Received:17 Aug 2022 | Revised: 28 Sep 2022 | Accepted: 28 Sep 2022

Electronic Journal of Plant Breeding

Research Article

Gene action and contribution of different traits for enhanced green fodder yield and quality in pearl millet - napier interspecific hybrids

K. Keerthana[1], K. N. Ganesan[1*], K. Iyanar[2], S. D. Sivakumar[3] and P. Jeyakumar[4]

[1]Department of Forage Crops, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore
[2]Department of Millets, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore
[3]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore.
[4]Directorate of Planning and Monitoring, Tamil Nadu Agricultural University, Coimbatore.
***E-Mail**: knganesan71@gmail.com

Abstract
In the current study, general combining ability (GCA) and specific combining ability (SCA) studies were carried out in 15 pearl millet hybrids derived from five lines and three testers The GCA for parents and SCA for hybrids showed highly significant differences among them. The genetic variances revealed pre-dominance of non-additive gene action for all the traits studied. The correlation showed that the traits namely leaf weight, dry matter yield per plant, stem weight, plant height, leaf to stem ratio and leaf breadth had significantly positive correlation with green fodder yield per plant. Contemplating the *per se* performance along with combining ability studies, the parents GP15073 and FD465 exhibited superior *gca*, whereas the hybrids GP16016 × FD465 and GP15074 × FD465 had better *sca* for green fodder yield and important yield contributing traits. The hybrid GP15958 × FD465 exhibited superior performance for fodder quality traits.

Keywords: Pearl millet napier cross , Combining ability, Correlation, Fodder quality, Green fodder.

INTRODUCTION

Forages are normally referred to those plants and plant parts that are consumed by domestic livestock, such as dairy cattle, sheep, horses and a wide range of other animals. Forages are considered as the backbone of grassland agriculture system. Furthermore, land allocated to green fodder production was limited to 8.4 million hectares (4.50 %) and rarely exceeded 5% of the gross cropped area in India (Babu *et al*., 2021). The development of pearl millet - napier hybrids have revolutionized the milk production in India. In terms of quality and availability of green fodder, pearl millet- napier hybrids proved to be a better option due to its perennial nature, profuse tillering habit, high yield, palatability, nutritional value and suitability for silage making under Indian conditions.

The triploid pearl millet - napier hybrid (2n= 3x =21) is an interspecific hybrid between diploid pearl millet [*Pennisetum glaucum*] (2n= 2x =14) and tetraploid napier grass [*Pennisetum purpurem*] (2n= 4x =28). It is a tall growing, erect, stout, deep rooted, perennial grass, holding the fodder quality characters of pearl millet with high yielding potential and perennial nature of napier grass (Lokhande, 2015). Once planted, it provides constant and consistent green fodder for at least three years (Babu *et al*., 2021).

The line × tester method (Kempthorne, 1957) is a robust statistical design, which is used to determine the relative capacity of female and male lines to produce hybrid combinations with better heterosis (Singh *et al*., 2005). Understanding the gene action and expression of associated trait is the key for any crop improvement programme (Rukundo *et al.,* 2017; Grami *et al*., 1977; Ma-Teresa *et al*., 1994). The process of selection, breeding and development of superior parental lines are not an easy task for the plant breeders as the choice of genotypes cannot be made merely on the basis of *per se* performance, thus an extra layer of information on gene action can ease the selection process (Gramaje *et al*., 2020). The goal of combining ability analysis in this study is to evaluate a specific parental lines ability to pass along its genetic information to their offspring (Aly, 2013; Sprague and Tatum, 1942). Parents with high GCA and parental combinations with high SCA can be identified *via* combining ability analysis (Fehr, 1993).

Green fodder yield is a polygenic trait, which depends on various other component traits. The selection based on a single trait will not be promising and hence, all the component traits, which directly or indirectly contribute to green fodder yield should be validated. Analysing the association of green fodder yield with its component traits and association among themselves can drive the selection process in a fruitful way.

With the above background, this research investigation was carried out to study the combining ability and association studies for important yield and quality traits in pearl millet - napier hybrids.

MATERIALS AND METHODS

The 15 hybrid crosses and five pearl millet lines and three napier grass testers were raised in a randomized block design with two replications at the experimental fields of New Area Farm, Department of Forage Crops, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India during *Kharif*, 2021. The 15 hybrids and three napier parents were planted using two budded sets by adopting the spacing of 60 x 30 cm and the five pearl millet parents were raised by seeds with a spacing of 30 x 15 cm. Each entry was planted/sown in two rows per replication. A total of 13 morphological traits and four fodder quality traits were recorded for all the hybrids and their parents. The observations were recorded on five randomly selected plants from each replication. The mean data from these five plants were used for statistical analysis.

Analysis of variance (ANOVA) was performed using Panse and Sukhatame (1964) model. Estimates of *gca* and *sca* effects and their variances were computed using L x T analysis according to the method of Singh and Chaudhary (1979).The estimates of phenotypic and

Table 1. ANOVA for L × T for various green fodder yield and quality traits

Source	Replication	Genotypes	Parents	Parents vs. crosses	Crosses	Lines	Testers	Lines × Testers	Error
Df	1	22	7	1	14	4	2	8	22
PH	32.61**	4513.32**	1672.79**	36801.04**	3627.31**	994.91**	8019.73**	3845.41**	38.82
NOT	0.0003	9.88**	10.22**	0.28	10.39**	12.13**	40.87**	1.90	0.03
NOI	0.0004	53.37**	24.99**	311.12**	49.14**	60.56**	54.58**	42.07**	0.09
NOL	0.002	15.66**	12.53**	155.48**	11.25**	11.19**	6.25**	12.53**	0.09
LL	0.57	610.57**	869.24**	3075.01**	305.21**	357.23**	159.73**	315.57**	3.53
LB	0.02	0.39	0.31	0.16	0.46	0.39	0.06	0.59	0.02
SG	0.02	2.21*	1.22	11.10**	1.41	2.18	0.02	1.37	0.03
LW	57.97**	252930.64**	161691.18**	495252.64**	281241.65**	261319.57**	353724.52**	273081.98**	300.28
SW	40.74**	148237.14**	280782.72**	501845.95**	56706.58**	49163.47**	28697.32**	67480.45**	398.77
L:S	0.0001	0.02	0.01	0.22	0.02	0.02	0.04	0.01	0.0002
DMY	135.09**	65764.24**	146537.11**	122510.31**	21324.51**	22121.47**	28551.18**	19119.34**	126.25
DMC	1.37	79.77**	156.14**	586.82**	5.37**	4.61**	5.33*	5.76**	0.16
CP	0.001	17.51**	25.83**	20.81**	13.12**	19.20**	25.91**	6.88**	0.08
CFT	0.02	10.39**	17.05**	52.24**	4.08**	2.54	2.58	5.23**	0.02
CFR	0.18	11.19**	28.78**	0.38	3.17**	5.26**	3.46*	2.05	0.57
ASH	0.003	2.51*	2.20	4.29	2.54*	0.47	2.94	3.48*	0.03
GFY	141.44**	678828.34**	818307.19**	103928.08**	650153.21**	466000.88**	987703.99**	657841.68**	642.26

PH – plant height, NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length , LB - leaf breadth, SG - stem girth, LW - leaf weight, SW - stem weight, L:S - leaf to stem ratio, DMY - dry matter yield per plant, DMC - dry matter content, CP - crude protein, CFT - crude fat, CFR - crude fibre, ASH - ash content and GFY - green fodder yield per plant.

* Significant at 5% level, ** Significant at 1% level

genotypic correlation coefficients were done based on the formula given by Al-Jibouri *et al*. (1958).

RESULTS AND DISCUSSION

The results of ANOVA showed significant differences between the genotypes for all the traits taken for the study except leaf breadth and leag : stem ratio (**Table 1**) which indicated the presence of wide variability among the genotypes.

Green fodder yield and its component traits exhibited significant genetic variation across parents and hybrids, as evidenced by the highly significant mean sum of square values for most of these traits. It acts as a platform for exploiting the suitable genetic information in pearl millet - napier breeding programme, as the choice of parents proved to be appropriate.

The mean sum of squares of lines, testers and line × tester also differed significantly for most of the traits including green fodder yield. This accentuated the presence of huge differences in the favourable gene frequency among them.

The performance of hybrids and their parents were encapsulated in **Table 2** and depicted in boxplot (**Fig. 1**). The overall performance of hybrids for green fodder yield was lower (1296.58 g) than testers (1841.63 g) but higher than lines (865.42 g). The overall mean values of various yield and fodder quality traits were : plant height 222.69 cm (ranged from 161.52 to 331.45 cm) , number of tillers per plant 6.44 (ranged from 1.98 to 11.02), number of internodes per tiller 8.77 (ranged from 1.67 to 26.9), number of leaves per tiller 10.76 cm (ranged from 7.01 to 15.92), leaf length – 75.83 cm (ranged from 38.41 to 99.52 cm) , leaf breadth 2.91 cm (ranged from 2.30 to 3.86 cm) , stem girth 4.28 cm (ranged from 2.26 to 6.05 cm) , leaf weight 719.03 cm (ranged from 33.48 to 1435.19 cm) , stem weight 501.73 (ranged from 65.13 to 1182.13), leaf to stem ratio 0.58 (ranged from 0.35 to 0.73), dry matter yield per plant 285.90 ng (ranged from 31.12 to 784.69 ng) , dry matter content 21.47 per cent (ranged from 16.88 to 40.86 %), crude protein 11.00 per cent (ranged from 7.54 to 18.57 %), crude fat 6.27 per cent (ranged from 2.19 to 11.93 %), crude fibre 31.69 per cent (ranged from 28.90 to 35.40 %) and ash content 6.40 per cent (4.30 to 8.55%).

The overall performance of parents and hybrids revealed that the hybrids were taller (243.35 cm) with more number of internodes (10.67) and leaves (12.11) than the parents. The hybrids also had more stem girth (4.54cm), more leaf weight (794.80 g) and higher leaf to stem ratio (0.63) than both of their parents. The hybrids recorded the favourable fodder quality traits with high protein (11.56 %) and ash content (6.35 %) and low fat (5.50 %) and fibre (31.28 %) content.

Among the hybrids, GP15074 × FD465, GP16016 × FD465, GP15073 × FD482, GP15073 × FD464, GP15073 × FD465 and GP15958 × FD482 recorded significantly higher mean values for green fodder yield, whereas among the parents, FD464, FD482, GP15988 and FD465 had significantly higher green fodder yield. It is concluded that the hybrids outperformed their parents for green fodder yield, yield related traits and fodder quality traits. It could be attributed that the desirable traits from both the parents were converged in the interspecific hybrids generated.

Variance of SCA (σ^2SCA) was higher than the variance of GCA (σ^2GCA) for all the traits studied which depicts the preponderance of non-additive gene action. It was substantiated by the values of σ^2GCA/σ^2SCA ratio, which was less than unity (**Table 3**).

The higher variances of lines than testers for the number of internodes per tiller, number of leaves per tiller, leaf length, leaf breadth, stem girth, stem weight, dry matter content, crude protein and crude fibre demonstrated that lines contributed more to the σ^2GCA for these traits (**Table 3)**. Similarly, the testers revealed higher variances for the traits namely plant height, number of tillers per plant, leaf weight, leaf to stem ratio, dry matter yield, crude fat, ash content and green fodder yield per plant which demonstrate the accountability of testers to the GCA variance. This is in accordance with the results reported by Patel *et al*. (2019) in forage sorghum.

Proportional contribution of lines, testers and L×T interactions to total variance (**Table 4**) disclosed that L×T interactions had bestowed the most variance with respect to all the traits except number of tillers per plant and crude protein. Number of tillers per plant had major contribution from testers while crude protein from lines.

Combining ability is an assessment of the genotypic values of lines and testers in proportion to the performance of their offspring. Both *gca* and *sca* influences the appraisal of inbred lines, which is important for hybrid development (Sprague and Tautum, 1942).

The *gca* effects for all the lines and testers for the morphological and fodder quality traits are presented in **Table 5**. It is evident from the result that no single parent could manifest the positive *gca* effects in the aggregate of all the traits. For the trait green fodder yield, the line GP15073 and tester FD465 were found to be identified as the best combiners. Also, the line GP15073 showed the highest *gca* effect for number of internodes per tiller, leaf weight, stem weight and dry matter yield per plant, whereas the tester FD465 recorded highest *gca* for leaf to stem ratio. For the traits plant height and number of tillers plant, highest *gca* were recorded by the parents FD482 and GP15074, respectively. Similarly, the line

Table 2. ***Per se*** **performance of green fodder yield and quality traits**

Hybrids	PH	NOT	NOI	NOL	LL	LB	SG	LW	SW	L:S	DMY	DMC	CP	CFT	CFR	ASH	GFY
GP15074 × FD482	240.29**	7.90**	12.30**	15.92**	86.89**	3.26*	3.92	522.95	401.02	0.57	167.35	17.16	7.54	3.67**	30.75	6.53*	995.82
GP15074 × FD464	189.85	6.65	8.97	10.44	75.54	2.36	3.54	366.00	270.49	0.57	137.53	19.94	9.02	7.02	30.09*	6.11	680.37
GP15074 × FD465	281.04**	11.02**	10.27**	12.79**	85.46**	3.45*	4.77**	1196.07**	731.68**	0.63**	356.36**	16.88	10.08	5.19**	31.56	4.98	2090.58**
GP16016 × FD482	267.94**	6.54	10.96**	14.76**	93.49**	2.99	5.45**	716.62	552.59*	0.57	273.38	20.69	12.54**	5.72**	30.99	5.48	1328.86
GP16016 × FD464	162.89	1.98	3.96	9.97	84.41**	2.49	4.36	33.48	65.13	0.35	31.12	22.40*	11.11	5.73**	32.64	5.22	140.32
GP16016 × FD465	331.45**	5.36	12.44**	15.28**	99.52**	3.62*	6.05**	1357.71**	497.40	0.73**	371.84**	17.13	12.57**	6.98	31.21	8.55**	2169.58**
GP15073 × FD482	291.36**	5.93	11.66**	13.04**	88.85**	2.86	5.83**	1068.38**	546.49*	0.67**	345.16**	20.00	9.49	6.99	29.19**	6.47*	1704.00**
GP15073 × FD464	254.85**	3.79	10.04***	12.54**	82.84**	2.67	5.12**	1435.19**	611.86**	0.69**	393.59**	18.13	10.02	3.88**	28.90**	7.56**	2165.89**
GP15073 × FD465	227.78	7.74**	26.90**	11.07	84.09**	2.56	4.36	955.79**	521.45	0.65**	327.61**	20.16	13.19**	5.54**	32.49	5.48	1588.17**
GP15958 × FD482	267.65**	6.20	9.02	10.86	69.45	2.82	3.99	905.41**	379.61	0.72**	255.01	18.46	12.08**	6.21	31.09	5.15	1389.88**
GP15958 × FD464	236.71*	4.75	9.15	15.57**	97.89**	3.86**	5.15**	711.13	504.56	0.59	248.91	19.88	10.20	5.19**	31.23	6.33	1266.26
GP15958 × FD465	219.48	9.09**	7.84	9.82	54.79	2.53	3.22	765.14*	312.64	0.72	195.46	17.67	18.57**	2.19**	30.99	7.68**	1103.49
GP15988 × FD482	257.97**	5.51	9.05	10.39	74.99	2.69	3.82	487.81	223.16	0.69**	136.01	16.98	13.67**	6.34	32.25	5.09	793.16
GP15988 × FD464	212.27	4.54	9.72**	10.78	85.60**	2.51	4.49	654.44	420.39	0.62**	200.69	18.04	10.96	7.16	32.32	7.45**	1102.51
GP15988 × FD465	208.77	8.71**	7.74	8.41	63.28	2.30	4.12	745.95	343.31	0.69**	283.22	19.47	12.42**	4.64**	33.48	7.23**	1450.45**
Lines																	
GP15074	192.99	4.59	3.76	7.01	60.98	3.46*	3.38	406.12	353.02	0.54	153.97	19.79	10.02	11.93	29.16**	5.24	771.64
GP16016	165.93	5.48	4.00	7.03	45.19	2.74	2.26	439.24	413.17	0.52	176.07	20.50	9.19	6.97	32.43	5.64	882.04
GP15073	171.94	2.98	1.67	7.02	52.34	3.42*	3.37	173.81	151.51	0.53	74.51	22.65	14.49**	8.51	35.02	4.30	328.97
GP15958	197.74	6.69	4.08	7.97	54.96	3.31*	3.37	373.01	356.73	0.51	148.70	19.94	9.94	11.72	34.41	5.34	739.93
GP15988	169.41	9.31	13.51**	7.27	38.41	2.56	2.93	814.72**	781.86**	0.50	302.09	18.17	11.10	5.01**	32.57	6.13	1604.47**
Testers																	
FD482	247.44**	9.52**	5.60	11.01	86.92**	2.92	3.59	813.63**	883.47**	0.48	553.61**	33.06**	8.11	7.46	35.40	6.07	1705.60**
FD464	161.52	7.12**	4.68	9.00	85.98**	3.08	4.56*	1025.34**	1182.13**	0.46	784.69**	35.95**	8.29	6.55	30.97	6.12	2218.39**
FD465	164.76	6.05	4.36	9.67	92.33**	2.42	4.61**	569.72	1036.16**	0.35	658.90**	40.86**	8.39	3.73**	29.81*	6.12	1600.89**
Mean of lines	179.60	5.81	5.40	7.26	50.38	3.09	3.06	441.38	411.26	0.52	171.07	20.21	10.95	8.83	32.71	5.33	865.42
Mean of testers	191.24	7.76	4.88	9.89	88.41	2.80	4.25	802.89	1033.92	0.43	665.73	36.62	8.27	5.91	32.47	6.10	1841.63
Mean of crosses	243.35	6.38	10.67	12.11	81.80	2.86	4.54	794.80	425.45	0.63	248.21	18.86	11.56	5.50	31.28	6.35	1331.29
Grand mean	222.69	6.44	8.77	10.76	75.83	2.91	4.18	719.03	501.73	0.58	285.90	21.47	11.00	6.27	31.69	6.10	1296.58
CV(%)	2.80	2.67	3.48	2.72	2.48	4.24	3.86	2.41	3.98	2.15	3.93	1.89	2.62	2.24	2.42	2.73	1.95
CD (5%)	12.89	0.36	0.63	0.61	3.89	0.25	0.33	35.87	41.34	0.03	23.26	0.84	0.67	0.29	1.57	0.34	52.46
CD(1%)	17.57	0.48	0.86	0.83	5.29	0.35	0.46	48.87	56.31	0.04	31.69	1.14	0.91	0.39	2.14	0.47	71.47

PH – plant height (cm), NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length (cm), LB - leaf breadth (cm), SG - stem girth (cm), LW - leaf weight (g), SW - stem weight (g), L:S - leaf to stem ratio, DMY - dry matter yield per plant (g), DMC - dry matter content (%), CP - crude protein (%), CFT - crude fat (%), CFR - crude fibre (%), ASH - ash content (%) and GFY - green fodder yield per plant (g).

* Significant at 5% level, ** Significant at 1% level

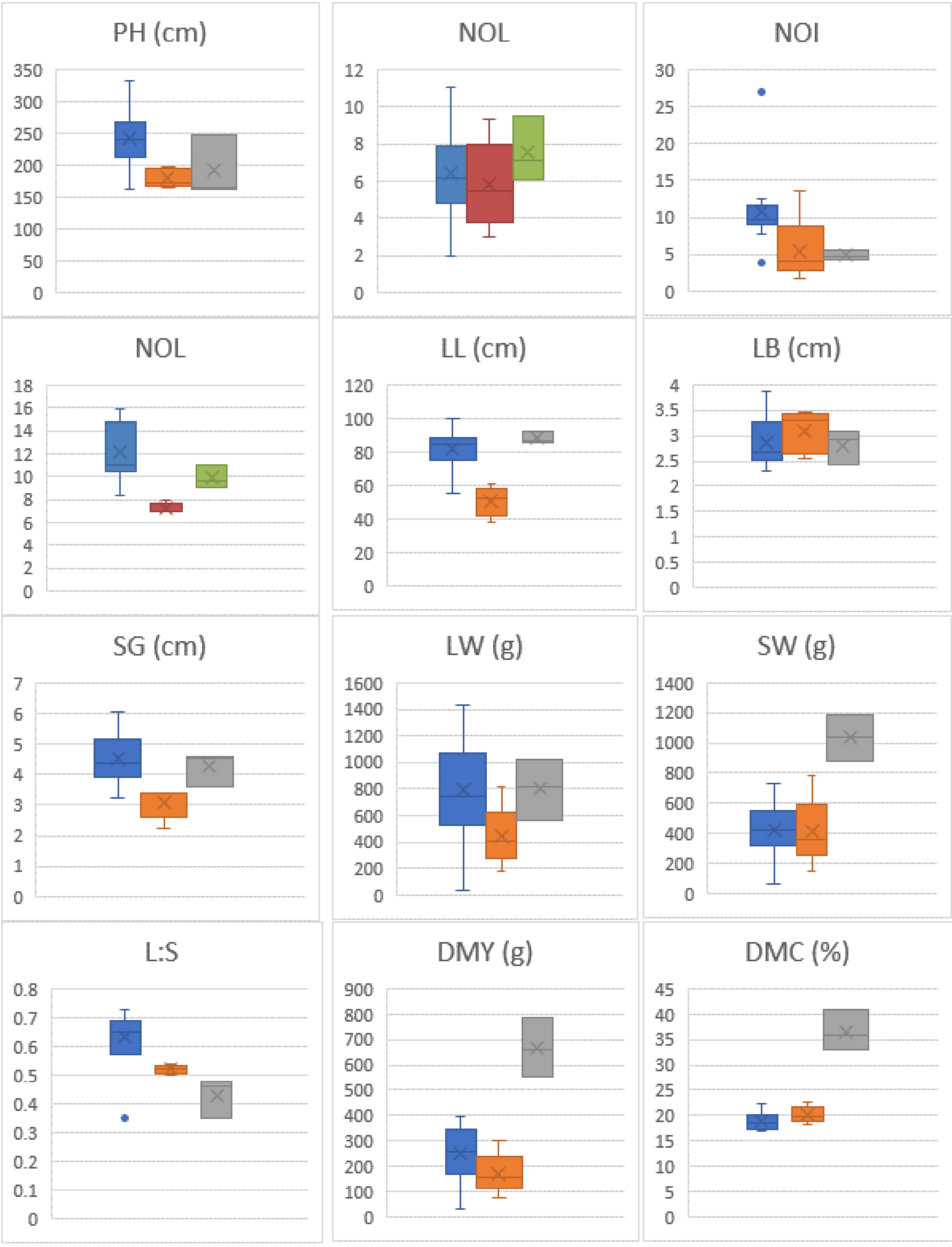

Fig. 1. Box plots for performance of hybrids and parents for green fodder yield and quality traits.

Fig. 1. Continued..

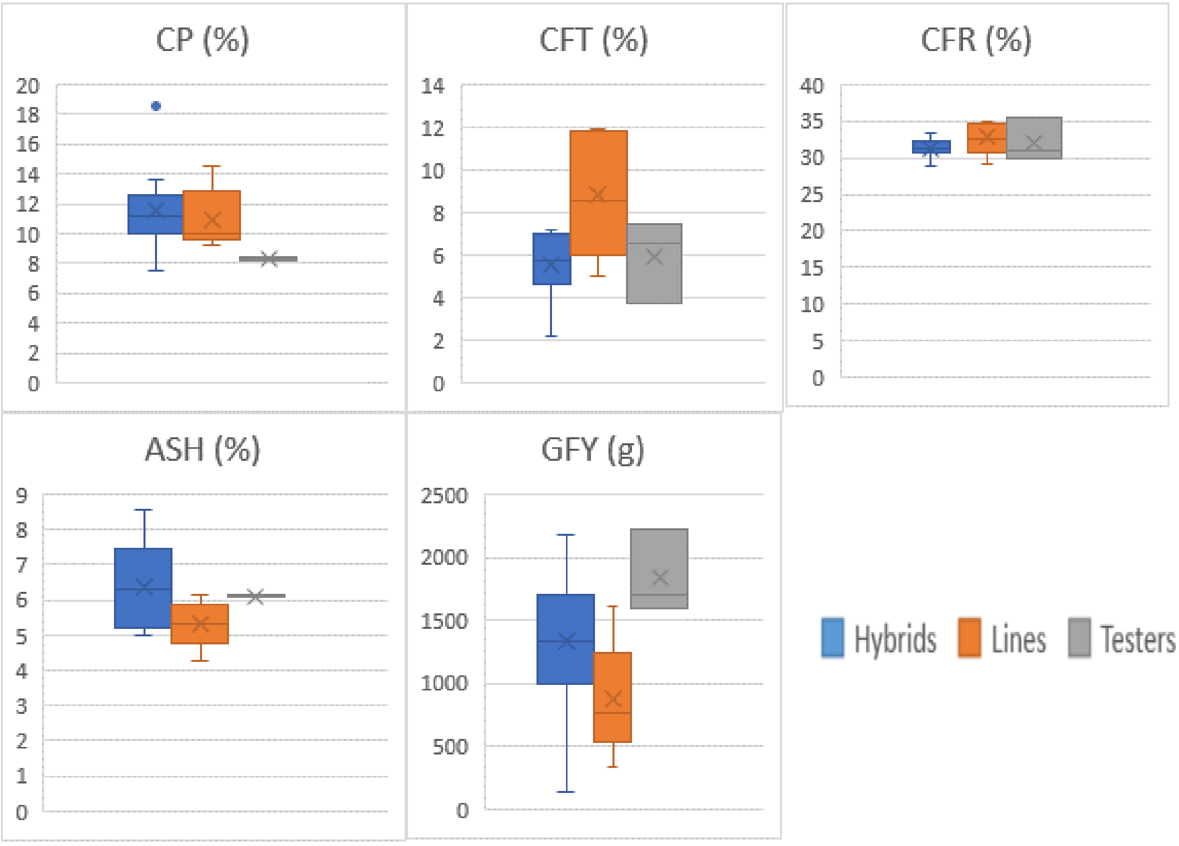

Fig. 1. Box plots for performance of hybrids and parents for green fodder yield and quality traits.
The '×' sign represents mean value. The '•' outside the box represents outliers. The upper and lower lines outside the box stand for maximum and minimum adjacent values, respectively. The upper and lower hinge of the box stand for 75% and 25% percentile, respectively.

PH – plant height (cm), NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length (cm), LB - leaf breadth (cm), SG - stem girth (cm), LW - leaf weight (g), SW - stem weight (g), L:S - leaf to stem ratio, DMY - dry matter yield per plant (g), DMC - dry matter content (%), CP - crude protein (%), CFT - crude fat (%), CFR - crude fibre (%), ASH - ash content (%) and GFY - green fodder yield per plant (g).

Table 3. Estimates of genetic variances for green fodder yield and quality traits

Parameter	PH	NOT	NOI	NOL	LL	LB	SG	LW	SW	L:S	DMY	DMC	CP	CFT	CFR	ASH	GFY
σ^2 L	-475.08	1.71	3.08	-0.22	6.94	-0.03	0.14	-1960.40	-3052.83	0.001	500.35	-0.19	1.98	-0.45	0.54	-0.50	-31973.47
σ^2 T	417.43	3.89	1.25	-0.63	-15.58	-0.05	-0.14	8064.25	-3878.31	0.002	943.18	-0.43	1.87	-0.27	0.14	-0.05	32986.23
σ^2 L×T	2131.24	8.84	25.89	4.99	137.53	0.18	0.59	147536.22	24490.89	0.01	11515.43	2.55	8.44	1.75	1.39	1.17	351854.66
σ^2_{GCA}	-11.57	0.45	0.37	-0.07	-0.55	-0.01	0.002	432.71	-571.34	0.0003	116.94	-0.02	0.32	-0.06	0.06	-0.05	-407.72
σ^2_{SCA}	1902.89	0.94	20.98	6.21	156.19	0.29	0.68	136344.67	33626.69	0.007	9521.07	2.78	3.55	2.60	0.69	1.72	328579.23
$\sigma^2_{GCA}/\sigma^2_{SCA}$	-0.006	0.479	0.018	-0.011	-0.004	-0.034	0.003	0.003	-0.017	0.043	0.012	-0.007	0.090	-0.023	0.087	-0.029	-0.001

PH – plant height, NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length, LB - leaf breadth, SG - stem girth , LW - leaf weight, SW - stem weight, L:S - leaf to stem ratio, DMY - dry matter yield per plant, DMC - dry matter content, CP - crude protein, CFT - crude fat, CFR - crude fibre, ASH - ash content and GFY - green fodder yield per plant.

Table 4. Proportional contribution of parents and hybrids for various green fodder yield and quality traits

Parameter	PH	NOT	NOI	NOL	LL	LB	SG	LW	SW	L:S	DMY	DMC	CP	CFT	CFR	ASH	GFY
Contribution of lines	7.84	33.36	35.21	28.43	33.44	24.24	44.25	26.55	24.77	30.00	29.64	24.53	41.05	17.76	47.43	5.31	20.48
Contribution of testers	31.58	56.19	15.87	7.93	7.48	1.90	0.16	17.97	7.23	28.68	19.13	14.16	22.89	9.03	15.61	16.51	21.70
Contribution of L x T	60.58	10.45	48.92	63.64	59.08	73.86	55.59	55.48	68.00	41.32	51.23	61.31	31.06	73.21	36.95	78.18	57.82

PH – plant height, NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length, LB - leaf breadth, SG - stem girth, LW - leaf weight, SW - stem weight, L:S - leaf to stem ratio, DMY - dry matter yield per plant, DMC - dry matter content, CP - crude protein, CFT - crude fat, CFR - crude fibre, ASH - ash content and GFY - green fodder yield per plant.

GP16016 was found to be identified as the best combiner for number of tillers per tiller, leaf length, stem girth and dry matter content. The parent GP15958 was the best combiner for the trait leaf breadth. With respect to quality traits, the parents GP15958 and FD465 recorded the highest *gca* effects for crude protein and ash content, respectively. The lines namely GP15958 and GP15073 recorded negative *gca* effects for the traits crude fat and crude fibre, respectively.

Collectively, the line GP15073 recorded significantly high *gca* for the traits namely green fodder yield per plant, plant height, number of internodes per tiller, leaf length, stem girth, leaf weight, stem weight, leaf to stem ratio, dry mater yield per plant, dry matter content and crude fibre. While, the tester FD465 exhibited significant *gca* effects for traits namely green fodder yield per plant, plant height, number of tillers per plant, number of internodes per tiller, leaf weight, stem weight, leaf to stem ratio, dry mater yield per plant, crude protein, crude fat and ash content. It is vital to choose parents that have a high *gca*, as this will enhance the performance of progeny. In the present study, the line GP15073 and the tester FD465 were the most promising parents, with high *gca* for green fodder yield per plant and an excellent combiner for most of the yield component traits. Akin results were reported earlier by Iyanar and Khan (2005), Patel and Patel (2010) and Mungra *et al.* (2011). The negative *sca* effects for the traits crude fat and crude fibre would increase the palatability and digestibility of resultant hybrids [Moran, (2005) and Santosh *et al*., (2017)].

There was no hybrid that concurrently yielded positive *sca* effects for every examined trait (**Table 6**). A highest percentage of hybrids (53%) with positive *sca* effects was recorded by the trait dry matter content followed by green fodder yield per plant, plant height, number of internodes per tiller, leaf length and leaf width with 47 per cent of hybrids with positive *sca* effects. The trait that has lowest percentage of hybrids with positive *sca* effects was crude protein (27%). The traits such as leaf breadth, stem width, dry matter content, crude fat and ash content consisted of 40 per cent crosses while number of tillers per plant and stem girth composed of 33 per cent crosses. Although, there is no significant effect on crude fibre, 53 per cent of crosses possessed negative *sca* effects which is desirable for that trait. The *sca* effect ranged from -812.38 (GP16016 × FD464) to 607.50 (GP16016 × FD465). The hybrid GP16016 × FD465 also recorded the highest *sca* effects for the traits, plant height, leaf width, leaf to stem ratio, dry matter yield per plant and ash content. The highest positive *sca* effects for the traits number of leaves per tiller (3.74), leaf length (20.40), leaf breadth (0.88) and stem girth (1.04) were observed by GP15958 × FD464. The crosses GP16016 × FD482, GP15073 × FD465, GP15074 × FD465, GP15988 × FD465 and GP15958 × FD465 exhibited highest positive *sca* effects for the traits number of tillers per plant (1.88), number of internodes per tiller (8.33), stem weight (208.10), dry matter content (87.71) and crude protein (3.15), respectively. A significantly negative *sca* effect for the fodder quality trait crude fat was recorded in the hybrid GP15074 × FD482.

The hybrid GP16016 × FD465 recorded the highest *sca* effects for the traits namely green fodder yield per plant, plant height, leaf weight, leaf to stem ratio, dry matter yield and ash content. It also recorded significant and positive *sca* effects for the traits of number of internodes per tiller, number of leaves per tiller, leaf length, leaf breadth, stem girth and stem weight. The findings are in accordance with the earlier results of Singh *et al.* (2005), Monteiro *et al*. (2008), Prakash *et al.* (2010), Tariq *et al*. (2012) and Kalpande *et al.* (2015) reported significant *sca* effects for high green fodder yielding hybrids in fodder sorghum. The hybrid GP15958 × FD465 had the *sca* effects in desirable direction for fodder quality traits.

Correlation analysis is an effective approach for indirect selection since it helps the plant breeder to understand the multiple traits that can influence the yield. The correlation studies unveiled that all the yield component and fodder quality traits were positively correlated with green fodder yield per plant except crude protein, crude fat and crude fibre (**Table 7 and Fig.2**). The correlation

Table 5. Estimates of general combining ability effects of parents for green fodder yield and quality traits

Parents	PH	NOT	NOI	NOL	LL	LB	SG	LW	SW	L:S	DMY	DMC	CP	CFT	CFR	ASH	GFY
Lines																	
GP15074	-6.29**	2.14**	-0.15	0.94**	0.82	0.16**	-0.50**	-99.80**	42.28**	-0.04**	-27.80**	-0.87**	-2.68**	-0.20**	-0.47	-0.48**	-75.70**
GP16016	10.74**	-1.75**	-1.55**	1.23**	10.66**	0.17**	0.75**	-92.20**	-53.75**	-0.08**	-22.77**	1.21**	0.51**	0.65**	0.33	-0.06	-118.37**
GP15073	14.64**	-0.56**	5.53**	0.11	3.45**	-0.17**	0.56**	358.32**	134.48**	0.04**	107.24**	0.56**	-0.67**	-0.03	-1.09**	0.15	488.07**
GP15958	-2.07	0.30**	-2.00**	-0.03	-7.76**	0.20**	-0.42**	-0.91	-26.52**	0.04**	-15.09**	-0.20	2.05**	-0.96**	-0.17	0.03	-78.08**
GP15988	-17.02**	-0.13*	-1.83**	-2.25**	-7.18**	-0.37**	-0.40**	-165.41**	-96.50**	0.04**	-41.58**	-0.70**	0.79**	0.55**	1.40**	0.24**	-215.92**
SE	3.63	0.07	0.20	0.19	1.03	0.04	0.07	11.44	8.70	0.01	5.07	0.24	0.21	0.09	0.49	0.11	15.09
Testers																	
FD482	21.69**	0.03	-0.07	0.89	0.93	0.06**	0.04	-54.57**	-4.88	0.01**	-12.83**	-0.21	-0.50**	0.29**	-0.43	-0.61**	-88.95**
FD464	-32.04**	-2.04	-2.30**	-0.25**	3.45**	-0.09**	-0.01	-154.76**	-50.96**	-0.07**	-45.85**	0.81**	-1.30**	0.30**	-0.24	0.18**	-260.22**
FD465	10.35**	2.00**	2.37**	-0.64**	-4.38**	0.03	-0.04	209.33**	55.84**	0.05**	58.68**	-0.60**	1.80**	-0.59**	0.67*	0.43**	349.16**
SE	2.82	0.06	0.15	0.14	0.80	0.03	0.05	8.86	6.74	0.01	3.93	0.18	0.16	0.07	0.38	0.08	11.69

Table 6. Estimates of specific combining ability effects of crosses for green fodder yield and quality traits

Hybrids	PH	NOT	NOI	NOL	LL	LB	SG	LW	SW	L:S	DMY	DMC	CP	CFT	CFR	ASH	GFY
GP15074 × FD482	-18.46**	-0.66**	1.86**	1.99**	3.33*	0.18**	-0.27**	-117.49**	-61.83**	-0.03**	-40.23**	-0.62*	-0.84**	-1.91**	0.37	1.26**	-170.83**
GP15074 × FD464	-15.17**	0.16	0.76**	-2.36**	-10.54**	-0.58**	-0.50**	-174.25**	-146.27**	0.05**	-37.04**	1.14**	1.44**	1.42**	-0.47	0.06	-315.00**
GP15074 × FD465	33.63**	0.49**	-2.62**	0.37	7.21**	0.40**	0.76**	291.74**	208.10**	-0.01	77.26**	-0.51	-0.60*	0.49**	0.10	-1.32**	485.83**
GP16016 × FD482	-7.84	1.88**	1.91**	0.54*	0.09**	-0.10**	0.12	68.59**	185.76**	0.01	60.77**	0.82*	0.97**	-0.71**	-0.20	-0.33*	204.88**
GP16016 × FD464	-59.16**	-0.61**	-2.86**	-3.12**	-11.51**	-0.45**	-0.92**	-514.36**	-225.61**	-0.13**	-148.48**	1.52**	0.33	-0.71**	1.27	-1.37**	-812.38**
GP16016 × FD465	67.01**	-1.27**	0.95**	2.58**	11.43**	0.55**	0.80**	445.78**	69.85**	0.13**	87.71**	-2.34**	-1.30**	1.43**	-1.07	1.70**	607.50**
GP15073 × FD482	11.68**	0.07	-4.47**	-0.06	2.66	0.10*	0.68**	-30.17*	-8.57	-0.02	2.54	0.78*	-0.91**	1.23**	-0.58	0.58**	-26.41
GP15073 × FD464	28.89**	0.01	-3.86**	0.57*	-5.87**	0.06	0.02	436.83**	102.89**	0.09**	83.99**	-2.11**	0.42	-1.89**	-1.05	0.88**	606.76**
GP15073 × FD465	-40.57**	-0.08	8.33**	-0.51*	3.21*	-0.17**	-0.71**	-406.66**	-94.32**	-0.08**	-86.53**	1.34**	0.49	0.66**	1.63*	-1.45**	-580.35**
GP15958 × FD482	4.68	-0.52	0.42	-2.11**	-5.52**	-0.31**	-0.17	166.09**	-14.45	0.03**	34.71**	-0.00	-1.04**	1.39**	0.42	-0.63**	225.62**
GP15958 × FD464	27.47**	0.11	2.78**	3.74**	20.40**	0.88**	1.04**	71.99**	156.59**	-0.02*	61.63**	0.40	-2.12**	0.36**	0.36	-0.24	273.27**
GP15958 × FD465	-32.15**	0.41**	-3.20**	-1.63**	-14.87**	-0.57**	-0.87**	-238.08**	-142.14**	-0.01	-96.35**	-0.40	3.15**	-1.75**	-0.78	0.86**	-498.89**
GP15988 × FD482	9.95*	-0.78**	0.28	-0.35	-0.56	0.13*	-0.36**	-87.02**	-100.91**	0.01	-57.79**	-0.97**	1.82**	0.01	-0.01	-0.89**	-233.27**
GP15988 × FD464	17.97**	0.33**	3.18**	1.17**	7.53**	0.09	0.35**	179.80**	142.41**	0.01	39.90**	-0.94**	0.09	0.81**	-0.12	0.68**	247.36**
GP15988 × FD465	-27.92**	0.45**	-3.46**	-0.82**	-6.96**	-0.22**	0.01	-92.78**	-41.49**	-0.03**	17.90*	1.91**	-1.73**	-0.82**	0.13	0.21	-14.09
SE	6.30	0.13	0.34	0.32	1.79	0.06	0.12	19.82	15.07	0.01	8.79	0.41	0.36	0.16	0.86	0.19	26.14

PH – plant height, NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length , LB - leaf breadth, SG - stem girth, LW - leaf weight, SW - stem weight, L:S - leaf to stem ratio, DMY - dry matter yield per plant, DMC - dry matter content, CP - crude protein, CFT - crude fat, CFR - crude fibre, ASH - ash content and GFY - green fodder yield per plant

* Significant at 5% level, ** Significant at 1% level

https://doi.org/10.37992/2022.1303.148

Table 7. Correlation among green fodder yield and quality traits

	PH	NOT	NOI	NOL	LL	LB	SG	LW	SW	L:S	DMY	DMC	CP	CFT	CFR	ASH	GFY
PH	1.00	0.18	0.44*	0.75**	0.52	0.34	0.64**	0.66**	-0.17	0.71**	0.06	-0.42*	0.14	-0.13	-0.23	0.32	0.48*
NOT		1.00	0.32	0.05	-0.11	-0.09	-0.16	0.37	0.44*	0.18	0.36	0.03	-0.01	-0.29	0.14	0.09	0.46*
NOI			1.00	0.44*	0.27	-0.14	0.32	0.49*	0.07	0.47*	0.05	-0.37	0.16	-0.34	-0.16	0.21	0.38
NOL				1.00	0.80**	0.35	0.74**	0.46*	0.09	0.36	0.11	-0.22	-0.12	-0.39	-0.36	0.37	0.37
LL					1.00	0.21	0.84**	0.38	0.30	0.04	0.41*	0.24	-0.30	-0.24	-0.34	0.26	0.41*
LB						1.00	0.25	0.12	0.04	0.06	-0.03	-0.13	-0.13	0.39	0.02	-0.15	0.09
SG							1.00	0.58**	0.24	0.26	0.35	0.02	-0.08	-0.21	-0.42*	0.37	0.54**
LW								1.00	0.54**	0.56**	0.59**	-0.08	-0.01	-0.34	-0.35	0.53**	0.94**
SW									1.00	-0.29	0.95**	0.68**	-0.47*	-0.21	-0.17	0.15	0.77**
L:S										1.00	-0.19	-0.68**	0.49*	-0.21	-0.20	0.41*	0.30
DMY											1.00	0.74**	-0.38	-0.24	-0.18	0.25	0.81**
DMC												1.00	-0.41*	-0.02	0.07	-0.12	0.21
CP													1.00	-0.21	0.18	0.08	-0.20
CFT														1.00	0.26	-0.40	-0.34
CFR															1.00	-0.29	-0.29
ASH																1.00	0.47*
GFY																	1.00

PH – plant height, NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length, LB - leaf breadth, SG - stem girth, LW - leaf weight, SW - stem weight, L:S - leaf to stem ratio, DMY - dry matter yield per plant, DMC - dry matter content, CP - crude protein, CFT - crude fat, CFR - crude fibre, ASH - ash content and GFY - green fodder yield per plant

* Significant at 5% level, ** Significant at 1% level

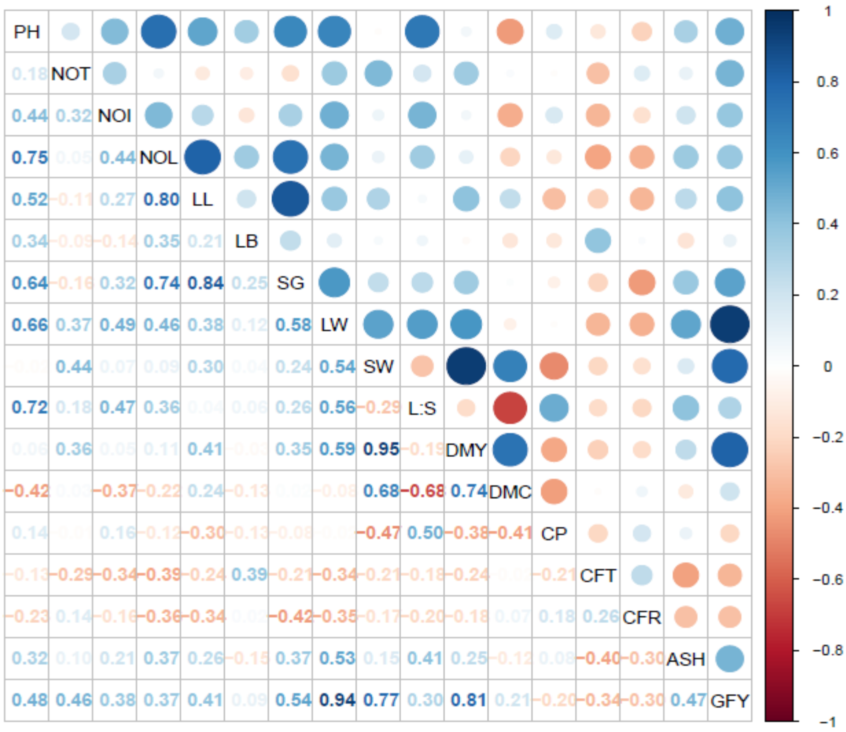

Fig. 2 Correlogram for correlation coefficients in bajra napier hybrids and their parents
PH – plant height, NOT - number of tillers per plant, NOI - number of internodes per tiller, NOL - number of leaves per tiller, LL - leaf length, LB - leaf breadth, SG - stem girth, LW - leaf weight, SW - stem weight, L:S - leaf to stem ratio, DMY - dry matter yield per plant, DMC - dry matter content, CP - crude protein, CFT - crude fat, CFR - crude fibre, ASH - ash content and GFY - green fodder yield per plant.

coefficient of green fodder yield per plant ranged from -0.34 (crude fibre) to 0.94 (leaf weight). A significantly positive correlation with green fodder yield per plant was observed with leaf weight (r = 0.94), dry matter yield per plant (r = 0.81), stem weight (r = 0.77), stem girth (r = 0.54), plant height (r = 0.48), ash content (r = 0.47), number of tillers per plant (r = 0.46) and leaf to stem ratio (r = 0.41). Plant height exhibited significantly positive association with number of internodes per tiller (r = 0.44), number of leaves per tiller (r = 0.75), stem girth (r = 0.64), leaf weight (r = 0.66), leaf to stem ratio (r = 0.71) and significantly negative association with dry matter content (r = -0.42). Positive correlation was observed between number of tillers per plant and stem weight (r = 0.44). Number of internodes per tiller revealed significantly positive association with number of leaves per tiller (r = 0.44), leaf weight (r = 0.49) and leaf to stem ratio (r = 0.47). Number of leaves per tiller had significantly positive association with leaf length (r = 0.80), stem girth (0.74) and leaf weight (r = 0.46). Leaf length exhibited positive correlation with stem girth (r = 0.84) and dry matter yield per plant (r = 0.41). Significantly positive correlation was recorded between stem girth and leaf weight (r = 0.58). Similarly, leaf weight had positive correlation with stem weight (r = 0.54), leaf to stem ratio (r = 0.56), dry matter yield per plant (r = 0.59) and ash content (r = 0.53). Stem weight revealed positive association with dry matter yield per plant (r = 0.95) and dry matter content (r = 0.68) and a negative correlation with crude protein (r = -0.47). Leaf to stem ratio have significantly positive correlation with crude protein (r = 0.49) and ash content (r = 0.41) and negative correlation with dry matter content (r = -0.68). Dry matter yield per plant had significantly positive correlation with dry matter content (r = 0.74). Significantly negative correlation was exhibited between dry matter content and crude protein (r = -0.41).

Green fodder yield per plant is regulated and influenced by various yield contributing traits plant height, number of tillers per plant, leaf length, leaf weight, stem weight, leaf to stem ratio, dry matter yield and ash content. This result is in agreement with the studies of Elangovan *et al*. (2010), Godbharle *et al*. (2010), Iyanar *et al*. (2010) and Tariq *et al*. (2012) in fodder sorghum and Kumari and Nagarajan (2008) and Aswini *et al*. (2022) in pearl millet. This result implied that selecting these characters in parental lines will aid in the generation of hybrids with enhanced green fodder yield.

The combining ability of five lines and three testers was analysed through L × T mating design for green fodder yield per plant and its component traits with fodder quality traits. Variances of GCA and SCA implies the preponderance of non-additive gene action for the traits taken for the study which indicates the appropriateness of heterosis breeding for the improvement of green fodder yield. Even though SCAs were low, the hybrids obtained from two parents with better GCA demonstrated greater hybrid performance. This indicated that the parents should be chosen mostly on the basis of GCAs. The crosses GP16016 × FD 465 and GP15958 × FD465, which were identified as best specific combiners for green fodder yield traits and fodder quality traits, respectively also exhibited high *per se* performance for those traits. From the study it is concluded that the traits leaf weight, dry matter yield per plant, stem weight, plant height, leaf to stem ratio and leaf breadth could be given importance while selecting parents for hybridization to enhance green fodder yield per plant.

REFERENCES

Al-Jibouri, H., Miller, P. A. and Robinson, H. F. 1958. Genotypic and environmental variances and covariances in an upland Cotton cross of interspecific origin 1. *Agronomy journal*, **50**(10): 633-636. [Cross Ref]

Aly, R. S. H. 2013. Relationship between combining ability of grain yield and yield components for some newly yellow maize inbred lines via line x tester analysis. *Alexandria Journal of Agricultural Sciences*, **58**(2):115-124.

Aswini, M. S., Ganesan, K. N., Ezhilarasi, T. and Sivakumar, S. D. 2022. Genetic studies on association and inter-relationship of green fodder yield and fodder quality traits in hybrids of fodder pearl millet [*Pennisetum glaucum* (L.) r. br]. *International Journal of Multidisciplinary Research and Growth Evaluation*, **3**(1):01-06.

Babu, C., Sudhagar, R., Iyanar, K., Sivakumar, S. D., Ezhilarasi, T., Ganesamurthy, K. and Geetha, S. 2021. A high green fodder yielding Cumbu Napier hybrid grass CO 6 suited for the states of Central and North Western Zones. *Electronic Journal of Plant Breeding*, **12**(1):17-21. [Cross Ref]

Elangovan, M., Prabhakar, P. and Chandra Sekara Reddy, D. 2010. Characterization and evaluation of Sorghum [*Sorghum bicolor* (L.) Moench] germplasm from Karnataka, India. *Karnataka Journal of Agricultural Sciences*, **20**(4): 840-842.

Fehr, W.R. 1993. Principles of cultivar development: development of hybrid cultivars, Macmillan Publishing Company, New York, USA.

Godbharle, A. R., More, A. W. and Ambekar, S. S. 2010. Genetic variability and correlation studies in elite 'B'and 'R'lines in kharif sorghum. *Electronic Journal of Plant Breeding*, **1**(4):989-993.

Gramaje, L. V., Caguiat, J. D., Enriquez, J. O. S., Millas, R. A., Carampatana, J. E. and Tabanao, D. A. A. 2020. Heterosis and combining ability analysis in CMS hybrid rice. *Euphytica*, **216**(1):1-22. [Cross Ref]

Grami, B., Stefansson, B.R. and Baker, R.J. 1977. Genetics of protein and oil content in summer rape: heritability, number of effective factors, and correlations. *Canadian Journal Plant Science,* **57**(3):937-943. [Cross Ref]

Iyanar, K. and Khan, A. K. F. 2005. Combining ability analysis in forage sorghum for multicut habit. *Crop Research*, **29**(1):129-133.

Iyanar, K., Vijayakumar, G. and Khan, A. K. 2010. Correlation and path analysis in multicut fodder sorghum. *Electronic Journal of Plant Breeding*, **1**(4):1006-1009.

Kalpande, V. V., Sakhare, B. A., Ghorade, R. B. and Lad, A. P. 2015. Combining ability analysis for grain and fodder yield in post rainy sorghum. *Plant Archives*, **15**(1):105-107.

Kempthorne, O. 1957. An introduction of genetic statistics, John Willey & Sons Inc, New York.

Kumari, B. M. and Nagarajan, P. 2008. Character association and path analysis of yield components in pearlmillet (*Pennisetum glaucum* LR Br.). *Madras Agricultural Journal*, **95**(1/6):192-195.

Lokhande, L.R. 2015. Selection indices for fodder yield and its components in bajra [*Pennisetum glaucum* (L.) R. Br.] x napier [*Pennisetum purpureum* (K) Schum] hybrid. M.Sc. thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra.

Ma-Teresa, L., Gerpcio-Sta, C. and Enrique, C. 1994. Heritability estimates of some root characters in sweetpotato. *Philippine Journal of Crop Science*, **19**: 27-32.

Monteiro Filho, M. C. D., CJA, O. F., Bastos, G. Q., Reis, O. V. and Tabosa, J. N. 2008. Analysis of the combining ability in inter specific hybrids of forage sorghum. *Revista Brasileira de Ciencias Agrarias*, **3**(2):111-115. [Cross Ref]

Moran, J. 2005. Tropical dairy farming: feeding management for small holder dairy farmers in the humid tropics, Landlinks Press: Colling Wood. [Cross Ref]

Mungra, K. D., Jadhav, B. D. and Khandelwal, V. 2011. Genetic analysis for yield and quality traits in forage sorghum [*Sorghum bicolor* (L.) Moench]. *Indian Journal of Genetics and Plant Breeding*, **71**(3):241.

Panse, V.G. and Sukhatme, P.V. 1954. Statistical methods for agricultural workers.

Patel, K.V. and Patel, A.D. 2010. Combining ability analysis for green fodder yield and quality attributes in sorghum [*Sorghum bicolor* (L.) Moench] over environments. *Advance research journal of crop improvement,* **1**(2):187-193.

Patel, P. R., Chauhan, R. M., Jain, S. K. and Patel, D. G. 2019. Combining ability and heterosis for fodder yield, quality and its component traits in forage sorghum [*Sorghum bicolor* (L.) Moench]. *International Journal of Chemical Studies,* **7**(3):3931-3938

Prakash, R., Ganesamurthy, K., Nirmalakumari, A. and Nagarajan, P. 2010. Combining ability for fodder yield and its components in Sorghum (*Sorghum bicolor* L). *Electronic Journal of Plant Breeding*, **1**(2):124-128.

Rukundo, P., Shimelis, H., Laing, M. and Gahakwa, D. 2017. Combining ability, maternal effects, and heritability of drought tolerance, yield and yield components in sweetpotato. *Frontiers in plant science*, **7**:1981. [Cross Ref]

Santosh, K., Babu, C., Sumathi, P. and Revathi, S. 2017. Estimation of per se performance of yield traits in fodder pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Environment and Ecology*, **35**(3C):2316-2321.

Singh, R., Agarwal, M. and Shrotria, P.K. 2005. Combining ability analysis for forage yield and quality characters in sorghum, *Forage Research,* **31**(1):8-11.

Singh, R. K. and Chaudhary, B. D. 1979. Biometrical Method in Quantitative Genetic Analysis. Kalyani Publishers, Ludhiana, New Delhi.

Sprague, G. F. and Tatum, L. A. 1942. General vs. specific combining ability in single crosses of corn. *Journal of the American Society of Agronomy*, **34**(10):923-932. [Cross Ref]

Tariq, A. S., Akram, Z., Shabbir, G., Gulfraz, M., Khan, K. S., Iqbal, M. S. and Mahmood, T. 2012. Character association and inheritance studies of different sorghum genotypes for fodder yield and quality under irrigated and rainfed conditions. *African Journal of Biotechnology*, **11**(38):9189-9195. [Cross Ref]