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Triple test cross analysis in sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract
Experiment was having two sub experiments viz., cross SPV245 x SPV 1430 (A X B) and SPV 245 x SPV 1822 (A X C). Test crosses for this experiment was obtained by crossing the 10 MS lines with both the parents and their $F_{1's}$ for both the sets. In this way the each sub experiment was having 30 hybrids. Both the sub experiments were conducted in RBD with three replications following the 45 cm between rows and 10 cm between plants spacing. In present investigation difference between testers in line in both sets of TTC were significant. The total and "j+l" type of epistasis were significant for all the characters in most of the sets. In present investigation difference between testers in line in both the sets of triple test cross were significant. The total and "j+l" type of epistasis were significant for all the characters in most of the sets. Whereas, "i" type epistasis was significant for 4 and 3 characters in set SPV 245 × SPV 1430 and SPV 245 × SPV 1822, respectively. This was on account of significance of epistasis in one or other lines. Both D and H were significant for all the characters except days to maturity in set SPV 245 x SPV 1430 and ear head lenght in set SPV 245 x SPV 1822.

Keywords: Triple test cross, sorghum, *Sorghum bicolor*

Introduction
Sorghum bicolor (L.) Moench (2n = 20), family poaceae is one of the most important crops in the world because of its adaptation to a wide range of ecological conditions, suitability for low input cultivation and diverse uses (Doggett, 1988) [8]. Sorghum occupies fifth position after wheat, rice, maize and barley at world level, both in area and production. The crop is widely grown for food, feed, fodder, forage and fuel in the semi-arid tropics (SAT) of Asia, Africa, America and Australia. It occupies 58.20 m ha area in the world with an annual grain production of 68.87 m tones and productivity of 1535 kg/ha (FAO, 2015) [1]. In India, it covers about 5.82 m ha with an annual grain production of 5.39 m tonnes and productivity of 926 kg/ha (FAO, 2015) [1]. India is largest producer of sorghum in the world (FAO, 2015) [1]. The major sorghum growing states in India are Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh and Gujarat. Area under sorghum reduced a large since independence. Area under sorghum reduced from 17.40 m hectares (1970-71) to 5.82 m hectares (2014-15). But production increased from 8.1 m tones (1970-71) to 5.39 m tones (2014-15)

In Rajasthan, it is grown for dual purpose with high emphasis on fodder, mainly it is grown under sub-marginal agro-climatic and edaphic conditions which, is characterized by low soil fertility and recurring moisture stress. It occupies an area of about 6.61 lakh hectares with 5.05 lakh tones production in the year 2015. The productivity of sorghum in the state is 763 kg/ha (Anonymous, 2015) [1]. Low productivity is due to cultivation of sorghum on marginal soil, low inputs and more emphasis on fodder. Being C_4 sorghum has great potentiality. Its grain yield productivity in rice fellow fields is up to 80 q ha^{-1}. Area under sorghum reduced a large since independence. Area under sorghum reduced from 10.08 lakh hectares (1970-71) to 6.61 lakh hectares (2015). But production increased from 3.20 lakh tones (1970-71) to 5.05 lakh tones (2015). The reduction in the area is mainly due to replacement of sorghum by more remunerating crops like maize, soybean etc**.** The stability in the production is on account of availability of high yielding varieties and inputs.

Sorghum green fodder is one of the cheapest sources of feed for milch, meat and draft animals. Among the cereals, sorghum plays an important role being grain cum fodder crop. Mainly three type of sorghum is cultivated i.e. grain, fodder and multicut sorghum. Grain sorghum is having low plant height and high harvest index, fodder sorghum having tall plants and multicut is leafy, thin stem and more tillering ability.

The multicut sorghum fulfills the requirement of green fodder particularly during summer but needs irrigation facilities. The grain and fodder sorghum mainly cultivated in rainy season in north India and in both rainy and post rainy in south India. In Rajasthan area under grain sorghum is very low. Mainly fodder sorghum is cultivated in Rajasthan during rainy season and that too without bird watching.

Sorghum is predominantly self-pollinated crop endowed with a wide range of genetic variability due to its wide range of adaption and free gene exchange among various races. Careful selection of parents for hybridization is a key of success in any breeding programme. Some idea about the usefulness of parents may be obtained from their *per se* performance, but the knowledge of nature of inheritance is essential for success of breeding programme. Breeding for wide adaption is another important aspect in genetic improvement of crop plants. It is well known that a specific genotype may not exhibit the same performance in all the environments nor all the genotypes respond alike to a specific environment. Such differential response of genotypes to varying environmental conditions reduces the agricultural production. Therefore, knowledge about behavior of genotypes in different environment is essential for their recommendation and their further use in breeding programme. For this, it is desirable to see the impact of various environments on the sorghum genotypes in order to identify the parents and /or crosses for further utilization in breeding programme. L x T for combining ability and TTC for working out the nature of inheritance are most appropriate mating designs for the type of genetic material used in present investigation and information to be derived.

Maintenance of plant population in per unit area is very difficult. Buffering ability of the genotypes is the only way to cope up with the available space. Therefore, breeding for buffering ability is another important aspect in genetic improvement of crop plants. Development of such a hybrid/variety, which gives a constant and desirable performance over wide range of spacing, is needed. For this, it is desirable to see the impact of various spacing on the yield of sorghum genotypes and identification of genotypes having buffering ability.

The information on the nature and magnitude of gene action is important in understanding the genetic potential of population and to decide the breeding procedure to be adopted in given population. Among the available mating designs Triple Test Cross (TTC) is the most efficient mating design provide information about epistasis.

Materials and Methods

On the basis of days to flowering and suitability for dual purpose 36 lines were received from ICRISAT. After evaluation 10 lines were identified on the basis of nicking of flowering. Three testers were identified on the basis of availability of restorer gene and past performance. Checks CSV 23, CSV 27 and CSH 25 were national checks in coordinated trials. Experiment having three testers viz., SPV 245 (A) , SPV 1430 (B) and SPV 1822 (C) were crossed in all possible combination during kharif 2014 to obtained three F_1's *i.e.* A X B , A x C and B x C at Udaipur. In the next season all 10 lines were crossed with three testers *i.e.* T_1, T_2 and F_1 ($T_1 \times T_2$) of all the three cross (set) at Warangal. In this way 30 hybrids were obtained for each set (cross).

This experiment was having two sub experiments viz., cross SPV 245 x SPV 1430 (A X B) and SPV245 x SPV 1822 (A X C). Test crosses for this experiment was obtained by crossing the 10 MS lines (ICSA 29003(L_1), ICSA 29004 (L_2), ICSA 29006 (L_3), ICSA 29010 (L_4), ICSA 29011 L_5), ICSA 29012 (L_6), ICSA 29013 (L_7), ICSA 29014 (L_8), ICSA 29015 (L_9) and ICSA 29016 (L_{10})) with both the parents and their F_1's for both the sets. In this way the each sub experiment was having 30 hybrids. All the three sub experiments were conducted in RBD with three replications following the 45 cm between rows and 10 cm between plants spacing. On both the side of all the experiments two non experimental rows were planted to eliminate the border effects. The other agronomical practices were used as per the recommendation of this agro climatic zone to raise the healthy crop. The NPK fertilizer was applied at the rate of 80:40:00 kg/ha. The total amount of phosphatic fertilizer and half of the nitrogenous fertilizer was applied as basal dose using DAP and Urea and rest of the nitrogen was applied through Urea in two equal doses, one at knee-high stage and another at flowering stage of the crop. Observations were recorded on following 13 characters. To record different observation five competitive plants in each plot were tagged at random. Days to 50 % flowering, days to maturity, plant height (cm),green fodder yield (q ha^{-1}), dry fodder yield (q ha^{-1}), ear head length (cm), number of primaries per plant, number of seeds per primaries, seed index, harvest index (%), grain yield (q ha^{-1}), Protein content in fodder (%) and rotein content in grain (%).

Statistical Analysis

Plot means of all the characters were subjected to various statistical analysis.The statistical analysis followed for experiment were as follows:

Triple test cross analysis

Triple test cross analysis was performed according to the method proposed by Ketata *et. al.* (1976) for detecting epistasis which is essentially the same as that of Bauman (1959). This method employs a set of lines crossed to testers T_1, T_2 and T_3 where T_3 is the F_1 of T_1 x T_2.

Detection of epistasis

The procedure put forth by Kearsey and Jinks (1968) was followed to detect the presence of epistasis. The procedure involves a set of lines, crossed to three T_1, T_2 and T_3, T_3 being the F_1 of T_1 x T_2. Ketata *et al.* (1976) suggested the use of different varieties instead of F_2 plants. This test is based on following model.

$$L_{ik} = X_{i1k} + X_{i2k} - 2X_{i3k}$$

Where, L_{ik} is the epistasis in i^{th} lines and k^{th} block/condition, X_{i1k}, X_{i2k} and X_{i3k} are the value of cross between i^{th} line and 1^{st}, 2^{nd} and 3^{rd} tester in k the block/ condition.

This value was calculated for each line (variety) in each replication and over the replications.

Significance of each epistasis was tested by F test using respective interaction with block as denominator.

Significance of epistasis for each line was tested by using t test as follows

$$t_{[(g-1)(r-1)]} = \frac{x}{SE}$$

Where,

$$x = \overline{L_1} + \overline{L_2} - 2\overline{L_3}$$

$$SE = \sqrt{\frac{6MSE}{r}}$$

$$MSE = \sum_{i=1}^{t}\sum_{j=1}^{r} x_{ij}^2 - \sum_{i=1}^{t}(\sum_{j=1}^{r} x_{ij})^2/r - \sum_{j=1}^{r}(\sum_{i=1}^{t} x_{ij})^2/t + (\sum_{j=1}^{r}\sum_{i=1}^{t} x_{ij})^2/tr$$

Where,
x_{ij} = Value of i^{th} genotype in j^{th} replication
r and t = Number of replications and genotype, respectively
$\overline{L_1}$, $\overline{L_2}$ and $\overline{L_3}$ = mean of cross between $P_1 \times V_i$, $P_2 \times V_i$ and $(P_1 \times P_2) \times V_i$, respectivly
V_i = i^{th} variety used as line in crossing programme.

Estimation of 'D' and 'H' Components
For unbiased estimation of D and H components i.e. in the absence of epistasis, only those lines were used for estimation of these components epistasis was absent.

D component
To estimate the additive variance (D) the sum of $L_{1i} + L_{2i}$ was worked out for each variety in each replication and over the replications where epistasis was not significant. Whereever the estimate was negative it was considered zero.
Significance of additive variance (D) was tested using F test
$\sigma^2 s = (MS_2 - MS_3) / 2r$
$D = 8\ \sigma^2 s$.

'H' component
To estimate the H components (dominance variance) differences between cross of i^{th} lines and tester T_1 and T_2 were used. Only those values were conderd which were lacking the epistasis.
Significance of dominance variance (H) was tested using F test. The value of H was calculated as follows:

$\sigma^2 s = (MS_2 - MS_3) /2r$

$H = 8\ \sigma^2 s$.

The negative value was considered zero.
The degree of dominance was calculated only for those characters where both D and H were present. Formula used for this was as follows:

$$= \sqrt{(H/D)}$$

Direction of dominance: To determine the direction of dominance correlation between sums (S_i) and differences (D_i) was worked out.

$$r_{SD} = \frac{\sum_{i=1}^{l} S_i D_i - \sum_{i=1}^{l} S_i \sum_{i=1}^{l} D_i}{\sqrt{[\sum_{i=1}^{l} S_i^2 - (\sum_{i=1}^{l} S_i)^2/_l X \sum_{i=1}^{l} D_i^2 - (\sum_{i=1}^{l} D_i)^2/_l]}}$$

Significance was tested using 't' test

$$t_{(l-2)} = \frac{r}{\sqrt{\frac{1-r^2}{l-2}}}$$

The negative and significant value of 'r' suggested that increasing genes were dominant and vice-versa.
Where S_i and D_i is the sums and difference between crosses obtained by crossing i^{th} line with T_1 and T_2 testers. And r and *l* are the number of replications and lines respectively.

Experimental Results
Analysis of variance
The analysis of variance for different characters indicated significant differences between lines for all the characters in both the crosses (SPV 245 x SPV 1430 and SPV 245 X SPV 1822) except days to maturity in cross SPV 245 x SPV 1430 and harvest index in SPV 245 x SPV 1822 (Table 1).

Table 1: ANOVA (MS) for different characters

S. No.	Characters	Cross	Rep/Lines	TC/Lines	Error
			[20]	[20]	[40]
1	Days to 50% flowering	A × B	19.86	51.36**	17.27
		A × C	13.99	46.42**	13.96
2	Days to maturity	A × B	24.16**	11.46	6.76
		A × C	3.13	14.80**	2.37
3	Plant height	A × B	118.92	892.26**	198.59
		A × C	286.93	1727.17**	229.82
4	Green fodder yield	A × B	1338.80	13649.30**	1808.45
		A × C	1767.38	39309.24**	1055.26
5	Dry fodder yield	A × B	599.46	3545.06**	326.91
		A × C	350.50	11047.60**	275.97
6	Ear head length	A × B	9.02	23.12**	6.26
		A × C	7.49	17.22*	8.52
7	Number of primaries per plant	A × B	32.10	199.40**	42.83
		A × C	46.19*	180.19**	23.62
8	Number of seeds per primary	A × B	41.88	512.44**	35.94
		A × C	42.98	357.04**	64.29
9	Seed index	A × B	0.03	0.09**	0.03
		A × C	0.07	0.25**	0.05
10	Harvest index	A × B	5.05	66.68**	8.86
		A × C	8.01	13.77	7.97
11	Grain yield	A × B	33.31	969.44**	55.03
		A × C	73.74	1599.14**	66.93
12	Protein content in grain	A × B	0.02	7.06**	0.01
		A × C	0.23	10.15**	0.21
13	Protein content in fodder	A × B	0.21**	2.69**	0.02
		A × C	0.07**	1.84**	0.03

Set 1- SPV 245 x SPV1430

Total epistasis was significant for green fodder yield, dry fodder yield, ear head length, number of primaries per plant, number of seeds per primary, seed index, harvest index, grain yield, protein content in grain and protein content in fodder. All these characters also had significance 'j + l' epistasis. where as 'i' is significant for green fodder yield, number of seeds per primary, protein content in grain and protein content in fodder (Table 2). As for as epistasis in each line is concern L_1 was not having epistasis for any of the character. The L_6 had only epistasis for grain yield and L_4 had for grain yield and number of seeds per primary. Rest of the lines having epistasis for three characters except L_2 which has epistasis for four characters (3). The magnitude of unbiased estimation of D and H did not have any specific trend in comparison to estimation from all the line. The D and H was increased in 6 and 7 characters, remain constant in 2 and 2 characters and decreased in 5 and 4 characters, respectively. It was remain same only in those characters where none of the lines was epistatic (Table 5). The additive variance D and dominance variance H was significant for all the characters except D in days to maturity and H in harvest index (Table 4). Average degree of dominance ($\sqrt{(H/D)}$) were greater than unity for grain yield (1.37), harvest index (1.36), days to maturity (1.22), plant height (1.17), seed index (1.16) and number of primaries per plant (1.14). For rest of the characters it was less than unity. The direction of dominance was positive i.e. negative correlation differences sums and differences between L_1 and L_2 for days to 50 % flowering, days to maturity, green fodder yield, dry fodder yield, ear head length, seed index, protein content in grain and protein content in fodder where as direction of dominance was negative for plant height, number of primaries per plant, number of seeds per primary, harvest index and grain yield (2).

Table 2: ANOVA for epistasis and correlation between per se and direction of dominance

SN	Charactar	Cross	i	j+l	Total	i x B	j+l x B	TEpixB	R
			[1]	[9]	[10]	[2]	[18]	[20]	[8]
1	Days to 50% flowering	A x B	61.63	254.89	235.57	8.13	112.06	101.67	-0.17*
		A x C	907.50	156.91	231.97*	79.30	83.71	83.27	0.35*
2	Days to maturity	A x B	0.83	38.98	35.17	2.13	43.84	39.67	-0.41*
		A x C	710.53	28.83*	97.00**	57.43	8.62	13.50	0.05*
3	Plant height	A x B	1104.13	2196.50	2087.27	1752.43	1137.25	1198.77	0.44*
		A x C	374.53	11746.61**	10609.40**	1158.63	795.82	832.10	-0.74*
4	Green fodder yield	A x B	57203.33*	84524.52**	81792.40**	2326.93	16267.23	14873.20	-0.28*
		A x C	5713.20	358132.01**	322890.13**	2770.00	8309.59	7755.63	0.68
5	Dry fodder yield	A x B	326.70	24648.11**	22215.97**	1220.70	2479.44	2353.57	-0.02*
		A x C	51750.53*	84321.27**	81064.20**	1619.43	1539.95	1547.90	-0.23*
6	Ear head length	A x B	104.53	83.35*	85.47*	18.43	26.69	25.87	-0.60*
		A x C	64.53*	31.35	34.67	1.63	59.34	53.57	0.48*
7	Number of primaries per plant	A x B	842.70	1380.48**	1326.70**	153.30	290.19	276.50	0.28*
		A x C	276.03	1778.85**	1628.57**	119.63	205.00	196.47	0.05*
8	Number of seeds per primary	A x B	4392.30*	3311.78**	3419.83**	132.40	169.10	165.43	0.43*
		A x C	367.50	2131.65**	1955.23**	529.60	507.64	509.83	-0.47*
9	Seed index	A x B	0.05	0.40*	0.37*	0.04	0.16	0.14	-0.40*
		A x C	0.39	1.85**	1.71**	0.62*	0.17	0.22	0.04*
10	Harvest index	A x B	589.19	286.87**	317.10**	36.06	58.33	56.10	0.09*
		A x C	58.02	53.64	54.08	40.44	31.93	32.79	0.12*
11	Grain yield	A x B	410.70	3237.29**	2954.63**	456.30	205.67	230.73	0.09*
		A x C	2881.20	14233.13**	13097.93**	310.00	368.59	362.73	0.33*
12	Protein content in grain	A x B	174.53**	67.46**	78.17**	0.02	0.06	0.06	-0.37*
		A x C	549.72*	48.13**	98.29**	1.72	2.38	2.32	-0.64*
13	Protein content in fodder	A x B	15.24**	26.20**	25.11**	0.01	0.12	0.11	-0.37*
		A x C	1.71	17.94**	16.32**	0.92**	0.12	0.20	-0.49*

Table 3: Significance of epistasis in individual line in different sets

Line	Days to 50% flowering	Days to maturity	Plant height	Green fodder yield	Dry fodder yield	Ear head length	Number of primaries per plant	Number of seeds per primary	Seed index	Harvest index	Grain yield	Protein content in grain	Protein content in fodder
L1													
L2	1				1		1	1					
L3								1		1	1		
L4								1			1		
L5									1			1	1
L6											1		
L7			1		1			1					
L8				1								1	1
L9								1				1	1
L10							1					1	1

Set- SPV 245 × SPV 1430

Line	Days to 50% flowering	Days to maturity	Plant height	Green fodder yield	Dry fodder yield	Ear head length	Number of primaries per plant	Number of seeds per primary	Seed index	Harvest index	Grain yield	Protein content in grain	Protein content in fodder
L1				1	1		1						
L2	1	1		1	1			1			1		
L3			1	1	1		1		1		1		
L4		1			1					1	1		
L5							1	1					1
L6		1						1					
L7		1							1				
L8													1
L9	1	1											1
L10	1	1											1

Set- SPV 245 × SPV 1822

Table 4: Additive (D), dominance (H) and degree of dominance (DD)

SN	Charactar	D	H	DD
1	Days to 50% flowering	212.74**	49.11	0.48
2	Days to maturity	20.55	30.39*	1.22
3	Plant height	3035.81**	4144.52**	1.17
4	Green fodder yield	34381.15**	28840.07**	0.92
5	Dry fodder yield	11895.67**	7993.33**	0.82
6	Ear head length	41.02*	32.13*	0.89
7	Number of primaries per plant	320.17*	417.83*	1.14
8	Number of seeds per primary	1676.33**	283.27	0.41
9	Seed index	0.25*	0.34**	1.16
10	Harvest index	131.29**	242.83**	1.36
11	Grain yield	2018.13**	3809.37**	1.37
12	Protein content in grain	11.00**	3.75**	0.58
13	Protein content in fodder	12.13**	4.09**	0.58

Set- SPV 245 × SPV 1430

SN	Charactar	D	H	DD
1	Days to 50% flowering	367.81**	11.05	0.17
2	Days to maturity	351.78**	0.00	0.00
3	Plant height	3630.56**	4480.52**	1.11
4	Green fodder yield	134389.68**	24622.13**	0.43
5	Dry fodder yield	36693.33**	12177.78**	0.58
6	Ear head length	7.10	59.42*	2.89
7	Number of primaries per plant	1188.32**	246.73**	0.46
8	Number of seeds per primary	2052.16**	762.63**	0.61
9	Seed index	0.53*	0.63**	1.09
10	Harvest index	127.72**	33.49	0.51
11	Grain yield	8926.16**	2179.17**	0.49
12	Protein content in grain	20.65**	10.87**	0.73
13	Protein content in fodder	10.78**	3.67**	0.58

Set- SPV 245 × SPV 1822

Table 5: D and H components with and without epistatic lines

S. No.	Character	Cross	Epitasis	No of epistatic lines	All lines			Without epistatic lines		
					D	H	H/D	D	H	H/D
1	Days to 50% flowering	A x B	235.57	1	191.75**	78.21*	0.64	212.74**	110.90**	0.72
		A x C	231.97*	3	321.45**	93.04*	0.54	367.81**	81.56**	0.47
2	Days to maturity	A x B	35.17	0	20.55	30.39*	1.22	20.55	41.72**	1.42
		A x C	97.00**	6	126.89**	25.50**	0.45	351.78**	9.94**	0.17
3	Plant height	A x B	2087.27	1	2807.75**	3700.52**	1.15	3035.81**	4765.77**	1.25
		A x C	10609.40**	1	3163.16**	3863.04**	1.11	3630.56**	5629.59**	1.25
4	Green fodder yield	A x B	81792.40**	1	40038.52**	27692.21**	0.83	34381.15**	44655.66**	1.14
		A x C	322890.13**	3	187193.45**	57100.71**	0.55	134389.68**	34047.52**	0.50
5	Dry fodder yield	A x B	22215.97**	2	12396.71**	9238.96**	0.86	11895.67**	10505.67**	0.94
		A x C	81064.20**	4	47004.10**	24548.07**	0.72	36693.33**	14635.42**	0.63
6	Ear head length	A x B	85.47*	0	41.02*	32.13*	0.89	41.02*	111.83**	1.65
		A x C	34.67	0	7.10	59.42*	2.89	7.10	85.57**	3.47
7	Number of primaries / plant	A x B	1326.70**	2	400.98**	409.99**	1.01	320.17*	497.87**	1.25
		A x C	1628.57**	3	1600.68**	191.56**	0.35	1188.32**	301.06**	0.50
8	Number of seeds/ primary	A x B	3419.83**	5	1032.67**	1224.01**	1.09	1676.33**	435.80**	0.51
		A x C	1955.23**	3	1957.05**	818.27**	0.65	2052.16**	865.83**	0.65

9	Seed index	A x B	0.37*	1	0.27*	0.30**	1.04	0.25*	0.49**	1.39
		A x C	1.71**	2	0.55**	0.47**	0.93	0.53*	0.75**	1.19
10	Harvest index	A x B	317.10**	1	118.69**	215.63**	1.35	131.29**	286.09**	1.48
		A x C	54.08	1	114.29**	29.10	0.50	127.72**	81.43**	0.80
11	Grain yield	A x B	2954.63**	3	2180.00**	3669.99**	1.30	2018.13**	4193.32**	1.44
		A x C	13097.93**	3	6938.61**	2516.56**	0.60	8926.16**	2464.76**	0.53
12	Protein content in grain	A x B	78.17**	4	6.70**	2.99**	0.67	11.00**	4.44**	0.64
		A x C	98.29**	0	20.65**	10.87**	0.73	20.65**	12.99**	0.79
13	Protein content in fodder	A x B	25.11**	4	7.45**	3.28**	0.66	12.13**	4.99**	0.64
		A x C	16.32**	4	6.96**	2.69**	0.62	10.78**	4.24**	0.63

*, ** Significant at 5 and 1 percent level of significance, respectively.
Set 2- SPV 245 x SPV 1822

The analysis of variance for detection of epistasis for thirteen characters is given in Table 2. The effect of line in epistasis was significant in 33 combinations out of 130. All the lines were having epistasis for one or other characters. The numbers of characters ranged from 1 (L_8) to 6 (L_2 &L_3). For ear head length and protein content in grain none was having significant epistasis. Whereas for plant height (L_3) and harvest index (L_4) only one line was having epistasis. In rest of the characters it ranged from 2 to 6 (Table 3). Magnitude of D and H increased in 7 and 5 characters, remain constant in 2 characters and decreased in 4 and 6 characters. Consistency was observed only in those characters where none of the line was epistatic (Table 4).

Total epistasis was significant for days to 50% flowering, days to maturity, plant height, green fodder yield, dry fodder yield, number of primaries per plant, number of seeds per primary, seed index, grain yield, protein content in grain and protein content in fodder. All these characters also had significant 'j + l'epistasis, except days to 50% flowering, where as 'i' is significant for dry fodder yield, ear head length and protein content in grain (Table 2). The direction of dominance was positive *i.e.* negative correlation between sums and differences between L_1 and L_2 for dry fodder yield, number of seeds per primary, protein content in grain and protein content in fodder where as direction of dominance was negative for days to 50% flowering, days to maturity, plant height, green fodder yield, ear head length, number of primaries per plant, seed index, harvest index and grain yield (Table 4).

Discussion

Triple Test Cross Analysis is the best mating design for unbiased estimation of D and H components. The triple test cross analysis proposed by Ketataa (1976) provide unbiased estimation of D and H components. In present investigation difference between test crosses in lines were significant for all the characters in both sets (SPV 245 x SPV 1430 and SPV 245 X SPV 1822) except days to maturity in set SPV 245 x SPV 1430 and harvest index in set SPV 245 X SPV 1822. This indicates presence of variability in test crosses in lines (Meena *et al*., 2020) [17, 20]

In case of unbiased estimation, the magnitude of D and H may change in any direction accordingly the degree of dominance may also change. The cross SPV 245 x SPV 1430 (25) was least epistatic *i.e.* out of 130 combinations (10 lines x 13 characters) epistasis was significant in 25. As for as epistasis in each line concern it was absent for ear head length. The ear head length was followed by harvest index (2), plant height (4) and protein content in grain (4) number of primaries per plant (5), number of seeds per primary (8). In these lines in three testers epistasis was present in less than 10 combinations. The lines depicted epistasis in cross SPV 245 x SPV 1822 (33) followed by SPV 245 x SPV 1430 (25). Among the lines L_1 was not having epistasis for any of the character in cross SPV 245 x SPV 1430. It was followed by L_6 (SPV 245 x SPV 1430), L_8 (SPV 245 x SPV 1822), which were having epistasis for one character only in above mentioned crosses.

The total epistasis was significant for all the characters in both the crosses except days to 50 % flowering, days to maturity and plant height in SPV 245 x SPV 1430 and ear head length in SPV 245 X SPV 1822. In both the crosses the j + l type of epistatisis was also significant. The additive x additive (i) epistasis was significant for four characters in set SPV 245 x SPV1430 and 3 characters in set SPV 245 x SPV 1822. It was significant in both the sets for protein content in grain. This indicates the present of epistasis and need to unbiased estimation of D and H components. The significance of epistastic effect further tested for each line, none of the line exhibited significant epistasis for ear head length. The other characters having less epistatic lines were harvest index (2), plant height (4) and protein content in grain (4) number of primaries per plant (5), number of seeds per primary (8). In cross SPV 245 x SPV 1822 maximum epistasis was observed condidering different crosses and different characters, it was followed by SPV 245 x SPV 1430. Among the lines L_1 was not having epistasis for any of the character in cross SPV 245 x SPV 1430 it was followed by L_6 in (PV 245 x SPV 1430 and L_8 in SPV 245 X SPV 1822 set which were having epistasis for one character only in above mentioned crosses.

After dropping the epistatic lines unbiased D and H were estimated. This indicates that epistasis may bias the D and H components in any direction and average degree of dominance may change accordingly (Table 5). The unbiased estimation revealed significance of D and H components for all the characters in both the crosses except additive variance (D) for days to maturity in SPV 245 x SPV 1430, ear head length in SPV 245 X SPV 1822 sets. The total epistasis was also absent in all the above exceptional sets for above characters. This indicates that significance of epistasis more biased the D in present investigation. The average degree of dominance for days to 50 % flowering, number of seeds per primary and protein content in fodder was less than one and for ear head length and seed index the degree of dominance was more than one. For rest of the characters it was varied from set to set. The crosses having economic heterosis for grain yield having significance of epistasis in one or other set similarly the crosses having economic heterosis for dry fodder yield also following the same trend. As the environmental conditions in which the hybrids showing economic heterosis for grain yield and dry fodder yield was different than the crosses evaluated for triple test cross therefore, in the absence of uniform trend in different environments and crosses we cannot use this information directly in the exploitation of crosses having economic heterosis for grain yield and dry fodder yield. Similar results for one or more characters were

also obtained by Singh *et al*. (1991), Kashyap and Rastogi (2006), Singh *et al*. (2006), Sood *et al*. (2007), Meena *et al*. (2018, 2020) [17, 20].

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