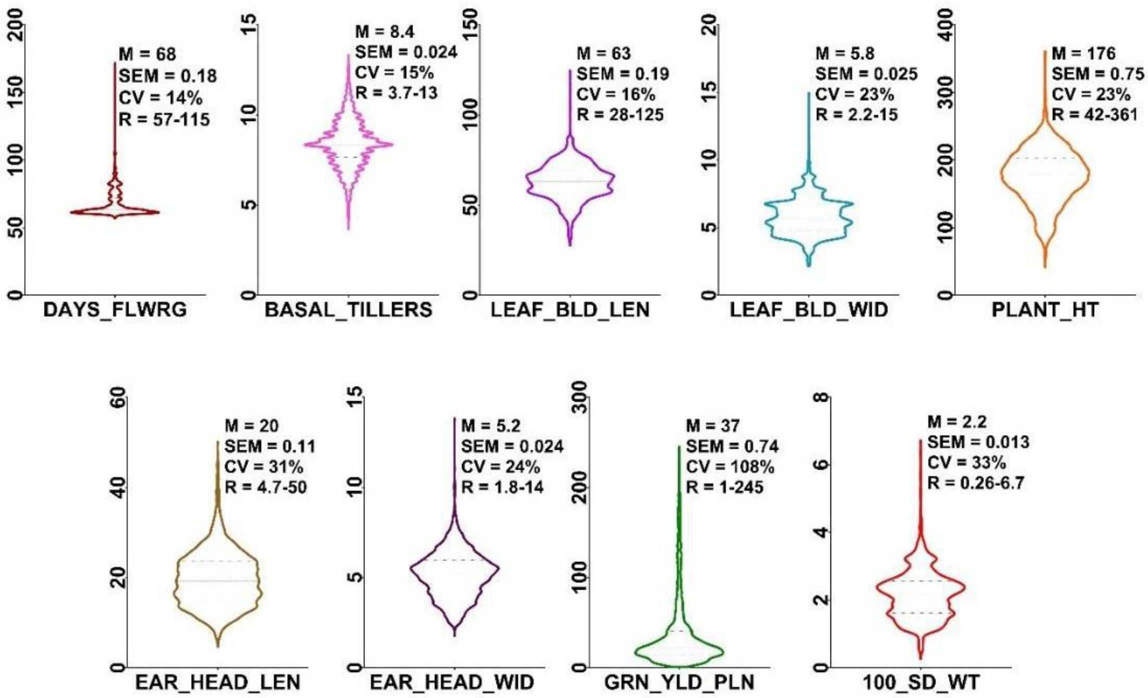


Fig. 2. Violin-plot distributions for the 2834 accessions of sorghum germplasm

Punitha & Elangovan, 2010). Sejake *et al.*, 2020 reported the existence of wide genetic variability for the studied 14 quantitative traits in sorghum accessions and their usefulness in the sorghum improvement as potential donors.

Genetic diversity analysis of 2834 accessions of sorghum germplasm using Shannon diversity index indicated high variability (**Fig.3**). Among the quantitative traits, the 100 seed weight had the highest Shannon diversity (H'=1.08) followed by plant height (H'=1.00) and ear head length (H'=0.96), while ear head width had the least Shannon diversity index of H'=0.54. Earlier researchers also reported wide variability in sorghum germplasm resources (Elangovan *et al*., 2009; Jain *et al*., 2019). Seetharam and Ganesamurthy (2013), Ganesamurthy *et al*. (2010) and Subramanian *et al*. (2019) reported highest Shannon-Weaver diversity index (H') values for the traits like the number of leaves per plant, plant height and leaf width in the study conducted with 39 genotypes characterized for nine quantitative traits.

The Pearson correlation analysis among the traits studied is shown in **Fig. 4**. Due to the presence of a large amount of variability and also a large number of accessions in the study the correlation values observed were small. Among the traits studied, grain yield per plant was positively correlated with ear head width (r=0.14), plant height (r=0.1), the number of basal tillers (r= 0.07) and 100seed weight (r= 0.09). The presence of association among the traits of importance and the possibility of selection for one trait improving the other associated traits have been earlier reported *(*Elangovan *et al., 2009;* Elangovan *et al.,* 2020 b). The improvement in grain yield per plant can be achieved by selecting plants having superiority for ear head width, plant height and basal tiller numbers because of the good correlation observed between these traits. A significant strong positive correlation was found between leaf blade length, leaf blade width (r=0.455) and plant height (r=0.381). Strong (p=<0.001) negative relation was found among ear head length and 100 seed weight (r=-0.16). Similar kinds of results were reported (Mumtaz *et al*., 2017) to have higher brix values in sorghum genotypes and the strongly associated smaller flag leaf area trait can be used as a trait of selection.

The top accessions for each of the quantitative traits are tabulated in **Table 3**. The largest value was considered as a top for all the quantitative traits except in the case of days to 50% flowering for which breeders prefer earliness. The multi-trait specific sorghum accessions which are superior for more than three traits are given in **Table 4**. These accessions can be used as specific trait donors in the crop improvement programme. The lines identified for specific traits like earliness are the excellent source for development of early maturing cultivars, lines identified for tall plant height and with a greater number

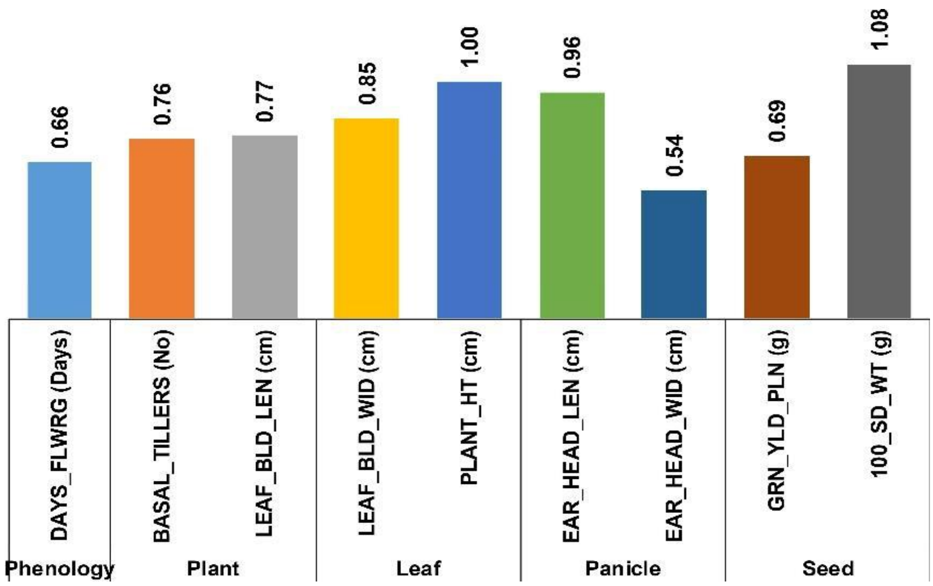
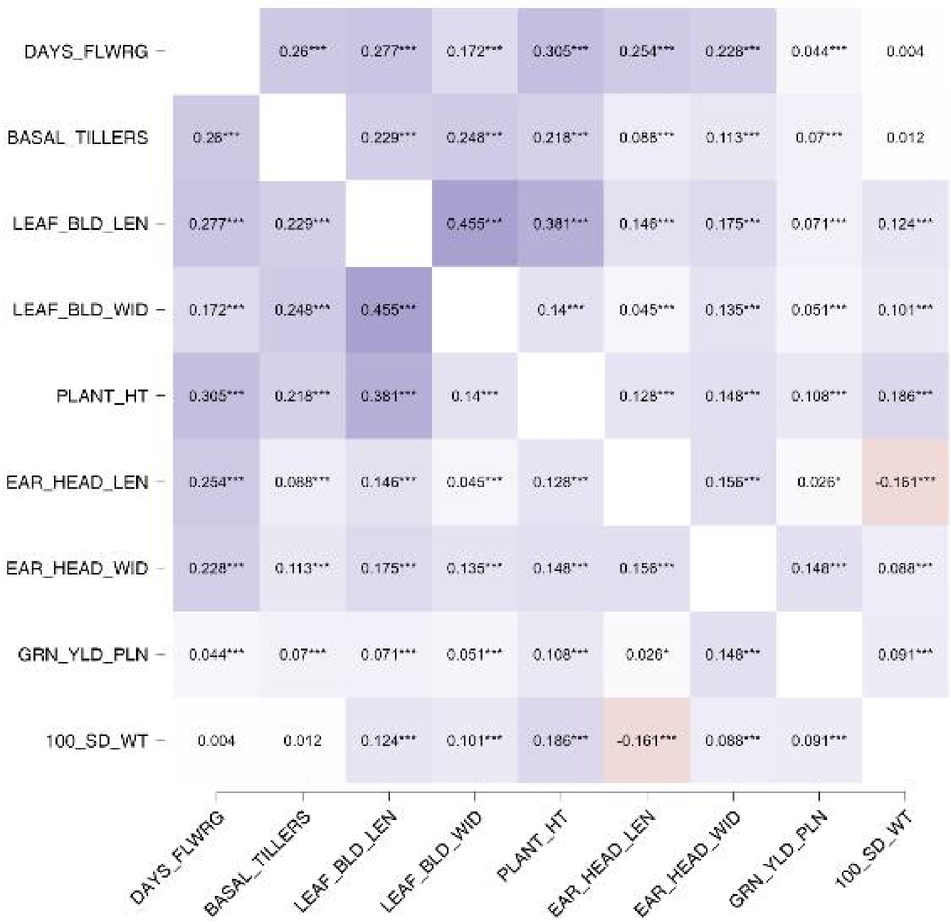


Fig. 3. Diversity among 2834 accessions. of sorghum germplasm based on Shannon diversity index



Blank, indicates not significant, ∗, ∗∗, ∗∗∗ indicates significant at $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively.

Fig. 4. Pearson correlation coefficients among nine quantitative traits in 2834 sorghum accessions

Table 3. Trait-specific sorghum germplasm accessions identified for quantitative traits

S.No.	Trait	Range		No.
1	Days to 50% flowering	Early: 56-65 days	EC0533192 (57 days), EC0533334, EC0524806, EC0515279, EC0542225, IC0319892, IC0541332, IC0544757, EC0524767, IC0544811, IC0415826, EC0524755, EC0507619, EC0507627, EC0507689, EC0524643, EC0524813, EC0524823, EC0533381, EC0533385, EC0542241, IC0291029, IC0343568, IC0345196, IC0383761, IC0409462, IC0409468, IC0409469, IC0409657, IC0409669, IC0409790, IC0409807, IC0409825, IC0409888, EC0524612, EC0524641, IC0409656, IC0291031, IC0409660, IC0338806, IC0409920, EC0507630, EC0507645, EC0533382, IC0409813	45
2	Days to 50% flowering	Very late: >85 days	IC0392147 (172 days), IC0392146, IC0417763, IC0392132, IC0392145, IC0392148, IC0392128, IC0332472, EC0580797, ELS117, EC0580652, IC0524585, EC0515181, IC0372102, IC0527021, IC0430573, IC0344004, IC0430574, IC0382929, IC0375907, IC0544753, EC0580760, EC0580791, EC0533177, EC0580564, IC0409693, EC0515182, EC0580667, IC0273719, IC0309274, EC0580763, EC0580793, IC0257188, EC0524849, IC0320663, EC0580803, IC0382947, IC0257176, EC0580669, IC0305904, IC0430622, EC0580531, EC0580562, IC0424609, EC0524721, IC0544785, ELS85	47
3	Leaf blade length	Short: < 40 cm	IC0409924 (27.6 cm), EC0542214, EC0542219, IC0470772, EC0533227, IC0409837, IC0409784, EC0524806, IC0369131, EC0524657, EC0542209, IC0409605, IC0409705, EC0524471, IC0470771, EC0524779, IC0338999, IC0409711, IC0409710, IC0470781, IC0409785, IC0409718, IC0413289, EC0580715, IC0291059, IC0409239, EC0524551, EC0524613, IC0470782, IC0339022, EC0006856, IC0409712, EC0524490, IC0339013, IC0413288, EC0580534, IC0597631, IC0369253, IC0409781, EC0524689, IC0341213, IC0397330, EC0542218, IC0409574, EC0580644, EC0524561, EC0580706, EC0524501, EC0542216	49
4	Leaf blade length	Very long: >80 cm	IC0392132 (124.6 cm), IC0392146, IC0392147, IC0392148, IC0392145, IC0417763, IC0392128, IC0332472, IC0333373, IC0333380, IC0372583, EC0580629, IC0308646, EC0580788, IC0409803, IC0409399, EC0580569, EC0580821, IC0409439, IC0372560, IC0308640, IC0541355, IC0256469, IC0345207, EC0580758, EC0580735, EC0580607, EC0580603, EC0580679, EC0533395, EC0580567, EC0580859, IC0541314, IC0372595, EC0580767, EC0580655, EC0580681, IC0409390, IC0339020, IC0333396, IC0308652, IC0409878, IC0291113, IC0597627, IC0336048, IC0596017, EC0524632, IC0291001, EC0580791, IC0333416, IC0409702, IC0409975, IC0336784, EC0580797, EC0524663, IC0290961, EC0507637, IC0383775, EC0533351, IC0383757, IC0393426, IC0409389, IC0333363, IC0373208, EC0515257, EC0515268, IC0347569, EC0580754, IC0541309, 5EC0507694, EC0524690, IC0320664, EC0515229, IC0409506, IC0331557, IC0383767, IC0320661, EC0533260, IC0409413, IC0392155, EC0533330, IC0426295, IC0320663, IC0372585, IC0305745, IC0345726, IC0256452, EC0538163, IC0336045	89
5	Leaf blade width	Narrow: <4 cm	EC0524753 (2.16 cm), EC0524752, EC0524762, EC0524751, EC0524755, IC0409616, IC0409568, IC0544813, IC0410153, IC0409837, EC0507686, IC0409562, EC0524770, IC0409924, EC0580745, IC0410170, EC0524747, EC0507876, IC0409566, EC0580552, IC0409785, IC0544773, EC0524657, EC0524756, IC0369263, IC0409171, IC0409797, IC0470772, EC0524546, IC0291059, EC0580668, IC0338999, IC0369267, IC0470771, EC0542214, EC0524764, IC0470781, IC0597770, EC0542218, EC0580713, EC0580632, IC0409704, IC0401518, EC0524767, EC0524806, IC0409623, EC0524551, IC0544771, IC0409485, IC0471367, EC0580604, IC0413289, EC0524765, EC0524630, EC0524850, EC0524763, EC0524846, EC0580561, IC0369131, EC0533275, IC0291043, IC0385263, EC0580644, IC0320661, IC0290965, IC0339013, IC0369253	69
6	Leaf blade width	Wider: >8.5 cm	IC0392132 (14.9 cm), IC0392128, IC0417763, IC0392146, IC0392145, IC0409406, IC0392148, IC0409553, IC0541355, IC0345207, EC0533199, IC0350357, IC0355482, IC0541358, EC0515178, EC0580767, EC0580791, EC0507694, IC0392133, IC0308652, IC0333383, EC0533212, IC0392130, IC0409301, IC0409413, IC0372583, IC0409392, IC0330934, IC0409878, IC0409371, IC0372595, IC0409643, IC0409656, IC0333380, IC0308640, IC0311979, IC0376232, IC0376233, IC0350143, IC0249061, IC0308604, IC0350044, IC0308657, EC0533204, IC0249079, EC0507685, IC0305753, IC0333424, IC0333412, IC0333405, IC0333399, IC0541356, IC0541354, IC0333410, IC0345723, IC0372587, IC0333411, IC0541352, IC0383772, IC0309947, IC0333370, IC0333407, IC0541351, IC0339023, IC0355483, IC0338806, IC0409974, EC0533200, EC0533205, IC0333373, IC0350335, IC0308634, IC0333416, IC0339957, IC0409376, IC0345735, IC0409648, EC0524503, EC0524816, EC0580765, IC0392147, IC0409390, IC0336048, IC0552364, IC0333423	85

7	Plant height	Short: < 90 cm	EC0542209 (41.6 cm), EC0542214, IC0409784, IC0338999, EC0507669, EC0515256, IC0343592, EC0542218, EC0507673, EC0507662, EC0515276, EC0515277, EC0542219, IC0409785, EC0524471, IC0385271, EC0524815, EC0507672, EC0515254, EC0515239, EC0515287, EC0507674, IC0290945, EC0542216, EC0580536, EC0533247, IC0409924, IC0409724, EC0542237, EC0580715, EC0524693, IC0291130, EC0524481, EC0524866, EC0515296, EC0515250, EC0542239, EC0515214, EC0515234, EC0507857, EC0507623, EC0507659, IC0470772, EC0507671, EC0524821, EC0542220, EC0515226, EC0515225, EC0580805, EC0524506, IC0409496, IC0409768	52
8	Plant height	Very tall: >250 cm	IC0392146 (360.8 cm), EC0580763, IC0392147, IC0392132, IC0392145, IC0392148, EC0580758, IC0392128, EC0580679, EC0580762, EC0580753, EC0580603, IC0596022, EC0580616, IC0345201, EC0580565, IC0417763, EC0580653, EC0580750, EC0580564, IC0544774, EC0580826, EC0580609, IC0544759, IC0544757, EC0533430, EC0580823, IC0409978, IC0393424, EC0533187, EC0533234, IC0291075, EC0580555, IC0541311, IC0308644, EC0533431, IC0345204, IC0409430, IC0393428, EC0580551, EC0507682, IC0409420, IC0290985, IC0291031, EC0580552, EC0580613	46
9	Ear head length	Very short: <10 cm	IC0541862 (4.7 cm), IC0338999, IC0541338, IC0291122, IC0409383, IC0291117, EC0533377, IC0409851, IC0291105, IC0409846, IC0291115, IC0385256, IC0599489, IC0345712, IC0409879, IC0291094, IC0372557, IC0291113, IC0409601, IC0325749, IC0409218, IC0409392, IC0343592, IC0409269, IC0339012, IC0409857, IC0409435, IC0409194, IC0333382, IC0597667, IC0409212, IC0291080, IC0409439, IC0409707, IC0409822, IC0345253, EC0533261, IC0345245, IC0339010, IC0332462, IC0409204, IC0409331, IC0290948, IC0409198, IC0409454, IC0291015, IC0291111, IC0409731, IC0308616, IC0409275, IC0409381, IC0409750, IC0541335, IC0409975, EC0533446, IC0290965, IC0430572, IC0409952, IC0324037, IC0597643, IC0409188, IC0291076, EC0580586, IC0338974, EC0533321, IC0409466, EC0524774, IC0291142, IC0409203, IC0345249, IC0541362, IC0409426, IC0339022, IC0409882, IC0409939	75
10	Ear head length	Long: >35 cm	IC0417763 (50.1 cm), IC0597627, EC0580514, IC0597604, EC0524734, IC0597625, IC0279635, EC0580603, IC0597623, EC0580654, EC0580826, IC0597619, EC0580604, IC0392146, EC0580658, IC0332472, EC0580731, EC0507874, EC0580653, IC0597620, EC0580555, EC0580606, IC0597615, IC0597602, EC0580640, EC0515169, EC0507703, EC0580732, IC0597621, EC0580797, IC0597607, EC0580608, IC0369268, EC0580747, IC0597616, EC0515160, IC0597629, IC0406552, EC0580609, EC0533431, IC0409700	41
11	100-Seed weight	Low: <1.6 g	EC0515218 (0.26 g), EC0515256, IC0401611, EC0533199, EC0507639, EC0515277, EC0515225, EC0580799, EC0515228, EC0533193, IC0345247, IC0409395, EC0515160, EC0524691, IC0597626, EC0515271, IC0584535, EC0580747, IC0311976, IC0290954, EC0524752, EC0524747, EC0524755, EC0507849, IC0430573, EC0524762, EC0515182, EC0507806, IC0410002, IC0409220, IC0410153, EC0524783, IC0397567, IC0291001, IC0350001, IC0597627, EC0524730, ELS117, IC0259865, IC0249079, IC0597629, EC0580805, IC0279362, EC0507885, IC0375907, IC0424606, IC0355664, EC0515166, IC0415826, IC0409802, IC0541032	51
12	100-Seed weight	Very high: >4 g	IC0392132 (6.72 g), IC0392146, IC0392148, EC0580822, EC0580776, IC0392147, IC0392145, IC0392128, EC0533213, IC0332472, EC0533194, EC0533319, IC0409803, EC0533230, EC0533395, EC0533390, EC0533327, IC0372547, EC0533394, IC0393426, IC0305933, EC0580843, IC0409246, IC0425132, IC0345186, EC0533420, EC0533269, EC0533354, EC0533334	29
13	Number of basal tillers	High: >11	IC0305919 (13.3), IC0373227, EC0580514, IC0355248, EC0533189, IC0339962, EC0580697, IC0315677, IC0541348, IC0345201, IC0305882, IC0342559, EC0580797, IC0369542, IC0372620, EC0580754, IC0401270, IC0336060, IC0541347, EC0580515, IC0544757, EC0502057, IC0369627, IC0598698, IC0308636, IC0332471, IC0342561, IC0544783, IC0392157, IC0401521, IC0382866, IC0291021, IC0305895, IC0382844, IC0527018, IC0597626, IC0308646, EC0524644, EC0580517, IC0343561, EC0533192, IC0347569, ELS117, IC0350357, IC0409878, IC0350178, IC0260836, IC0333411, IC0375892, IC0541310, IC0332080, IC0544808, IC0279635, IC0541323, IC0392154, ERP102, IC0392158, IC0305884, IC0331798, IC0417594, IC0249078, IC0308666, IC0308667	63
14	Grain yield plant^{-1}	High: >170 g.	IC0355254 (245.3 g), IC0343588, IC0345722, IC0375874, IC0308600, EC0524642, IC0345731, IC0541871, IC0393430, IC0410021, IC0396684, IC0305753, IC0541356, IC0345208, IC0392150, EC0580550, EC0580558, IC0345188, IC0345711, IC0345715, IC0345720, IC0343847, IC0345713, IC0413508, IC0290961, IC0541313, IC0290950, IC0409459, IC0392148, IC0597283, IC0343569, EC0524560, IC0415813, IC0338817, EC0507855, IC0345716, IC0544772, IC0258771, IC0291108, IC0347568, EC0524794, IC0345726, IC0347575, IC0308599, IC0345735, IC0541850, EC0533212, IC0369274, EC0580640, EC0524670, EC0507622, IC0291093, IC0369540, IC0401519, IC0546444, IC0382951, IC0347571, IC0420056, EC0524688, IC0420022, IC0397467	61

of leaves are the potential donors for high biomass line development, lines with more number of basal tillers are suitable sources for forage line development and lines identified for more 100 seed weight are the potential sources of high grain yield. Based on the specificity of the accession for a particular trait, these identified potential accessions may serve as excellent donors for trait diversity and trait introgression in the crop improvement programs of sorghum.

Twenty superior accessions for each of the 14 trait classes mentioned in **Table 4** were clubbed to study their geographical distribution. When the total 641 accessions were distributed among countries, India with 444 accessions contributed 69.3 % accessions to the top group followed by unknown origin group (60 acc., 9.4 %) which lacked any of the associated passport data and USA (41 acc., 6.4 %) (**Fig. 5**). Central African Republic, Zimbabwe, East Africa, Kenya, South Africa and Egypt were contributing the least with one accession each. When the 444 accessions of Indian origin were distributed among the contributing states, accessions with an unknown origin were the highest (175 acc., 39.4 %) followed by Maharashtra (43 acc., 9.7 %) and Andhra Pradesh (40 acc., 9%). West Bengal, Arunachal Pradesh, Kerala and Haryana states contributed least accession with single accession each.

There were 23 accessions found to have superiority consecutively for three or more traits at a time which comprised of 7 exotics and 16 indigenous accessions (**Table 4**). Earlier studies also have identified trait specific germplasm accessions which were either registered as genetic stocks or used by breeders for trait improvement (Elangovan *et al.*, 2020b; Elangovan *et al.,* 2020 a). Earlier Upadhyaya *et al.* (2019) identified the significantly early flowering accessions of sorghum (<69 DAS), 10 accessions were identified for 100-seed weight (3.72-5.15 g) and 21 accessions were selected for multiple traits of early flowering, 100-seed weight and grain yield.

Table 4. Sorghum accessions with superiority for multiple traits (>3 traits)

S.No.	Accession	Name of the traits	Number of traits
1	IC0392146	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Longer ear head length, Higher 100-seed weight	6
2	IC0392148	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Higher grain yield, Higher 100-seed weight	6
3	IC0392128	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Higher 100-seed weight	5
4	IC0392132	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Higher 100-seed weight	5
5	IC0392145	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Higher 100-seed weight	5
6	IC0392147	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Higher 100-seed weight	5
7	IC0417763	Very late flowering, Longer leaf blade, Wider leaf blade, Taller plant height, Longer ear head length	5
8	EC0580797	Very late flowering, High basal tiller number, Longer leaf blade, Longer ear head length	4
9	IC0332472	Very late flowering, Longer leaf blade, Longer ear head, High 100-seed weight	4
10	IC0338999	Shorter leaf blade length, Shorter leaf blade, Dwarf height, Shorter ear head length	4
11	EC0524755	Early flowering, Shorter leaf blade, Low 100-seed weight	3
12	EC0524806	Early flowering, Shorter leaf blade, Shorter leaf blade	3
13	EC0542214	Shorter leaf blade, Shorter leaf blade, Dwarf plant height	3
14	EC0542218	Shorter leaf blade, Shorter leaf blade, Dwarf plant height	3
15	EC0580603	Longer leaf blade, Taller plant height, Longer ear head length	3
16	EC0580791	Very late flowering, Longer leaf blade, Wider leaf blade	3
17	ELS117	Very late flowering, High basal tiller number, Low 100-seed weight	3
18	IC0409785	Shorter leaf blade, Shorter leaf blade, Dwarf plant height	3
19	IC0409878	High basal tiller number, Longer leaf blade, Wider leaf blade	3
20	IC0409924	Shorter leaf blade, Shorter leaf blade, Dwarf plant height	3
21	IC0470772	Shorter leaf blade, Shorter leaf blade, Dwarf plant height	3
22	IC0544757	Early flowering, High basal tiller number, Taller plant height	3
23	IC0597627	Longer leaf blade, Longer ear head, Low 100-seed weight	3

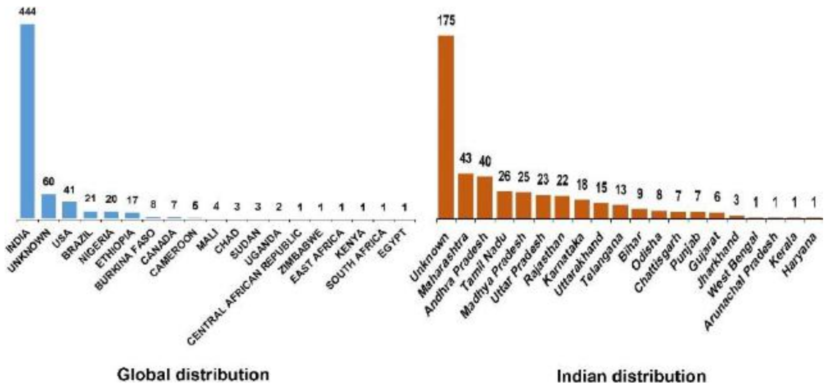


Fig. 5. Global and Indian distribution of top performing accessions for yield and yield attributing traits

Twenty-three trait specific sorghum germplasm accessions identified are either superior for a single trait or more than two traits. A wider range of variability was observed in the traits *viz.*, days to 50% flowering (57-172 days), the number of basal tillers (3.7-13.0), leaf blade length (28-125 cm), leaf blade width (2.2-15.0 cm), plant height (42-361 cm), ear head length 4.7-50.0 cm), ear head width (1.8-14.0 cm), grain yield (1-245 g/plant), 100-seed weight (0.26-6.70 g)which can be used for the sorghum improvement.

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