FIELD EVALUATION OF SIXTEEN MULTI-CUT FODDER SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH] GENOTYPES BASED ON THEIR AGRO-MORPHOLOGICAL ATTRIBUTES

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Abstract. Agro-morphological attributes are the key parameters for evaluating field crops including fodders. The genetic divergence of cereal forages provide sustainability to modern intensive production systems in the worlds. Changing climate situation is challenging for sorghum and other field crops. Therefore, characterization of agro-morphological attributes of sorghum is crucial for plant fitness, adaptability, livestock and human food supply in the worlds. A field study in the regular arrangement of randomized complete block design (RCBD) with three replications was conducted at the experimental farm, RCA, Udaipur. The study was aimed to evaluate and characterize sixteen multi-cut fodder sorghum genotypes for various agro-morphological traits. As per recorded data, genotypes displayed significant variability for various traits. Additionally, green fodder yield (GFY) at first cut manifested significant and positive association with regeneration score whereas genotypic and phenotypic coefficient variation (GCV & PCV) remained high for dry fodder yield at second cut. Furthermore, high heritability (h^2) along with high expected genetic gains were exhibited by dry fodder yield at second cut. Moreover, plant height exhibited the maximum direct effect on green fodder yield at first cut followed by regeneration ability score and leaf: stem ratio. To conclude, genotype SPH-1877 showed better performance for green fodder and dry fodder yield, and also exhibited better regeneration score compared to the rest of the genotypes. This study suggests that the best sorghum cultivar with better agro-morphological and yield related traits can be useful for sustainable sorghum production and ensuring the fodder supply for livestock.
Keywords. *Sorghum, fodder, livestock, variability, heritability, continent, correlation coefficient, path analysis*

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench; 2n = 20] is an often-cross pollinated crop which belongs to the Poaceae family and used as food, feed and bio-energy source. It is commonly called as great millet and believed to be originated from Ethiopia in the

African continent (Iqbal et al., 2017; Suvarna et al., 2020). Sorghum exhibits a diverse range from annual to perennial types. Globally, sorghum is cultivated in tropical, sub-tropical and arid regions. It holds a good promise as a fodder crop in low and uncertain rainfall areas owing to its high tolerance to high temperature, great adaptability to soil toxicities, resistance to lodging and a very remarkable ability to recover from short interval of drought (Rooney, 2014; Iqbal et al., 2021). In India, forage sorghum has been cultivated on an area of 5.9 Mha with a production of 900 MT during 2018-19 (Iqbal et al., 2019). In arid regions, scarcity of green forage during scorching heat of milk summers results in serious decline of milk production compromising the attainment of sustainable development goals (SDGs) of zero hunger and poverty alleviation in South Asian countries especially in the Indo-Pak subcontinent (Iqbal et al., 2019, 2021). Currently, the total fodder requirement of the country is 53.19 MT whereas production is 22.74 MT so there is huge gap between demand and supply. To combat this gap, multi-cut fodder sorghum is a better choice due to its high dry matter production coupled with better quality, tolerance to biotic and abiotic stress and wider adaptability (Tokas et al., 2017; Bhat et al.,2020). It is considered as the main source of green forage and roughages for the livestock in tropical areas and has a significant potential to catalyze region adaptability, growth and increasing global food security (Muhammad et al., 2015). Sorghum fodder can be utilized in various forms green, chopped, hay and silage. Among cereal fodder crops sorghum ranks first because of its climate resilient nature, higher yield, palatability and nutritious quality (Xiong et al., 2019). Multi-cut fodder sorghum gives almost uniform green fodder yield round the year due to its superior regeneration capacity than other cereal forages like maize. The International Food Policy Research Institute (IFPRI) based on their model projections suggested that by the year 2050 yield of other cereal crops like wheat, rice and tuber crops will decline by 5 to 25% while yield of sorghum will increase and sorghum is one of the only cereal crop which has adopted to changing climate globally by facing drought and higher temperature continuously (Teferra and Awika, 2019; Ringler, 2010). Therefore, sorghum is the most desirable crop for future as food and feed security.

Sorghum productivity has remained suboptimal owing to lesser attention on its genetic improvement owing to yield complexity as polygenic trait which gets influenced by the genotype x environment interaction (Bhat, 2019). So the genetic improvement mainly depends upon the variability in plant characters, overall genetic diversity among these genotypes and association among traits (Ahalawat et al., 2018). Sorghum is a good source of forage, dried fodder and pasture (Mbarki et al., 2022). In order to make forage sorghum as an enterprising and remunerative crop, there is need to develop varieties or hybrids having early maturity, faster growth and high forage yield coupled with high protein content and low HCN content at flowering stage (Pushpa et al., 2019). Variability is the prerequisite for the effective selection. The success of any crop improvement program not only depends on the amount of genetic variability present in the population but also on the extent to which it is heritable, which sets the limit of progress that can be achieved through selection (Swamy et al., 2018). The presence of appropriate knowledge on heritability of sorghum genotypes influences the choice of selection procedures used by the plant breeder to select most suitable selection methods in order to produce desirable traits. Characters with high heritability can easily be fixed with simple selection resulting in quick progress (Ranjith et al., 2017). There remains a considerable research and knowledge gap regarding field evaluation of sorghum genotypes and screening studies might sort out high yielding genotypes suitable for

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green biomass production under changing climate and global warming scenarios which have manifested as heat and drought stresses especially in rainfed regions of arid and semi-arid areas.

Therefore, the present research was aimed to evaluate the extent of variability, heritability and expected genetic gain along with correlation, coefficient and path analysis in multi-cut fodder sorghum genotypes leading to identification of superior genotype (s) for boosting herbage yield and successful utilization in future breeding programs.

Materials and methods

Experimental site details

The experiment was conducted at Instructional Farm of Rajasthan College of Agriculture, Udaipur (Rajasthan) (24°35’ N latitude and 74°42’ E longitude) under rainfed conditions during *Kharif* season 2017-18. The region falls under agro-climatic zone IVa (Sub-Humid Southern Plain and Aravalli Hills) of Rajasthan. The mean annual rainfall of the region is 637 mm, most of which is contributed by South-West monsoon (80-85 per cent) from July to September. The physical and chemical properties of experimental field have been described in *Table 1*.

Table 1. *Physico-chemical features of experimental field*

Physico-chemical features	Values of 2017-18
Sand (%)	37.18
Silt (%)	28.86
Clay	33.90
Texture class	Clay loam
Bulk density (Mgm^{-3})	1.47
Particle density (Mgm^{-3})	2.64
Porosity (%)	44.32
Organic carbon (%)	0.76
Available N ($Nkgha^{-1}$)	279.61
Available P (P_2O_5 $kgha^{-1}$)	19.27
Available K (K_2O $kgha^{-1}$)	318.15
Electrical conductivity dSm^{-1}	1.01
pH	8.00

*Data were obtained from Agriculture Farm, Department of Agronomy, RCA, Udaipur (Rajasthan)

Experimental design and details

The genotypes of multi-cut sorghum for current experiment were provided by All India Coordinated Research Project (AICRP) on Sorghum. The details of genotypes taken for present experiment is showed in *Table 2*.

The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications having 12 rows of 5.5 m length and 25 cm plant to plant spacing. All the recommended cultural practices such as field preparation, line sowing, fertilizer application (NPK at the rate of 120:60:40 kg ha^{-1}), and irrigations, were applied in accordance with the production technology package developed by RCA, Udaipur, India

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for ensuring optimum plant stand. The total of four irrigations were given during sowing to grain filling stage. The response variables were recorded by ten randomly selected plants from each experimental unit and some characters were recorded on whole plot basis. Thirteen agro-morphological traits were recorded as per below given methodology. *Figure 1* represents the different stage of sorghum grown in field condition and showing higher fodder germplasm.

Table 2. *List of genotypes studied in the screening experiment*

Sr. No.	Genotype	Source
1	SPH 1807	AICRP, Sorghum, RCA, Udaipur
2	SPH 1838	AICRP, Sorghum, RCA, Udaipur
3	SPH 1840	AICRP, Sorghum, RCA, Udaipur
4	SPH 1841	AICRP, Sorghum, RCA, Udaipur
5	SPH 1876	AICRP, Sorghum, RCA, Udaipur
6	SPH 1877	AICRP, Sorghum, RCA, Udaipur
7	SPH 1878	AICRP, Sorghum, RCA, Udaipur
8	SPH 1879	AICRP, Sorghum, RCA, Udaipur
9	SPH 1880	AICRP, Sorghum, RCA, Udaipur
10	SPH 1881	AICRP, Sorghum, RCA, Udaipur
11	SPV 2491	AICRP, Sorghum, RCA, Udaipur
12	SPV 2492	AICRP, Sorghum, RCA, Udaipur
13	CSH 24MF	PBG, Dept. RCA, Udaipur
14	SSG 59-3	PBG, Dept. RCA, Udaipur
15	CSV 33MF	PBG, Dept. RCA, Udaipur
16	CoFS-29C	PBG, Dept. RCA, Udaipur

AICRP; All India Coordinated Research Project, PBG; Department of Plant Breeding and Genetics; RCA; Rajasthan College of Agriculture

Figure 1. *A view of experimental field area a) initial vegetative stage b) initiation of flowering c) individual plant selected for various forage yield contributing traits*

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Observations recorded

The thirteen agro-morphological observations were recorded on randomly selected five individual plants viz., early vigor score (1-5 scale, Podde et al., 2020), plant height (cm), leaf length (cm), leaf breadth (cm), stem girth (cm), total soluble solids (%), number of leaves per plant and stem juiciness (Brix refractometer), green fodder yield (kg/ha), dry matter yield (kg/ha), leaf–stem ratio, crude protein (%) and regeneration ability score (1-5, Kumari, 2016) scale. Following calculations were used to examine green fodder yield (kg/ha), dry matter yield (kg/ha), leaf: stem ratio, crude protein (%).

Green fodder yield (kg/ha)

The green fodder yield was recorded on whole plot basis. All the plants of a were harvested at 60 days after sowing, 45 days after first cutting and 45 days after second cutting. These randomly selected plants were harvested separately and green leaf and stem weight were recorded. The plot yield was then converted into per hectare yield for each cut by using the below formula:

$$Green\ fodder\ yield\ (kg.ha^{-1}) = \frac{Green\ fodder\ yield\ per\ plot\ (kg)\ \times 10{,}000}{5.5\ \times .25\ \times 12} \quad \text{(Eq.1)}$$

Dry fodder yield (kg/ha)

Sample of ten randomly selected plants from, each plot at each cut will be weighted. They will be sun dried for three days and then oven dried at 60°C till constant weight is obtained. Dry fodder yield for each cut was calculated by using the following formula.

$$Dry\ fodder\ yield\ (kg.ha^{-1}) = \frac{Green\ fodder\ yield\ (kg.ha^{-1}) \times Dry\ sample\ weight}{Green\ sample\ weight} \quad \text{(Eq.2)}$$

Protein content (%)

Protein content was determined by Kjeldahl (1883), In which crude protein content in first cut of the fodder sorghum was determined by multiplying the nitrogen percentage with factor 6.25.

$$\text{Crude protein (\%)} = \text{Nitrogen content (\%)} \times 6.25$$

where nitrogen content was determined from the dried plant samples from each plot. The samples were grinded in a “Willey Mill” and passed through a 100-mesh sieve. From each sample, the required quantity was weighed separately for chemical analysis to determine nitrogen by Nessler’s reagent colorimetric method (Lindner, 1994).

Statistical analysis

To test the significance of variation among the various genotypes, analysis of variance (ANOVA) was carried-out by following the methodology of Fisher using computer run program of SPSS (Fisher, 1918). Genotypic and phenotypic correlation coefficients between different characters were calculated by using the genotypic and phenotypic variances and covariance’s as suggested by Fisher (1954) and Al-Jibouri et al. (1958) by using the same statistical package. Path coefficient analysis was employed

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for green fodder yield at I and II cut using the principles of Wright (1921). The following are the formulas for were used for determining the GCV, PCV, h^2 and GA (% of mean):

$$\text{GCV (\%)} = \frac{\sqrt{\hat{\sigma}_g^2}}{\overline{X}} \times 100 \quad \text{(Eq.3)}$$

$$\text{PCV (\%)} = \frac{\sqrt{\hat{\sigma}_p^2}}{\overline{X}} \times 100 \quad \text{(Eq.4)}$$

$$h^2 = \frac{\hat{\sigma}_g^2}{\hat{\sigma}_p^2} \times 100 \quad \text{(Eq.5)}$$

$$\text{GA (\% of mean)} = \text{GA} \times 100 \quad \text{(Eq.6)}$$

Results and discussion

Variability parameters

Analysis of variance for measured traits

The results revealed that sorghum genotypes differed significantly for experimental variables including plant height, leaf number and area (length and width), stem girth and stem juiciness etc. (*Table 3*). These findings were clear indication of genetic variability among multi-cut sorghum genotypes which manifested significantly for different morphological traits. Similar results were observed previously by number of researchers pertaining to the variability in sorghum genotypes regarding forage traits (Diwakar et al., 2015; Kour and Pradhan, 2016; Singh et al., 2018). These findings also corroborate with those of Iqbal et al. (2017, 2021), who opined that under same production technology package, sorghum cultivars performed differently and it was inferred that genetic divergence among sorghum cultivars might be attributed for superior performance of few genotypes over the others under semi-arid conditions. It was also suggested that superior genotypes had better root network which assisted in absorbing more nutrients and moisture from soil solution which led to maximum yield attributes such as leaf area, leaf number and plant height.

The estimation of range with mean values is presented in *Table 4*. The maximum early vigor was observed in SPH-1807 (4), SPH-1838 (4) and SPV-2491 (4) while lowest in SPH 1879 (2.33). SPH-1807 (298.67 cm) was the tallest and SPV-2492 (257.06 cm) was the shortest genotype. Maximum leaf length was exhibited by SPH-1879 (99.07 cm) and minimum leaf length was the genotype SPH 1840 (82.57 cm). For the leaf breadth SPH-1807 (10.18) to SPV-2492 (14.05) range difference was observed. Genotypes SPV-2491 and SPV-1876 expressed thickest and thinnest stem (7.40 cm and 4.83 cm) respectively. Total soluble solids ranged from SPH-1841(9.23%) to SPV-2491 (5.57%). The maximum number of leaves was observed in SPH-1876 (13) where, minimum number of leaves per plant was recorded in CSH-24MF (8.11). Genotype

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SPH-1881 (4.05) showed highest juiciness content among all genotypes. The leaf: stem ratio at first cut varied from 0.39 (SPH-1879) to 0.68 (SPV-2491) respectively. At the first cut, highest GFY were the genotype SPH-1877 (73679.02 kg. ha^{-1}) and during second cut SPH 1840 and SPH-1880 genotypes showed highest and lowest GFY (23530.3 and 7394.43 $kg.ha^{-1}$) respectively. Dry fodder yield range varied from SPH-1877 (24889.93 $kg.ha^{-1}$) to SPH-1880 (10593.7 kg. ha^{-1}) for the first cut. During the second cut, genotype SPH-1840 (8254.56 $kg.ha^{-1}$) exhibited maximum dry fodder yield and SPH-1880 (1381.87 $kg.ha^{-1}$) was least performer. The highest protein content was observed in genotype SPH-1876 (9.54%). Highest regeneration ability score after first cut was expressed by SPH-1877 (4.17) minimum in SPH-1878(2.03). The results suggested that genotype SPH 1877 was better performing for high biomass production. This genotype could be used in further multi-cut fodder sorghum breeding programs which may boost the biomass production and productivity. Genotypes like SPH1807, SPH1879 and SPV2491 are better genotypes for indirect selection of forage yield contributing traits i.e., plant height, leaf length and breadth and stem girth for high biomass production. Genotype SPH 1841 could be further genetically improved in direction to sweet sorghum which is now days great in demand. The results are in consonance with findings of earlier workers in sorghum fodder (Diwakar et al., 2015; Kour and Pradhan, 2016; Jadhav et al., 2017; Singh et al., 2018; Kavipriya et al., 2020; Toor, 2020), who inferred that owing to superior genetic make-up, sorghum genotypes performed well under unfavorable conditions by developing extensive roots network to extract moisture from deeper soil horizons. It was also reported that superior genotypes developed thick waxy cuticle layers on the leaf surface which minimized water losses and plants were able to survive short to moderate spells of drought and thus it was suggested to screen out sorghum genotypes having better roots development and agro-botanical traits.

Table 3. *Mean sum of squares for 13 characters in multi-cut fodder sorghum during 2017*

Traits	Replication	Genotype	Error
Early vigor	0.68	1.96**	0.23
Plant height (cm)	66.16	446.74**	89.82
Leaf length (cm)	42.57	168.52**	30.20
Leaf breadth (cm)	0.21	2.17**	0.39
Stem girth (cm)	2.037	3.48**	0.68
Total soluble solids (%)	2.13	4.40**	0.76
Number of leaves per plant	2.80	6.15**	0.85
Stem Juiciness (%)	0.256	2.07**	0.46
GFY ($kg.ha^{-1}$) I cut	44420500.00	115852750.7**	16718113.9
GFY ($kg.ha^{-1}$) II cut	20995740.00	90580352.53**	12184645.62
GFY ($kg.ha^{-1}$) III cut	5027270.00	51724701.49**	4272858.32
Dry fodder yield ($kg.ha^{-1}$) I cut	13059770.00	31430426.67**	4624008.98
Dry fodder yield ($kg.ha^{-1}$) II cut	104324.50	10585980.4**	605353.08
Leaf: stem ratio	0.00194	0.016641**	0.00356
Protein percent	0.37	0.83**	0.14
Regeneration ability (1-5 scale)	0.080	1.33**	0.10

*Significance level at 0.1, highly significant

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Table 4. *Agro-morphological performances of 16 multi-cut fodder sorghum genotypes*

Traits	**Mean**	**Range**	
		Low	**High**
Early vigor (1-5 scale)	2.97	1.96	4.0
Plant height (cm)	277.37	257.08	298.67
Leaf length (cm)	91.20	70.67	99.07
Leaf breadth (cm)	11.45	9.89	14.05
Stem girth (cm)	6.28	4.83	7.40
Total soluble solids (%)	7.13	5.57	9.23
Number of leaves per plant	10.44	8.00	13.00
Stem juiciness (%)	2.94	1.11	4.05
Green fodder yield ($kg.ha^{-1}$) I cut	61320.80	51933.00	73679.00
Green fodder yield ($kg.ha^{-1}$) II cut	15130.40	7394.00	27193.00
Green fodder yield ($kg.ha^{-1}$) III cut	10247.10	5454.00	20048.00
Dry fodder yield ($kg.ha^{-1}$) I cut	15793.00	10593.00	24889.00
Dry fodder yield ($kg.ha^{-1}$) II cut	3999.70	1382.00	8255.00
Leaf stem ratio	0.55	0.39	0.68
Protein percent	8.60	7.87	9.54
Regeneration ability score (1-5 scale)	3.56	2.03	4.83

Genotypic and phenotypic coefficient of variance (GCV and PCV) in measured traits

On account of higher SD values, traits were classified in only two categories including greater than mean ± SD or in between mean SD. The GCV and PCV are categorized as low (less than 10%), moderate (10-20%) and high (more than 20%) as suggested by Burton and Devana (1953). The range of GCV was low in plant height (3.41) and too high for Dry fodder yield at II cut (45.60). In addition, GCV was high (more than 20) for Dry fodder yield at II cut (45.60) that was followed by GFY at III cut (38.81), GFY II cut (33.78), early vigor data (25.62) and stem juiciness (24.91); moderate GCV was in dry fodder yield I cut (18.92) followed by Regeneration ability score (17.91), total soluble solid (15.45), number of leaves per plant (12.73) and leaf: stem ratio (11.91); lowest GCV was in GFY at I cut (9.37), stem girth (8.43), leaf length (7.44), protein concentration (5.48) and plant height (3.41). The PCV was high (more than 20) for dry fodder yield at II cut (49.57), GFY at III cut (43.74) with regeneration ability score (20.22), moderate (between 10 to 20) for total soluble solid (19.72), leaf–stem ratio (16.06), leaves number (15.49), leaf breadth (12.26), GFY at I cut (11.50) and stem girth (11.11). In contrast, low PCV (less than 10) was recorded for leaf length (9.57), protein percent (7.08) and plant height (5.20). From the above stated results, it was concluded that the PCV remained on higher side than GCV as there was no significant difference between PCV and GCV among all traits under investigation (*Table 5*). This narrow difference indicates the reliability of phenotypic selection for a particular trait. It also manifests that natural variation persists for various agro-morphological traits of sorghum genotypes that might be exploited for yield improvement. These findings are in conformity with the results reported by earlier workers (Diwakar et al., 2015; Kour and Pradhan, 2016; Jadhav et al., 2017; Bhrdwaj et

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al., 2017; Singh et al., 2018; Kavipriya et al., 2020; Toor, 2020), which depicted that there existed a considerable variability of yield attributes among sorghum genotypes which needs to be screened out and exploited for boosting yield contributing traits and herbage yield.

Table 5. *Spectrum of variability observed among 13 traits studied in 16 multi-cut fodder sorghum genotypes*

Characters	GCV	PCV	h^2	GG
Early vigor (1-5 scale)	25.62	30.33	71.37	44.59
Plant height (cm)	3.41	5.20	56.98	6.11
Leaf length (cm)	7.44	9.57	60.42	11.92
Leaf breadth (cm)	10.00	12.26	60.04	19.58
Stem girth (mm)	8.43	11.11	57.58	13.18
Total soluble solids (%)	15.45	19.72	61.42	24.98
Number of leaves per plant	12.73	15.49	67.51	21.55
Stem juiciness (%)	24.91	34.13	53.26	37.45
GFY (kg.ha^{-1}) I cut	9.37	11.50	66.40	15.73
GFY (kg.ha^{-1}) II cut	33.78	40.91	68.20	57.48
GFY (kg.ha^{-1}) III cut	38.81	43.74	78.73	70.94
Dry fodder yield (kg.ha^{-1}) I cut	18.92	23.31	65.90	31.65
Dry fodder yield (kg.ha^{-1}) II cut	45.60	49.57	84.61	86.40
Leaf stem ratio	11.91	16.06	55.04	18.21
Protein percent	5.58	7.08	62.25	9.08
Regeneration ability score (1-5 scale)	17.97	20.22	79.01	32.91

Heritability (h2) and expected genetic gains

High heritability plays a major role in selecting suitable genotypes based on their phenotypic traits and yield performance under specific pedo-climatic conditions. Genetic advancement based on screening out the genotypes having vigorous growth potential has recently emerged as an indication of the expected genetic progress for breeding a particular trait by following a variety of selection procedures (Iqbal et al., 2017, 2019, 2021). High heritability (h2) (84.61%) (more than 60) was observed for Dry fodder yield at II harvest was coupled with high expected genetic gain of 86.40 which was followed by GFY atIII cut (78.03) with expected genetic gain (70.94); regeneration ability score (79.01) with expected genetic gain 32.91; Early vigor score (71.37, 44.59); GFY at II cut (68.20, 57.48). Additionally, significant difference was recorded for number of leaves per plant (67.51, 21.55), dry fodder yield at I cut (65.90, 31.65); total soluble solids (61.42, 24.98), stem juiciness (53.26, 37.45) respectively. High heritability with moderate expected genetic gains (10-20) was observed for traits like, GFY at I cut (66.40, 15.43); leaf length (60.42, 11.92); leaf breadth (60.04, 19.58). These findings suggested preponderance of additive and fixable genetic variance, therefore any selection scheme might be applied for developing stable genotypes for these traits. It was noted that these characters also exhibited high genetic coefficient of variation. Thus, it may also be inferred that better genetic gains could be obtained when the phenotypic expression is not greatly altered by the influence of environment. High heritability coupled with low expected genetic gain (less than 10) showed by protein

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percent (62.25, 9.08). Moderate heritability (30-60) with moderate expected genetic gain was expressed by traits i.e., stem girth (57.58, 13.18); leaf: stem ratio (55.04, 18.21). Moreover, plant height showed moderate heritability with less expected genetic gain (56.98, 6.11) (*Table 5*). High heritability coupled with high expected genetic gain indicates the additive gene action for that particular traits selection for this kind of trait could be effective for improvement of this crop. These findings are in agreement with findings of earlier workers (Soujanya et al., 2019; Kumar et al., 2020), whereby significant genotypic and phenotypic correlation was observed for sorghum botanical traits such as leaf–stem ratio, plant height etc.

Correlation coefficient

Using the variability parameters, identification of the characters having high response to selection becomes evident as plant breeders are mainly interested in yield attributes which contribute significantly to economic yield. Low variability limits the scope to improve green forage yield and dry matter production under varying agro-ecological conditions. The genotypic and phenotypic correlation coefficients have the potential to identify yield attributes which can assist to improve biomass production of sorghum. The estimates of correlation coefficient at genotypic level are presented in *Table 6*. In the present investigation, the GFY of I cut was manifested significant and positive association with regeneration ability score (rg = 0.65) whereas, it was significant and negatively correlated with protein (rg = -0.58). Moreover, leaf stem ratio was positively and significantly correlated with Early hybrid vigor (rg = 0.42) and leaf breadth (rg = 0.37). Stem girth was positively and significantly correlated with plant height (rg = 0.53) and early hybrid vigor (rg = 0.45). Leaf breadth was positively and significantly correlated with early hybrid vigor (rg = 0.45). Hence, selection for traits like regeneration ability, leaf stem ratio, leaf breadth, plant height and stem girth is effective for yield improvement in fodder sorghum. Above stated result is in line with experimental findings of (Vendruscolo et al., 2016; Soujanya et al., 2018; Rohila et al., 2020).

Path coefficient analysis

Path coefficients for GFY at first cut estimated using genotypic correlation between independent characters had significant difference among sorghum genotypes. Further path coefficients were performed again and again after dropping the characters one by one till the residual effect became positive (*Table 7*). The residual effect (R = 0.6580) indicated that only 35.20 per cent variability of green fodder yield ($kg.ha^{-1}$) in I^{st} cut was explained by plant height, total soluble solid, stem girth and stem juiciness. The direct effect was maximum for plant height (-0.45) which was followed by regeneration ability score (0.44), leaf: stem ratio (0.43), total soluble solid (-0.28), stem girth (0.24), early vigor (-0.18), stem juiciness (-0.14), leaf length (0.12), number of leaves per plant (-0.046), protein per cent (-0.033) and leaf breadth (0.017). Indirect effect via, these characters was also in the same order. Direction of direct effect and correlation coefficients were same in all the cases except where, plant height, stem girth, total soluble solid, number of leaves per plant and stem juiciness. The results are in consonance with the findings of (Deep et al., 2019; Patel et al., 2019; Iqbal et al., 2018, 2019), who recorded significant variation among sorghum genotypes having varying agro-botanical traits as depicted by path coefficient analysis.

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Table 6. *Genotypic (r_g) correlation coefficients among 13 traits studied in 16 multi-cut fodder sorghum genotypes in 2017*

Character	Early vigor	Plant height	Leaf length	Leaf breadth	Stem girth	Total soluble solid	Number of leaves per plant	Stem juiciness	Leaf stem ratio	Protein percent	Regeneration ability score	GFY I[st] cut
Early vigor (1-5)	**1.000**	0.349*	0.359*	0.457**	0.450**	-0.211	-0.149	0.416**	0.425**	-0.08	0.035	-0.054
Plant height (cm)		**1.000**	-0.181	-0.132	0.530**	-0.567**	-0.0006	-0.387**	0.077	-0.525**	0.078	-0.326*
Leaf length (cm)			**1.000**	-0.242	0.198	0.239	-0.229	0.780**	-0.201	0.125	0.126	-0.129
Leaf breadth (cm)				**1.000**	0.099	0.022	-0.220	-0.130	0.375**	0.108	-0.118	0.232
Stem girth (mm)					**1.000**	0.082	0.1	0.459**	0.0003	-0.634**	-0.588**	-0.588**
Total soluble solids (%)						**1.000**	0.139	0.555**	-0.463**	0.030	-0.261	-0.433**
Number of leaves per plant							**1.000**	0.107	-0.870**	-0.087	-0.214	-0.214
Stem juiciness (%)								**1.000**	-0.476**	-0.358*	-0.477**	-0.477**
Leaf–stem ratio									**1.000**	0.352*	0.186	0.539
Protein percent										**1.000**	0.576**	0.582**
Regeneration ability score (1-5)											**1.000**	0.651**
GFY I[st] cut												**1.000**

**Significant at 5% and 1% level of significance respectively

Table 7. *Direct (diagonal) and indirect effects of 13 traits towards green fodder yield at first cut in multi-cut fodder sorghum*

Character	EV	PH	LL	LB	SG	TSS	NLP	SJ	L/S	P%	RAS	GFY
Early vigor (1-5)	**-0.187**	-0.027	-0.059	-0.064	-0.051	0.017	0.019	-0.039	-0.049	-0.005	-0.025	0.0297
Plant height (cm)	-0.066	**-0.458**	0.117	0.006	-0.125	0.157	0.022	0.103	-0.096	0.167	-0.025	-0.192
Leaf length (cm)	0.039	-0.032	**0.125**	-0.025	0.010	0.024	-0.022	0.046	-0.016	0.003	0.003	0.0536
Leaf breadth (cm)	0.006	0.000	-0.003	**0.017**	0.001	0.001	-0.004	0.000	0.005	0.001	0.000	0.0718
Stem girth (mm)	0.066	0.067	0.019	0.018	**0.244**	-0.005	0.005	0.083	-0.032	-0.091	-0.088	-0.1693
Total soluble solids (%)	0.025	0.096	-0.054	-0.017	0.005	**-0.281**	-0.023	-0.077	0.075	0.009	0.035	-0.301
Number of leaves per plant	0.005	0.002	0.008	0.011	-0.001	-0.004	**-0.046**	-0.006	0.025	0.002	0.009	-0.3863
Stem juiciness (%)	-0.030	0.033	-0.053	-0.003	-0.049	-0.040	-0.018	**-0.145**	0.043	0.020	0.033	-0.262
Leaf: stem ratio	0.114	0.091	-0.057	0.122	-0.058	-0.117	-0.236	-0.131	**0.438**	0.085	0.065	0.4521
Protein percent	-0.001	0.012	-0.001	-0.002	0.012	0.001	0.001	0.004	-0.006	**-0.033**	-0.015	0.362
Regeneration ability score (1-5)	0.058	0.024	0.012	0.009	-0.159	-0.054	-0.086	-0.101	0.066	0.205	**0.440**	**0.432**

Residual effect = 0.6580, ** significant at 5% and 1% level of significance

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Conclusion

This research findings imply the significant genetic variability among the sorghum genotypes in terms of their agro-morphological yield attributes, and correlations. Trait like regenerability score showed positive and significant correlation with green fodder yield. This desirable trait can be considered for developing multi-cut fodder sorghum and could be used for selection after hybridization for generating favorable wide spectrum genetic variability for multi-cut fodder sorghum. According to the variability parameters, high heritability coupled with high genetic advance was governed by additive genetic effects to a great extent and improvement of it would be effective through selection. The results showed that genotype SPH-1877 the better performance for green fodder yield and dry fodder yield and also exhibited better regeneration score among all the genotypes. However, the filed based agro-morphological characterization of sorghum traits might be useful to sorghum breeder and farmers for developing better fodder yielding cultivar for livestock and human food security in the world.

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