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Principal component analysis for agronomic traits in multi-cut forage sorghum

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Abstract
The present investigation in fodder sorghum was conducted in parental entries for estimation of principal components involving thirteen yield and component traits. Four principal components (PCs) were identified reporting more than one Eigen values and explaining 86.51 percent of the cumulative variance attributing to divergence. The biplot constructed using first two principal components (PC1 and PC2) have identified traits exhibiting positive and negative correlation with total green fodder yield per plant. Based on the angle between trait vectors, the traits *viz.*, number of leaves per plant at first cut, leaf length at first cut, number of nodes per plant at first, plant height at first and second cut, and number of tillers per plant at third cut have exhibited high positive correlation with total green fodder yield per plant. Thus, these traits can be considered important for selections in fodder sorghum hybrid breeding programmes.

Keywords: Fodder sorghum, principal components, yield traits, component traits, Eigen values, cumulative variance

Introduction
Sorghum [*Sorghum bicolor* (L.) Moench], a member of the Poaceae family, is widely cultivated as source of livestock fodder with both green and dry fodder. It grows quickly, adapts to a variety of environmental circumstances, and can be fed to animals as hay, silage, green fodder, or dry stover (Satpal *et al.*, 2018) [12]. In both wet and dry conditions, sorghum crop shows a high yield potential and a better energy balance than a number of cultivated plants (Habyarimana *et al.*, 2016) [7]. With increasing demand for livestock-based products, there is need to increase the livestock production which in turn is dependent on fodder availability. The climate change and changing land use patterns have severely affected the fodder availability and necessitates the importance of crops suitable for climate change conditions that can be cultivated in variety of soil types with high fodder yielding ability. Sorghum, which does well under both hot and dry climate and also provides good quality and quantity of fodder is popular among fodder cultivating regions of India. The forage sorghum cultivars are either single cut types or multi-cut types. The multi-cut types provide a continuous supply of green fodder for a longer period of time.

Currently few multi-cut forage sorghum hybrids are cultivated in India, and looking in to the fodder deficit that the country is facing, it is essential to breed for hybrids with higher yields and nutritive value to enhance the productivity of the crop. To develop hybrids in any crop, it is important to evaluate the inbreds for diversity for producing high heterotic hybrids. The approach of phenotypic characterisation has been an efficient technique among the many characterisation techniques, including morphological, biochemical, cytological, and molecular methods for the evaluation, description, and classification of germplasm collections. (Al-Naggar *et al.*, 2020; Fuzatto *et al.*, 2002; Singh *et al.*, 2020) [2, 5, 14]. Estimation of the extent of genetic diversity can be done using both univariate and multivariate techniques. Recently, multivariate studies have gained popularity as a way to quantify the genetic variation among different traits (Chavan *et al.*, 2023) [4].

Principal component analysis (PCA) is the foundation of multivariate data analysis and has been widely used in breeding programmes to reduce the dimensionality of large datasets, increase interpretability, and minimise information loss while not discarding any samples or characteristics (Variables). In multi-cut forage sorghum, where fodder yield is attributed by several traits, it is important to retrieve few principal components (PCs) accounting for most of the variations in the dataset. The study was thus conducted to deduce the trait(s) in multi-cut forage sorghum to prefer the important traits in multi-cut forage sorghum hybrid breeding programmes.

Materials and Methods

The field experiment was conducted at Regional Agricultural Research Station (RARS), Warangal, Telangana with a longitude of 79º60'E and latitude of 18º01'N at 259 meter above mean sea level in *Kharif* season, 2022. The experimental material [ICSA1 (G1), ICSA38 (G2), ICSA52 (G3), ICSA81 (G4), ICSA 398 (G5), ICSA474 (G6), ICSA484 (G7), ICSA594 (G8), ICSA510 × ICSB14019 (G9), ICSA358 × ICSB14020 (G10), PC-6 (G11), SSG 59-3 (G12), IS 23143 (G13), IS 33871 (G14) and ICSR 93036(G15)] were sown in three replications for each entry and the planting was done following a spacing of 30 × 10 cm. All standard agronomic practices were followed for the crop. The first harvesting of the entries was done when the entries have reached the 50% flowering stage, while the second cut was done 30 days after first cut and similarly the third cut was done after 30 days of second cut. Plot size was two rows of 2-meter length and five random plants were taken observations on different agronomic traits. At first cut, observations were noted for the traits *viz.*, days to 50% flowering, plant height in cm (PH1), number of tillers per plant (NTP1), number of nodes per plant (NNP1), number of leaves per plant (NLP1), leaf length in cm (LLT1), leaf breadth in cm (LBT1), stem diameter in mm (SD), brix content in % (BRIX1). At second, the traits plant height in cm (PH2) and number of tillers per plant (NTP2), and at third cut - plant height in cm (PH3) and number of tillers per plant (NTP3)were observed, and the fresh green fodder yield per plant observed on plot basis over all three cuts was summed up to obtain the total fresh green fodder yield over all cuts (FYPTOTAL). The BLUE values obtained were used to perform PCA using "FactoMineR" package in "R" software version 4.2.2.

Results and Discussion

In the principal component analysis done for the thirteen traits in multi-cut forage sorghum to reduce the dimensionality of data by reducing the number of traits, only four principal components (PCs) have exhibited eigen value of more than one (Table 1, Figure 1). The first four PCs accounted for 86.51 percent of the total variance among the traits studied and thus these four PCs were considered important for further discussion in the current study. The first PC with eigen value of 5.86 have exhibited 45.11 percent of the total variance, while the second PC, third PC and fourth PC with eigen value of 2.492, 1.797 and 1.093 have recorded 19.17 percent, 13.82 percent, and 8.40 percent of the variance. Similar results were reported by Ali *et al*. (2022) [1] in fodder sorghum where four PCs with eigen value of more than one has explained 79.10% of the total variance. While Jain and Patel (2016) [8] have recorded three PCs to have eigen value of more than one and explaining 70.89% of the cumulative variance in fodder sorghum (Ali *et al*., 2022; Jain and Patel, 2016) [1, 8]. Similarly, four PCs and three PCs were observed to contribute 73.69% and 81.5% towards total variance in sorghum by Geetha and Divya, 2021 [6] and Malini *et al*., 2023 [10], respectively.

Table 1: Eigen value, percentage of variance and cumulative percentage of variance for all the thirteen principal components

Principal components (PCs)	Eigenvalue	Percentage of variance	Cumulative percentage of variance
1	5.865	45.11	45.11
2	2.492	19.17	64.29
3	1.797	13.82	78.11
4	1.093	8.41	86.51
5	0.618	4.76	91.27
6	0.396	3.04	94.31
7	0.333	2.56	96.87
8	0.180	1.38	98.26
9	0.123	0.95	99.21
10	0.053	0.41	99.61
11	0.034	0.26	99.88
12	0.015	0.12	99.99
13	0.001	0.01	100.00

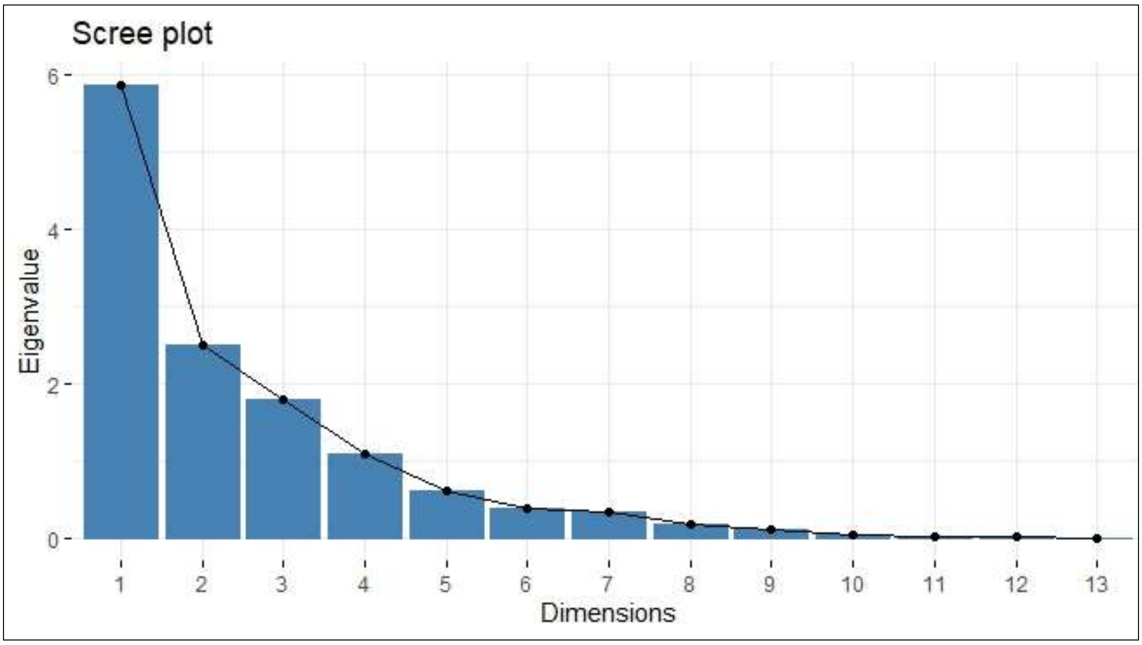

Fig 1: Scree plot of thirteen principal components (PCs) against its eigen values

Important traits were identified using a cut-off threshold of 0.3 or higher for the absolute magnitude of eigen vector coefficients. Any trait with a coefficient value of greater than 0.3 was considered significant. While the traits with a coefficient value of lesser than 0.2 were regarded insignificant with no effect of it on the overall variation (Badu-Apraku *et al*., 2006; Laude and Carena, 2015, Sharifi *et al*., 2018) [3, 9, 13]. As presented in table 2, for the first PC (PC1) explaining 45.11 percent of the total variance, the traits *viz*., plant height at first cut, number of tillers per plant at first cut, number of nodes per plant at first cut, plant height at second cut and number of tillers per plant at second cut have recorded coefficient value of >0.3 and thus signifying the traits contribution in variability. Second PC (PC2) that registered 19.17 percent of the total variance has not reported any trait having positive coefficient value of >0.3. In third PC (PC3), that contributed 13.82 percent of the total variance, the traits such as number of leaves per plant at first cut and leaf length at first cut had reported greater than 0.3 coefficient value, explaining their importance in PC3. While in fourth PC (PC4) that contributed to 8.41 percent of the total variance had the trait number of tillers per plant in second cut exhibiting >0.3 coefficient value.

Table 2: Principal component analysis coefficient values for thirteen yield and component traits

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
PH1	0.376	-0.225	0.003	-0.123	0.003	-0.078	0.167	-0.089	0.175	-0.097	-0.303	0.718	0.323
NTP1	0.306	0.242	-0.111	0.202	-0.181	0.464	0.592	0.232	-0.114	0.235	0.025	-0.141	0.231
NNP1	0.311	-0.237	-0.100	0.278	-0.459	-0.184	-0.208	-0.265	-0.296	-0.241	0.361	-0.146	0.324
NLP1	0.134	-0.439	0.419	0.217	0.038	-0.175	0.061	-0.071	0.393	0.444	-0.152	-0.370	0.122
LLT1	0.141	-0.277	0.318	-0.512	-0.463	0.399	-0.215	0.261	-0.078	-0.031	-0.061	-0.043	-0.200
LBT1	-0.343	-0.188	-0.171	-0.051	-0.201	0.375	0.157	-0.605	0.237	0.233	0.285	0.192	-0.125
SD1	-0.276	-0.360	-0.291	-0.105	-0.035	0.031	0.343	0.059	0.182	-0.562	-0.281	-0.357	0.141
BRIX1	-0.082	-0.331	-0.566	0.077	-0.211	-0.264	-0.036	0.480	0.023	0.379	0.074	0.158	-0.192
PH2	0.353	-0.101	-0.164	-0.106	0.415	0.239	-0.171	0.186	0.451	-0.172	0.542	-0.070	0.043
NTP2	0.339	0.197	-0.079	0.366	-0.275	0.002	-0.024	-0.111	0.367	-0.244	-0.231	-0.006	-0.608
PH3	0.269	0.146	-0.045	-0.568	-0.068	-0.490	0.422	-0.196	0.003	0.078	0.209	-0.180	-0.198
NTP3	0.266	0.078	-0.482	-0.231	0.125	0.167	-0.373	-0.303	-0.068	0.263	-0.440	-0.280	0.134
FYP Total	0.216	-0.463	0.011	0.132	0.432	0.136	0.197	-0.133	-0.526	-0.035	-0.018	0.023	-0.426

In the biplot constructed using the PC1 and PC2, the traits/variables recorded were grouped as three groups based on the behaviour of the traits with PC1 and PC2 (Figure 2). The traits total green fodder yield per plant, plant height at first cut, plant height at second cut, number of nodes per plant at first cut, number of leaves per plant at first cut and leaf length at first cut have exhibited positive correlation with both principal component 1 and principal component 2 and these six traits can be considered as a group with positive association with first two PCs. In the second set of traits, four traits namely, number of tillers per plant at first cut, number of tillers per plant at second cut, number of tillers per plant at third cut and plant height at third cut have shown positive correlation with PC1 and negative correlation with PC2. The third group that had positive correlation with PC2 and negative correlation with PC1 comprised of the traits *viz*., leaf breadth at first cut, stem diameter at first cut and brix content at first cut.

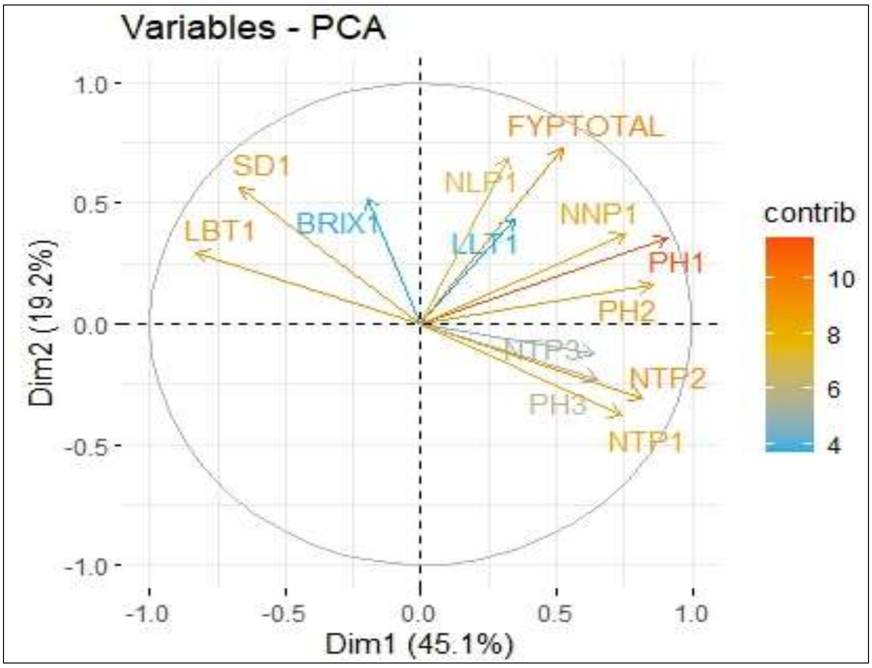

Fig 2: Two dimensional biplot of thirteen yield and component trait's contribution on principal component axes

To understand the role of traits in terms of their contribution, it was observed that total green fodder yield per plant and plant height at first cut have shown highest contribution towards the total divergence. While the traits – Brix content and leaf length at first cut have contributed least towards the total observed divergence among the genotypes under study. This was followed by the variables *viz*., plant height at third cut and number of tillers per plant at third cut that contributed less towards divergence. While a good amount of contribution was observed by the remaining traits such as number of nodes per plant at first cut, number of leaves per plant at first cut, plant height at second cut, leaf breadth at first cut and stem diameter at first cut.

The biplot also provided a visual representation of correlation between traits in the form of angles between the trait vectors. The traits with their vectors having an angle of less than 90° can be considered as positively correlated traits. While the trait whose vectors have an angle of equal to 90° are considered as independent traits and an angle of more than 90° depicts negative correlation among traits (Yan and Rajcan, 2002) [15]. Among the traits under study, less than 90° angle between vectors that depict positive correlation was observed for total green fodder yield per plant with no. of nodes per plant at first cut, no. of leaves per plant at first cut, leaf length at first cut, plant height at first and second cut, and no. of tillers at third cut. However, total green fodder yield per plant was highly correlated with no. of leaves per plant at first cut, leaf length at first cut, no. of nodes per plant at first cut and plant height at first cut, with an angle measuring less than 45° between them. The traits leaf breadth at first cut had an angle measuring 180° with plant height at third cut and no. of tillers per plant at second cut reporting a high negative correlation among these traits. Jain and Patel have reported similar results with positive correlation of fodder yield with plant height, number of leaves/plant and leaf length in fodder sorghum (Jain and Patel, 2016) [8].

The biplot with genotypes plotted on it as illustrated in figure 3, were observed for diversity. The parents studied were dispersed in all directions in the biplot and two groups were observed on broad sense where the restorers formed one group and male sterile parents were clustered as another group. The lines located closely on the biplot when rated on given attributes were perceived to be alike. The entry SSG 59-3 was located far away from the biplot origin, depicting its diverse nature from other lines in the study.

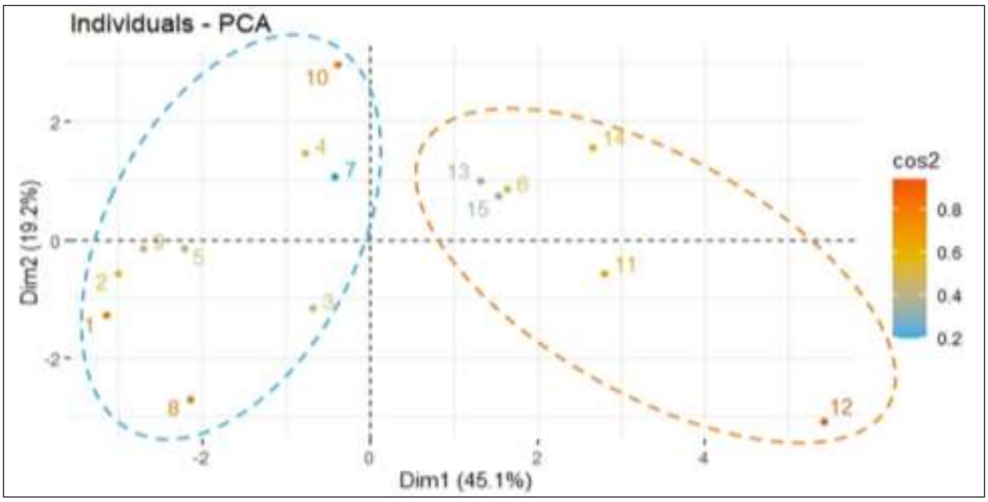

Fig 3: Biplot dispersion graph of fifteen fodder sorghum parent entries

Conclusion

The observation of Principal components has revealed more and instant contribution of the characters *viz*., total green fodder yield per plant, plant height at first cut, number of leaves and nodes at first cut, plant height at second cut and number of tillers at second cut towards variability. Thus, these traits will be of considerate importance for selection in the future hybridization programmes.

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