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Research article

Studies on correlation, path analysis and principal component analysis for yield, quality and seed parameters in forage sorghum

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Abstract

Character association studies are very important for developing improved cultivars in any crop. An experiment was planned to study the correlations and path coefficients between various green and dry fodder yields affecting morphological and quality traits in forage sorghum germplasm lines. The correlation and path analysis studies were carried out on 50 germplasm lines of *Sorghum bicolor* (L.) Moench. Green fodder yield was found to be positively and significantly associated with plant height, leaf breadth, dry fodder yield, green fodder yield/plant/day, dry fodder yield/plant/day, crude protein yield, seedling length and seedling vigor index I. This indicated that selection based on these characters would undoubtedly enhance the fodder yield performance of forage sorghum genotypes. Path coefficient analysis showed that seed germination, green fodder yield, plant height and crude protein percent were important characteristics for the improvement of dry fodder yield in forage sorghum. The first six principal components (PCs) explained 76.28% of the total variability.

Keywords: Correlation, Forage sorghum, Path analysis, Seed yield, Variability

Introduction

Livestock is the integral part of rural economy and the backbone of Indian agriculture. The cost of feed accounts for 60-65% of the overall cost of milk production in dairy sector (Anonymous, 2019). India is the world's highest producer of milk. However, animal output is low (1538 kg/year) as compared to the global average (2238 kg/year), which is associated with malnutrition because of an acute shortage of animal feed (Vijay *et al*., 2018). Green fodder is required throughout the year for livestock to lower the cost of milk production (Mahanta *et al*., 2020). Green fodder is the most cost-effective option for milch and draught animals. Around 54% of total cultivated fodder area is under sorghum (2.6 M ha) in the *kharif* season (Dagar, 2017). Sorghum fodder is thought to contribute 20-45% of the dry weight of total feed used by dairy animals during the normal season and up to 60% during the lean summer and winter months (Anonymous, 2023). Sorghum requires approximately 40-50% less water than corn to produce the same amount of dry fodder (Miller and Stroup, 2004) and has the potential to tap into subsoil moisture reserves, making it most appropriate for rain-fed farming.

Grain and fodder yield are complex characters which depend upon many characters that contribute directly and indirectly. Thorough knowledge about its genetics and trait association greatly helps to evaluate the contribution of different component traits towards yield improvement. Information on the nature of association between yield and its components helps to select many characters associated with yield improvement (Ezeaku and Mohammed, 2006). Correlation analysis is very helpful for breeders in selecting superior genotypes from diverse genetic populations. Combined use of these biometrical techniques, like correlation and path coefficient analysis, provide a clear understanding of the cause-and-effect relationship between different pairs of characters for selection. Principal component analysis is a tool for data volume reduction. It helps to save time and effort to identify major agronomic traits contributing the most to production, and this information could be utilized in development of superior genotypes of forage sorghum having early maturity, faster growth rate and high forage production with high protein content and low HCN concentration. Hence, the present investigation was planned to study the correlations and path coefficients between various green and dry fodder yields affecting morphological and quality traits in forage sorghum germplasm lines.

Materials and Methods

***Experimental site and design*:** The experimental material was planted in Research Area of the Forage Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, a semi-arid sub-tropical region in Western Haryana during *Kharif*, 2021. The experimental material consisted of fifty distinct germplasm lines of forage sorghum (Table 1), each replicated three times in a completely randomized block design. Each genotype was raised in two rows with a spacing of 30 cm between rows and 15 cm between plants. Recommended agronomic practices and plant protection measures were followed.

***Observations and analysis*:** Observations were recorded from five competitive plants of each line in each replication for twenty-two quantitative and yield parameters. Hydrocyanic acid content was estimated from 30 days old fresh plants after sowing as per Gilchrist *et al.* (1967). A hand refractometer was used to measure total soluble solids (TSS) content of stem. A 500 g sample was taken at 50% flowering stage to estimate dry fodder yield and further quality analysis. After drying, the samples were ground and used to estimate crude protein (%) following Micro-Kjeldhal's method. Seed germination and vigor were estimated after harvesting. The correlation analysis was worked out using the method suggested by Al-jibouri *et al.* (1958) and the path analysis was as per Dewey and Lu (1959). Principal component analysis (PCA) was also carried out on the mean data using INDOSTAT software.

Results and Discussion

***Analysis of variance*:** The analysis of variance depicting the mean sum of squares for twenty-two traits revealed highly significant differences among the germplasm lines for all the traits studied, which suggested that all germplasm lines were genetically diverse and there was ample scope for selection of characters from these lines (Table 2).

***Genetic analysis*:** In the present study, the phenotypic coefficient of variation (PCV) was found to be higher than that of the corresponding genotypic coefficient of variation (GCV) for all the traits (Table 3), indicating that environmental factors influenced the expression of these traits to some degree. Similar results were reported earlier by Dalip *et al.* (2024) and Arvinth *et al.* (2021). The higher magnitude of GCV found for the traits HCN content, TSS content and crude protein yield indicated more genetic control for these traits. The remaining traits showed a moderate magnitude of GCV. Vijaylaxmi *et al.* (2019a) also reported similar results. Estimation of heritability is very important for the genetic study of any trait. High heritability followed high genetic advance as percent of mean was observed for the traits like plant height, number of tillers per plant, number of leaves per plant, stem diameter, leaf: stem ratio, green fodder yield, dry

Table 1. List of forage sorghum genotypes evaluated

S. No.	Genotypes	S. No.	Genotypes	S. No.	Genotypes	S. No.	Genotypes
1	IS 1283	14	ICSR 17004	27	SPV 2314	40	SH1488
2	IS 33844	15	ICSR 17005	28	IS 23992	41	IC 285850
3	ICSR 90008	16	Duggi	29	S 537	42	IS 33998
4	ICSR 113	17	S-722	30	IS 29687	43	SSG 59-3
5	YPS 5	18	GP-2	31	IS 29614	44	G 46
6	ICSR 93012	19	SOR 6507	32	S 536	45	PGN 56
7	ICSR 93023	20	IS 896	33	IC 484464	46	IC 285913
8	IS 7173	21	S-71	34	IC 485151	47	IS 34638
9	IS 25699	22	SSG-233	35	IS 3260	48	IS 30508
10	CSM 335	23	IS 5049	36	SPV 2312	49	IS 31681
11	IS 16382	24	IS 12135	37	SPV 2394	50	HJ 541
12	IS 21645	25	IS 14278	38	UTMC 1539		
13	PFR 3	26	IS 2351	39	SPV 2389		

Table 2. Analysis of variance of different morphological and quality characters

S. No.	Source of variation	Replication	Genotypes#	Error#
	df	**2**	**49**	**98**
1	Days to 50 % flowering	98.21	116.81*	13.87
2	Plant height	352.8	4317.6**	89.7
3	Number of tillers per plant	2.43	0.64**	0.26
4	Number of leaves per plant	4.4	33.9**	3.8
5	Leaf length (cm)	4.14	166.03**	16.27
6	Leaf breadth (cm)	0.01	1.37**	0.09
7	Stem diameter (cm)	0.004	0.132**	0.009
8	Leaf: Stem ratio	0.001	0.008**	0.001
9	Green fodder yield (g/plant)	2134.91	6135.66**	1210.11
10	Dry fodder yield (g/plant)	114.98	246.42*	151.84
11	Green fodder yield per plant per day (g/plant/day)	0.07	0.40**	0.1
12	Dry fodder yield per plant per day (g/plant/day)	0.03	0.018**	0.01
13	Grain yield (g/plant)	10.64	113.48**	34.62
14	Hydrocyanic acid content (μg/g)	603.92	1079.56*	48.71
15	Total soluble solids (^{0} brix)	0.02	29.72**	0.16
16	Crude protein (%)	1.74	1.85**	0.26
17	Crude protein yield (g/plant)	2.01	2.04**	0.99
18	Seed germination (%)	102.49	25.99*	17.77
19	Seedling length (cm)	4	14.5*	6.5
20	Seedling dry weight (mg)	17.5	24.2*	6.6
21	Seedling vigor index-I	16434.75	124081.18*	60851.54
22	Seedling vigor index-II	84070.6	177005.1*	52683.3

*(P<0.05); **(P<0.01); # Mean square values

fodder yield, green fodder yield per plant per day, dry fodder yield per plant per day, grain yield, HCN content, TSS content, seedling dry weight and seedling vigor index-II. It might be due to the presence of additive gene action for these characters, and hence, simple selection need to be practised to improve these traits. Traits like days to flowering, leaf length, and seed germination recorded high heritability associated with moderate genetic advance as a percentage of the mean. This might be due to presence of both additive and non-additive gene action. These results were similar to those reported by Nirosh *et al.* (2021).

***Character association*:** The correlation coefficient is a biometrical technique to estimate the traits association. Dalip *et al.* (2022) reported that magnitudes and directions of association between yield and its component characters are critical for improving the desired direction and building selection indices. Thus, genotypic and phenotypic correlation coefficients were recorded (Table 4). Green fodder yield (GFY) was found to have a significant positive association with plant height, leaf breadth, dry fodder yield, green fodder yield/plant/day, dry fodder yield/plant/day, crude protein yield, seedling length and seedling vigor index I and II which suggested that indirect selection for these traits would help in the improvement of green fodder yield. A negative association of GFY with leaf length, HCN content, TSS content and seed germination was also observed. Jain and Patel (2016) reported that green fodder yield was positively correlated with plant height, leaf length, leaf width, number of leaves/plant and days to maturity. Dry fodder yield was positively correlated with plant height, number of tillers per plant, number of leaves per plant, green fodder yield/plant/day, dry fodder yield/plant/day, grain yield, crude protein yield, seedling length and seedling vigor index-II, whereas negatively correlated with leaf breadth, HCN content and L/S ratio (leaf: stem). Similar results were also reported by Aruna *et al.* (2015) and Vijaylaxmi *et al.* (2019a).

In any forage sorghum breeding program, quality analysis (*viz*., hydrocyanic acid content, crude protein

Table 3. Classification of characters on the basis of high, moderate and low GCV, PCV, heritability and genetic advance

GCV	High (>20)	HCN content, TSS content, crude protein yield
	Moderate (10-20)	Plant height, number of tillers/plant, number of leaves/plant, lead breadth, stem diameter, leaf :stem ratio, green fodder yield, dry fodder yield, green fodder yield(g/plant/day), dry fodder yield(g/plant/day), grain yield, crude protein percent, seedling dry weight, seedling vigor index-II
	Low (<10)	Days to 50% flowering, leaf length, seed germination, seedling length , seedling vigor index-I
PCV	High (>20)	Plant height, HCN content, TSS content, crude protein yield, seedling dry weight
	Moderate (10-20)	Number of tillers per plant, number of leaves per plant, leaf length, leaf breadth, leaf :stem ratio, green fodder yield, dry fodder yield, green fodder yield per plant per day, dry fodder yield per plant per day , grain yield, crude protein percent, seedling length, seedling vigor index-I, seedling vigor index-II
	Low (<10)	Days to 50% flowering, seed germination
Heritability (%)	High (>60)	Days to 50% flowering, plant height, number of tillers per plant, number of leaves per plant, leaf length, leaf breadth, stem diameter, leaf:stem ratio, green fodder yield, dry fodder yield, green fodder yield per plant per day, dry fodder yield per plant per day, grain yield, crude protein percent, HCN content, TSS content, seed germination, seedling length, seedling dry weight, seedling vigor index I & II
	Moderate (30-60)	crude protein yield
GAM	High (>20)	Plant height, number of tillers per plant, number of leaves per plant, leaf breadth, stem diameter, leaf:stem ratio, green fodder yield, dry fodder yield, green fodder yield per plant per day, dry fodder yield per plant per day, grain yield, crude protein percent, HCN content, TSS content, crude protein yield, seedling dry weight, seedling vigor index II
	Moderate (10-20)	Days to 50% flowering, leaf length, seed germination, seedling length, seedling vigor index-I

GCV: Genotypic coefficient of variation; PCV: Phenotypic coefficient of variation; GAM: Genetic advance as percent of mean

(CP%), and TSS content) is also very important due to their direct effect on livestock productivity. HCN content showed a significant positive association with TSS content and a negative association with plant height, number of leaves/plant, and dry fodder yield/plant/day. Similar results were reported by Deep *et al.* (2019), who found that HCN showed a negative association with plant height, number of leaves/plant, green fodder yield, and dry fodder yield. Arvinth *et al.* (2021) also reported a negative association of HCN content with plant height in forage sorghum. These results contradicted that of Chakraborty *et al.* (2020), who reported that HCN was negatively correlated with TSS content in forage sorghum. Furthermore, a positive association was observed between crude protein content and crude protein yield, number of tillers per plant and dry fodder yield. These results were in conformation with Thant *et al.* (2021), who also reported a positive correlation between protein content and dry fodder yield. TSS content had shown a positive association with dry fodder yield.

Regarding seed parameters, seed germination showed a significant positive association with crude protein, seed vigor index-I and II, indicating that higher seed germination leads to more vigorous seedlings and a negative correlation with days to flowering and TSS content. Seedling length showed a high positive correlation with plant height, green and dry fodder yield, seedling dry weight, and seed vigor index-I and II, indicating that higher seedling length leads to higher plant height and dry weight, subsequently increasing fodder yield. Similar studies were not conducted earlier, and more research needs to be undertaken to confirm the validity of the present findings.

***Path coefficient analysis*:** Green and dry fodder yield are both important parameters in forage crop improvement programs; however, dry fodder yield is more important regarding animal performance. Thus path coefficient analysis was performed in the current study with dry fodder yield (dependent character). The calculated residual effect (r^2) was 0.275. This indicated a significant magnitude of variation (72.5%) in the association of dry fodder yield with independent traits.

Seed germination had a high direct positive effect on dry fodder yield, followed by green fodder yield, plant height, dry fodder yield/plant/ day, and crude protein percent, whereas the number of leaves/plant showed a high negative direct effect on dry fodder yield followed by leaf length. These results revealed that crude protein content, seed germination, green fodder yield, plant height, and dry fodder yield/plant/day could be used as selection indices to enhance dry fodder yield.

Table 4. Genotypic (below diagonal) and phenotypic (above diagonal) correlation matrix between different traits of forage sorghum

	DF	PH	NTP	NLP	LL	LB	SD	LSR	GFY	DFY	GFYPD	DFYPD	GY	HCN	TSS	CPP	CPY	SG	SL	SDW	SVI-I	SVI-II
DF	**1**	0.162*	-0.044	0.006	-0.021	0.083	0.026	0.198*	0.125	0.059	0.582*	0.541*	-0.067	-0.072	0.157	-0.104*	-0.017	-0.106*	0.095	0.064	0.034	0.035
PH	0.166*	**1**	0.047	0.121	-0.059	0.219**	0.099	0.188*	0.593**	0.760**	0.595**	0.430**	0.293**	-0.269**	-0.014	-0.062	0.296**	-0.002	0.458**	0.324**	0.411**	0.318**
NTP	-0.152	0.151	**1**	0.201*	-0.130*	-0.121*	-0.167*	0.12	0.251	0.493**	0.218	-0.075	-0.028	-0.048	-0.075	0.105	0.065	-0.006	-0.048	-0.033	-0.037	-0.032
NLP	-0.037	0.158	0.298**	**1**	-0.154*	-0.121*	-0.181*	0.108	0.106	0.222*	0.119	0.021	-0.071	-0.158	0.091	0.556**	0.306**	0.012	0.123	-0.066	0.108	-0.065
LL	-0.062	-0.089	-0.188*	-0.170*	**1**	0.035	0.067	0.046	-0.074*	0.335*	-0.054*	0.052	-0.048	-0.205*	-0.219**	-0.074	0.027	0.004	-0.074	-0.034	-0.061	-0.029
LB	0.127	0.235**	-0.243**	-0.175*	0.051	**1**	0.201*	0.024	0.232**	-0.105*	0.224**	0.083	0.102	-0.087	-0.180*	-0.118*	0.103	0.008	0.097	0.177*	0.096	0.170*
SD	0.055	0.104	-0.219**	-0.238**	0.036	0.250**	**1**	-0.031	0.019	-0.025	0.039	-0.028	0.137	-0.145	0.076	-0.146	-0.134*	0.168	0.172*	0.156	0.227**	0.194*
LSR	0.255**	0.271**	0.363**	0.166*	0.027	0.075	-0.069	**1**	0.139	-0.190*	0.111	-0.012	-0.085	-0.217**	0.213**	-0.215**	-0.105*	-0.029	0.156	0.201*	0.123	0.188*
GFY	0.213**	0.790**	0.352	0.113	-0.047*	0.229**	0.033	0.276**	**1**	0.445**	0.947**	0.457**	0.062	-0.054*	-0.053*	0.144	0.390**	-0.005*	0.278**	0.155	0.252**	0.154
DFY	0.111	0.861**	0.524**	0.392*	0.386	-0.195*	-0.082	-0.207*	0.528**	**1**	0.468**	0.724**	0.277	-0.272*	0.340*	0.274*	0.399*	0.231	0.345**	0.18	0.421**	0.137
GFYPD	0.595*	0.871**	0.139	0.192	-0.013*	0.230**	0.067	0.280**	0.981**	0.521**	**1**	0.459**	0.101	-0.076*	-0.036*	-0.035*	0.387**	0.013	0.276**	0.196*	0.255**	0.196*
DFYPD	0.573*	0.955**	0.163	0.167*	0.071	0.021	-0.170*	0.409**	0.968**	0.754**	0.922**	**1**	0.093	-0.127*	-0.077	-0.093	0.651**	0.024	0.162*	0.135	0.162*	0.012
GY	-0.041	0.415**	-0.033	-0.069	-0.058	0.252**	0.192*	-0.033	0.147	0.208*	0.206*	0.051	**1**	-0.101*	-0.049	0.021	0.143	0.049	0.105	0.096	0.111	0.105
HCN	-0.081	-0.281**	-0.153	-0.222**	-0.231**	-0.094*	-0.126	-0.358**	-0.062*	-0.285*	-0.133*	-0.246**	-0.136*	**1**	0.186*	0.072	-0.088	-0.044	-0.138	-0.154	-0.146	-0.167*
TSS	0.172*	-0.015	-0.105	0.124	-0.251**	-0.193*	0.094	0.281**	-0.057*	0.391*	-0.032*	-0.126	-0.075	0.204*	**1**	-0.024	-0.115	-0.168*	0.176*	-0.066	0.071	-0.109
CPP	-0.158*	-0.058	0.182*	0.762**	-0.081	-0.150*	-0.225**	-0.375**	0.153	0.322*	-0.149*	-0.215**	-0.008	0.068	-0.032	**1**	0.439**	0.173*	0.008	-0.123	0.078	-0.082
CPY	-0.054	0.608**	0.425**	0.715**	0.073	0.144	-0.287**	0.008*	0.525**	0.401**	0.590**	0.196*	0.213**	-0.151	-0.198*	0.802**	**1**	0.101	0.152	-0.047	0.184*	-0.011
SG	-0.255**	-0.127	-0.003	0.168*	0.057	-0.131	0.472**	-0.013	-0.296**	0.279	-0.272**	-0.333**	-0.036	0.026	-0.470**	0.420**	0.105	**1**	-0.014	-0.007	0.450**	0.250**
SL	0.132	0.845**	0.097	0.146	-0.250**	0.292**	0.217**	0.328**	0.660**	0.396**	0.654**	0.565**	0.212**	-0.290**	0.327**	-0.003	0.164*	0.031	**1**	0.300**	0.887**	0.295**
SDW	0.086	0.485**	-0.152	-0.093	0.04	0.297**	0.280**	0.311**	0.268**	0.192	0.316**	0.222**	0.269**	-0.270**	-0.152	-0.332**	-0.173*	-0.105	0.583**	**1**	0.271**	0.965**
SVI-I	0.046	0.765**	0.094	0.180*	-0.214**	0.246**	0.361**	0.297**	0.541**	0.528**	0.545**	0.444**	0.198*	-0.258**	0.137	0.117	0.196*	0.343**	0.949**	0.523**	**1**	0.385**
SVI-II	0.049	0.474**	-0.128	-0.075	0.041	0.271**	0.343**	0.314**	0.234**	0.179	0.284**	0.186*	0.276**	-0.275**	-0.169*	-0.283**	-0.159	0.032	0.587**	0.990**	0.570**	**1**

DF: Days to 50 % flowering; PH: Plant height (cm); NTP: Number of tillers per plant; NLP: Number of leaves per plant; LL: Leaf length (cm); LB: Leaf breadth (cm); SD: Stem diameter (cm); LSR: Leaf: Stem ratio; GFY: Green fodder yield (g/plant); DFY: Dry fodder yield(g/plant); GFYPD: Green fodder yield per plant per day (g/plant/day); DFYPD: Dry fodder yield per plant per day (g/plant/day); GY: Grain yield (g/plant); HCN: Hydrocyanic acid content (µg/g); TSS: Total soluble solids (^{0} brix); CPP: Crude protein (%); CPY: Crude protein yield (g/plant); SG: Seed germination (%); SL: Seedling length (cm); SDW: Seedling dry weight (mg); SV-I: Seed vigor index-I; SV-II: Seed vigor index-II

Table 5. Path coefficient analysis in fifty forage sorghum genotypes based on dry fodder yield

	DF	PH	NTP	NLP	LL	LB	SD	LSR	GFY	GFYPD	DFYPD	GY	HCN	TSS	CPP	CPY	SG	SL	SDW	SVI-I	SVI-II	Correlation with DMY
DF	**0.183**	0.029	-0.020	-0.023	-0.014	0.005	0.002	0.009	-0.079	0.112	-0.069	0.002	-0.006	0.019	-0.003	-0.005	-0.042	-0.008	0.015	0.009	-0.057	**0.059**
PH	0.178	**0.378**	0.047	-0.016	0.084	-0.018	-0.081	0.077	0.365	-0.052	0.362	-0.008	-0.024	-0.082	-0.218	0.094	-0.001	-0.040	0.131	0.103	-0.519	**0.760****
NTP	0.084	0.008	**0.093**	0.006	-0.032	-0.009	-0.015	0.028	0.182	0.025	0.167	0.001	-0.004	-0.010	-0.037	0.019	-0.002	0.004	-0.054	-0.009	0.049	**0.493****
NLP	-0.165	0.022	0.084	**-0.134**	0.081	-0.017	-0.016	0.074	0.334	-0.047	0.323	0.002	-0.014	0.012	-0.217	0.097	0.005	-0.011	-0.108	0.027	-0.107	**0.222***
LL	0.064	-0.010	0.030	0.036	**-0.123**	-0.007	0.006	0.023	0.125	0.177	0.125	0.001	-0.018	-0.028	0.026	-0.081	0.001	0.007	-0.050	-0.015	0.047	**0.335**
LB	0.015	0.039	0.014	-0.004	0.012	**-0.004**	0.018	-0.005	-0.149	-0.070	0.039	-0.003	-0.008	-0.023	0.041	0.032	0.003	-0.009	0.210	0.024	-0.279	**-0.105***
SD	0.157	0.018	0.081	0.001	-0.076	-0.017	**-0.090**	0.067	0.299	-0.042	-0.305	-0.003	-0.013	0.010	-0.014	-0.042	0.064	-0.015	0.155	0.057	-0.316	**-0.025**
LSR	0.130	0.033	0.063	0.020	-0.036	-0.015	-0.003	**0.110**	0.273	0.039	-0.260	0.002	-0.019	0.027	-0.006	-0.033	-0.011	-0.014	-0.215	0.031	-0.308	**-0.190**
GFY	-0.166	0.106	0.087	-0.126	0.072	-0.017	0.002	0.068	**0.392**	-0.056	-0.353	-0.002	-0.004	-0.007	0.296	0.123	-0.002	-0.025	0.214	0.063	-0.251	**0.445****
GFYPD	-0.063	0.106	-0.035	-0.004	0.032	0.009	0.004	-0.031	-0.145	**0.255**	-0.138	-0.003	-0.007	-0.005	0.228	0.122	0.302	-0.024	0.120	0.064	-0.320	**0.468****
DFYPD	0.166	0.077	0.087	0.018	-0.072	-0.017	-0.003	0.068	0.392	0.068	**0.353**	-0.002	-0.011	-0.010	0.017	-0.206	0.010	-0.014	-0.216	0.041	-0.020	**0.724****
GY	0.175	0.052	0.091	0.010	-0.082	-0.018	-0.012	0.077	0.172	0.053	-0.312	**-0.026**	-0.009	-0.006	0.046	0.045	0.016	-0.009	0.158	0.028	-0.172	**0.277**
HCN	0.017	-0.048	0.009	-0.015	-0.008	-0.004	-0.013	0.008	0.042	-0.059	0.047	0.003	**0.088**	0.024	-0.063	-0.028	0.017	0.012	-0.253	-0.035	-0.013	**-0.272***
TSS	0.150	-0.002	0.077	0.010	-0.052	-0.022	0.007	0.052	0.312	0.044	-0.311	0.001	0.016	**0.129**	-0.038	-0.036	-0.068	-0.015	-0.108	0.018	0.178	**0.340***
CPP	-0.171	-0.011	0.087	-0.024	-0.084	-0.017	-0.013	0.078	-0.223	0.046	0.147	-0.001	0.006	-0.003	**0.327**	0.139	0.070	-0.001	-0.202	0.020	0.135	0.274*
CPY	-0.009	0.053	-0.004	0.037	-0.007	0.002	-0.012	0.007	-0.052	0.073	-0.027	-0.004	-0.008	-0.015	0.123	**0.216**	0.040	-0.013	-0.065	0.046	0.018	**0.399***
SG	0.065	0.000	0.033	-0.006	-0.084	-0.002	0.014	0.057	0.100	0.042	0.114	0.001	-0.004	-0.022	0.012	0.032	**0.402**	0.011	-0.012	-0.113	-0.409	**0.231**
SL	0.131	0.082	0.065	-0.009	-0.120	-0.010	0.016	0.063	0.241	0.034	0.258	-0.003	-0.012	0.023	0.081	0.048	-0.004	**-0.088**	-0.191	0.223	-0.482	**0.345****
SDW	0.121	0.058	0.091	0.007	-0.086	-0.018	0.014	0.079	0.357	-0.051	-0.357	-0.003	-0.014	-0.009	0.004	-0.013	-0.003	-0.026	**0.237**	0.068	-0.278	**0.180**
SVI-I	0.127	0.073	0.063	-0.008	0.064	-0.009	0.020	0.108	0.229	-0.032	0.248	-0.003	-0.012	0.009	0.081	-0.058	0.181	-0.078	-0.204	**0.252**	-0.629	**0.421****
SVI-II	0.178	0.057	0.088	0.006	-0.097	-0.016	0.017	0.084	-0.341	0.048	-0.345	-0.003	-0.015	-0.014	0.006	-0.003	0.100	-0.026	0.180	0.097	**0.274**	**0.137**

Residual is 0.275; * bold values show the direct effects

Indirect positive effect of dry fodder yield/plant/day, crude protein yield and seedling dry weight *via* number of leaves/plant and plant height, crude protein content and green fodder yield, respectively, were reported on dry fodder yield. The indirect negative effect of green fodder yield *via*. seed vigor index-II and crude protein; dry fodder yield per plant/day *via*. stem diameter, leaf: stem ratio, green fodder yield, grain yield and TSS% were observed (Table 5). Our results were in accordance with a study conducted by Goswami *et al.* (2020), where a positive direct effect of green fodder yield on dry fodder yield was observed. Damor *et al.* (2018) reported a direct positive impact of crude protein yield on fodder yield, which was similar to our study.

Principal component analysis: An eigenvalue of more than one was observed for six components. The principal components (PCs) having eigenvalues of more than one showed more variation among the forage sorghum lines, which will be helpful in selection of diverse parents. A total of 76.28% variability was reported from first six components (PC1, PC2, PC3, PC4, PC5 and PC6) together (Table 6), and the remaining components accounted for only 23.72% of variability. These findings were supported by the earlier studies of different workers (Madhubabu *et al*., 2020; Sheela *et al*., 2020).

Scree plot elucidated the variation percentage between eigenvalues and the principal components (Fig 1). In this study, PC1 showed 38.02% variability with an eigenvalue of 8.36. The graph showed that the maximum variation was observed in PC1 compared to other PCs. Hence, the genotypes selected from PC1 would be useful in future breeding programs to improve the traits contributing to maximum variability for green and dry fodder yield. Jain and Patel (2016) reported that first three principal components had eigenvalues of more than 1, explaining 70.89% of the total variation with different yield and yield component traits in sorghum. Malini *et al.* (2023) observed the contribution of PC I for 50% flowering and days to maturity accounted for 36.85% of the total variability, and the first three axes explained the total variation of 81.5% for six quantitative characters similar to our study. A biplot based on PC1 and PC2 was also recorded

Table 6. Eigen values, percentage of variation and cumulative percentage for principal components

S. No.	Eigen values	Percentage of variation	Cumulative percentage
1	8.365	38.024	38.024
2	2.200	10.000	48.024
3	2.084	9.472	57.496
4	1.682	7.646	65.142
5	1.380	6.272	71.414
6	1.071	4.870	76.284
7	.934	4.247	80.531
8	.838	3.808	84.339
9	.738	3.355	87.694
10	.646	2.936	90.630
11	.496	2.255	92.885
12	.455	2.067	94.952
13	.283	1.286	96.237
14	.203	.923	97.160
15	.192	.875	98.035
16	.167	.760	98.795
17	.137	.624	99.419
18	.111	.503	99.922
19	.010	.044	99.965
20	.007	.031	99.996
21	.001	.004	100.000
22	5.842E-5	.000	100.000

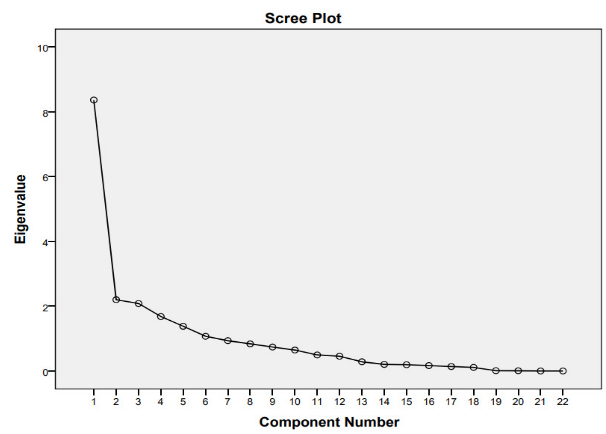

Fig 1. Scree plot diagram using principal components of forage sorghum genotypes

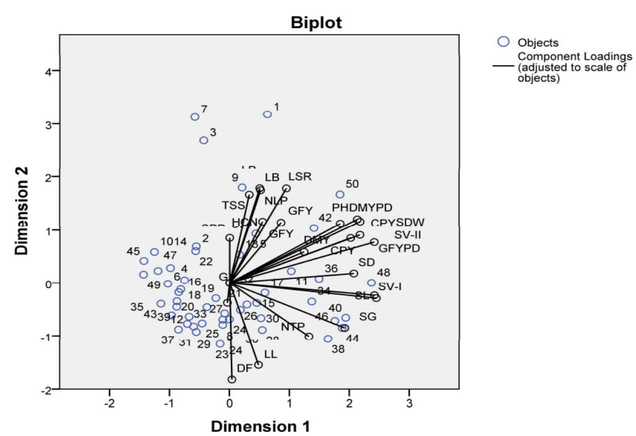

Fig 2. Biplot based on principal components 1 and 2 **(**corresponding genotypes for serial numbers mentioned in the figure, furnished in Table 1)

(Fig 2). Germplasm lines distributed near the origin had trait values close to the mean. The traits like plant height, green and dry fodder yield/plant/day, seed germination, seedling length, *etc*. showed maximum vector length, indicating its contribution to the total divergence. The angle between the trait vectors indicated the direction of association between these traits. An acute angle indicates a positive correlation; a right angle indicates no correlation, and obtuse angles suggest a negative correlation. Out of twenty-two traits studied, the traits such as plant height, green and dry fodder yield per plant per day, seed germination, number of tillers per plant, crude protein yield, seedling vigor index I and II *etc*., showed a positive correlation with dry fodder yield. The genotypes close to the trait vector of the same quadrant would perform best for those traits. Similar results were reported earlier (Govintharaj *et al*., 2018; Vijaylaxmi *et al*., 2019b).

Conclusion

From the above study, it was concluded that plant height, number of tillers per plant, leaf breadth, crude protein yield, dry fodder yield, dry fodder yield/plant/day, and green fodder yield/plant/day were found to be important fodder yield components. Therefore, selection based on these component traits would certainly boost forage sorghum yield and quality. Path analysis showed that seed germination, green fodder yield and plant height exhibited a maximum positive direct effect on the expression of dry matter yield. Hence, it indicated that a high seed germination rate is associated with vigorous plant growth, ultimately leading to improved green and dry biomass production with high crude protein content.

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