INTERSPECIFIC HYBRIDIZATION IN SORGHUM

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DECLARATION

I hereby declare that this thesis entitled "**Interspecific hybridization in Sorghum**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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16-06-2005.

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CERTIFICATE

Certified that this thesis entitled "**Interspecific hybridization in Sorghum**" is a record of research work done independently by Mr. Jithesh. V.G. (2002-11-40) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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Dedicated to

My Beloved Parents and Sister

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LIST OF ABBREVIATIONS

%	per cent
σ^2A	Additive variance
σ^2D	Dominance variance
μg	Micro gram
^0C	Degree Celsius
ANOVA	Analysis of variance
CD	Critical difference
cm	Centimetre(s)
et al.	And others
F_1	First filial generation
Fig.	Figure
g	Gram(s)
GCA	General combining ability variance
gca	General combining ability effect
ha	Hectare
i.e.	That is
KAU	Kerala Agricultural University
kg	Kilogram
L x T	Line x Tester
ml	Millilitre
MSE	Error mean square
ne	Not estimable
NS	Non significant
SCA	Specific combining ability variance
sca	Specific combining ability effect
SE	Standard error
SS	Sum of squares
t	Tonne(s)
viz.	Namely

INTRODUCTION

1. INTRODUCTION

In world food production and rural economy, the role and importance of forages for feeding domestic herbivores is not so small. It needs greater attention and research. The soaring prices of dairy products and sometimes their non-availability in sufficient quantities are often attributed to the increasing price of cattle feeds. Therefore large-scale production of green fodder will help to bring down the prices of concentrates and rear healthy milch animals. In dairy production, the cost of feed constitutes about 60-65 per cent of total cost of milk production. Year round supply of forage is very important in order to stabilize animal production especially in the milk-shed areas and also for farmers who maintain dairy animals as a source of income. The green nutritious fodder paves the way not only for augmenting the economic production of animal products, but also for the availability of draught power in the era of energy crisis.

Indian agriculture is oriented towards a mixed farming in which livestock is an important part of the crop production system. Eventhough there is large population of livestock in India, the productivity is low which is attributed to shortage of feed both in quantity and quality. In Kerala, fodder crops are grown in an area of 3241 ha and the production is only 48660 million tonnes. At present, the deficit is too high that we are able to meet only 40 per cent of the animal feed. Because of increased pressure on arable land for grains and commercial crops it is not possible to extent area under fodder crops.

The present status of fodder production and productivity in the state are not satisfactory. The present statistics reveals that there is 41 per cent deficit in the availability of dry matter for feeding livestock. The only solution for bridging the gap between the demand and supply of green fodder lies in maximizing the fodder production in space and time, by identifying new forage resources and increasing the fodder production within the existing farming system. This calls for the need to rejuvenate and also to increase the productivity of fodder crops by developing new varieties.

Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal crop which is widely used for forage production due to its quick growing habit, high yield potential, better palatability and digestibility (Tarumoto, 1971). But it is shy tillering. Sudan grass (*Sorghum sudanense*) is high tillering and perennial in nature.

Breeding for forage sorghum can be meaningful only when the new stable variety evolved combines high yield and better quality for improvement in such an important crop, the prerequisite is the selection of suitable parents, which could combine well and produced desirable hybrids and segregants. Selection of appropriate parents is the key to success even for successful exploitation of heterosis. The combining ability elucidates the nature of gene action involved in the inheritance of a trait. The nature of gene effect for yield and its component traits has a bearing on the development of efficient breeding procedure. Line x tester mating design was used to generate material for estimation of combining ability effects, which provide basic idea about the genetic potential of the parents. Interspecific hybridization between genetically divergent species of sorghum [*Sorghum bicolor* (L.) Moench] and sudan grass (*Sorghum sudanense*) has been attempted to develop hybrids by combining the high yield potential and quality attributes of sorghum and the high tillering and perennial nature of sudan grass.

Keeping in view of the above facts, the present study was undertaken with the following objectives:

- To study the type of gene action involved in the inheritance of different characters.
- To study the magnitude of heterosis and combining ability of parents and crosses for fodder yield and other related characters.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The selection of suitable parents for hybridization is one of the most important steps in breeding programme. Selection of parents on the basis of phenotypic performance alone is not a sound procedure since phenotypically superior lines may yield poor recombinants in the segregating generations. It is therefore, essential that parents should be chosen on the basis of their genetic value.

Interspecific hybrids between *Sorghum bicolor* (L.) Moench, 2n = 20 and *Sorghum sudanense*, 2n = 20 are the most widely studied in the genus sorghum. A review of research on different aspects like heterosis, combining ability and gene action is presented below.

2.1 HETEROSIS

Breeders of crop species usually observe that mean performance of F_1 generation obtained by crossing two genotypes, is superior than mean performance of the parent and this phenomenon is known as heterosis. Genetic diversity, genetic base and adaptability of parental lines influence the expression of heterosis. Existence of a significant amount of dominance variance is essential for undertaking heterosis breeding programme.

Conner and Karper (1927) reported heterosis in sorghum first. Since then several workers have reported heterosis for various characters in sorghum (Shambulingappa and Magoon, 1963; Chandra *et al.*, 1969).

Argikar and Chavan (1957) observed heterosis for number of leaves. Kambal and Webster (1966) reported that hybrids and parents possessed approximately same number of leaves. However, Kirby and Atkins (1968) and (Chandra *et al.*, 1971) observed increased number of leaves in hybrids.

Ramalingam and Raman (1974) studied several interspecific hybrids *viz.*, *Sorghum subglabrescens* x *Sorghum sudanense*, *Sorghum dochna* x *S. sudanense*, *S. sublabrescens* x *S. halepense* and *S. sudanense* x *S. halepense* and reported that interspecific hybrids were vigorous but differed in the degree of expression of heterosis in respect to plant height, length of panicle and peduncle.

Rao and Goud (1975) reported the presence of heterosis in sorghum for number of leaves. Kambal and Abu-El-Gasim (1976) detected only low heterosis for this trait. Indi and Goud (1981) recorded non-significant heterobeltiosis. Saradamani (1982) observed relative heterosis upto 118.50 per cent and heterobeltiosis upto 111.48 per cent.

Chaudhary *et al.* (1980) studied F_1 hybrids of ten varieties of *Sorghum biocolor* with one variety of *S. sudanense* on a reciprocal basis. The hybrids had significant increase over both the parents in respect of number of leaves per plant and dry weight of the plant and a considerable increase in leaf area. They were intermediate in stem thickness and moisture content.

Muhammad *et al.* (1981) studied F_1 hybrids of four cytoplasmic male sterile sorghum varieties with four sudan grass varieties. The hybrids showed improved vigour for fodder yield and seven yield related quality traits. Like sudan grass, the hybrids could be ratooned.

Girko (1985) crossed inbred sudan grass lines with CMS forms of grain sorghum and reported that relative heterosis for vegetative weight from two cuts was 93.3 per cent and for number of internodes 26.13 per cent. Heterosis was -13.93 per cent in the first cut. Partial dominance was observed for leaf width, degree of tillering and panicle length.

Bhagmal and Mishra (1985) crossed F_1 hybrids of *Sorghum bicolor* with *Sorghum sudanense*. From this three way cross hybrids showed significant positive transgressive segregation for plant height, culm thickness and leaf breadth and both positive and negative transgression for number of leaves and leaf length. Highest per cent of individuals showing heterosis were observed for plant height (68.96 per cent) followed by leaf length (62.67 per cent), leaf number (48.27 per cent), culm thickness (27.58 per cent) and leaf breadth (24.14 per cent).

Nayeem *et al.* (1987) studied 80 sorghum hybrids produced by a line x tester mating system and reported marked variation in protein content among hybrids. Rathore and Singhania (1987) observed high heterosis as well as in breeding depression for number of leaves and stem thickness. Geetha and Rana (1987) found that the grain yield was highest in F_1 followed by successive depression in F_2 and F_3 generations.

Cheralu and Rao (1989) recorded heterosis for plant height, stem thickness and grain yield. Heterosis for days to 50 per cent flowering, plant height and grain yield was reported by Amsalu and Bapat (1990). Nandanwalker (1990) studied 33 hybrids involving three male sterile and 11 diverse restorer lines and observed that the lines 1258 A produced greater proportion of hybrids with significant heterosis for grain yield than the other two male steriles 136 A and 1202 A. Highest heterosis of 78.50 per cent was reported for grain yield. Significant heterosis was also noticed for panicle weight and panicle length.

Pathak and Sanghi (1992) observed highly significant heterosis for green fodder yield and varying degrees of heterosis for all the characters studied.

Jayamani and Dorairaj (1993) reported the combing ability for seven quantitative characters through line x tester analysis involving six *Sorghum bicolor* lines and five *Sorgum halepense* (2n = 40) testers. They reported the heterotic vigour of the hybrids for green fodder yield and its component characters.

Jayamani and Dorairaj (1994b) studied 30 hybrids produced from interspecific crosses between five sorghum bicolor varieties and five accessions of *S. halepense*. Heterosis for green fodder yield in both the main fodder crop and the ratoon crop was best in the hybrids SS31 x FD 1693, SS 30 x FD 1694, SS 30 x FD 1693, SS 44 x FD 1694 and SS 44 x FD 1692.

Sanakarapandian *et al.* (1994 b) reported heterosis in fodder traits of sorghum in 42 hybrid combinations. They reported best performance for plant height, crude protein content, total soluble solids and dry matter production.

Ganesh *et al.* (1997) reported sorghum genotype Co 26 as a good donor for panicle weight and yield. They observed high negative heterosis for days to 50 per cent flowering and the highest standard heterosis for panicle length and 100 grain weight. An experiment conducted by Ghorade *et al.* (1997) with four lines and 10 testers was found to exhibit significant positive heterosis and heterobeltiosis for days to 50 per cent flowering, plant height and grain yield.

Kumar and Kumar (1998) studied interspecific hybrids between sorghum [*Sorghum bicolor* (L.) Moench] and sudan grass (*Sorghum sudanense*) in a line x tester design and reported predominance of SCA variance for all the characters except leaf area and number of nodes per plant. ICS A 101 and ICSR 93014 were found to be good combiners for most of the characters studied. Among the hybrids ICSA 101 x SSG-59-3 and ICSA 75 x SSG-59-3 were found to have high SCA effects.

Grewal *et al.* (2003) studied the heterotic potential of fodder yield and its component traits in forage sorghum. The extent of heterosis varied from green fodder yield, dry fodder yield, plant height, tiller number per plant and days to 50 per cent flowering. On the basis of heterosis, crosses ICS 13A x S 241, IMS 9A x SSG-59-3 and ICS 4A x HC 308 were identified as the most promising hybrids for green and dry fodder yield.

2.2 COMBINING ABILITY AND GENE ACTION

Studies on combining ability are useful in understanding the nature of genetic variance present in the material for deciding the appropriate breeding procedures that could be used for crop improvement. Combining ability is defined as relative ability of a genotype to transmit its desirable performance to its crosses.

Kempthorne (1957) defined the GCA and SCA as σ^2GCA and σ^2SCA respectively in terms of covariance of half sibs (HS) and full sibs (FS) in random mating population where GCA is covariance HS and SCA is covariance FS-2 (Cov.HS). Allard (1960) classified combining ability into general combining ability and specific combining ability (SCA). He defined the GCA as average performance of a strain in a series of crosses and SCA as the deviation from the performance on the basis of GCA. Studies on combining ability carried out in sorghum are summarized below.

Dangi *et al.* (1980) in a line x tester analysis involving five pollinators with 17 lines observed preponderance of additive gene action for fodder yield.

Lazanyi and Bajaj (1986) and Chandrashekerappa (1987) found predominant role of additive gene action for plant height and panicle weight as indicated by the higher estimates of GCA variance.

Nimbalkar and Bapat (1987) reported the involvement of both additive and non-additive gene action controlling days to 50 per cent flowering, plant height and predominance of non-additive gene action for number of leaves. Kulkarni and Shinde (1987) found the predominance of additive gene action for days to 50 per cent flowering.

Sahib *et al.* (1988) reported the predominant role of GCA variance for days to 50 per cent flowering, number of leaves and grain yield. Mallick *et al.* (1988) found significant SCA effects for protein content.

Mallick and Gupta (1988) reported significant additive and non-additive gene action for days to 50 per cent flowering, plant height and number of leaves.

Lakshmaiah (1988) reported non-additive gene action for days to 50 per cent flowering, plant height and grain yield.

Shaug (1992) reported that the mean square of GCA for HCN at 60 (HCN 60) days and HCN at maturity (HCNM) was highly significant in males but not in females. SCA was only significant for HCN 60. GCA for HCN 60 and HCN M exceeded SCA. He reported that those traits in males with higher genotypic components also had higher combining ability effects and can be used as breeding materials for reducing HCN potential in forage sorghum.

Senthil and Palanisamy (1993) reported that the cross combinations IS 1112 A x TNS 30 had high relative heterosis and IS 111 2A x AKR 1 had high heterobeltiosis for days to 50 per cent flowering.

Naik *et al.* (1994) studied the combining ability of five females and two males in line x tester analysis and reported the predominance of non-additive gene action for days to 50 per cent flowering, plant height and grain yield.

Sankarapandian *et al.* (1994a) were evaluated for combining ability. Three lines were crossed with 14 testers and resultant 42 hybrid combinations and their parents for fodder yield and their component characters. They observed non-additive gene action for number of leaves, leaf stem ratio, total soluble solids at maturity, crude protein and dry matter yield per plant whereas plant height was observed to be controlled by additive gene action. Among the different combinations, 2077A x FS 35-1, 2077 A x FS 1, 2219 A x FS 1 were the best combiners having high sca effects.

Veerabadhiran *et al.* (1994b) reported higher SCA than GCA for different yield characters except for number of leaves.

Jayamani and Dorairaj (1995) reported that the variance due to GCA was more than the variance due to SCA for days to 50 per cent flowering. Manickam and Das (1995b) in a line x tester analysis involving three lines and fourteen testers reported that SCA variance was predominant over GCA variance for plant height, stem girth and grain yield. For number of leaves predominance of additive gene action was noticed.

Suepea and Kuoduhng (1995) reported that the mean squares of GCA and SCA of potassium and hydrocyanic acid at heading and maturity were all significantly different. The additive variances of chemical components were higher than the dominant variances at heading, however, similar variances were observed between additive and dominant components at maturity. The SCA of crude protein was highly significant at heading and maturity.

Chand (1996) reported both additive and non-additive gene action in grain yield and plant height. His studies indicated the cultivar Co 26 as the best combiner for all the traits studied.

Badhe and Patil (1997) reported additive gene action for plant height and non-additive gene action for grain yield and other attributes. SCA variance was predominant for grain yield, which could profitably be exploited for the production of hybrids. The female MS 2077 A and male SPV 386 were observed to be the best combiners for almost all traits except plant height and 100 grain weight.

Bhadouriya and Saxena (1997) observed the predominance of both additive and non-additive gene action for days to 50 per cent flowering and grain yield, while the inheritance of plant height and panicle length showed predominance of additive gene action.

Rao and Aruna (1997) in a line x tester analysis involving three lines and four testers reported the preponderance of non-additive gene action for days to 50 per cent flowering, panicle weight and grain yield. The predominance of additive gene action was noticed in plant height and panicle length.

Hovny *et al.* (2000) studied the combining ability of thirty exotic lines (CMS) with two restorers and reported non-additive genetic variance in determining yield.

Iyanar *et al.* (2001) studied forty hybrids in line x tester design with four lines and ten testers and observed that non-additive gene action was predominant for days to 50 per cent flowering, panicle weight, panicle length, plant height, leaf number, test weight and seed yield.

Kanawade *et al.* (2001) analysed a line x tester set of F_1's along with parents and reported additive gene effects for inheritance of panicle breadth, 1000 grain weight and grain yield per plant, while plant height, days to 50 per cent flowering, leaves per plant and panicle length were predominantly under non-additive gene effects.

Combining ability for seed yield and its components were studied using five lines and 12 testers by Siddiqui and Baig (2001). The results indicated the presence of non-additive gene action for plant height, grain yield and ear head characters, while additive gene action for days to 50 per cent flowering.

Khatri and Lodhi (2004) estimated the genetic and interaction components was carried out for green fodder yield and dry fodder yield in six generations of six crosses involving four sorghum genotypes at two stages, *i.e.*, crop without cutting and in ratoon sorghum crop. Both additive and dominance gene effects were found significant in majority of crosses both green fodder and dry fodder yield with preponderance of additive gene effects.

2.3 QUALITY TRAITS

Gupta *et al.* (1976) studied green forage, dry matter and crude protein yields per plant and reported higher yield of hybrids than the parent varieties.

Paroda *et al.* (1977) also reported higher green forage and dry forage yields of hybrids than the good forage lines.

Natarajaratnam and Chandrasekharan (1983) while studying heterosis in the hybrid TNAU CN 2 observed a higher photosynthetic rate, phospho enol pyruvate carboxylase activity and nitrate reductase activity than its parents.

Surendran *et al.* (1988) crossed *S. bicolor* var. mediocre (Co 11) and a wild diploid species *S. halepense*. The hybrid, FS 1, was identified that combined the juicy stem of Co 11 with the hardiness, tillering and ratooning ability of *S. halepense*. The green fodder yield of 44.5 t ha^{-1} in the first crop, being 21.4 per cent and 10.0 increases over Co 11 and K 7, respectively. It had a DM content of 24.2 per cent, protein content of 9.8 per cent, brix content of 7.4 per cent and digestibility of 65.8 per cent, which were higher than those of Co 11 and K 7. It was also rich in mineral elements. In multilocation and adaptive research trials it performed better than Co 11 and K 7 and was released for cultivation in 1986 under the name Co 27.

Jayamani and Dorairaj (1994a) developed five sweet sorghum varieties and Co 27, a fodder sorghum variety were crossed with *Sorghum halepense*. All the hybrids produced twice as much green fodder yield in both the first and second cuts as compared with Co 27, the control variety. The majority of hybrids had much higher numbers of tiller per plant than the parents. SS 25 x FD 1690 and SS 25 x FD 1692 were the most promising and are recommended for breeding multi cut sorghum types.

Gaiko *et al.* (1997) reported that six sudan grass (*Sorghum sudanese*) varieties and sorghum (*S. bicolor*) × Sudan grass hybrids were used to prepare dried fodder. The hybrids exceeded the varieties in green matter production; the highest green matter yields at the first + second cuts were given among the varieties of Stanichnaya 7 (20.8 + 14.4 t ha^{-1}) and Stepnyachka (15.7 + 12.7 t ha^{-1}) and among the hybrids by Intensivnyi (29.2 + 14.1 t ha^{-1}). These forms also had the highest sugar content in the fodder. The highest content of digestible protein and carotene in the dried fodder was found in Intensivnyi.

Joshi *et al.* (1998) reported dry matter partitioning and nutritive value of forage sorghum plant components. Total carbon, nitrogen as well as dry weight of leaves and roots increased gradually upto 75 days after sowing and then decreased, whereas shoot, dry weight and its carbon and nitrogen content increased throughout the vegetative and reproductive period. Shoots were much more fibrous in comparison to leaves, since the concentration of natural detergent fibre (NDF), acid detergent fibre (ADF), cellulose and lignin was higher in shoots than in leaves at all stages of growth and development. The observed significant decrease in *in vitro* dry matter digestibility (IVDMD) of leaves and shoots with an advancement in plant growth was mainly due to their corresponding increase in fibre components (NDF and ADF) and tannin content.

Khan *et al.* (2002) released a multi cut fodder sorghum COFS 29 (TNS 30 x *S. sudanense*) with an yield potential of 170 t ha^{-1} of green fodder per year in five harvests (main crop + four ratoons) at 65 – 70 days intervals. It is tall in stature and produces 10-15 thin tillers, highly leafy with high palatability. It has more crude protein content than Co 27 and less crude fibre and HCN content. The digestible dry matter and *in vitro* digestible dry matter were also higher than Co 27.

2.4 HCN CONTENT

Sorghum plants contain a cyanogenic glucoside, dhurrin, a group of nitrogenous secondary compounds which during enzymatic hydrolysis release hydrocyanic acid (HCN), glucose and P-hydroxy benzaldehyde. In sorghum, the HCN content was found to be higher in summer than in the kharif season. This was reported by Eberhart and Russell (1966).

The HCN is toxic to animals and the lethal dose is 200 ppm or 20 mg / 100 g DM (Gillingham *et al.*, 1969; Mc Bee *et al.*, 1980). The HCN content is found to be maximum at 30 days stage. It increases with nitrogen fertilization, water stress, frost and decreases with phosphorus application, plant age, drying, irrigation and ensling.

Rabas *et al.* (1970) studied two sudan grass varieties and four sorghum x sudan grass hybrids and reported that the grazing performance of cattle for the sudan grass and sorghum x sudan grass hybrids was negatively correlated with HCN concentration. The results suggested that selection for low HCN concentration to avoid prussic acid poisoning might also result in increased palatability.

Luthra *et al.* (1976) analysed 55 yellow endospermic strains of sorghum and observed that varietal differences in accumulation of nitrate nitrogen and hydrocyanic acid existed. Both the toxic constituents co-existed at a particular stage, thereby necessitating the estimation of these poisonous constituents.

Liu and Wu (1986) studied 118 varieties of sorghum and observed that the seedlings at four days after germination recorded the highest HCN content. Grain and roots had a low content, while the content in leaf sheath and leaves was considerably higher, the first leaf having the highest content.

Wheeler *et al.* (1990) studied the effect of plant maturity, nitrogen fertilizer, phosphorus fertilizer, water stress, light intensity and temperature on HCN potential (HCNp) of *Sorghum bicolor* × *Sorghum sudanense*) and (*Sorghum halepense* × *Sorghum roxburghii*) × *Sorghum arundinaceum* hybrids and reported that nitrogen fertilizer (200 kg N/ha) increased HCNp but more so in full light (100 m/kg compared with 1430 mg) than in 50 per cent shade (190 mg compared with 690 mg). Acute water stress appeared to reduce HCNp but this was confounded with the strong decline due to aging. Neither the application of super phosphate nor change in light intensity and change in temperature had direct significant effect on HCNp. They concluded that breeding and selection for low HCNp is a promising approach to ensure that sorghum plants could provide non-toxic forage from an early stage of growth.

MATERIAL AND METHODS

3. MATERIAL AND METHODS

The present study on "Interspecific hybridization in Sorghum" was carried out at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Thiruvananthapuram during September 2003 to July 2004. The details of the materials used as well as the method adopted are given in this chapter.

3.1 MATERIALS

The five superior Sorghum [*Sorghum bicolor* (L.) Moench] accessions *viz.*, GD 65174-1, GD 65174-2, GD 65195, GD 65239 and Acc. No. 846 with high yield potential and better palatability selected from the previous study were used as lines. Three sudan grass (*Sorghum sudanense*) accessions *viz.*, Jhansi local, SSG-59-3 and IS-720 with high tillering were used as testers. The lines and testers are given in Plates 1 and 2.

3.2 METHODS

3.2.1 Hybridization between Lines and Testers

The five lines and three testers were crossed and seeds of fifteen hybrids were collected. The lines, testers and their hybrids are presented in Table 1.

3.2.1.1 Emasculation and Crossing

Hand emasculation suggested by Quinby and Martin (1954) was followed. The panicles of both the parents were enclosed in craft paper bags immediately after the emergence of the panicle from the boot leaf. On the evening of the day preceding the day of crossing, a few plants of the female parents in which flowering had commenced were chosen. A small bunch of spikelets about to bloom on the next day was selected for emasculation with the help of pointed needle. The three stamens were

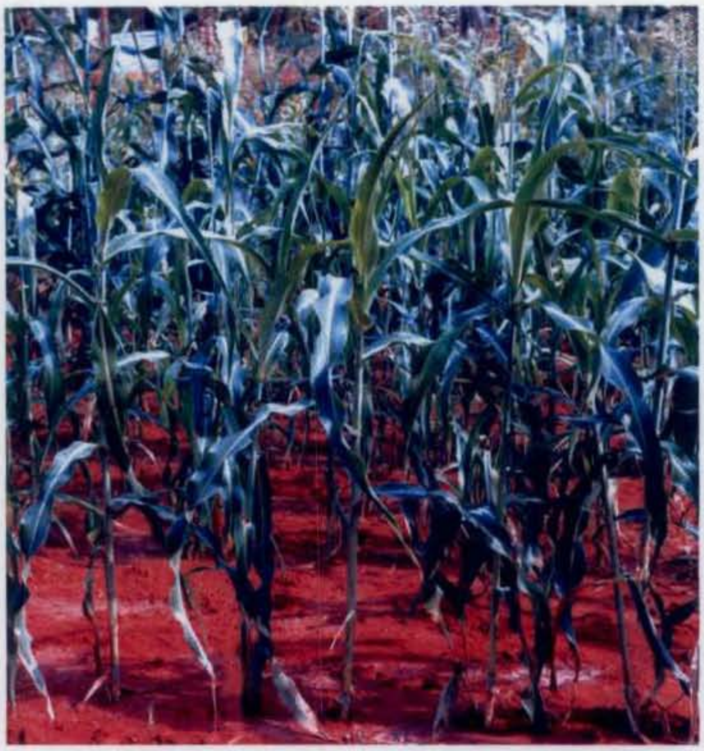


Plate 1. ***Sorghum bicolor*** **(Lines)**

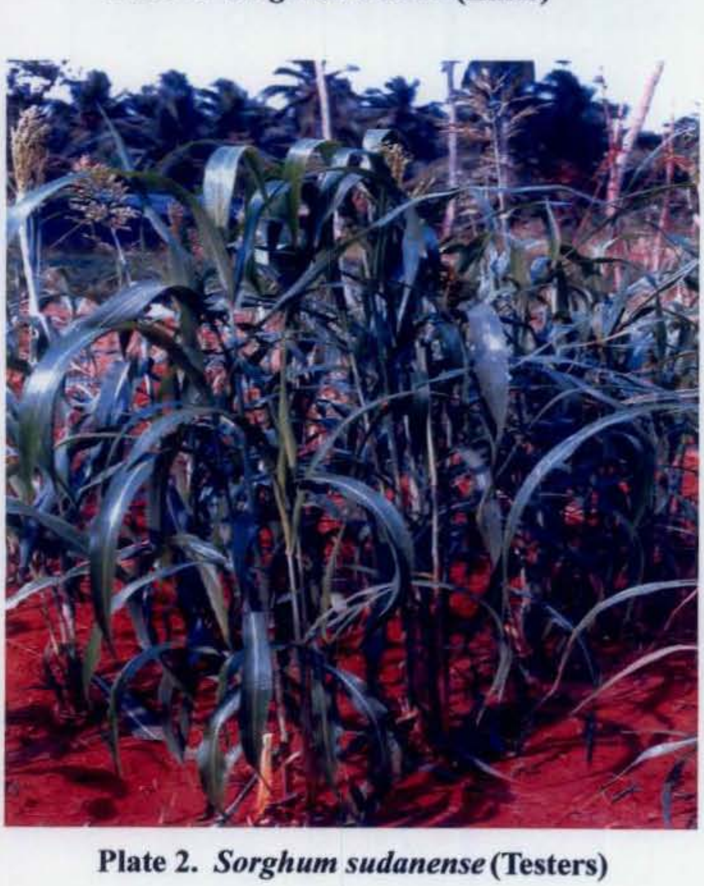


Plate 2. ***Sorghum sudanense*** **(Testers)**

Table 1. List of parents and hybrids

Sl. No.	Treatments	Name of variety / cross
1	L_1	GD65174-1
2	L_2	GD65174-2
3	L_3	GD65195
4	L_4	GD65239
5	L_5	Acc. No. 846
6	T_1	Jhansi local
7	T_2	SSG-59-3
8	T_3	IS 720
9	$L_1 \times T_1$	GD65174-1 × Jhansi local
10	$L_1 \times T_2$	GD65174-1 × SSG-59-3
11	$L_1 \times T_3$	GD65174-1 × IS-720
12	$L_2 \times T_1$	GD65174-2 × Jhansi local
13	$L_2 \times T_2$	GD65174-2 × SSG-59-3
14	$L_2 \times T_3$	GD65174-2 × IS-720
15	$L_3 \times T_1$	GD65195 × Jhansi local
16	$L_3 \times T_2$	GD65195 × SSG-59-3
17	$L_3 \times T_3$	GD65195 × IS-720
18	$L_4 \times T_1$	GD65239 × Jhansi local
19	$L_4 \times T_2$	GD65239 × SSG-59-3
20	$L_4 \times T_3$	GD65239 × IS-720
21	$L_5 \times T_1$	Acc. No. 846 × Jhansi local
22	$L_5 \times T_2$	Acc. No. 846 × SSG-59-3
23	$L_5 \times T_3$	Acc. No. 846 × IS-720

pushed out one by one from the interior of the spikelet without injuring the ovary. The pedicellate spikelets which are staminate are then cut off using scissors. The emasculated spikelets were then covered by a small butter paper bag (Plate 3). On the next day morning pollen collected from the pollen parent was dusted on the stigma of the emasculated spikelets. To avoid contamination the bag was fastened. This was repeated for the succeeding two or three days. The seeds were collected 20 to 25 days after pollination. The seed set percentage was computed by counting the number of spikelets emasculated and the number of seeds obtained.

3.2.2 Evaluation of Hybrids

The lines, testers and their hybrids were raised along with a check COFS-29 in randomized block design with two replications during January to June, 2004. The spacing was 50 × 30 cm in plots of size 3.5 × 1.5 m (Plate 4). The 15 hybrids and parents were allowed for natural pollination. The recommended agronomic practices and need based plant protection measures were followed in accordance with the Recommendations of Package of Practices of the Kerala Agricultural University (KAU, 2002). The observations were recorded on various biometric characters at each harvest, replication wise from a random sample of five plants each with respect to treatments and the mean values were used for statistical analysis.

3.2.3 Observations

3.2.3.1 Plant Height

The height of the plant from the ground level to the tip of the main tiller at the time of harvest was measured in cm.

3.2.3.2 Tiller Number per Plant

The total number of tillers from a random sample of ten plants per plot was counted at harvest and the mean value was calculated.

Plate 3. Crossing block

Plate 4. Sorghum x sudan grass hybrids - Field view

3.2.3.3 Stem Girth

The girth at the middle of the fourth internode from the top was measured and expressed in cm.

3.2.3.4 Internodal Length

The length of the fourth internode from the top was measured in centimeters.

3.2.3.5 Leaf : Stem Ratio

Ten plants selected at random from each plot were harvested and leaf and stem of each plant were separated. Weight of leaf and stem was recorded separately and leaf : stem ratio worked out.

3.2.3.6 Pollen Fertility

Pollen fertility of the observational plants was estimated by staining pollen grains from mature anthers on a glass slide with glycerine-acetocarmine (1 : 1). The partly and poorly stained, shrivelled and empty pollen grains were considered as sterile while pollen grains which were full and well stained were considered as fertile. Pollen fertility was expressed in percentage.

3.2.3.7 Leaf Number per Plant

The total number of leaves from a random sample of ten plants per plot was counted at harvest and the mean number recorded.

3.2.3.8 Leaf Weight per Plant

Ten plants were selected at random from each plot, leaves were separated and the mean leaf weight per plant was estimated and expressed in gram.

3.2.3.9 Days to 50 per cent Flowering

Number of days from sowing to the day on which 50 per cent plants of an accession have started flowering.

3.2.3.10 Green Fodder Yield

The total weight of the observational plants were taken at the time of harvest and mean weight calculated and multiplied with the number of plants in one hectare and expressed in tonnes per hectare.

3.2.3.11 Dry Fodder Yield

One hundred gram of the fresh sample from the observational plants were taken and dried under normal conditions for 10 days. This was then dried in an electric oven at 60°C for 24 hours. The dried samples were weighed and the dry matter content was calculated in percentage. The green fodder yield was multiplied with dry matter content to get the dry fodder yield per hectare in tonnes.

3.2.3.12 Cruder Protein Content

The total nitrogen content of the oven dried samples of the observational plants was estimated by modified Microkjeldhal method (Jackson, 1967). The nitrogen value was multiplied by the factor 6.25 to obtain the crude protein content expressed as percentage.

3.2.3.13 Crude Fibre Content

Dried plant samples collected at the time of plant harvest were utilized for the estimation of crude fibre by acid and alkali digestion method (Sadasivam and Manickam, 1992).

From the representative sample of the dried plant, two grams taken and boiled with 200 ml of sulphuric acid for 30 minutes. Then it was filtered through a muslin cloth and the filtrate was washed with boiling water until the washings were no longer acidic. The residue obtained was again boiled with 200 ml of sodium hydroxide solution for 30 minutes. It was again filtered through muslin cloth and washed with 25 ml of 1.25 per cent boiling sulphuric acid, 350 ml of water and 25 ml alcohol. The residue was transferred to ashing dish which was pre weighed (W_1). The residue was then dried for two hours at 130 ± 2°C. The dish was cooled and weighed (W_2). Then the residue was ignited for 30 minutes at 600 ± 15°C, cooled in desiccator and weighed (W_3).

Percentage crude fibre in the sample was estimated as :

$$= \frac{\text{Loss of weight on ignition}}{\text{Weight of sample}} \times 100$$

$$= \frac{(W_2 - W_1) - (W_3 - W_1)}{\text{Weight of sample}} \times 100$$

3.2.3.14 HCN Content

The HCN content was determined by the picric acid method of Hogg and Ahlgren (1942). The samples for the analysis of HCN were taken from the portion of the tiller immediately below the upper most leaf collar. Transferred 0.2 g chopped green plant material to test tube (2.5 cm x 20 cm), then added 3-4 drops of chloroform and suspended a strip of moist Whatman No. 1 filter paper (15.5 cm x 1.7 cm) saturated with sodium picrate solution (prepared by dissolving 25 g sodium carbonate and 5 g picric acid in one litre of distilled water. The saturated filter paper strip was held in place with a cork stopper, which was used to seal the test tube. The incubation was carried out at room temperature for 24 h. The sodium picrate present on the filter paper was reduced in the presence of HCN. After 24h, the paper strip was removed and colour was eluted in 10 ml of distilled water. The absorbance of the colour was measured at 515 nm against a reagent blank treated in the same manner as the plant sample. The amount of HCN in ppm on dry weight basis was calculated by calibrating the absorbance with KCN (5-40 ppm) in water as standard (Gillchrist *et al.*, 1967).

3.2.3.15 Palatability

Equal quantities of sudan grass, sorghum and hybrids were fed to the cattle and it was found that hybrids had been completely consumed.

3.3 STATISTICAL ANALYSIS

Analysis of variance was done for all the characters under study and tested for significance (Singh and Chaudhary, 1985).

3.3.1 Combining Ability Analysis

Combing ability analysis of the Line x Tester was done through ANOVA technique (Dabholkar, 1992) as follows (Table 2).

Table 2. Analysis of variance for line x tester design

Source	df	SS	MS	Expected mean square
Replication	r – 1	SSR	MSR	
Genotypes	n – 1	SSG	MSG	
Parents	(l + t) – 1	SSP	MSP	
Parents vs. crosses	1	SSO	MSO	
Crosses	l x t -1	SSC	MSC	
a. Lines	l – 1	SSL	M_L	$\sigma^2_e + r\sigma^2_{sca} + rt\ \sigma^2_{gca}$ (l)
b. Testes	t – 1	SST	M_T	$\sigma^2_e + r\sigma^2_{sca} + rl\ \sigma^2_{gca}$ (t)
c. Line x tester	(l – 1) (t – 1)	SSLT	ML_T	$\sigma^2_e + r\ \sigma^2_{sca}$
Error	(n – 1) (r – 1)	SSE	M_e	σ^2_e
Total	nr – 1			

Where, n = number of treatment materials (l + t + lt)

r = number of replications

l = number of lines

t = number of testers

3.3.1.1 Estimation of General and Specific Combining Ability Effects

General combing ability effect (*gca*) of parents and specific combining ability effect (*sca*) of hybrids were estimated using he following model.

$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$

Where, μ = population mean

g_i = *gca* effect of i^{th} line

g_j = *gca* effect of j^{th} tester

s_{ij} = *sca* effect of ij^{th} hybrid.

e_{ijk} = error associated with ijk^{th} observation.

$i = 1, 2, \ldots, l$

$j = 1, 2, \ldots, t$

$k = 1, 2, \ldots, r$

The individual effects were estimated as follows:

(i) Mean $= \dfrac{X_{\ldots}}{rlt}$

(ii) *gca* effect of lines

$$g_i = \frac{X_{i..}}{rt} - \frac{X_{\ldots}}{rlt}$$

(iii) *gca* effect of testers

$$g_j = \frac{X_{.j.}}{rl} - \frac{X_{\ldots}}{rlt}$$

(iv) *sca* effect of hybrids

$$S_{ij} = \frac{X_{ij}}{r} - \frac{X_{i..}}{rt} - \frac{X_{.j.}}{rl} + \frac{X_{...}}{rlt}$$

Where,

$X_{...}$ = totality of observations on all hybrids over 'r' number of replications.

$X_{i..}$ = totality of observations on i^{th} line over 't' testers and 'r' replications.

$X_{.j.}$ = totality of observations on j^{th} tester over 'l' lines and 'r' replications.

Significance of combining ability effects was tested as :

$$t = \frac{(\text{Effect})}{\text{SE (effect)}}$$

where,

$$\text{SE of } gca \text{ (lines)} = \sqrt{\frac{M_e}{rt}}$$

$$\text{SE of } gca \text{ (testers)} = \sqrt{\frac{M_e}{rl}}$$

$$\text{SE of } sca \text{ (hybrids)} = \sqrt{\frac{M_e}{r}}$$

3.3.1.2 Combining Ability Analysis

The GCA variance for lines and testers and SCA variance for the hybrids were calculated as follows:

$$\sigma^2 \text{ GCA (lines)} = \frac{ML - ML_T}{rt} = \text{Cov. H.S. (lines)}$$

$$\sigma^2 \text{ GCA (testers)} = \frac{MT - ML_T}{rl} = \text{Cov. H.S. (testers)}$$

$$\sigma^2 \text{ SCA (hybrids)} = \frac{MLT - Me}{r}$$

3.3.1.3 Gene Action

After estimating the variances due to general combining ability (σ^2 GCA) and specific combining ability (σ^2 SCA) the gene action was worked out as :

$$\sigma^2 \text{ GCA} = \left(\frac{1 + F}{4}\right) \sigma^2 A$$

$$\sigma^2 \text{ SCA} = \left(\frac{1 + F}{2}\right)^2 \sigma^2 D$$

Where, F = inbreeding coefficient

If inbreeding is absent (F = 0)

σ^2 GCA = ¼ σ^2A

σ^2 SCA = ¼ σ^2D

So, σ^2a = 4σ^2 GCA

σ^2d = 4σ^2 SCA

The significance of $\sigma^2 A$ is tested respectively for lines and testers as :

$$F\left[(l - 1), (l - 1)(t - 1)\right] = ML / MLT$$

$$F\left[(t - 1), (l - 1)(t - 1)\right] = MT / ML_T$$

and that of σ^2 D from

$$F\left[(l - 1)(t - 1), (n - 1)(r - 1)\right] = MLT / Me$$

3.3.1.4 Proportional Contribution of Lines, Testers and Line x Tester to the Total Sum of Squares of the Hybrids

$$\text{Contribution of lines} = \frac{\text{S.S. (lines)}}{\text{S.S. (hybrids)}} \times 100$$

$$\text{Contribution of testers} = \frac{\text{S.S. (testers)}}{\text{S.S. (hybrids)}} \times 100$$

$$\text{Contribution of lines x testers} = \frac{\text{S.S. (line x tester)}}{\text{S.S. (hybrids)}} \times 100$$

3.3.2 Estimation of Heterosis

Heterosis (expressed in percentage) was estimated for all the characters over mid parent (relative heterosis), better parent (heterobeltiosis) and standard variety (standard heterosis) as suggested by Rai (1979).

3.3.2.1 Relative Heterosis

Relative heterosis was estimated as the percentage deviation of the mean performance of F_1 ($\overline{F_1}$) over the mean performance of the parents ($\overline{MP}$).

$$\text{Relative heterosis (RH)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Where $\overline{MP}$ = mid parental mean value

$\overline{F_1}$ = average performance of F_1

3.3.2.2 Heterobeltiosis

Heterobeltiosis was estimated in comparison to the better parent as

$$\text{Heterobeltiosis (HB)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where $\overline{BP}$ = better parental mean of a particular cross.

3.3.2.3 Standard Heterosis

Standard heterosis was estimated in comparison to the standard variety as

$$\text{Standard heterosis (SH)} = \frac{\overline{F_1} - \overline{SP}}{\overline{SP}} \times 100$$

Where $\overline{SP}$ = mean of the standard variety.

The significance of different types of heterosis was tested by 't' test with (n – 1) (r – 1) degrees of freedom. The critical difference (CD) for comparison of

F_1 with $\overline{MP}$ is $$t\sqrt{\frac{3\,Me}{2r}}$$

F_1 with $\overline{BP}$ is $$t\sqrt{\frac{2\,Me}{r}}$$

F_1 with $\overline{SP}$ is $$t\sqrt{\frac{2\,Me}{r}}$$

RESULTS

4. RESULTS

Fifteen hybrids derived from the cross between *Sorghum bicolor* and *Sorghum sudanense* were evaluated along with their parents for heterosis and combining ability for 13 characters namely, plant height, tiller number per plant, stem girth, internodal length, leaf : stem ratio, leaf number per plant, leaf weight per plant, days to 50 per cent flowering, green fodder yield, dry fodder yield, crude protein content, crude fibre content and HCN content. Apart from these palatability and pollen sterility were also studied.

The data were subjected to Line x Tester analysis and the results are presented below.

4.1 MEAN PERFORMANCE

Significant genotypic differences were observed for all the characters. The mean performance of lines, testers and their hybrids for different characters are presented in Table 3a and 3b.

4.1.1 Plant Height, cm

The mean plant height ranged from 147.90 cm (GD 65174-2) to 185.00 cm (GD 65174-1) in lines, 167.80 cm (Jhansi local) to 204.00 cm (IS-720) in testers and 114.10 cm (GD 65174-2 x SSG-59-3) to 205.50 cm (GD 65195 x IS-720) in hybrids with their average height being 166.45 cm, 185.90 cm and 159.80 cm respectively.

4.1.2 Tiller Number per Plant

The mean tiller number per plant ranged from 2.10 (GD 65239) to 2.70 (Acc. No. 846) in lines, 3.90 (IS-720) to 4.05 (SSG-59-3) in testers and 2.40 (Ac. No. 846 x Jhansi local) to 6.60 (GD 65174-2 x Jhansi local) in hybrids with their average tiller number per plant being 2.40, 3.80 and 4.50 respectively.

Table 3a Mean performance of lines and testers for various characters

Characters / Treatments	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN Content (ppm)
LINES													
GD65174-1	185.00	2.15	3.50	25.30	0.23	20.75	157.25	68.50	101.00	5.78	7.05	33.23	183.18
GD65174-2	147.90	2.05	4.70	18.50	0.29	16.80	158.50	64.75	151.50	10.15	7.48	32.57	183.35
GD65195	160.50	2.55	3.40	16.50	0.21	19.55	149.75	70.75	77.30	5.13	7.35	32.25	166.71
GD65239	160.40	2.10	3.40	20.60	0.31	29.35	153.75	68.60	122.50	8.49	7.25	31.26	156.40
Acc. No. 846	180.90	2.70	7.10	18.80	0.29	23.80	196.35	68.75	168.80	11.30	5.77	32.49	133.00
TESTERS													
Jhansi local	167.80	4.00	3.50	16.90	0.34	50.20	98.75	77.50	61.50	4.10	6.16	35.65	36.68
SSG-59-3	187.80	4.05	3.40	17.30	0.29	100.20	149.40	73.75	148.50	10.16	5.77	35.64	46.17
IS 720	204.00	3.90	2.70	19.70	0.31	49.00	181.50	75.50	125.50	8.16	5.08	34.95	66.17
COFS-29	146.0	3.4	3.1	12.5	0.5	81.6	150.4	67.5	168.3	11.4	7.5	31.5	182.5
SE	1.25	0.41	0.18	0.24	0.012	0.81	2.09	0.83	1.39	0.15	0.15	0.16	0.54
CD (0.05)	3.67	1.21	0.52	0.73	0.036	2.39	6.15	2.43	4.09	0.44	0.44	0.46	1.58

Table 3b   Mean performance of hybrids for various characters

Characters / Treatments	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN Content (ppm)
GD65174-1 × Jhansi local	139.20	3.80	3.50	20.60	0.38	33.50	100.25	67.25	55.40	3.48	7.45	31.50	182.50
GD65174-1 × SSG-59-3	201.90	3.45	7.70	20.50	0.37	96.40	358.00	67.50	270.30	18.15	4.24	33.01	166.36
GD65174-1 × IS-720	140.50	4.60	3.30	16.70	0.25	79.65	124.00	70.75	100.50	6.48	5.52	33.25	133.28
GD65174-2 × Jhansi local	142.30	6.60	2.70	15.70	0.24	52.85	78.80	69.00	101.00	8.46	4.49	32.03	83.11
GD65174-2 × SSG-59-3	114.10	4.90	3.70	13.70	0.51	106.10	175.50	80.10	200.50	13.46	6.70	30.57	10.31
GD65174-2 × IS-720	135.90	3.80	6.60	15.70	0.28	50.10	197.00	72.00	180.50	14.79	8.27	30.04	33.16
GD65195 × Jhansi local	154.00	4.60	3.10	14.70	0.61	61.75	159.25	91.55	176.00	14.45	8.48	30.41	33.35
GD65195 × SSG-59-3	144.10	3.50	3.50	13.10	0.23	99.65	127.75	69.50	108.40	9.23	9.56	30.01	31.30
GD65195 × IS-720	205.50	4.70	9.70	29.70	0.71	57.50	652.75	66.75	597.00	40.30	5.08	32.30	33.25

Table 3b. Continued

Characters / Treatments	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN content (ppm)
GD65239 × Jhansi local	162.60	3.50	4.30	20.30	0.23	45.60	149.75	71.00	176.00	14.62	7.38	31.25	150.16
GD65239 × SSG-59-3	176.20	3.70	4.30	19.70	0.34	109.15	294.25	66.75	560.50	37.46	5.52	31.26	50.16
GD65239 × IS-720	200.30	4.40	3.50	15.60	0.44	97.10	149.50	67.50	151.95	12.40	4.78	31.44	100.00
Acc. No. 846 × Jhansi local	151.50	2.40	7.50	12.50	0.27	78.50	377.75	70.75	356.50	29.40	8.58	30.58	50.16
Acc. No. 846 × SSG-59-3	202.90	3.90	6.70	27.70	0.66	231.85	649.50	68.25	548.90	36.45	5.32	31.49	166.60
Acc. No. 846 × IS-720	149.10	3.60	3.50	22.30	0.55	78.90	98.75	72.25	100.40	7.00	6.85	32.34	156.00
SE	1.25	0.41	0.18	0.24	0.012	0.81	2.09	0.83	1.39	0.15	0.15	0.16	0.54
CD (0.05)	3.67	1.21	0.52	0.73	0.036	2.39	6.15	2.43	4.09	0.44	0.44	0.46	1.58

4.1.3 Stem Girth, cm

The mean stem girth ranged from 3.40 cm (GD 65195 and GD 65239) to 7.10 cm (Acc. No. 846) in lines, 2.70 cm (IS-720) to 3.50 cm (Jhansi local) in testers and 2.70 cm (GD 65174-2 x Jhansi local) to 9.70 cm (GD 65195 x IS-720) in hybrids with their average stem girth being 5.25 cm, 3.10 cm and 6.20 cm respectively.

4.1.4 Inernodal Length, cm

The mean internodal length ranged from 16.50 cm (GD 65195) to 25.30 cm (GD 65174-1) in lines, 16.90 cm (Jhansi local) to 19.70 cm (IS-720) in testers and 12.50 cm (Acc. No. 846 x Jhansi local) to 29.70 cm (GD 65195 x IS-720) in hybrids with their average internodal length being 20.90 cm, 18.30 cm and 21.10 cm respectively.

4.1.5 Leaf : Stem Ratio

The mean leaf : stem ratio ranged from 0.21 (GD 65195) to 0.32 (GD 65239) in lines, 0.28 (SSG-59-3) to 0.34 (Jhansi local) in testers and 0.23 (GD 65195 x SSG-59-3) to 0.72 (GD 65195x IS-720) in hybrids with their average leaf : stem ratio being 0.26, 0.31 and 0.47 respectively.

4.1.6 Leaf Number per Plant

The mean leaf number per plant ranged from 16.80 (GD 65174-2) to 29.25 (GD 65239) in lines, 49.00 (IS-720) to 100.20 (SSG-59-3) in testers and 33.50 (GD 65174-1 x Jhansi local) to 231.85 (Acc. No. 846 x SSG-59-3) in hybrids with their average leaf number per plant ratio being 23.02, 74.6 and 132.67 respectively.

4.1.7 Leaf Weight per Plant, g

The mean leaf weight per plant ranged from 149.75 g (GD 65195) to 196.35 g (Acc. No. 846) in lines, 98.75 g (Jhansi local) to 181.5 g (IS-720) in testers and 78.8 g (GD 65174-2 x Jhansi local) to 652.75 g

(GD 65195 x IS-720) in hybrids with their average leaf weight per plant being 173.05 g, 140.12 g and 365.77 g respectively.

4.1.8 Days to 50 Per cent Flowering

The mean days to 50 per cent flowering ranged from 64.75 (GD 65174-2) to 70.75 (GD 65195) in lines, 73.75 (SSG-59-3) to 77.5 (Jhansi local) in testers and 66.75 (GD 65195 x IS-720) to 91.55 (GD 65239 x SSG-59-3) in hybrids with these average days to 50 per cent flowering being 67.75, 75.62 and 79.15 respectively.

4.1.9 Green Fodder Yield, t ha^{-1}

The mean green fodder yield ranged from 77.30 t ha^{-1} (GD 65195) to 168.80 t ha^{-1} (Acc. No. 846) in lines, 61.50 t ha^{-1} (Jhansi local) to 148.50 t ha^{-1} (SSG-59-3) in testers and 55.40 t ha^{-1} (GD 65174-1 x Jhansi local) to 597.00 t ha^{-1} (GD 65195 x IS-720) in hybrids with their average fodder yield being 123.05 t ha^{-1}, 105.00 t ha^{-1} and 326.20 t ha^{-1} respectively.

4.1.10 Dry Fodder Yield, t ha^{-1}

The mean dry matter yield ranged from 5.13 t ha^{-1} (GD 65195) to 11.30 t ha^{-1} (Acc. No. 846) in lines, 4.10 t ha^{-1} (Jhansi local) to 10.16 t ha^{-1} (SG-59-3) in testers and 3.48 t ha^{-1} (GD 65174-1 x Jhansi local) to 40.30 t ha^{-1} (GD 65195 x IS-720) in hybrids with their average dry matter yield being 8.21 t ha^{-1}, 7.13 t ha^{-1} and 21.89 t ha^{-1} respectively.

4.1.11 Crude Protein Content, %

The mean crude protein content ranged from 5.77 per cent (Acc. No. 846) to 7.48 per cent (GD 65174-2) in lines, 5.08 per cent (IS-720) to 6.16 per cent (Jhansi local) in testers and 4.24 per cent (GD 65174-1 x SSG-59-3) to 9.56 per cent (GD 65195 x SSG-59-3) in hybrids with their average crude protein content being 6.62 per cent, 5.62 per cent and 6.90 per cent respectively.

4.1.12 Crude Fibre Content, %

The mean crude fibre content ranged from 31.26 per cent (GD 65239) to 33.23 per cent (GD 65174-1) in lines, 34.95 per cent (IS-720) to 35.65 per cent (Jhansi local) in testers and 30.01 per cent (GD 65195 x SSG-59-3) to 33.25 per cent (GD 65174-1 x IS-720) in hybrids with their average fibre content being 32.24 per cent, 35.3 per cent and 31.63 per cent respectively.

4.1.13 HCN Content, ppm

The mean HCN content ranged from 133.00 ppm (Acc. No. 846) to 183.35 ppm (GD 65174-2) in lines, 36.68 ppm (Jhansi local) to 66.17 ppm (IS-720) in testers and 31.30 ppm (GD 65195 x SSG-59-3) to 182.50 ppm (GD 65174-1 x Jhansi local) in hybrids with their average cyanide content being 158.17 ppm, 51.42 ppm and 106.90 ppm respectively.

4.2 COMBINING ABILITY AND GENE ACTION

All the characters were subjected to line x tester analysis to study gene action in terms of general combining ability and specific combining ability effects (Table 4). The gca effects of lines and also that of testers did not differ significantly but highly significant difference in sca effect was observed in hybrids.

4.2.1 General Combining Ability Effects

The general combining ability effects of parents for 13 characters are presented in Table 5.

4.2.1.1 Plant height, cm

General combining ability effects of lines varied from –30.57 for GD 65174-2 to 18.36 for GD 65239. The lines GD 65195 (6.53), GD 65239 (18.36) and Acc. No. 846 (6.49) showed significant positive gca effects while line GD 65174-2 had significant but negative gca effect.

Table 4 Abstract of ANOVA of the characters

Source	Mean square							
	df	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)
Lines (female parent)	4	2035.84	2.62	3.54	27.71	0.05	4024.45	53096.78
Testers (male parent)	2	984.34	0.32	3.58	27.29	0.02	10122.54	54665.57
Line x Tester	8	1692.56**	1.74*	13.43**	71.20**	0.06**	4352.13**	83212.50**
Error	22	3.14	0.34	0.06	0.12	0.0003	1.33	8.78

*Significant at 5 per cent level **Significant at 1 per cent level

Table 4 Continued

Source	Mean square						
	df	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN content (ppm)
Lines (female oarent)	4	66.17	46277.22	255.12	3.85	2.89	14347.37
Testers (male parent)	2	48.30	70705.81	214.59	4.04	1.50	374.87
Line x Tester	8	103.33**	76765.05**	334.82**	7.05**	1.75**	4152.70**
Error	22	1.38	3.90	0.04	0.045	0.05	0.58

*Significant at 5 per cent level **Significant at 1 per cent level

Table 5 General combining ability effects of lines and testers

Characters / Treatment	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)
Lines							
GD65174-1	-0.81	-0.15	-0.07	0.69**	-0.07**	-22.06**	-52.10**
GD65174-2	-30.57**	1.00**	-0.57**	-3.53**	-0.06**	-22.22**	-95.75**
GD65195	6.53**	0.17	0.53**	0.59**	0.11**	14.39**	67.06**
GD65239	18.36**	-0.23	-0.87**	-0.03	-0.07**	-7.96**	-48.35**
Acc. No. 846	6.49**	-0.79**	0.99**	2.27**	-0.09	37.84**	129.15**
SE ±	0.72	0.24	0.10	0.14	0.01	0.47	1.21
Testers							
Jhansi local	-11.42**	0.08	-0.69**	-1.81**	-0.06	-17.47**	-73.03**
SSG-59-3	6.50**	-0.21	0.27*	0.37**	0.02	36.72**	74.81**
IS 720	4.92**	0.12	0.41**	1.43	0.04	-19.26**	-1.79
SE ±	0.56	0.18	0.11	0.005	0.36	0.94	0.94

*Significant at 5 per cent level **Significant at 1 per cent level

Table 5 Continued

Characters / Treatment	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN content (ppm)
Lines						
GD65174-1	-2.89**	-103.52**	-8.37**	-0.81**	1.15**	62.73**
GD65174-2	2.31**	-84.92**	-5.50**	-0.06	-0.55**	-25.78**
GD65195	4.54**	48.21**	3.58**	1.16**	-0.52**	-65.34**
GD65239	-2.98**	50.56**	3.75**	-0.65**	-0.11	2.12**
Acc. No. 846	-0.98*	89.68**	6.54**	0.37**	-0.04	26.27**
SE ±	0.48	0.81	0.09	0.09	0.09	0.31
Testers						
Jhansi local	2.52**	-72.61**	-3.66**	0.73**	-0.28**	1.88**
SSG-59-3	-0.97**	92.13**	5.21**	0.28**	-0.16*	4.96**
IS 720	-1.54**	-19.52**	-1.55**	-0.45**	0.44**	-6.84**
SE ±	0.37	0.62	0.07	0.07	0.07	0.24

*Significant at 5 per cent level   **Significant at 1 per cent level

Among testers SSG-59-3 (6.50) and IS-720 (4.92) had significant positive gca effects while Jhansi local had significant negative gca effect (-11.42).

4.2.1.2 Tiller Number per Plant

The general combining ability effects of lines varied from –0.79 for Acc. No. 846 to 1.00 for GD 65174-2. GD 65174-2 (1.00) showed significant positive gca effect while Acc. No. 846 had significant but negative gca effects. None of the testers showed significance for gca effect.

4.2.1.3 Stem Girth, cm

Among lines Acc. No. 846 (0.99) and GD 65195 (0.53) showed significant positive gca effects for stem girth. Significant negative gca effect was shown by GD 65239 (-0.87) and GD 65174-2 (-0.57). Only two out of three testers had significant gca effects for stem girth. SSG-59-3 (0.27) and IS-720 (0.41) had significant positive gca effect while Jhansi local showed significant negative gca effect (-0.69).

4.2.1.4 Internodal Length, cm

Three lines namely Acc. No. 846 (2.27), GD 65174-1 (0.69) and GD 65195 (0.59) recorded significant positive gca effects for internodal length. GD 65174-2 (-3.53) and GD 65239 (-0.03) recorded significant but negative gca effects. Among testers, IS-720 (1.43) and SSG-59-3 (0.37) had significant positive gca effects while only Jhansi local had significant negative gca effect (-1.81).

4.2.1.5 Leaf : Stem Ratio

Among lines, only GD 65195 showed significant positive gca effect (0.11) for leaf : stem ratio. Significant but negative gca effects were observed for Acc. No. 846 (-0.09), GD 65174-2 (-0.06) and GD 65174-1 (-0.07) and GD 65239 (-0.07). None of the testers showed significance for gca effects.

4.2.1.6 Leaf Number per Plant

The gca effect of lines showed significant values for leaf number per plant. The lines, Acc. No. 846 (37.84) and GD 65195 (14.39) had significant positive gca effects while the remaining three lines had significant but negative gca effects. Among testers, SSG-59-3 (36.72) had significant positive gca effect while IS-720 and Jhansi local showed significant negative gca effects of –19.26 and –17.47 respectively.

4.2.1.7 Leaf Weight per Plant, g

The general combining ability effects for leaf weight per plant had significant positive values for Acc. No. 846 (129.15) and GD 65195 (67.06). The lines, GD 65174-2 (-95.75), GD 65174-1 (-52.10) and GD 65239 (-48.35) had significant negative gca effects. Among testers, only SSG-59-3 had significant positive gca effect (74.81) while Jhansi local (-73.03) and IS-720 (-1.79) showed significant negative gca effects.

4.2.1.8 Days to 50 per cent Flowering

All lines had significant gca effects for days to 50 per cent flowering. Lines, GD 65195 (4.54) and GD 65174-2 (2.31) had significant positive gca effects. Significant negative gca effect was shown by GD 65239 (-2.98), GD 65174-1 (-2.89) and Acc. No. 846 (-0.98). Among testers, Jhansi local showed significant positive gca effect (2.52) while significant negative gca effects were shown by IS-720 (-1.54) and SSG-59-3 (-0.97).

4.2.1.9 Green Fodder Yield, t ha^{-1}

All the five lines had significant general combining ability effects for green fodder yield. The lines Acc. No. 846 (89.68), GD 65239 (50.56) and GD 65195 (48.21) had significant positive gca effects while the remaining lines showed negative gca effects. Among testers SSG-59-3 (92.13) recorded significant positive gca effect while Jhansi local (-72.61) and IS-720 (-19.52) recorded significant negative gca effects.

4.2.1.10 *Dry Fodder Yield, t ha^{-1}*

For dry fodder yield, the gca effect of lines showed significant values. The lines Acc. No. 846 (6.54), GD 65239 (3.75) and GD 65195 (3.58) had significant positive gca effects while others had significant negative gca effects. Among testers, SSG-59-3 (5.21) recorded significant positive gca effect while Jhansi local (-3.66) and IS-720 (-1.55) recorded significant negative gca effects.

4.2.1.11 *Crude Protein Content, %*

Among lines, the gca for crude protein content had significant positive values for GD 65195 (1.16) and Acc. No. 846 (0.37). Significant but negative gca effects were shown by lines GD 65174-1 (-0.81), GD 65239 (-0.65) and GD 65174-2 (-0.06). Among testers, Jhansi local (0.73) and SSG-59-3 (0.28) had significant positive gca effects while IS-720 had negative gca effect (-0.45).

4.2.1.12 *Crude Fibre Content, %*

Regarding the gca effects of lines, significantly negative gca effects were shown by GD 65195 (-0.52) and GD 65174-2 (-0.55) for crude fibre content. Among lines, only GD 65174-1 showed significant positive gca effect (1.15) for crude fibre content. Among testers, SSG-59-3 (-0.16) and Jhansi local (-0.28) had significant negative gca effects while IS-720 had significant positive gca effect (0.44).

4.2.1.13 *HCN Content, ppm*

Three lines *viz.*, GD 65239 (2.12), Acc. No. 846 (26.27) and GD 65174-1 (62.73) recorded significant positive gca effects for HCN content. Significant but negative gca effects were shown by GD 65174-2 (-25.78) and GD 65195 (-65.34). Among the testers, SSG-59-3 (4.96) and Jhansi local (1.88) had significant positive gca effects while only IS-720 had significant negative gca effect (-6.84).

4.2.2 Specific Combining ability effects

The specific combining ability effects of hybrids for 13 characters are given in Table 6 and Fig. 1.

4.2.2.1 Plant Height, cm

The specific combining ability effects of fourteen out of 15 hybrids were found to be significant for plant height. Five hybrids had significant positive sca effects. The highest positive effect was shown by the cross GD 65174-1 x SSG-59-3 (34.87). All other hybrids differed significantly from the hybrid GD 65174-1 x SSG-59-3 for sca effect. The lowest positively significant sca effect was shown by GD 65239 x IS-720 (15.68). In the case of negatively significant sca effects, the highest negative effect was recorded by GD 65195 x SSG-59-3 (-30.27) and the lowest by GD 65195 x Jhansi local (-2.45).

4.2.2.2 Tiller Number per Plant

Three out of 15 hybrids showed significant positive sca effects while two had significant negative sca effects. The highest positive significant sca effect was shown by GD65174-2 x Jhansi local (1.42) and lowest positive value by GD 65174-1 x IS-720 (0.53). All other hybrids differed significantly from the hybrid GD 65174-2 x Jhansi local for sca effects. GD 65174-2 x IS-720 recorded highest negatively significant sca effect (-1.42) while Acc. No. 846 x Jhansi local recorded the least negative effect.

4.2.2.3 Stem Girth, cm

Fourteen out of 15 hybrids had significant sca effect for stem girth. Six hybrids had significant positive sca effects. The highest positive sca effect was recorded by GD 65195 x IS 720 (3.81) and the least by Acc. No. 846 x SSG-59-3 (0.53). All the hybrids with significant positive sca effects except Acc. No. 846 x SSG-59-3 were on par with each other. Nine hybrids had significant negative sca effects. The hybrid Acc. No. 846 x

Table 6 Specific combining ability effects of hybrids

Characters / Treatments	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN content (ppm)
GD65174-1 × Jhansi local	-9.91**	-0.23	-0.65**	3.14**	0.10**	-18.58**	-20.81**	-3.77**	-14.06**	-2.23**	0.98**	-0.80**	19.91**
GD65174-1 × SSG-59-3	34.87**	-0.29	2.59**	0.86**	0.02	-10.17**	89.10**	-0.03	36.10**	3.57**	-1.21**	0.59**	0.68
GD65174-1 × IS-720	-24.95**	0.53*	1.95**	-3.99**	-0.12**	29.06**	-68.29**	3.79**	-22.05**	-1.34**	0.23	0.22	-20.59**
GD65174-2 × Jhansi local	22.95**	1.42**	-0.95**	2.47**	-0.04**	0.63	1.39	-7.22**	12.94**	-0.12	-2.72**	1.43**	9.04**
GD65174-2 × SSG-59-3	-23.17**	0.01	-0.91**	-1.71**	0.15**	-0.31	-49.75**	7.37**	-52.29**	-3.98**	0.49**	-0.14	23.15**
GD65174-2 × IS-720	0.21	-1.42**	1.85**	-0.77**	-0.10**	-0.33	48.35**	-0.16	39.35**	4.10**	2.23**	-1.28**	-32.19**
GD65195 × Jhansi local	-2.45*	0.25	-1.65**	-2.66**	0.15**	72.92**	-80.97**	13.10**	-45.19**	-3.21**	0.04	-0.22	-1.16*
GD65195 × SSG-59-3	-30.27**	-0.56	-2.21**	-6.44**	-0.30**	-43.97**	-260.31**	-5.46**	-277.53**	-17.31**	2.13**	-0.73**	-6.30**
GD65195 × IS-720	32.71**	0.31	3.81**	9.10**	0.15**	-29.54**	341.29**	-7.64**	322.72**	20.52**	-2.18**	0.95**	7.46**
SE	1.25	0.41	0.18	0.24	0.012	0.81	2.09	0.83	1.39	0.15	0.15	0.16	0.54
CD (0.05)	3.67	1.21	0.52	0.73	0.036	2.39	6.15	2.43	4.09	0.44	0.44	0.46	1.58

Table 6 Continued

Characters / Treatments	Plant height (cm)	Tiller number per plant	Stem girth (cm)	Internodal length (cm)	Leaf: stem ratio	Leaf number per plant	Leaf weight per plant (g)	Days to 50 per cent flowering	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})	Crude protein content (%)	Crude fibre content (%)	HCN content (ppm)
GD65239 × Jhansi local	-5.68**	-0.45	0.95**	3.57**	-0.04**	-20.88**	24.95**	0.06	-47.54**	-3.21**	0.76**	0.21	48.18**
GD65239 × SSG-59-3	-10.00**	-0.39	-0.01	0.79**	-0.01	-11.52**	21.60**	-0.69	172.22**	10.76**	-0.09	0.11	-54.91**
GD65239 × IS-720	15.68**	0.41	-0.95**	-4.37**	0.06**	32.41**	-46.55**	0.63	-124.68**	-7.55**	-0.66**	-0.32*	6.73**
Acc. No. 846 × Jhansi local	-4.91**	-0.98*	2.29**	-6.53**	-0.16**	-33.78**	75.44**	-2.18**	93.84**	8.78**	0.93**	-0.61**	-75.97**
Acc. No. 846 × SSG-59-3	28.57**	0.81*	0.53**	6.49**	0.15**	65.38**	199.35**	-1.19	121.50**	6.96**	-1.31**	0.18	37.38**
Acc. No. 846 × IS-720	-23.65**	0.18	-2.81**	0.03	0.01	-31.59**	-274.79**	3.38**	-215.35**	-15.73**	0.38*	0.43**	38.59**
SE	1.25	0.41	0.18	0.24	0.012	0.81	2.09	0.83	1.39	0.15	0.15	0.16	0.54
CD (0.05)	3.67	1.21	0.52	0.73	0.036	2.39	6.15	2.43	4.09	0.44	0.44	0.46	1.58

*Significant at 5 per cent level **Significant at 1 per cent level

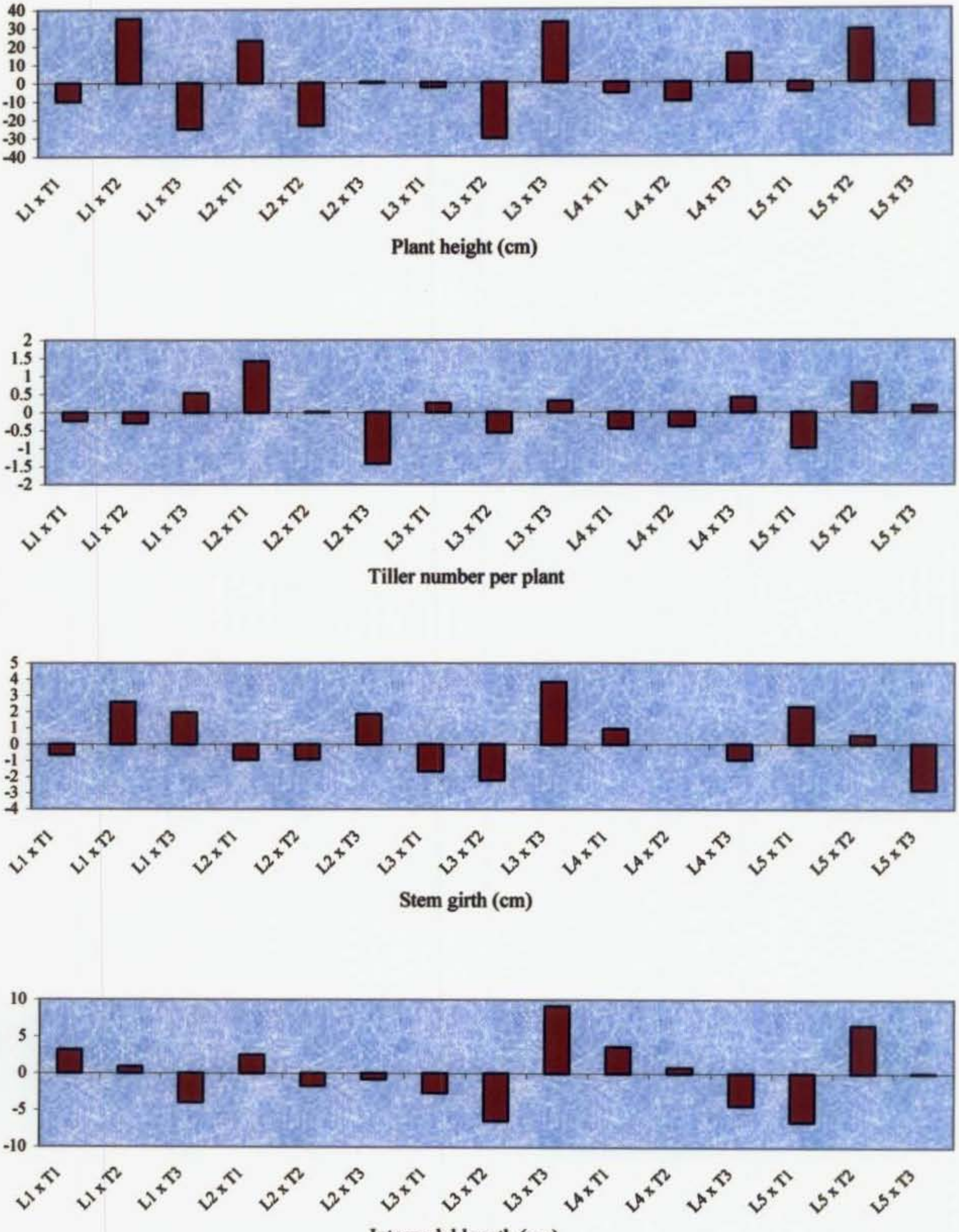
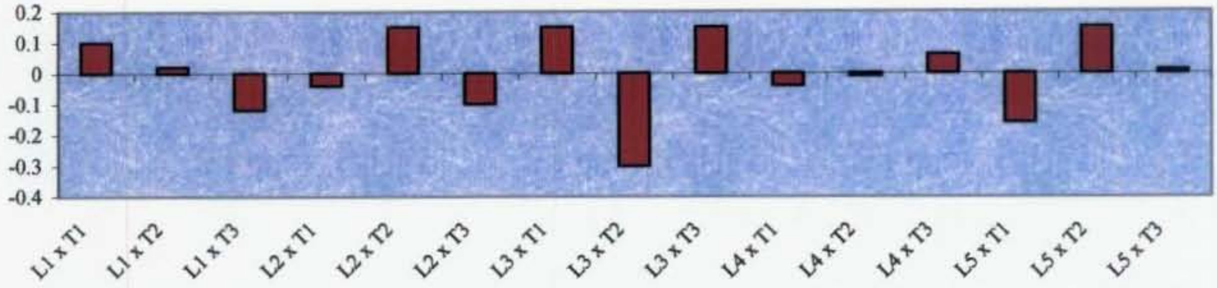
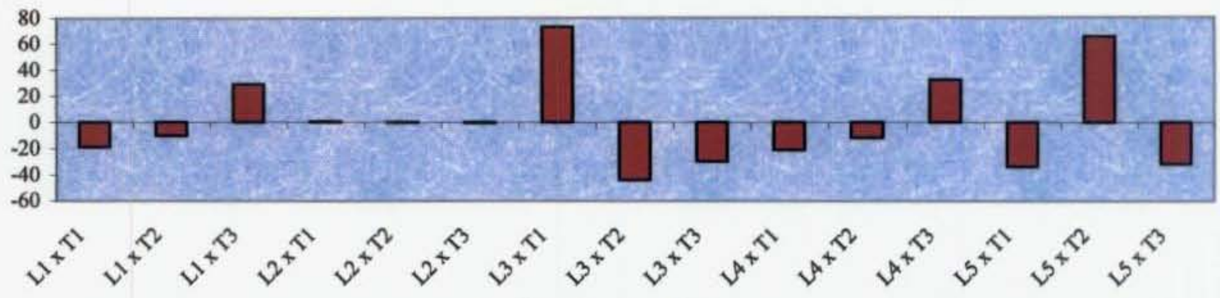


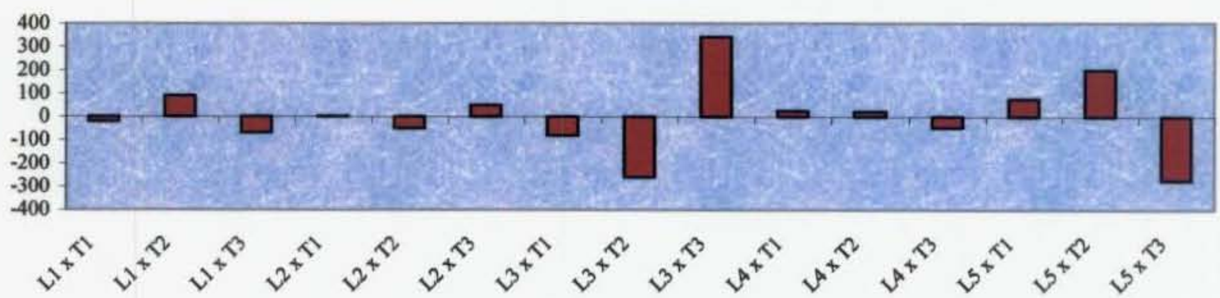
Fig. 1. Specific combining ability effects of hybrids



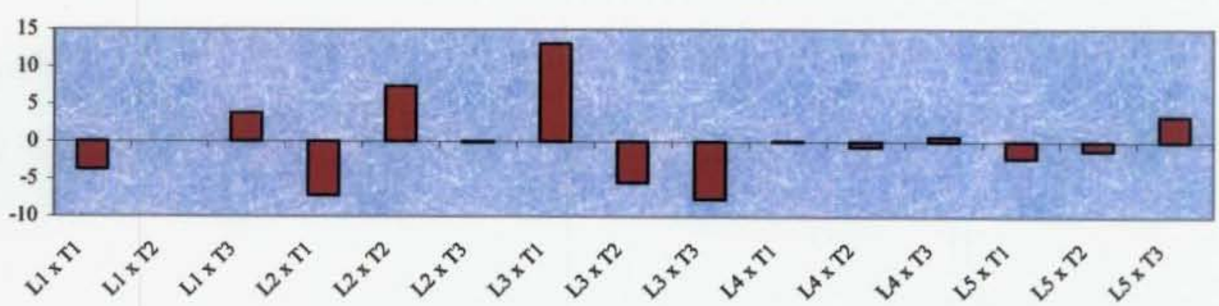
Leaf: stem ratio



Leaf number per plant



Leaf weight per plant (g)



Days to 50 per cent flowering

Fig. 1. Continued

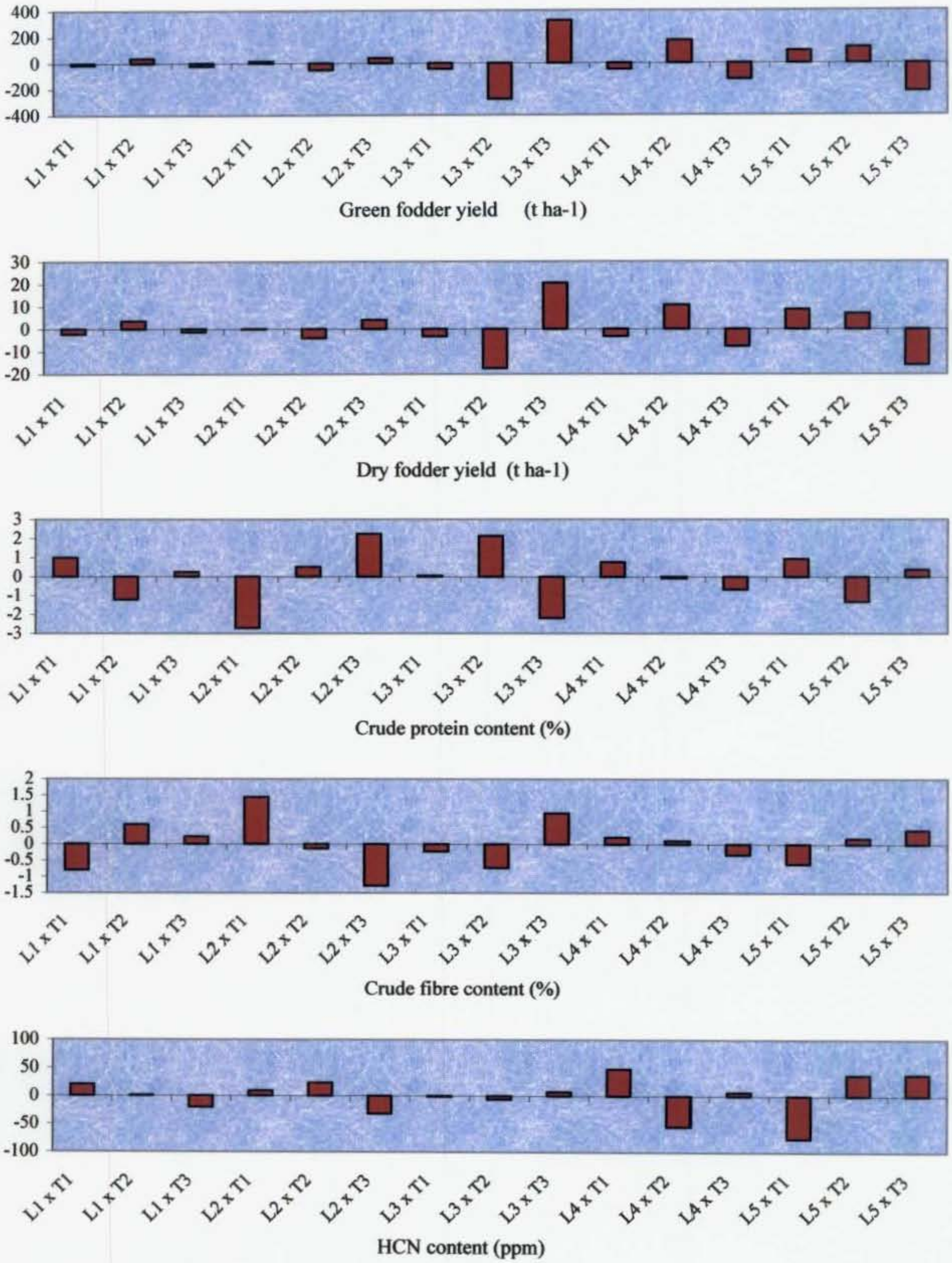


Fig. 1. Continued

IS-720 had the highest negative value (-2.81) while GD 65174-1 x Jhansi local had the least negative value (-0.65).

4.2.2.4 Internodal Length, cm

All hybrids except Acc. No. 846 x IS-720 had significant sca effect for internodal length. Out of the 15 hybrids, seven had significant negative sca effects. The hybrid. Acc. No. 846 x Jhansi local had the highest negative effect of –6.53 and GD 65174-2 x IS-720 had the lowest negative effect of –0.77. The positively significant sca effects ranged from 0.79 (GD 65239 x SSG-59-3) to 9.10 (GD 65195 x IS-720).

4.2.2.5 Leaf : Stem Ratio

Regarding leaf : stem ratio, six out of 15 hybrids had positive significant sca effects while six hybrids had significant negative sca effects. The highest positively significant sca effect was recorded by the hybrids GD 65174-2 x SSG-59-3, GD 65195 x Jhansi local, GD 65195 x IS-720 and Acc. No. 846 x SSG-59-3 (0.15). The hybrid GD 65239 x IS-720 had the lowest positive sca effect. The significant negative sca effects ranged from –0.30 (GD 65195 x SSG-59-3) to –0.04 (GD 65174-2 x Jhansi local and GD 65195 x IS-720).

4.2.2.6 Leaf Number per Plant

All the hybrids except GD 65174-1 x Jhansi local, GD 65174-1 x SSG-59-3 and GD 65174-1 x IS-720 had significant sca effects for leaf number per plant. Four out of 15 crosses had the highest positive significant sca effects. The hybrid GD 65195 x Jhansi local had the highest positive significant sca effect of 72.92 while GD 65174-1 x IS-720 had the lowest value of 29.06. All the hybrids differed significantly from GD 65195 x Jhansi local. Eight hybrids showed significant negative sca effects ranging from –43.37 in GD 65195 x SSG-59-3 to –10.17 in GD 65174-1 x SSG-59-3.

4.2.2.7 Leaf Weight per Plant, g

All the sca effects for leaf weight per plant were found to be significant except for the hybrid GD 65174-2 x Jhansi local. Out of the 15 hybrids, seven showed positive sca effects and the remaining seven showed negative sca effects. The highest positively significant sca effect was shown by the hybrid GD 65195 x IS-720 (341.29) and the lowest by GD 65239 x SSG-59-3 (21.60). The hybrids differed significantly from each other. In the case of negatively significant sca effects, the values ranged from –274.79 (Acc. No. 846 x IS-720) to –20.81 (GD 65174-1 x Jhansi local).

4.2.2.8 Days to 50 per cent Flowering

Four out of 15 hybrids had positively significant sca effects while five hybrids had significant negative sca effects. The highest positive significant sca effect was recorded by the hybrid GD 65195 x Jhansi local (13.10) and the lowest by Acc. No. 846 x IS-720 (3.38). The hybrids differed significantly from each other. In the case of negatively significant sca effects, the values ranged from –7.64 (GD 65195 x IS-720) to –2.18 (Acc. No. 846 x Jhansi local).

4.2.2.9 Green Fodder Yield, t ha^{-1}

All the sca effects were found to be significant for green fodder yield. Seven out of 15 hybrids showed significant positive sca effects. The highest positive significant sca effect was recorded by the hybrid GD 65195 x IS-720 (322.72) while the lowest significant positive sca effect was for GD 65174-2 x Jhansi local. All the seven hybrids differed significantly from each other. Eight hybrids had negatively significant sca effects ranging from –277.53 to –14.06 in GD 65195 x SSG-59-3 and GD 65174-1 x Jhansi local respectively.

4.2.2.10 *Dry Fodder Yield, t ha⁻*

All the hybrids except GD 65174-2 x Jhansi local had significant sca effects for dry fodder yield. Six out of 15 hybrids had significant positive sca effects. The hybrids, GD 65195 x IS-720 recorded the highest positive sca effect (20.52) while GD 65174-1 x SSG-59-3 recorded the lowest value (3.57). The hybrid GD 65195 x IS-720 was significantly superior to all other hybrids for dry fodder yield. Eight hybrids had negatively significant sca effects which ranged from –17.31 for GD 65195 x SSG-59-3 to–0.12 for GD 65174-2 x Jhansi local.

4.2.2.11 *Crude Protein Content, %*

Seven out of 15 hybrids had significant positive sca effects for crude protein content. The highest significant positive sca effect was recorded by GD 65174-2 x IS-720 (2.25) and the lowest by Acc. No. 846 x IS-720 (0.38). All the hybrids differed significantly from GD 65174-2 x IS-720. Five hybrids showed significant negative sca effects ranging from –2.72 for GD 65174-2 x Jhansi local to –0.66 for GD 65239 x IS-720.

4.2.2.12 *Crude Fibre Content, %*

For crude fibre content, nine out of 15 hybrids had significant sca effects. Five hybrids had significant negative sca. The highest negatively significant sca effect was shown by the hybrid GD 65174-2 x IS-720 (-1.28). The lowest value was recorded by GD 65239 x IS-720 (-0.32). Four hybrids showed significant positive sca effects. The highest positively significant sca effect was shown by GD 65174-2 x Jhansi local (1.43) and lowest by Acc. No. 846 x IS-720 (0.43).

4.2.2.13 *HCN Content, ppm*

All the hybrids except GD 65174-1 x SSG-59-3 had significant sca effects for HCN content. Eight out of 15 hybrids had significant positive sca effects. The hybrids GD 65239 x Jhansi local recorded the highest positive sca effect (48.18) while GD 65239 x IS-720 recorded the lowest value (6.73). Six F_1s showed significant sca effect was shown by Acc. No. 846 x Jhansi local (-75.97) and lowest by GD 65195 x Jhansi local (-1.16).

4.3 COMPONENTS OF GENETIC VARIANCE

Dominance variance were high for all the characters. Additive variance was not estimable for the characters except tiller number per plant, leaf number per plant, crude fibre content and HCN content. The ratio of additive variance to dominance variance was less than unity for HCN content (0.06), leaf number per plant (0.0178), crude fibre content (0.017) and tiller number per plant (0.0035), while for all other characters the ratio was not estimable.

4.4 PROPORTIONAL CONTRIBUTION

The proportional contribution of lines, testers and crosses to total variance of the characters under study is presented in Table 7 and Fig. 2

The values ranged from 10.99 for stem girth to 62.82 for HCN content among lines. Among testers, the values ranged from 0.82 for HCN content to 28.45 for leaf number per plant. In the case of crosses, the values ranged from 36.36 for HCN content to 83.44 for stem girth.

The crosses had contributed maximum to the total variance for all the characters and the testers had the least contribution to the total variance with respect to crosses and lines.

4.5 HETEROSIS

The superiority of the hybrids was estimated on the basis of mid parental value (relative heterosis), better parental value (heterobeltiosis) and standard check, COFS-29 (standard heterosis) for the 13 characters studied. The graphical representation of relative heterosis, heterobeltiosis and standard heterosis for thirteen characters are given in Fig. 3. The values are expressed in percentage.

Table 7 Proportional contribution of lines, testers and line x testers to the total variance

Sl. No.	Character	Line, %	Tester, %	Line x Tester, %
1	Plant height (cm)	34.43	8.32	57.25
2	Tiller number per plant	41.86	2.59	55.54
3	Stem girth (cm)	10.99	5.57	83.44
4	Internodal length (cm)	15.08	7.42	77.49
5	Leaf : stem ratio	26.72	7.29	65.98
6	Leaf number per plant	22.62	28.45	48.93
7	Leaf weight per plant (g)	21.51	11.07	67.42
8	Days to 50 per cent flowering	22.28	8.13	69.58
9	Green fodder yield ($t\ ha^{-1}$)	19.68	15.03	65.29
10	Dry fodder yield ($t\ ha^{-1}$)	24.72	10.39	64.88
11	Crude protein content (%)	19.26	10.12	70.62
12	Crude fibre content (%)	14.54	10.51	48.95
13	HCN content (ppm)	62.82	0.82	36.36

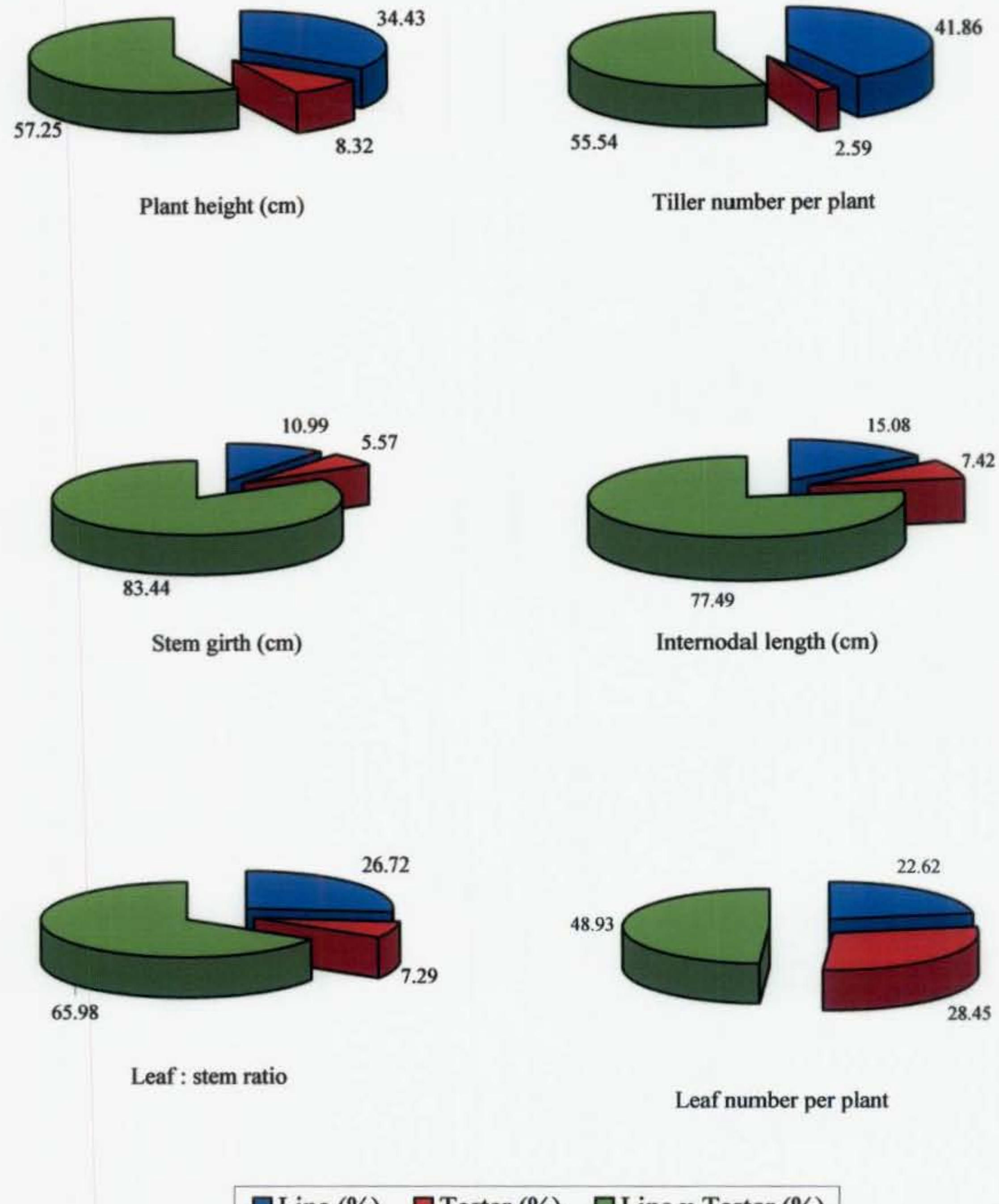


Fig. 2. Proportional contribution of lines, testers and line x tester to the total variance

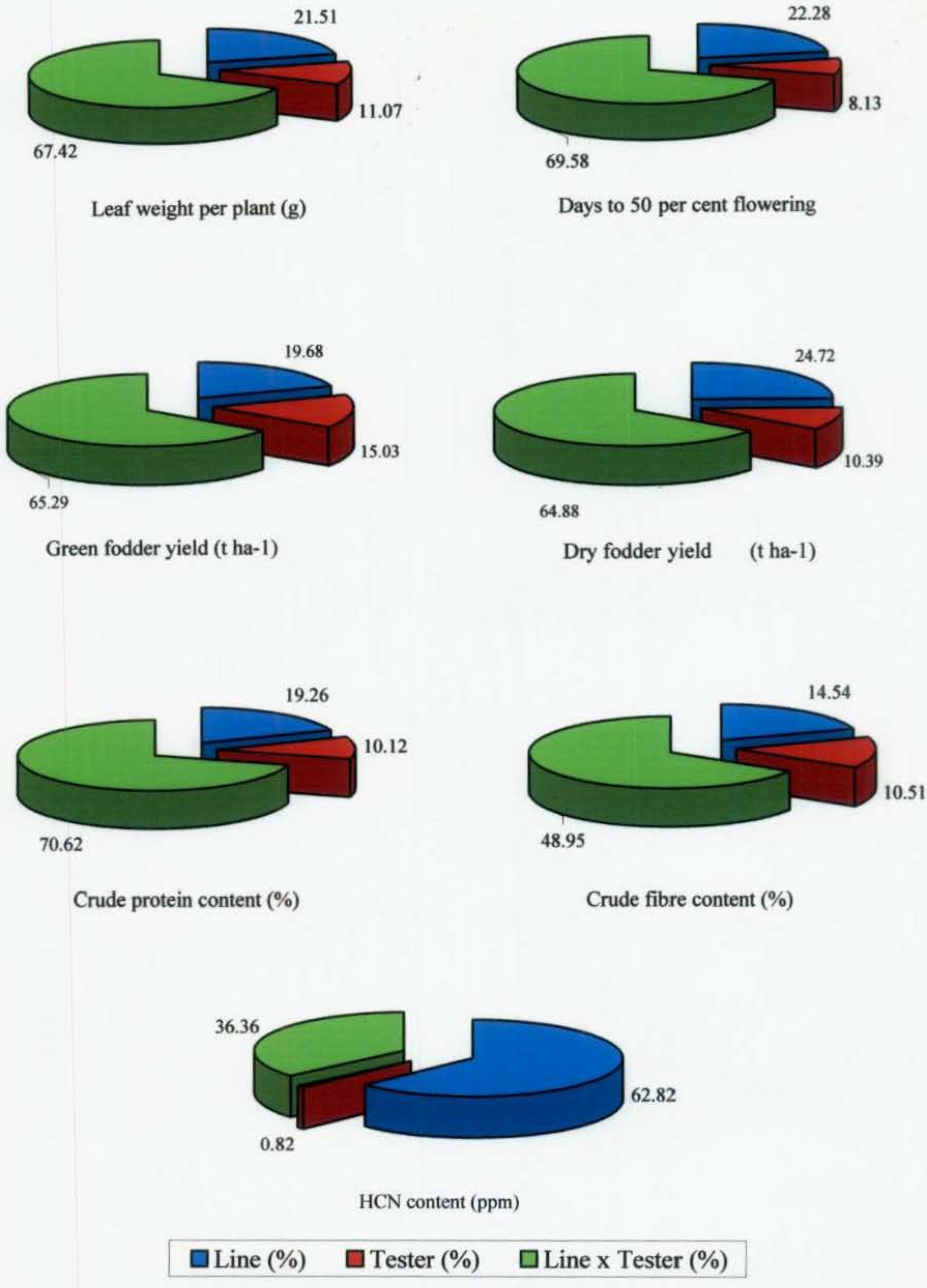


Fig. 2. Continued

4.5.1 Plant Height, cm

The heterosis per cent for plant height ranged from –32.02 (GD 65174-2 x SSG-59-3) to 12.76 (GD 65195 x IS-720) for relative heterosis, from –39.24 (GD 65174-2 x SSG-59-3) to 8.04 (Acc. No. 846 x SSG-59-3) for heterobeltiosis and –44.07 (GD 65174-2 x SSG-59-3) to 0.73 (GD 65195 x IS-720) for standard heterosis (Table 8). Positive and significant relative heterosis was shown by hybrids GD 65174-1 x SSG-59-3 (8.31 per cent), GD 65195 x IS-720 (12.76 per cent), GD 65239 x IS-720 (9.93 per cent) and Acc. No. 846 x SSG-59-3 (10.06 pr cent). Two hybrids showed significant positive heterobeltiosis, GD 65174-1 x SSG-59-3 (7.51 per cent) and Acc. No. 846 x SSG-59-3 (8.04 per cent). Maximum standard heterosis was recorded by GD 65195 x IS-720 (0.73 per cent).

4.5.2 Tiller Number per Plant

Eight hybrids showed significant positive heterotic vigour over the mid parents for this character. The heterosis per cent for tiller number per plant ranged from –28.36 (Acc. No. 846 x Jhansi local) to 118.18 (GD 65174-2 x Jhansi local). Positive significant heterobeltiosis was recorded by the hybrid GD 65174-2 x Jhansi local (65 per cent). Hybrids showing positive significant standard heterosis was GD 65174-1 x IS-720 (13.58 per cent) (Table 9), GD 65174-2 x Jhansi local (62.96 per cent), GD 65174-2 x SSG-59-3 (20.99 per cent), GD 65195 x Jhansi local (13.58 per cent) and GD 65195 x IS-720 (16.05 per cent).

4.5.3 Stem Girth

The heterosis per cent for stem girth ranged from –34.15 (GD 65174-2 x Jhansi local) to 218.03 (GD 65195 x IS-720) for relative heterosis, from –50.70 (Acc. No. 846 x IS-720) to 185.29 (GD 65195 x IS-720) for heterobeltiosis and –61.97 (GD 65174-2 x Jhansi local) to 36.62 (GD 65195 x IS-720) for standard heterosis (Table 10). Eight hybrids showed significant positive relative heterosis. Five hybrid showed

Table 8. Heterosis (%) for plant height, cm

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-21.09	-24.76	-31.76
GD65174-1 × SSG-59-3	8.31**	7.51**	-1.03**
GD65174-1 × IS-720	-27.76	-31.13	-31.13
GD65174-2 × Jhansi local	-9.85	-15.19	-30.24
GD65174-2 × SSG-59-3	-32.02	-39.24	-44.07
GD65174-2 × IS-720	-22.76	-33.38	-33.38
GD65195 × Jhansi local	-6.18	-8.22	-24.51**
GD65195 × SSG-59-3	-17.25	-23.27	-29.36
GD65195 × IS-720	12.76**	0.73	0.73**
GD65239 × Jhansi local	-0.91	-3.09	-20.29**
GD65239 × SSG-59-3	1.20	-6.18	-13.63**
GD65239 × IS-720	9.93**	-1.81	-1.81**
Acc. No. 846 × Jhansi local	-13.10	-16.25	-25.73**
Acc. No. 846 × SSG-59-3	10.06**	8.04**	-0.54**
Acc. No. 846 × IS-720	-22.52	-26.91	-26.91
CD (0.05)	3.18	3.67	3.67

**Significant at 1 per cent level

Table 9. Heterosis (%) for tiller number per plant

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	23.58	-5.00	-6.17
GD65174-1 × SSG-59-3	11.29	-14.81	-14.81
GD65174-1 × IS-720	52.07**	17.94	13.58*
GD65174-2 × Jhansi local	118.18**	65.00**	62.96**
GD65174-2 × SSG-59-3	60.65**	20.99	20.99*
GD65174-2 × IS-720	27.73**	-2.56	-6.17
GD65195 × Jhansi local	40.46*	15.00	13.58*
GD65195 × SSG-59-3	6.06*	-13.58	-13.58
GD65195 × IS-720	45.74**	20.51	16.05*
GD65239 × Jhansi local	14.75	-12.50	-13.58
GD65239 × SSG-59-3	20.32	-8.64	-8.64
GD65239 × IS-720	46.67*	12.82	8.64
Acc. No. 846 × Jhansi local	-28.36	-40.00	-40.74
Acc. No. 846 × SSG-59-3	15.55	-3.70	-3.70
Acc. No. 846 × IS-720	9.09	-7.69	-11.11
CD (0.05)	1.05	1.21	1.21

*Significant at 5 per cent level **Significant at 1 per cent level

significant positive heterobeltiosis. Hybrids of GD 65174-2 x SSG-59-3 (-47.89 per cent), GD 65174-2 X SSG-59-3 (-47.89 per cent), GD 65174-2 x IS-720 (-7.04 per cent), Acc. No. 846 x SSG-59-3 (-5.63 per cent) and GD 65239 x Jhansi local and GD 65239 x SSG-59-3 showing significant negative standard heterosis for this character (-39.44 per cent). Four hybrids showing significant positive standard heterosis.

4.5.4 Internodal Length

The extent of heterosis over mid parent ranged between -29.97 per cent (Acc. No. 846 x Jhansi local) and 64.09 per cent (GD 65195 x IS-720) for internodal length. Hybrids of GD 65195 x IS-720 (64.09 per cent), GD 65239 x Jhansi local (8.27 per cent), GD 65239 x SSG-59-3 (3.96 per cent), Acc. No. 846 x SSG-59-3 (53.46 per cent) and Acc. No. 846 x IS-720 (15.84 per cent) showing significant positive relative heterosis for this character. Three hybrids showed significant positive heterobeltiosis was GD 65195 x IS-720 (50.76 per cent), Acc. No. 846 x SSG-59-3 (47.34 per cent) and Acc. No. 846 x IS-720 (13.19 per cent). Eleven hybrids showed significant negative standard heterosis (Table 11). GD 65195 x IS-720 (17.39 per cent) and Acc. No. 846 x SSG-59-3 (9.49 per cent) showed significant positive standard heterosis.

4.5.5 Leaf : Stem Ratio

Nine hybrids showed significant positive relative heterosis for this character. The heterosis per cent for leaf/stem ratio ranged from -28.24 (GD 65239 x Jhansi local) to 175.00 (GD 65195 x IS-720) for relative heterosis, from –30.88 (GD65239 x Jhansi local) to 130.64 (GD 65195 x IS-720) for heterobeltiosis and –32.35 (GD 65195 x SSG-59-3) to 110.29 (GD 65195 x IS-720) for standard heterosis (Table 12). Nine hybrid showed significant positive heterobeltiosis for this character. Four hybrids showed significant positive standard heterosis was GD 65195 x Jhansi local (79.41 per cent), GD 65195 x IS-720 (110.29 per cent), Acc. No. 846 x SSG-59-3 (95.59 per cent) and Acc. No. 846 x IS-720 (63.23 per cent).

Table 10. Heterosis (%) for stem girth, cm

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	0.00	0.00	-50.70
GD65174-1 × SSG-59-3	123.19**	120.00**	8.45**
GD65174-1 × IS-720	6.45	-5.71	-53.52
GD65174-2 × Jhansi local	-34.15	-42.55	-61.97
GD65174-2 × SSG-59-3	-8.64	-21.28	-47.89*
GD65174-2 × IS-720	78.38**	40.42**	-7.04**
GD65195 × Jhansi local	-10.14	-11.43	-56.34
GD65195 × SSG-59-3	2.94	2.94	-50.70
GD65195 × IS-720	218.03**	185.29**	36.62**
GD65239 × Jhansi local	24.64**	22.86**	-39.44**
GD65239 × SSG-59-3	26.47**	26.47**	-39.44**
GD65239 × IS-720	14.75*	2.94	-50.70
Acc. No. 846 × Jhansi local	41.51**	5.63	5.63**
Acc. No. 846 × SSG-59-3	27.62**	-5.63	-5.63**
Acc. No. 846 × IS-720	-28.57	-50.70	-50.70
CD (0.05)	0.44	0.51	0.51

*Significant at 5 per cent level **Significant at 1 per cent level

Table 11. Heterosis (%) for internodal length, cm

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-2.37	-18.58	-18.58**
GD65174-1 × SSG-59-3	-3.75	-18.97	-18.97**
GD65174-1 × IS-720	-25.78	-33.99	-33.99**
GD65174-2 × Jhansi local	-11.29	-15.13	-37.94**
GD65174-2 × SSG-59-3	-23.46	-25.94	-45.85**
GD65174-2 × IS-720	-17.80	-20.30	-37.94**
GD65195 × Jhansi local	-11.98	-13.02	-41.89**
GD65195 × SSG-59-3	-22.48	-24.28	-48.22
GD65195 × IS-720	64.09**	50.76**	17.39**
GD65239 × Jhansi local	8.27**	-1.46	-19.76**
GD65239 × SSG-59-3	3.96*	-4.37	-22.13**
GD65239 × IS-720	-22.58	-24.27	-38.34**
Acc. No. 846 × Jhansi local	-29.97	-33.51	-50.59
Acc. No. 846 × SSG-59-3	53.46**	47.34**	9.49**
Acc. No. 846 × IS-720	15.84**	13.19**	-11.86**
CD (0.05)	0.62	0.72	0.72

*Significant at 5 per cent level **Significant at 1 per cent level

4.5.6 Leaf Number per Plant

Significant positive relative heterosis was observed for all the 14 hybrids, the range being 14.78 per cent (GD 65239 x Jhansi local) to 363.79 per cent (GD 65195 x Jhansi local) except GD 65174-1 x Jhansi local. Ten hybrids had positively significant values while one hybrid had negatively significant heterobeltiosis (Table 13). Maximum positively significant standard heterosis was recorded for Acc. No. 846 x SSG-59-3 (131.39 per cent) followed by GD 65195 x Jhansi local (61.43 per cent). GD 65239 x SSG-59-3 (8.93 per cent) and GD 65174-2 x SSG-59-3 (5.89 per cent).

4.5.7 Leaf Weight per Plant, g

The heterosis per cent for leaf weight per plant ranged from –47.73 (Acc. No. 846 x IS-720) to 294.11 GD 65195 x IS-720) for relative heterosis, from –50.28 (GD 65174-2 x Jhansi local) to 259.64 (GD 65195 x IS-720) for heterobeltiosis and –59.87 (GD 65174-2 x Jhansi local) to 232.44 (GD 65195 x IS-720) for standard heterosis (Table 14). Nine hybrids showed significant positive heterosis for relative heterosis. Eight hybrid showed significant positive heterosis over better parent. Six hybrids showed positive significant and two hybrids showed significant negative heterosis for this character.

4.5.8 Days to 50 per cent Flowering

The hybrids exhibited significant negative standard heterosis. Two hybrids showed significant negative relative heterosis. The hybrid GD 65195 x Jhansi local (23.51 per cent) exhibited the highest significant positive relative heterosis. Two hybrids recorded significant positive heterobeltiosis with the hybrids GD 65174-2 x SSG-59-3 (8.61 per cent) and GD 65195 x Jhansi local (18.13 per cent). Five hybrids recorded significant negative standard heterosis with the hybrids GD 65174-1 x IS-720 (-7.09 per cent) and Acc. No. 846 x IS-720 (-6.77 per cent) (Table 15).

Table 12. Heterosis (%) for leaf : stem ratio

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	32.74**	10.29*	10.29
GD65174-1 × SSG-59-3	48.00**	34.54**	8.82
GD65174-1 × IS-720	-4.67	-17.74	-25.00
GD65174-2 × Jhansi local	-21.60	-27.94	-27.94
GD65174-2 × SSG-59-3	82.14**	78.95**	50.00
GD65174-2 × IS-720	-4.20	-8.06	-16.18
GD65195 × Jhansi local	121.82**	79.41**	79.41**
GD65195 × SSG-59-3	-5.15	-16.36	-32.35
GD65195 × IS-720	175.00**	130.64**	110.29**
GD65239 × Jhansi local	-28.24	-30.88	-30.88
GD65239 × SSG-59-3	16.95**	9.52*	1.47
GD65239 × IS-720	40.80**	39.68**	29.41
Acc. No. 846 × Jhansi local	-12.69	-19.12	-19.12
Acc. No. 846 × SSG-59-3	135.39**	129.31**	95.59**
Acc. No. 846 × IS-720	85.00**	79.03**	63.23**
CD (0.05)	0.031	0.035	0.035

*Significant at 5 per cent level **Significant at 1 per cent level

Table 13. Heterosis (%) for leaf number per plant

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-5.57	-33.27	-66.57
GD65174-1 × SSG-59-3	59.40**	-3.79	-3.79**
GD65174-1 × IS-720	128.39**	62.54**	-20.51
GD65174-2 × Jhansi local	57.76**	5.28*	-47.25
GD65174-2 × SSG-59-3	81.37**	5.89**	5.89**
GD65174-2 × IS-720	52.27**	2.24	-50.00
GD65195 × Jhansi local	363.79**	222.21**	51.43**
GD65195 × SSG-59-3	66.43**	-0.55**	-0.55**
GD65195 × IS-720	67.76**	17.35**	-42.61
GD65239 × Jhansi local	14.78**	-9.16	-54.49
GD65239 × SSG-59-3	68.64**	8.93**	8.93**
GD65239 × IS-720	148.18**	98.16**	-3.09**
Acc. No. 846 × Jhansi local	112.16**	56.37**	-21.60
Acc. No. 846 × SSG-59-3	273.95**	131.39**	131.39**
Acc. No. 846 × IS-720	116.70**	61.02**	-21.26
CD (0.05)	2.07	2.39	2.39

**Significant at 1 per cent level

Table 14. Heterosis (%) for leaf weight per plant, g

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-21.68	-36.25	-48.94
GD65174-1 × SSG-59-3	133.49**	127.66**	82.33**
GD65174-1 × IS-720	-26.79**	-31.68	-36.85
GD65174-2 × Jhansi local	-38.73	-50.28	-59.87
GD65174-2 × SSG-59-3	13.99**	10.72**	-10.62**
GD65174-2 × IS-720	15.88**	8.54**	0.33**
GD65195 × Jhansi local	28.17**	6.34**	-18.89**
GD65195 × SSG-59-3	-14.59	-14.69	-34.94
GD65195 × IS-720	294.11**	259.64**	232.44**
GD65239 × Jhansi local	18.61**	-2.60	-23.73
GD65239 × SSG-59-3	94.12**	91.38**	49.86**
GD65239 × IS-720	-10.81	-17.63	-23.86
Acc. No. 846 × Jhansi local	156.01**	92.39**	92.39**
Acc. No. 846 × SSG-59-3	275.70**	230.79**	230.79**
Acc. No. 846 × IS-720	-47.73	-49.70	-49.71
CD (0.05)	5.32	6.14	6.14

**Significant at 1 per cent level

Table 15. Heterosis (%) for days to 50 per cent flowering

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-7.88	-13.22	-13.22
GD65174-1 × SSG-59-3	-5.09	-8.47	-12.90
GD65174-1 × IS-720	-1.74	-6.29	-8.71**
GD65174-2 × Jhansi local	-2.98	-10.97	-10.97
GD65174-2 × SSG-59-3	15.67**	8.61**	3.35**
GD65174-2 × IS-720	2.67	-4.63	-7.09**
GD65195 × Jhansi local	23.51**	18.13**	18.13**
GD65195 × SSG-59-3	-3.81	-5.76	-10.32
GD65195 × IS-720	-8.72	-11.59	-13.87
GD65239 × Jhansi local	-2.81	-8.39	-8.39**
GD65239 × SSG-59-3	-6.22	-9.49	-13.87
GD65239 × IS-720	-6.31	-10.59	-12.90
Acc. No. 846 × Jhansi local	-3.25	-8.71	-8.71*
Acc. No. 846 × SSG-59-3	-4.21	-7.46	-11.93
Acc. No. 846 × IS-720	0.17	-4.30	-6.77**
CD (0.05)	2.11	2.44	2.44

*Significant at 5 per cent level **Significant at 1 per cent level

GD 65174-2 x SSG-59-3 and GD 65193 x Jhansi local ranged being 3.35 to 18.13.

4.5.9 Green Fodder yield, t ha^{-1}

The heterosis value ranged from –31.81 per cent to 488.76 per cent for relative heterosis, from –45.15 per cent to 375.69 per cent for heterobeltiosis and –67.18 per cent to 253.67 per cent for heterosis in the hybrids of GD 65174-1 x Jhansi local, GD 65195 x IS-720 respectively. Ten hybrids showed positive significant heterosis for relative heterosis and heterobeltiosis for green fodder yield. Nine hybrids showed positive standard heterosis for this character (Table 16).

4.5.10 Dry Fodder Yield, t ha^{-1}

Significant positive relative heterosis for dry fodder yield was exhibited by twelve hybrids, of which the maximum value was shown by GD 65195 x IS-720 (506.24 per cent). Ten hybrids showed significant positive heterosis and standard heterosis for this character (Table 17).

4.5.11 Crude Protein Content, %

Seven hybrids showed significant positive relative heterosis for this character. The highest significant positive relative heterosis was shown by the hybrid GD 65195 x SSG-59-3 (45.68 per cent). Seven hybrids showed significant positive heterosis for better parent. GD 65174-2 x IS-720 (10.55 per cent), GD 65195 x Jhansi local (13.29 per cent), GD 65195 x SSG-59-3 (27.72 per cent) and Acc. No. 846 x Jhansi local (14.63 per cent) showed significant positive standard heterosis for crude protein content (Table 18).

4.5.12 Crude Fibre Content, %

Only two hybrids *viz.*, GD 65174-1 x SSG-59-3, GD 65174-1 x IS-720 showed significant negative standard heterosis. The values being –7.4 and –6.73 respectively. None of the hybrids showed significant positive values for relative heterosis and heterobeltiosis (Table 19).

Table 16. Heterosis (%) for green fodder yield, t ha^{-1}

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-31.81	-45.15	-67.18
GD65174-1 × SSG-59-3	116.67**	82.02**	60.13**
GD65174-1 × IS-720	-11.26	-19.92	-40.46
GD65174-2 × Jhansi local	-5.16	-33.33	-40.16
GD65174-2 × SSG-59-3	33.67**	32.34**	18.78**
GD65174-2 × IS-720	30.32**	19.14**	6.93**
GD65195 × Jhansi local	153.60**	127.68**	4.26**
GD65195 × SSG-59-3	-3.98	-27.00	-35.78
GD65195 × IS-720	488.76**	375.69**	253.67**
GD65239 × Jhansi local	91.30**	43.67**	4.26**
GD65239 × SSG-59-3	313.65**	277.44**	232.05**
GD65239 × IS-720	22.54**	21.07**	-9.98
Acc. No. 846 × Jhansi local	209.59**	111.19**	111.19**
Acc. No. 846 × SSG-59-3	245.98**	225.18**	225.18**
Acc. No. 846 × IS-720	-31.77	-40.52	-40.52
CD (0.05)	3.55	4.09	4.09

**Significant at 1 per cent level

Table 17. Heterosis (%) for dry fodder yield, t ha^{-1}

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-29.55	-39.79	-69.20
GD65174-1 × SSG-59-3	127.73**	78.64**	60.62**
GD65174-1 × IS-720	-7.06	-20.64	-42.65
GD65174-2 × Jhansi local	18.81**	-16.60	-25.09
GD65174-2 × SSG-59-3	32.59**	32.53**	19.16**
GD65174-2 × IS-720	61.56**	45.76**	30.93**
GD65195 × Jhansi local	213.22**	181.77**	27.92**
GD65195 × SSG-59-3	20.73**	-9.15	-18.32
GD65195 × IS-720	506.24**	393.57**	256.64**
GD65239 × Jhansi local	132.15**	72.10**	29.38**
GD65239 × SSG-59-3	301.66**	268.75**	231.55**
GD65239 × IS-720	48.86**	45.97**	9.73**
Acc. No. 846 × Jhansi local	281.82**	160.18**	160.18**
Acc. No. 846 × SSG-59-3	239.70**	220.57**	222.57**
Acc. No. 846 × IS-720	-28.08	-38.07	-38.05
CD (0.05)	0.38	0.44	0.44

**Significant at 1 per cent level

Table 18. Heterosis (%) for crude protein content, %

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	12.79**	5.67**	-0.47
GD65174-1 × SSG-59-3	-33.80	-39.79	-43.29
GD65174-1 × IS-720	-8.98	-21.70	-26.25
GD65174-2 × Jhansi local	-34.11	-39.95	-39.95
GD65174-2 × SSG-59-3	1.05	-10.49	-10.49
GD65174-2 × IS-720	31.71**	10.55**	10.55**
GD65195 × Jhansi local	25.54**	15.37**	13.29**
GD65195 × SSG-59-3	45.68**	30.07**	27.72**
GD65195 × IS-720	-18.26	-30.88	-32.13
GD65239 × Jhansi local	10.14**	1.86*	-1.33
GD65239 × SSG-59-3	-15.24**	-23.86	-26.25
GD65239 × IS-720	-22.38	-34.00	-36.07
Acc. No. 846 × Jhansi local	43.84**	39.28**	14.63**
Acc. No. 846 × SSG-59-3	-7.75*	-7.79	-28.86
Acc. No. 846 × IS-720	26.38**	18.80**	-8.42
CD (0.05)	0.38	0.093	0.093

**Significant at 1 per cent level

Table 19. Heterosis (%) for crude fibre content, %

Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	-8.54	-11.64	-11.64
GD65174-1 × SSG-59-3	-4.14	-7.38	-7.40*
GD65174-1 × IS-720	-2.47	-4.88	-6.73*
GD65174-2 × Jhansi local	-6.09	-10.15	-10.15
GD65174-2 × SSG-59-3	-10.36	-14.22	-14.25
GD65174-2 × IS-720	-11.02	-14.06	-15.74
GD65195 × Jhansi local	-10.43	-14.69	-14.69
GD65195 × SSG-59-3	-11.59	-15.79	-15.82
GD65195 × IS-720	-3.88	-7.59	-9.30
GD65239 × Jhansi local	-6.59	-12.34	-12.34
GD65239 × SSG-59-3	-6.55	-12.29	-12.31
GD65239 × IS-720	-5.04	-10.05	-11.81
Acc. No. 846 × Jhansi local	-10.23	-14.21	-14.21
Acc. No. 846 × SSG-59-3	-7.56	-11.64	-11.67
Acc. No. 846 × IS-720	-4.08	-7.47	-9.27
CD (0.05)	1.26	1.016	1.016

*Significant at 5 per cent level

4.5.13 HCN Content, ppm

Six hybrids showed significant positive relative heterosis ranging from 6.89 (GD 65174-1 x IS-720) to 85.96 (Acc. No. 846 x SSG-59-3) for HCN content. Acc. No. 846 x SSG-59-3 (25.26) and Acc. No. 846 x IS-720 (17.29) showed the significant positive heterobeltiosis. None of the hybrids showed significant positive values for standard heterosis (Table 20).

4.6 POLLEN FERTILITY

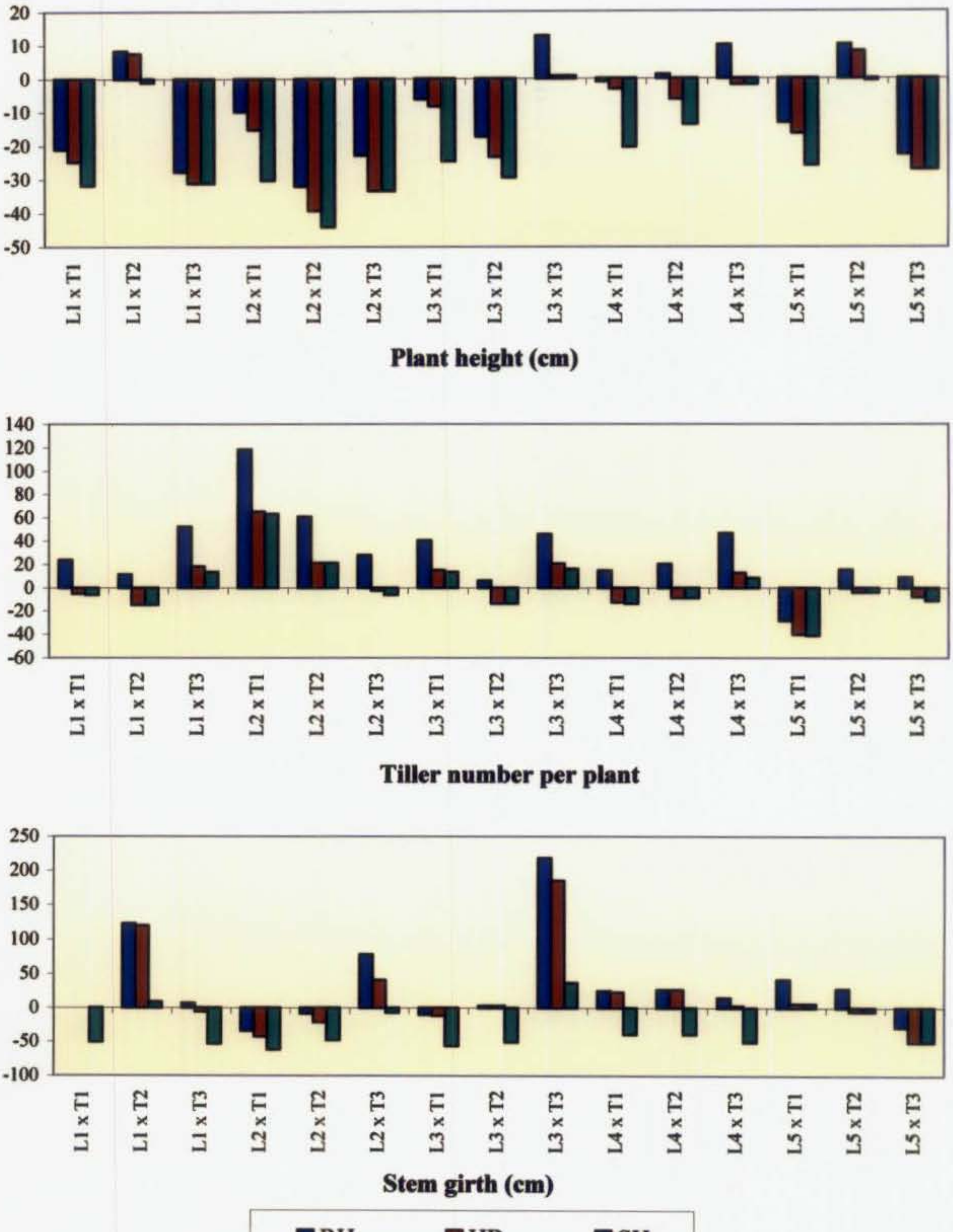
The pollen grains of lines, testers and hybrids were examined for pollen fertility.

The pollen grains of lines, testers and hybrids were fertile. Among lines pollen fertility ranged from 64.68 per cent in GD 65174-1 to 98.46 per cent in Acc. No. 846. Among testers it ranged from 36.82 per cent in Jhansi local to 39.91 per cent in IS-720. The pollen fertility of hybrids ranged from 26.72 per cent in GD 65174-1 x Jhansi local to 87.34 per cent in GD 65195 x SSG-59-3 (Table 21).

Table 20. Heterosis (%) for HCN content, ppm

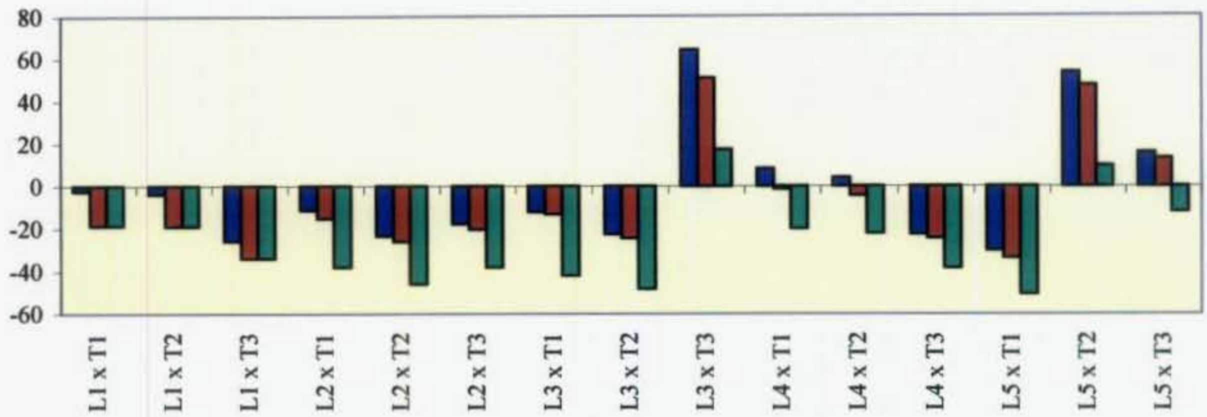
Hybrids	Relative Heterosis (RH)	Heterobeltiosis (HB)	Standard Heterosis (SH)
GD65174-1 × Jhansi local	66.01**	-0.37	-0.49
GD65174-1 × SSG-59-3	45.07**	-9.18	-9.27
GD65174-1 × IS-720	6.89**	-27.24	-27.31
GD65174-2 × Jhansi local	-24.46	-54.67	-54.67
GD65174-2 × SSG-59-3	-12.59	-45.29	-45.29
GD65174-2 × IS-720	-73.42	-81.91	-81.91
GD65195 × Jhansi local	-67.20	-79.99	-81.81
GD65195 × SSG-59-3	-70.59	-81.22	-82.93
GD65195 × IS-720	-71.44	-80.05	-81.86
GD65239 × Jhansi local	55.54**	-3.99	-18.10
GD65239 × SSG-59-3	-50.48	-67.93	-72.64
GD65239 × IS-720	-10.14	-36.06	-45.46
Acc. No. 846 × Jhansi local	-40.88	-62.28	-72.65
Acc. No. 846 × SSG-59-3	85.96**	25.26**	-9.14
Acc. No. 846 × IS-720	56.65**	17.29**	14.92
CD (0.05)	1.36	1.58	1.58

**Significant at 1 per cent level

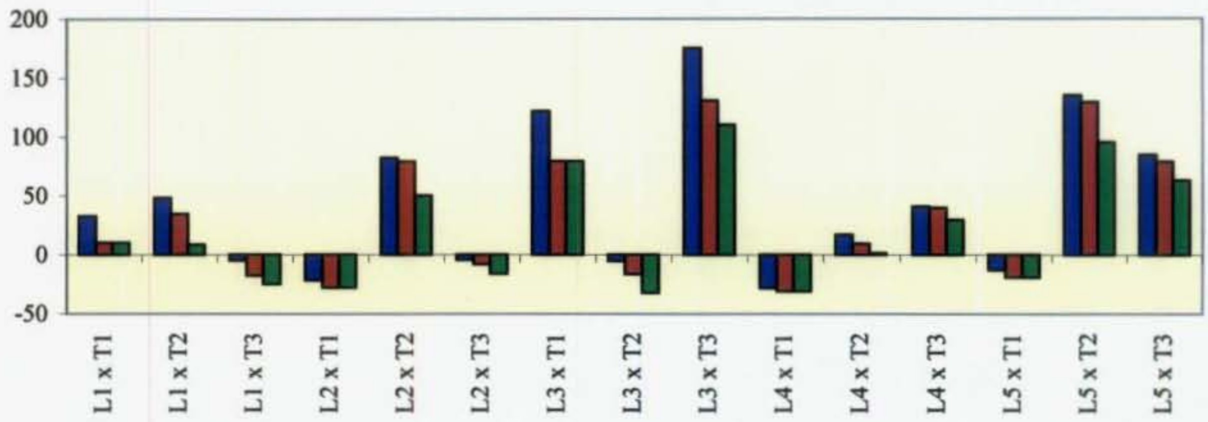


RH - Relative heterosis HB - Heterobeltiosis SH - Standard heterosis

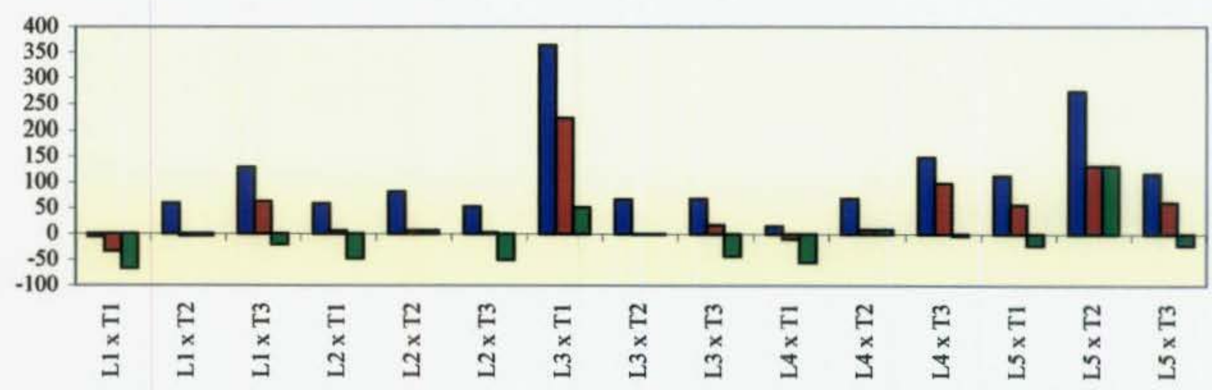
Fig. 3. Heterosis for various characters in fifteen hybrids



Internodal length (cm)



Leaf : stem ratio

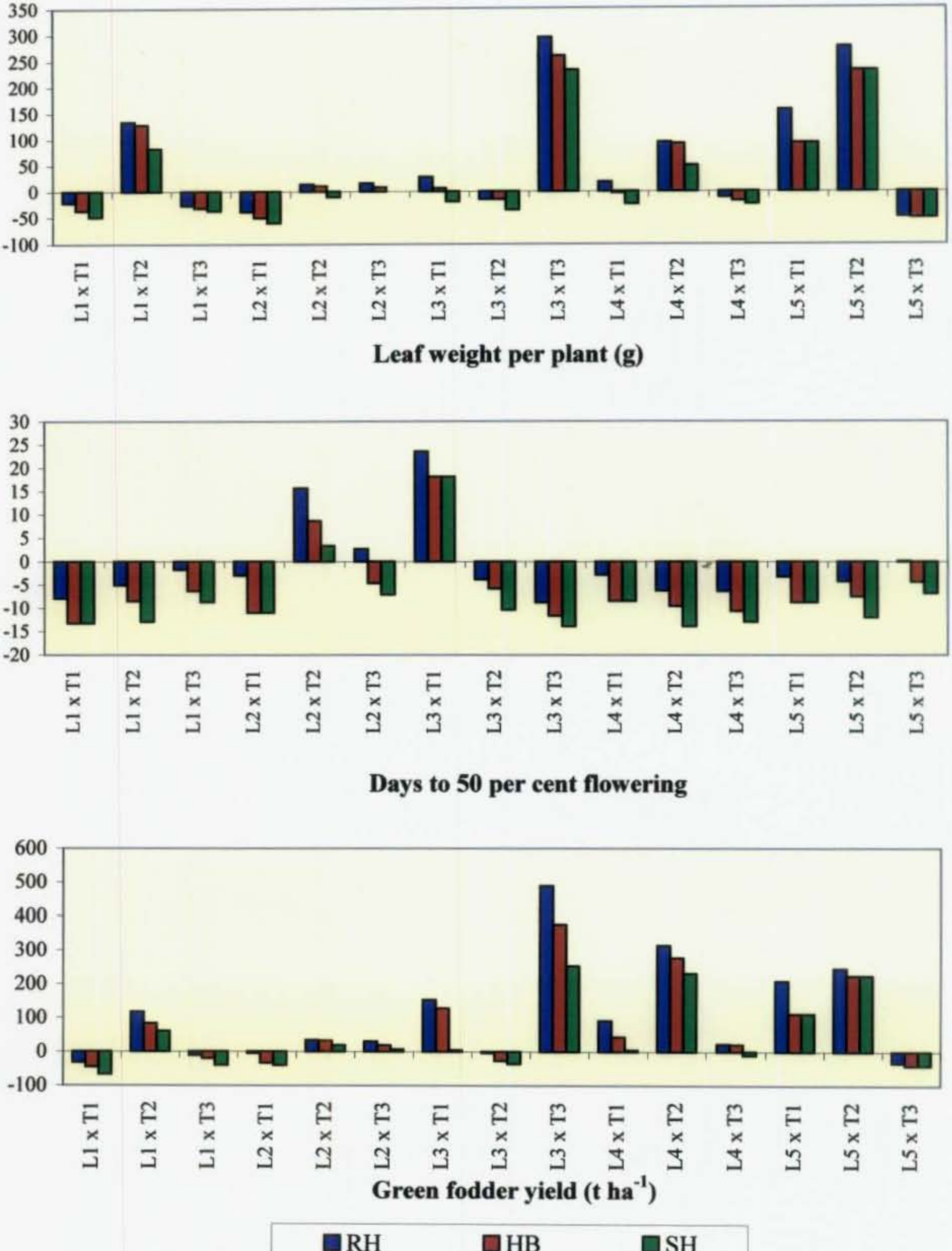


Leaf number per plant

■ RH ■ HB ■ SH

RH - Relative heterosis HB - Heterobeltiosis SH - Standard heterosis

Fig. 3. Continued



RH - Relative heterosis HB - Heterobeltiosis SH - Standard heterosis

Fig. 3. Continued

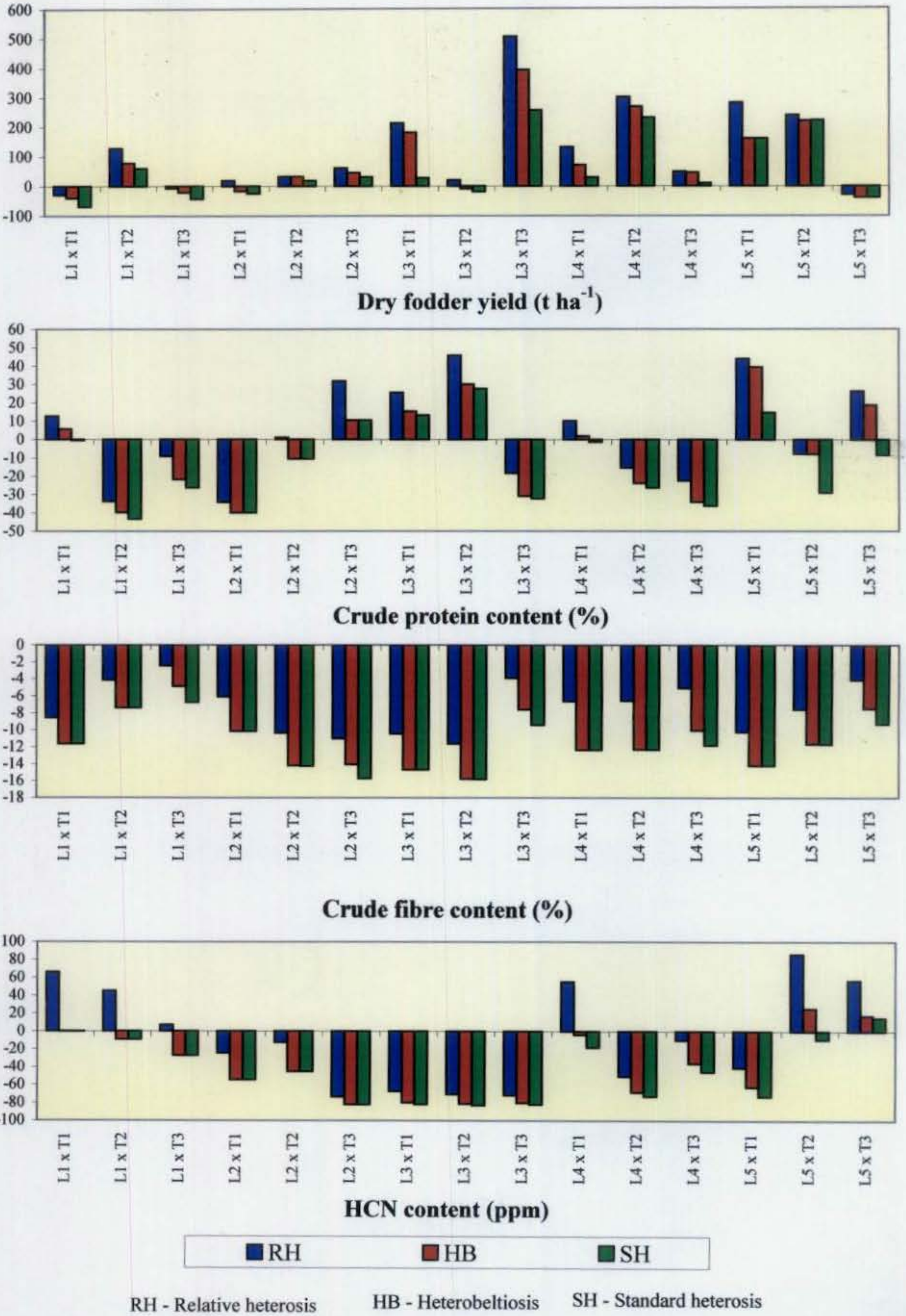


Fig. 3. Continued

Table 21. Pollen fertility of parents and hybrids

Sl. No.	Treatments	Pollen fertility (%)
1	GD65174-1	64.64
2	GD65174-2	72.69
3	GD65195	67.56
4	GD65239	87.76
5	Acc. No. 846	98.46
6	Jhansi local	36.82
7	SSG-59-3	37.01
8	IS 720	39.91
9	GD65174-1 × Jhansi local	26.72
10	GD65174-1 × SSG-59-3	48.68
11	GD65174-1 × IS-720	79.05
12	GD65174-2 × Jhansi local	36.22
13	GD65174-2 × SSG-59-3	73.82
14	GD65174-2 × IS-720	76.68
15	GD65195 × Jhansi local	58.38
16	GD65195 × SSG-59-3	87.34
17	GD65195 × IS-720	76.23
18	GD65239 × Jhansi local	67.26
19	GD65239 × SSG-59-3	80.36
20	GD65239 × IS-720	73.62
21	Acc. No. 846 × Jhansi local	69.46
22	Acc. No. 846 × SSG-59-3	78.26
23	Acc. No. 846 × IS-720	62.64

DISCUSSION

5. DISCUSSION

The primary aim of plant breeding is to evolve superior genotypes with high yield and better quality. Interspecific hybridization is used in fodder crops for developing high yielding varieties. Successful interspecific hybrids of *Sorghum bicolor* and *Sorghum sudanense* have been reported earlier. In view of this, the present study was undertaken to produce hybrids with high forage yield and quality. The results of the study are discussed.

5.1 MEAN PERFORMANCE

The five superior Sorghum [*Sorghum bicolor* (L.) Moench] accessions *viz.,* GD 65174-1, GD 65174-2, GD 65195, GD 65239 and Acc. No. 846 with high yield potential and better palatability selected from the previous study were used as lines. Three sudan grass (*Sorghum sudanense*) accessions *viz.*, Jhansi local, SSG-59-3 and IS-720 with high tillering were used as testers.

Among lines, Acc. No. 846 was found superior based on mean performance for tiller number per plant, stem girth, leaf weight per plant, green fodder yield and dry fodder yield. For plant height and crude fibre content, GD 65174-1 recorded maximum mean. Among the other lines, GD 65239 was found superior for leaf : stem ratio and leaf number per plant. Line GD 65195 recorded the highest mean for days to 50 per cent flowering. Line GD 65239 and Acc. No. 846 had the lowest crude fibre content and HCN content respectively. The internodal length was minimum in the line GD 65195.

Testers did not show much variation in mean performance for tiller number per plant, crude protein content and crude fibre content. Among testers, Jhansi local was found superior for stem girth, leaf : stem ratio, days to 50 per cent flowering and crude protein content. The tester, SSG-59-3 showed superiority over other testers for traits like tiller number per plant, leaf number per plant, green fodder yield and dry fodder yield. The maximum value for plant height and leaf weight per plant was recorded by IS-720. Minimum value was recorded for internodal length and HCN content by Jhansi local. IS-720 recorded the minimum value for crude fibre content.

Among hybrids, GD 65195 x IS-720 was found superior based on mean performance for plant height, stem girth, leaf : stem ratio, leaf weight per plant, green fodder yield and dry fodder yield. Among the other hybrids, GD 65174-2 x Jhansi local was found superior for tiller number per plant, Acc. No. 846 x SSG-59-3 for leaf number per plant and GD 65195 x Jhansi local for days to 50 per cent flowering. The minimum internodal length was recorded by Acc. No. 846 x Jhansi local. The hybrid GD 65195 x SSG-59-3 had low crude fibre content and HCN content. The highest mean performance for crude protein content was shown by GD 65195 x SSG-59-3.

5.2 STUDIES ON COMBING ABILITY AND HETEROSIS

Fifteen hybrids developed by crossing five lines (*Sorghum bicolor*) and three testers (*Sorghum sudanense*) were evaluated for combing ability. Relative heterosis, standard heterosis and heterobeltiosis were estimated for fodder yield and other yield attributes.

Combining ability analysis gives useful information regarding selection of parents in terms of performance of their hybrids. It also serves as a powerful tool to elucidate the expression of quantitative traits. There are several techniques for the evaluation of genotypes. The Line x Tester technique is a good approach for screening the germplasm and more number of parents on the basis of gca and sca variances. It also enables us to understand the nature of gene action involved in the expression of various quantitative traits. The technique measures the gca and sca variances and the genetic components of variance (additive and dominance variance).

The results of combining ability and heterosis are discussed, characterwise.

5.2.1 Plant Height

Genetic differences among lines as well as testers are not significant. Hence an estimate of additive genetic variance has no relevance. But plant height does not appear to be consistent over different testers. Only sca variance was found to be significant. Dominant gene action responsible in this case. The importance of this type of gene action for plant height was reported earlier by Nimbalkar and Bapat (1987), Lakshmaiah (1988), Naik *et al.* (1994), Iyanar *et al.* (2001), Kanawade *et al.* (2001) and Siddiqui and Baig (2001) in sorghum x sudan grass hybrids. On the other hand, the importance of additive gene action was reported by Lazanyi and Bajaj (1986), Sankarapandian *et al.* (1994a), Badhe and Patil (1997) and Rao and Aruna (1997) in sorghum. The importance of both additive and non-additive gene action for plant height was reported by Mallick and Gupta (1988), Chand (1996) and Bhadouriya and Saxena (1997) in sorghum.

Among lines, GD 65195, GD 65239 and Acc. No. 846 and among testers SSG-59-3 and IS-720 had positively significant gca effects. Positive sca effect was shown by the cross GD 65174-1 x SSG-59-3. Positively significant sca effect was shown by GD 65239 x IS-720 which had parents with minimum positive gca effects. The other good hybrids for plant height were GD 65174-2 x Jhansi local, GD 65195 x IS-720, GD 65239 x IS-720 and Acc. No. 846 x SSG-59-3. The better combination for plant height, therefore involved parents with negative x negative and positive x positive gene effects.

Significant positive heterosis over relative heterosis was recorded by four hybrids. The hybrid GD 65195 x IS-720 recorded the highest significant positive standard heterosis. Seven hybrids had significant but negative standard heterosis for this character. Only two hybrids had positive significant values for heterobeltiosis. Heterosis in plant height was reported by Ramalingam and Raman (1974), Bhagmal and Mishra (1985), Cheralu and Rao (1989), Amsalu and Bapat (1990), Sankarapandian *et al.* (1994b), Ghorade *et al.* (1997) and Grewal *et al.* (2003) in sorghum and sorghum x sudan hybrids.

5.2.2 Tiller Number per Plant

Genetic difference among lines as well as testers were not significant. Only sca variance was found to be significant. Hence dominant gene action is responsible in tiller number per plant. The predominance of sca variance was reported by Kumar and Kumar (1998). Contradictory to this predominance of additive gene action was reported by Badhe and Patil (1997) in fodder sorghum.

Line GD 65174-2 was found to have positively significant gca effect for tiller number per plant. None of the testers showed positive significant gca effects. Five out of 15 hybrids were found to have significant sca effects. GD 65174-2 x Jhansi local which had parents with negative x negative gca effects showed the maximum sca effects. Among the rest, GD 65174-1 x IS-720 and GD 65174-2 x IS-720 had negative x positive gca effects. Apart from this GD 65174-2 x IS-720 and Acc. No. 846 x Jhansi local also had significant sca effects. Out of these five hybrids, three resulted from parents, which were good x poor combiners and two of them resulted of parents with poor combiners.

In the present study, heterosis, the cross GD 65174-2 x Jhansi local had maximum standard heterosis followed by GD 65174-2 x SSG-59-3, GD 65195 x IS-720 and GD 65174-1 x IS-720. Out of the 15 hybrids, eight had significant positive relative heterosis and the cross GD 65174-2 x Jhansi local had significant positive heterobeltiosis. Heterosis in plant height was reported in sorghum by Shambulingappa and Magoon (1963) and Chandra *et al.* (1969). Similar results were also reported by Pathak and Sanghi (1992) and Grewal *et al.* (2003).

5.2.3 Stem Girth

Genetic differences among lines as well as testers were not significant. Hence an estimate for additive genetic variance has no relevance. But stem girth does not appear to be consistent over different testers. Dominant gene action was responsible in this case. Manickam and Das (1995) reported the predominance of sca variance over GCA variance for stem girth.

Among lines, only GD 65195 and Acc. No. 846 had positively significant gca effects. Among testers, Jhansi local had negative gca effects. The positively significant sca effect was recorded by the hybrids GD 65195 x SSG-59-3 and Acc. No. 846 x SSG-59-3, which had parents with positive gca effects. Apart from this, the crosses GD 65174-1 x SSG-59-3, GD 65174-2 x IS-720, GD 65239 x Jhansi local and Acc. No. 846 x Jhansi local had significant positive sca effects.

Regarding heterosis, eight out of 15 hybrids showed significant positive relative heterosis for this character. Only five hybrids showed significant positive heterobeltiosis. Significant positive standard heterosis was shown by the cross GD 65195 x IS-720. Rathore and Singhania (1987) observed high heterosis as well as inbreeding depression for stem girth. Charalu and Rao (1989) recorded heterosis for stem girth in sorghum. However, in forage sorghum, it was reported by Chaudhary *et al.* (1980) that hybrids were generally intermediate between both the parents.

5.2.4 Internodal Length

For internodal length, Line x Tester interaction alone was found to be significant. Since SCA variance alone was found to be significant it can be assumed that this trait is controlled by dominant gene action.

Lines, GD 65174-2 and GD 65239 had negatively significant gca effect while all testers except Jhansi local showed positively significant gca effects. Negatively significant sca effect was shown by the cross Acc. No. 846 x Jhansi local. Parents with positive gca effects were involved in the cross. The other good hybrids for reduced internodal length were GD 65174-1 x IS-720, GD 65174-2 x SSG-59-3, GD 65174-2 x IS-720, GD 65195 x Jhansi local, GD 65195 x SSG-59-3 and GD 65239 x IS-720 which were found to be on par. They had parents with positive x positive and positive x negative combining ability effects.

Out of the 15 hybrids, 11 showed significant negative standard heterosis, the maximum negative value shown by GD 65174-2 x SSG-59-3 followed by GD 65174-1 x IS-720, GD 65174-2 x Jhansi local, GD 65174-2 x IS-720, GD 65195 x Jhansi local and GD 65239 x IS-720. Five hybrids showed positive significant relative heterosis and three showed positively significant heterobeltiosis. Heterosis in internodal length was reported in sorghum by Giriraj and Goud (1981) and Dinakar (1985).

5.2.5 Leaf : stem Ratio

Genetic differences among lines as well as testers were not significant. Dominant gene action is responsible for this. Sankarapandian *et al.* (1994a) in sorghum reported similar trends.

Among lines, GD 65195 had significant positive gca effects. Out of 21 hybrids, only six hybrids showed positive significant sca effects. Positive sca effect was shown by the crosses GD 65174-2 x SSG-59-3, GD 65195 x Jhansi local, GD 65195 x IS-720 and Acc. No. 846 x SSG-59-3 *i.e.*, between parents with negative x positive, positive x positive and positive x negative gca effects. The remaining crosses *viz.*, GD 65174-1 x Jhansi local and GD 65239 x IS-720 were found to be significant.

All the hybrids except GD 65174-1 x Jhansi local showed significant positive relative heterosis. Out of 15 hybrids 10 showed significant positive heterobeltiosis. Crosses GD 65174-2 x SSG-59-3, GD 65195 x Jhansi local, GD 65239 x SSG-59-3 and Acc. No. 846 x SSG-59-3 showed significant positive standard heterosis for this character. Jayamani (1991) reported similar results in fodder sorghum. Pathak and Sanghi (1992) observed highly significant heterosis for this character.

5.2.6 Leaf Number per Plant

Genetic differences among line as well as testers were not significant. Hence an estimate of additive genetic variance has no relevance. But leaf number per plant does not appear to be consistent over different testers. Only sca variance was found to be significant. Dominant gene action responsible in this case. Similar results were reported by Sankarapandian *et al.* (1994a), Iyanar *et al.* (2001) and Kanawade *et al.* (2001) in fodder sorghum. Contrary to this Manickam and Das (1995) reported the prevalence of additive gene action for this character.

Nimbalkar and Bapat (1987) and Mallick and Gupta (1988) reported both additive and non-additive gene action for this character in sorghum. Sahib *et al.* (1988) reported the predominance of GCA variance for number of leaves. Veerabadhiran *et al.* (1994) reported higher sca than gca for different yield characters except for number of leaves.

Among lines, Acc. No. 846 and GD 65195 and among testers SSG-59-3 were found to be good general combiners for leaf number per plant. Four crosses had significant positive sca effects, of which GD 65195 x Jhansi local showed maximum effect. Both the parents involved in the cross had positive x negative gca effects. Of the remaining crosses with positive significant sca effects, GD 65174-1 x IS-720 and GD 65239 x IS-720 had parents with negative x negative effects and Acc. No. 846 x SSG-59-3 had parents with positive x positive gca effects.

Regarding heterosis, all those hybrids with significant positive sca effects, except GD 65174-1 x Jhansi local had positive and significant relative heterosis. Out of 15 hybrids, ten showed positive and significant heterobeltiosis. Only four hybrids showed significant positive standard heterosis for this character. Acc. No. 846 x SSG-59-3 had the maximum standard heterosis followed by GD 65195 x Jhansi local, GD 65239 x SSG-59-3 and GD 65174-2 x SSG-59-3. Similar results were reported by Argikar and Chavan (1957), Kambal and Webster (1966), Kirby and Atkins (1968), Chandra *et al.* (1971) in sorghum hybrids, and Rao and Goud (1975), Kambal and Abu-El-Gasim (1976), Indi and Goud (1981), Saradamani (1982), Bhagmal and Mishra (1985) and Rathore and Singhania (1987) in fodder sorghum.

5.2.7 Leaf Weight per Plant

There was significant variation among crosses and Line x Testers. Specific combing ability variance was significant and of higher magnitude indicating the predominance of dominant gene action in the expression of this character.

Among lines, GD 65195 and Acc. No. 846 showed positively significant gca effects for leaf weight per plant and among testers, SSG-59-3 had positively significant gca effect. Seven out of 15 crosses had positively significant sca effects. The cross GD 65195 x IS-720 is a good hybrid with parents having positive x negative gca effects. The other crosses which had positively significant sca effects were GD 65174-1 x SSG-59-3, GD 65174-2 x IS-720, GD 65239 x SSG-59-3, Acc. No. 846 x Jhansi local and Acc. No. 846 x SSG-59-3. These crosses had their parents with negative x positive, negative x negative and positive x negative gca effects.

Heterosis in leaf weight per plant was reported in sorghum by Shambulingappa and Magoon (1963) and Chandra *et al.* (1969). Only nine hybrids showed significant positive relative heterosis and eight hybrids showed significant positive heterobeltiosis. Six hybrids showed significant positive standard heterosis. The cross GD 69195 x IS-720 showed high relative heterosis, heterobeltiosis and standard heterosis. Heterosis in leaf weight per plant was reported in fodder sorghum by Pathak and Sanghi (1992).

5.2.8 Days to 50 per cent Flowering

The involvement of dominant gene action for days to 50 per cent flowering was indicated by the predominance of SCA variance over GCA variance. Similar results were reported by Lakshmaiah (1988), Naik *et al.* (1994), Rao and Aruna (1997), Iyanar *et al.* (2001), Kanawade *et al.* (2001) and Siddiqui and Baig (2001) in fodder sorghum. Contrary to this Kulkarni and Shinde (1987) reported the predominance of additive gene action. The involvement of both additive and non-additive gene action was reported by Nimbalkar and Bapat (1987), Mallick and Gupta (1988), Bhadouriya and Saxena (1997). Sahib *et al.* (1988) and Jayamani and Dorairaj (1995) reported the predominance of GCA variance for this character.

The lines, GD 65174-1, GD 65239 and Acc. No. 846 exhibited significant negative gca effects and were good general combiners. The testers SSG-59-3 and IS-720 exhibited significant negative gca effects. GD 65174-1 x Jhansi local, GD 65174-2 x Jhansi local, GD 65195 x SSG-59-3, GD 65195 x IS-720 and Acc. No. 846 x Jhansi local were good specific combiners as they exhibited significant sca effects.

Two hybrids exhibited significant relative heterosis and heterobeltiosis. None of the hybrids showed negative values for relative heterosis and heterobeltiosis. The hybrids, GD 65174-1 x IS-720, GD 65174-2 x IS-720, GD 65239 x Jhansi local Acc. No. 846 x Jhansi local and Acc. No. 846 x IS-720 recorded significant negative standard heterosis. The highest significant negative standard heterosis was shown by the cross GD 65195 x SSG-59-3. Ganesh *et al.* (1997) reported high negative heterosis for days to 50 per cent flowering in fodder sorghum. Heterosis for days to 50 per cent flowering was recorded by Cheralu and Rao (1989), Amsalu and Bapat (1990) and Grewal *et al.* (2003) in fodder sorghum. The significant positive heterosis and heterobeltiosis were reported by Senthil and Palanisami (1993) and Ghorade *et al.* (1997) in sorghum.

5.2.9 Green Fodder Yield

For green fodder yield, line x tester mean square alone was found significant, suggesting the significance of only sca effect for this trait. So this character is under control of dominant gene action. Similar results were reported by Dangi *et al.* (1980) in fodder sorghum. Gupta *et al.* (1976) and Paroda *et al.* (1977) reported higher green fodder yield in hybrids than in parents. Both additive and dominance gene action was reported by Khatri and Lodhi (2004).

Three lines and one tester recorded positively significant gca effects. Among lines, Acc. No. 846 recorded the maximum positive gca effect and among testers, SSG-59-3 showed maximum positive gca effect. The hybrid, GD 65195 x IS-720 showed the maximum sca effect followed by GD 65239 x SSG-59-3 and Acc. No. 846 x SSG-59-3. The parents involved in these crosses had positive x negative and positive x positive gca effects. The minimum positively significant sca effect was shown by GD 65174-2 x Jhansi local which had parents with negative x negative gca effects.

The hybrid GD 65195 x IS-720 recorded maximum significant positive values for all the three types of heterosis *viz.*, standard heterosis, relative heterosis and heterobeltiosis. This was followed by GD 65239 x SSG-59-3 and Acc. No. 846 x SSG-59-3. Only nine out of 15 hybrids had significant positive standard heterosis. Ten hybrids showed significant positive relative heterosis and heterobeltiosis. Similar results were reported earlier by Pathak and Sanghi (1992), Jayamani and Dorairaj (1993), Muhammad *et al.* (1981) and Grewal *et al.* (2003) in sorghum hybrids. They reported that the hybrids had improved vigour for green fodder yield. Heterosis for green fodder yield in both the main and ratoon crop was best in the hybrids as suggested by Jayamani and Dorairaj (1994b) in fodder sorghum.

5.2.10 Dry Fodder Yield

Line x tester mean square was found significant for dry fodder yield suggesting the significance of SCA variance. From this, it can be inferred that the expression of the character is under the influence of dominant gene action. Similar results were reported earlier by Sankarapandian *et al.* (1994a) in fodder sorghum. Gupta *et al.* (1976) and Paroda *et al.* (1977) reported higher dry fodder yields of hybrid in fodder sorghum. The importance of both additive and dominance gene action was reported by Khatri and Lodhi (2004).

The lines, GD 65195, GD 65239 and Acc. No. 846 and tester, SSG-59-3 had significant positive gca effects for dry fodder yield. Among hybrids, GD 65195 x IS-720 had the maximum positive sca effect where the parents with positive and negative gca effects. Other good hybrids, GD 65239 x SSG-59-3, Acc. No. 846 x Jhansi local, Acc. No. 846 x SSG-59-3, GD 65174-2 x IS-720 and GD 65174-1 x SSG-59-3 when the parents were having positive x positive, positive x negative and negative x negative gca effects.

Heterosis in dry fodder yield was reported in fodder sorghum by Shambulingappa and Magoon (1963) and Chandra *et al.* (1969). The hybrid GD 65195 x IS-720 recorded the highest significant positive standard heterosis for dry fodder yield. It was followed by GD 65239 x SSG-59-3 and Acc. No. 846 x SSG-59-3. Only nine out of 15 hybrids had significant positive standard heterosis. Significant positive relative heterosis was exhibited by 12 hybrids. Ten hybrids showed significant positive heterobeltiosis. Similar results were reported by Sankarapandian *et al.* (1994b) and Grewal *et al.* (2003) in fodder sorghum.

5.2.11 Crude Protein Content

For crude protein content, mean square was significant only for line x tester indicating the presence of dominant gene action. This was reported earlier by Sanakrapandian *et al.* (1994a) in fodder sorghum. Mallick *et al.* (1988) reported significant sca effect for this character. Gupta *et al.* (1976) reported higher crude protein content in sorghum hybrids compared to parents.

Among lines, GD 65195 and Acc. No. 846 and among testers, Jhansi local and SSG-59-3 showed positively significant gca effects for crude protein content. Seven out of 15 hybrids had positively significant sca effects. The maximum positively significant sca effect was shown by the cross GD 65174-2 x IS-720.

Only four hybrids showed significant positive standard heterosis for crude protein content. Seven hybrids showed significantly positive relative heterosis and six showed significant positive heterobeltiosis. The maximum standard heterosis was shown by the hybrid GD 65195 x SSG-59-3. Nayeem *et al.* (1987) reported a marked variation in protein content among hybrids. Heterosis in crude protein content was reported in sorghum by Sankarapandian *et al.* (1994b).

5.2.12 Crude Fibre Content

Only sca variance was found to be significant for crude fibre content indicating the effect of dominant gene action.

Lines, GD 65174-2, GD 65195 and testers, Jhansi local and SSG-59-3 recorded significant negative gca effects. The maximum negative sca effect was shown by GD 65174-2 x IS-720 which was evolved from parents with negative x positive gca effects. This was followed by GD 65174-1 x Jhansi local, GD 65174-1 x Jhansi local, GD 65195 x SSG-59-3, GD 65239 x IS-720 and Acc. No. 846 x Jhansi local. The parents involved in these hybrids had positive x negative, negative x negative and negative x positive gca effects.

Regarding heterotic effects, none of the hybrids showed any significant relative heterosis and heterobeltiosis. Only two hybrids, GD 65174-1 x SSG-59-3 and GD 65174-1 x IS 720 had significant negative standard heterosis. Heterosis in crude fibre content in sorghum was reported by Shambulingappa and Magoon (1963) and Chandra *et al.* (1969).

5.2.13 HCN Content

SCA variance was found to be significant for HCN content indicating the presence of dominant gene action.

Lines, GD65174-2 and GD 65195 and tester IS-720 recorded significant negative gca effects. The maximum negative sca effect was shown by Acc. No. 846 x Jhansi local which was evolved from parents with positive gca effects. This was followed by GD 65239 x SSG-59-3, GD 65239 x Jhansi local, GD 65174-2 x IS-720, GD 65174-1 x IS-720, GD 65195 x SSG-59-3 and GD 65195 x Jhansi local. The parents involved in these crosses had positive x positive, negative x negative, positive x negative and negative x positive gca effects.

Regarding heterotic effects, none of the hybrids showed significant values for standard heterosis, relative heterosis and heterobeltiosis. Hydro cyanic acid content has been found to be a hereditary character, influenced by environmental condition (Boyd *et al.*, 1938). All the parents and hybrids have HCN content below 200 ppm. The toxic level of hydro cyanic acid has been reported to be above 200 ppm (Gillingham *et al.*, 1969).

Pollen fertility of the hybrids showed wide range of variability (26.72 to 87.34 per cent). The high fertility percentage of the hybrids indicates that there is scope for recombination breeding to develop new varieties.

From the combining ability analysis, it is seen that three out of five lines namely, GD 65195, GD 65239 and Acc. No. 846 have significant gca effects for green fodder yield (Table 22). The line Acc. No. 846 is an outstanding general combiner for eight characters *viz.*, plant height, stem girth, leaf number per plant, leaf weight per plant, days to 50 per cent flowering, dry fodder yield and crude protein content and green fodder yield as the gca effects were significant for the these characters. The line GD 65195 had significant gca effects for plant height, stem girth, leaf : stem ratio, leaf number per plant, leaf weight per plant, green fodder yield, dry fodder yield, crude protein content, crude fibre content and HCN content. GD 65239 exhibited significant gca effects for plant height, days to 50 per cent flowering, green fodder yield, dry fodder yield and crude fibre content.

Among the three testers, alone SSG-59-3 is an outstanding general combiner for eight characters besides green fodder yield *viz.*, plant height, stem girth, leaf number per plant, leaf weight per plant, days to 50 per cent flowering, dry fodder yield, crude protein content and crude fibre content. IS-720 had significant gca effects for plant height, stem girth, days to 50 per cent flowering and HCN content. Jhansi local exhibited significant gca effects for internodal length, crude protein content and crude fibre content (Table 22).

Among the 15 hybrids evaluated, seven have significant sca effects for green fodder yield. Most of the hybrids exhibited significant sca effects for many characters simultaneously (Table 23). Two hybrids, GD 65174-2 x Jhansi local and GD 65195 x IS-720 have significant sca effects for plant height, stem girth, leaf : stem ratio, days to 50 per cent flowering

Table 22. Best lines and testers for various characters based on combining ability

Sl. No.	Characters	Best lines	Best testers
1	Plant height (cm)	GD 65239	SSG-59-3
2	Tiller number per plant	GD 65174-2	-
3	Stem girth (cm)	Acc. No. 846	IS-720, SSG-59-3
4	Internodal length (cm)	GD 65174-2	Jhansi local
5	Leaf : stem ratio	GD 65195	-
6	Leaf number per plant	Acc. No. 846	SSG-59-3
7	Leaf weight per plant (g)	Acc. No. 846	SSG-59-3
8	Days to 50 per cent flowering	GD 65239, GD 65174-1	IS-720
9	Green fodder yield (t ha^{-1})	Acc. No. 846	SSG-59-3
10	Dry fodder yield (t ha^{-1})	Acc. No. 846	SSG-59-3
11	Crude protein content (%)	GD 65195	Jhansi local
12	Crude fibre content (%)	GD 65174-2	Jhansi local
13	HCN content (ppm)	GD 65195	IS-720

Table 23. Combination of parents for various characters based on specific combining ability effects

Lines \ Testers	Jhansi local	SSG-59-3	IS-720
GD 65174-1	Leaf : stem ratio Crude protein content Crude fibre content	Plant height Stem girth Leaf weight per plant Green fodder yield Dry fodder yield	Tiller number per plant Inernodal length Leaf number per plant Days to 50 per cent flowering HCN content
GD 65174-2	Plant height Tiller number per plant Green fodder yield	Internodal length Leaf : stem ratio Days to 50 per cent flowering Crude protein content Crude fibre content	Stem girth Internodal length Leaf weight per plant Green fodder yield Dry fodder yield Crude protein content Crude fibre content HCN content
GD 65195	Internodal length Leaf : stem ratio Leaf number per plant Days to 50 per cent flowering HCN content	Internodal length Crude protein content Crude fibre content HCN content	Plant height Stem girth Leaf stem ratio Leaf weight per plant Green fodder yield Dry fodder yield
GD 65239	Stem girth Leaf weight per plant Crude protein content	Leaf weight per plant Green fodder yield Dry fodder yield HCN content	Plant height Internodal length Leaf : stem ratio Leaf number per plant Crude fibre content
Acc. No. 846	Stem girth Leaf weight per plant Green fodder yield Dry fodder yield Crude protein content Crude fibre content HCN content	Plant height Tiller number per plant Stem girth Leaf : stem ratio Leaf number per plant Leaf weight per plant Green fodder yield Dry fodder yield	Internodal length Days to 50 per cent flowering Crude protein content

and green fodder yield. Among the other hybrids Acc. No. 846 x SSG-59-3 have significant sca effects for seven characters, GD 65239 x IS-720 for five characters, Acc. No. 846 x Jhansi local for eight characters, GD 65174-2 x IS-720 for eight characters. The hybrids, GD 65174-1 x SSG-59-3 and GD 65239 x SSG-59-3 exhibited significant sca effect for green fodder yield. It is also observed that many of the parents involved in the superior cross combinations are also good general combiners.

The good hybrids, based on mean performance, sca effects and standard heterosis for various characters are presented in Table 24.

Among the hybrids, GD 65195 x IS-720 (Plate 5) recorded high mean performance, sca effect and standard heterosis for plant height, stem girth, leaf / stem ratio, leaf weight per plant, green fodder yield and dry fodder yield. The hybrid Acc. No. 846 x SSG-59-3 (Plate 6) recorded high mean performance, sca effect and standard heterosis for plant height, leaf : stem ratio, leaf number per plant, leaf weight per plant, green fodder yield and dry fodder yield. The hybrid GD 65195 x SSG-59-3 (Plate 7) recorded high mean performance, sca effect and standard heterosis for some characters. GD 65174-2 x Jhansi local (Plate 8) recorded high mean performance, sca effect and standard heterosis for tiller number per plant.

Thus among the 15 hybrids evaluated, GD 65195 x IS-720 and Acc. No. 846 x SSG-59-3 are found to be superior based on mean performance, sca effects and standard heterosis. Hence these hybrids can be advanced for further trials to develop high yielding hybrid varieties.

Table 24 Promising hybrids based on mean performance, sca effects and standard heterosis

Characters	Mean performance	sca effects	Standard heterosis
Plant height (cm)	GD 65195 × IS-720, GD 65239 × IS-720, Acc. No. 846 × SSG-59-3, GD 65174-1 × SSG-59-3	GD 65174-1 × SSG-59-3, GD 65195 × IS-720, Acc. No. 846 × SSG-59-3	GD 65195 × IS-720
Tiller number per plant	GD 65174-2 × Jhansi local, GD 65174-2 × SSG-59-3, GD 65195 × IS-720	GD 65174-2 × Jhansi local	GD 65174-2 × Jhansi local
Stem girth (cm)	GD 65195 × IS-720, GD 65174-1 × SSG-59-3, Acc. No. 846 × Jhansi local	GD 65195 × IS-720, GD 65174-1 × SSG-59-3, Acc. No. 846 × Jhansi local	GD 65195 × IS-720
Internodal length (cm)	Acc. No. 846 × Jhansi local, GD 65195 x SSG-59-3, GD 65174-2 × SSG-59-3	Acc. No. 846 × Jhansi local, GD 65195 x SSG-59-3	GD 65174-2 × SSG-59-3, GD 65195 × Jhansi local
Leaf : stem ratio	GD 65195 × IS-720, Acc. No. 846 × SSG-59-3, GD 65195 × Jhansi local	GD 65174-2 × SSG-59-3, GD 65195 × Jhansi local, GD 65195 × IS-720, Acc. No. 846 × SSG-59-3	GD 65195 × IS-720, Acc. No. 846 × SSG-59-3, GD 65195 × Jhansi local
Leaf number per plant	Acc. No. 846 × SSG-59-3	GD 65195 × Jhansi local, Acc. No. 846 × SSG-59-3	Acc. No. 846 × SSG-59-3
Leaf weight per plant (g)	GD 65195 × IS-720, Acc. No. 846 × SSG-59-3	GD 65195 × IS-720	GD 65195 × IS-720, Acc. No. 846 × SSG-59-3

Table 24 Continued

Characters	Mean performance	sca effects	Standard heterosis
Days to 50 per cent flowering	-	GD 65195 × IS-720, GD 65174-2 × Jhansi local	GD 65174-1 × IS-720, Acc. No. 846 × Jhansi local, GD 65239 × Jhansi local
Green fodder yield (t ha^{-1})	GD 65195 × IS-720, GD 65239 × SSG-59-3, Acc. No. 846 × SSG-59-3	GD 65195 × IS-720	GD 65195 × IS-720, GD 65239 × SSG-59-3, Acc. No. 846 × SSG-59-3
Dry fodder yield (t ha^{-1})	GD 65195 × IS-720, GD 65239 × SSG-59-3, Acc. No. 846 × SSG-59-3	GD 65195 × IS-720	GD 65195 × IS-720, GD 65239 × SSG-59-3, Acc. No. 846 × SSG-59-3
Crude protein content (%)	GD 65195 × SSG-59-3	GD 65174-2 × IS-720, GD 65195 × SSG-59-3	GD 65195 × SSG-59-3
Crude fibre content (%)	GD 65195 × SSG-59-3	GD 65174-2 × IS-720	-
HCN content (ppm)	GD 65195 × SSG-59-3	Acc. No. 846 × Jhansi local, GD 65239 × SSG-59-3	-

Plate 5. GD 65195 x IS-720

Plate 6. Acc. No. 846 x SSG-59-3

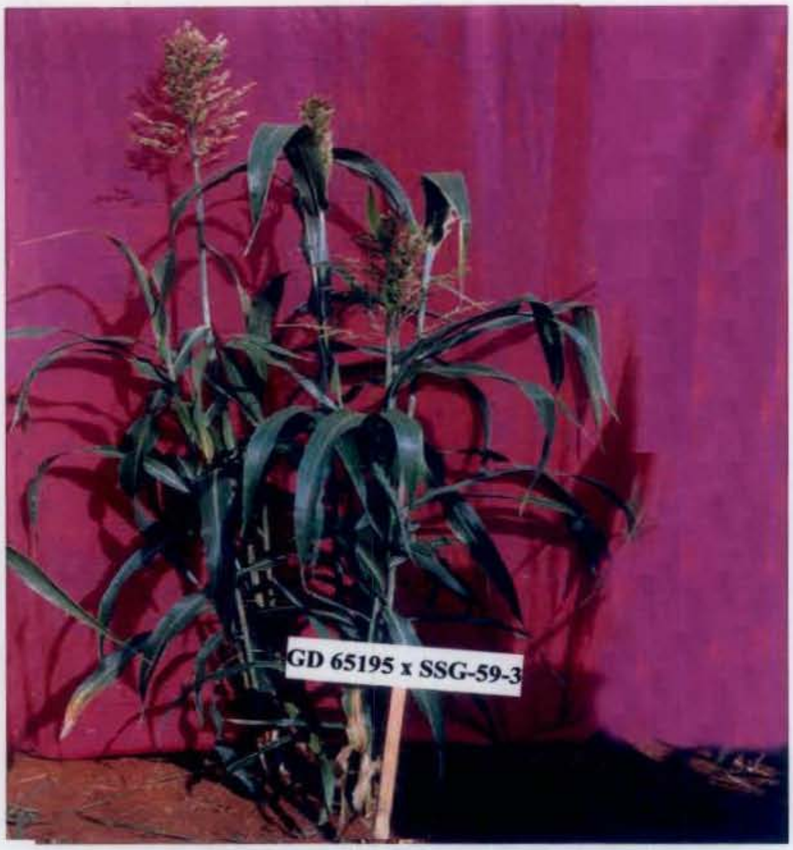


Plate 7. GD 65195 x SSG-59-3

Plate 8. GD 65174-2 x Jhansi local

SUMMARY

6. SUMMARY

The present study on 'Interspecific hybridization in Sorghum' was conducted in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2003-2004 with the objective of exploitation of hybrid vigour through interspecific hybridization in sorghum.

Hybridization was done between five accessions of sorghum [*Sorghum bicolor* (L.) Moench] as lines and three accessions of sudan grass (*Sorghum sudanense*) as testers adopting Line x Tester mating design. The 15 hybrids along with their parents were evaluated for. mean performance, combining ability, heterosis and gene action based on 13 characters namely, plant height, tiller number per plant, stem girth, internodal length, leaf / stem ratio, leaf number per plant, leaf weight per plant, days to 50 per cent flowering, green fodder yield, dry fodder yield, crude protein content, crude fibre content and HCN content.

Biometrical observations were recorded at 50 per cent flowering and at maturity. The analysis of variance indicated that the treatment differences among the parents and hybrids were significant for all the biometrical and quality attributes.

Studies on combining ability showed higher magnitude of SCA variance for all characters indicating the predominance of dominance gene action. Based on gca effects, the lines GD 65195, GD 65239 and Acc. No. 846 were found to be good general combiners for green fodder yield and other related characters. Among these GD 65239, Acc. No. 846 and GD 65239 had high gca effects along with good mean performance for green fodder yield and its component traits like stem girth, leaf number per plant and leaf weight per plant.

Among testers, SSG-59-3 and IS-720 were found to be good general combiners based on mean performance and gca effects. The tester

SSG-59-3 had good general combining ability for six traits *viz*., plant height, leaf number per plant, leaf weight per plant, green fodder yield, dry fodder yield and crude protein content. The tester SSG-59-3 had good mean performance for tiller number per plant, leaf number per plant, days to 50 per cent flowering, green fodder yield and dry fodder yield. Jhansi local had good mean performance for stem girth, leaf / stem ratio, crude protein content and HCN content. The tester, IS-720 had good gca for stem girth and mean performance for plant height, leaf weight per plant and crude fibre content.

Among hybrids, GD 65195 x IS-720 and Acc. No. 846 x SSG-59-3 were found to be good specific combiner for various characters. The hybrid GD 65195 x IS-720 was a good specific combination for five traits *viz*., stem girth, leaf / stem ratio, leaf weight per plant, green fodder yield and dry fodder yield and the hybrid Acc. No. 846 x SSG-59-3 was a good specific combination for leaf/stem ratio, leaf number per plant, leaf weight per plant and green fodder yield.

Based on mean performance, sca effects and standard heterosis, the hybrid GD 65195 x IS-720 was found superior for plant height, stem girth, leaf/stem ratio, leaf weight per plant, green fodder yield and dry fodder yield. Also the hybrid Acc. No. 846 x SSG-59-3 was found superior for plant height, leaf/stem ratio, leaf weight, leaf number, green fodder yield and dry fodder yield. Hence the hybrids GD 65195 x IS-720 and Acc. No. 846 x SSG-59-3 can be advanced for further trials to develop sorghum sudan grass hybrids with high fodder yield and better quality.

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INTERSPECIFIC HYBRIDIZATION IN SORGHUM

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ABSTRACT

A study on 'Interspecific hybridization in Sorghum' was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2003-2004 with the objective of developing sorghum-sudan grass hybrids with high fodder yield potential and better quality.

Five superior accessions of sorghum *viz.*, GD 65174-1,GD65174-2, GD 65195, GD 65239 and Acc. No. 846 (lines) with high yield potential and better palatability and three accessions of sudan grass *viz.*, Jhansi local, SSG-59-3 and IS-720 (testers) with high tillering ability were crossed in a Line x Tester mating design to obtain 15 hybrid combinations.

The lines, testers and their hybrids were evaluated along with a check COFS-29 in a replicated field trial for mean performance, combining ability and heterosis. Observations on plant height, tiller number per plant, stem girth, internodal length, leaf/stem ratio, leaf number per plant, leaf weight per plant, days to 50 per cent flowering, green fodder yield, dry fodder yield, crude protein content, crude fibre content and HCN content were recorded. Significant differences among treatments were observed for all characters. Significant differences among crosses were observed for all characters except tiller number per plant. General and specific combining ability variances and effects were studied. The magnitude of SCA variance alone was significant suggesting the predominance of dominance gene action in controlling these traits.

Based on mean performance and gca effects, Acc. No. 846 was identified as the best general combiner among lines and SSG-59-3 among testers. The crosses, GD 65195 x IS-720 and Acc. No. 846 x SSG-59-3 were found to be promising for green fodder yield and its component traits based on mean performance, sca effects and standard heterosis. Hence these crosses can be advanced for further trials for developing superior sorghum-sudan grass hybrid varieties.