"COMBINING ABILITY ANALYSIS IN *RABI* SORGHUM (*Sorghum bicolor* L. Moench)"

By

Mr. ASHOK GAHININATH GITE

(Reg. No. R/013/022)

A Thesis submitted to the

MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA.

In partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)

DEPARTMENT OF AGRICULTURAL BOTANY

POST GRADUATE INSTITUTE
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2015

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part there of has not been submitted by me or any other person to any other University or Institute for a Degree or Diploma.

Place: *MPKV, Rahuri*
Date : */ /2015.* **(Gite A. G.)**

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CERTIFICATE

This is to certify that the thesis entitled, **"COMBINING ABILITY ANALYSIS IN *RABI* SORGHUM [*Sorghum bicolor* (L.) Moench]",** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri in partial fulfilment of the requirements for the degree of ***MASTER OF SCIENCE (AGRICULTURE)*** *in* ***AGRICULTURAL BOTANY (GENETICS AND PLANT BREEDING),*** embodies the results of a piece of *bonafide* research work carried out by ***GITE ASHOK GAHININATH,*** under my guidance and supervision and that no part of the thesis has been submitted to any other University for degree or diploma.

The assistance and help rendered during the course of this investigation and sources of literature referred have been duly acknowledged.

Place : MPKV, Rahuri. **(N. S. Kute)**
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Maharashtra State (India).

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Place : MPKV, Rahuri. **(B.R. Ulmek)**
Date : / /2015.

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Place : *MPKV, Rahuri*
Date : */ /2015* ***(Gite A.G.)***

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LIST OF ABBREVIATIONS

%	Per cent
σ^2A	Additive variance
σ^2D	Dominance variance
σ^2gca	Variance due to general combining ability
σ^2sca	Variance due to specific combining ability
BP	Better parent
CD	Critical differences
Cm	Centimeter
Cov (F.S.)	Co-variance (full sib)
Cov (H.S.)	Co-variance (half-sib)
CSH	Co-ordinated Sorghum Hybrid
d.f.	Degrees of freedom
et al.	*et all* (and others)
F_1	First filial generation
g	Gram
GCA/gca	General combining ability
i.e.	That is
Kg	Kilogram
M	Meter
MP	Mid parent
MSS	Mean sum of square
Mha	Million hectare
MS	Male sterile
RSLG	Rahuri Sorghum Local Germplasm
SC	Standard check
S.E.	Standard error
SS	Sum of square
SCA/sca	Specific combining ability
viz.	Videlicet (Namely)

ABSTRACT

"COMBINING ABILITY ANALYSIS IN *RABI* SORGHUM (*Sorghum bicolor* L. Moench)"

by
GITE ASHOK GAHININATH
A candidate for the degree of
MASTER OF SCIENCE (AGRICULTURE)
in
AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)

Research Guide : Dr. N. S. Kute
Department : Agricultural Botany

The present investigation entitled "Combining ability analysis in *rabi* Sorghum (*Sorghum bicolor* L. Moench)" was carried out with an objectives to estimate the heterosis for grain and yield contributing characters and to estimate the general and specific combining ability effects of parents and its crosses respectively. The eighteen parents were crossed in Line X Tester mating design involving three cytoplasmic genetic male sterile lines and fifteen testers at Sorghum Improvement Project, M.P.K.V., Rahuri during *rabi* 2013-2014. The resulting forty-five hybrids along with parents and one hybrid check were evaluated in a randomized block design with two replications at Sorghum Improvement Project, Department of Botany, M.P.K.V., Rahuri during *rabi* 2014-15. The observations were recorded on twelve characters *viz.*, days to 50% flowering, plant height, number of internodes, panicle length, panicle girth, panicle weight, 1000-

seed weight, days to maturity, fodder yield per plant, grain yield per plant, harvest index and dead heart (%). The data was subjected to the analysis for heterosis over better parent and standard check as per Fonesca and Patterson (1968) and combining ability analysis as per Kempthorne (1957) and modified by Arunachalam (1974).

The hybrid combinations *viz.*, 185 A x RSV 458, 185 A x RSV 1093, 185 A x RSV 1145, RMS 2010-10A X RSLG 2291 showed significant heterosis over better parent and standard check CSH 15R for grain yield.

The female parent 185 A observed as a good general combiners for grain yield per plant, days to 50% flowering, days to maturity, panicle length, panicle girth, panicle weight, 1000 seed weight and harvest index. Among the testers, tester RSV 1145 observed good general combiner for grain yield and panicle weight, while tester RSV 458 for days to 50% flowering and days to maturity.

Among the hybrids, 185A x RSV 1093, RMS 2010-24A x CSV 216 were observed best specific combiners for grain yield per plant. The higher magnitude of SCA variance over GCA variance was observed for grain yield per plant, days to maturity, panicle weight and panicle girth which indicate the importance of non additive gene action.

Abstract Contd... ***GITE A.G.***

Based on result obtained on *per se* performance, general and specific combining ability and heterosis it was concluded that the hybrids 185 A x RSV 1093, 185 A x RSV 458, RMS 2010-10A x RSLG 2291, RMS 2010-24A x CSV 216, 185A x RSV 1145 were observed most promising and could be exploited for further hybrid development in *rabi* sorghum. While, parents 185A, RMS 2010-10B, RSV 1093, RSV 458, RSLG 1145 and CSV 216 can be used in future hybridization programme.

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CHAPTER I

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth important cereal of the world after wheat, maize, rice and barley. Sorghum is believed to be originated in Africa and spread all over the world. The large hectarage of sorghum occurs in the arid and semi-arid areas of India and Africa.

Sorghum belongs to family 'Poaceae'; plants of which are usually grass (10 pairs of chromosome, 2n = 20). The crop is considered to be Ethiopian origin (Vavilov, 1935). Sorghum is classified as often cross-pollinated crop though it is self-pollinated crop but due to the stigma exposure before the anther dehiscence, cross-pollination averaging about 6 per cent to as high as 30 per cent in Sudan grass is observed. Sorghum Moench is an extremely variable genus. Garber (1950) and Celarier (1959) subdivided the genus into five subgenera *viz. Sorghum, Choetosorghum, Heterosorghum, Parasorghum* and *Stiposorghum*. The cultivated sorghum is included in subgenera *'Sorghum'*. De Wet (1978) further classified the sorghum subgenera by recognizing three distinct species i.e. *S. propinguum*, *S. halepense* and *S. bicolor.* Furthermore, *S. bicolor* was divided into three subspecies *drumondii*, *bicolor* and *veticilliflorum*. Finally, Harlan and De Wet (1972) partitioned the primary gene pool of *S. bicolor* L. Moench into five basic races, designated as *bicolor, guinea, caudatum, kafir*and and *durra.*

Sorghum is used for food, fodder and the production of alcoholic beverages. In arid, less developed regions of the world, it is an important food crop especially for subsistence farmers. It is used to make such foods as couscous, porridge and molasses. '*Bhakari'*, a variety of unleavened bread made from sorghum, is the staple diet generally in many parts of India such as Maharashtra and northern Karnataka. It's grain contains about 56-73% starch, 10-12% protein, 72.6% carbohydrates, 1.6% mineral matter, 1.9% fat, 7.5-9.2% dietary fiber (Anonymous, 2014[b]).

Sorghum improvement work in India during sixties resulted in the development of number of hybrids possessing high yield potential than the local varieties. The first two commercial hybrids *viz.*, CSH-1 and CSH-2 were released in the year 1964 and 1965, respectively by All India Co-ordinated Sorghum Improvement Project.

The sorghum crop has wide range of flexibility to grow in various climatic conditions of the world hence it is known by diverse names *viz.*, *Jowar*, *Jaur*, *Cholam* or *Jola* in India, *Guinea corn*, *Kofir corn* and *Dhuma* in Africa, *Kaoling* in China and *Milo maize* in America. It can survive under prolonged drought. It has four features, which make it one of the most drought resistant crops of all as follows: It has a very large root-to-leaf surface area. In times of drought, it will roll its leaves to lesser water-loss by transpiration. If drought continues, it will go into dormancy rather than drying and a waxy cuticle protects its leaves.

Sorghum is alternately used in bread making, alcoholic beverages, sorghum molasses, wax, starch, dextrose, sorghum syrup, edible oil, jaggery, gruel, beer, malted beverages and popped grain making. In building industries, it is used as binder, stiffing agent and as adhesive. It is also useful in bio-fuel production, mineral processing, charcoal and briquette making and also used in paper industries (Quinby *et al.* 1958).

In India, 75% of sorghum area and 85% of production is concentrated in the three states viz., Maharashtra, Karnataka, and Andhra Pradesh. Only about 8% of area is under irrigated.

Area, production and productivity of Sorghum (2013-14)

	Season	**Area (mha)**	**Production (mt)**	**Productivity (kg/ha)**
World		39.97	57.00	1404
India		5.82	5.39	926
Maharashtra	***Kharif***	0.85	1.08	1270
	Rabi	3.22	2.51	779
Total		4.07	3.59	881

Source: - Director Economics and Statistics Department of Agriculture and Co-operation (Anonymous 2014[a]).

The scope for the exploitation of heterosis and the genetic improvement of the crop will depends upon the choice of the parents, direction and magnitude of heterosis and the inheritance of important quantitative traits. Thus, for further development of improved genotypes, the identification of genetically superior, diverse parents to be used in hybridization programme are an important prerequisite. It has also been realized by plant breeders that the choice of parents on the basis of *per se* performance alone has proved to be deceptive and results do not always lead to the desired goals. A number of biometrical techniques have been formulated for identifying superior parents for hybridization.

Line x tester analysis for combining ability suggested by Kempthrone (1957) is one of the powerful tools for identification of the best combining parents which may be hybridized to exploit heterosis or to accumulate desirable alleles. It is also helpful for assessing the nature and magnitude of gene action controlling the inheritance of quantitative traits.

The concept of combining ability plays an important role in identification of superior parents and hybrids. Allard (1960) pointed out that the common approach of selecting the parents on the basis of *per se* performance is not a good indication of their superior combining ability. The choice of parents in any breeding programme has to be based on complete genetic information and knowledge of combing ability of parents and not merely on field performance of different genotype.

In the present investigation entitled, "Combining ability analysis in *rabi* sorghum (*Sorghum bicolor* L. Moench)" by line x tester analysis, performance of 45 F_1's as compared to three male sterile lines (females), fifteen testers (males) and one standard check has been studied with the following objectives.

1) To estimate the heterosis for grain and yield contributing characters.
2) To estimate the general combining ability effects and specific combining ability effects of parents and its crosses.

CHAPTER II

REVIEW OF LITERATURE

The literature related to the present investigation has been reviewed and presented under the following sub-headings.

2.1 Heterosis

2.2 Combining ability

2.1 Heterosis

The term heterosis refers to the phenomenon in which the F_1 population obtained by crossing of two genetically dissimilar gametes or individuals showing increased or decreased vigour over the mid or better parental values. Shull (1914) coined the term 'heterosis' and he derived it from Greek words 'hetero' means' different and 'osis' means a different condition, i.e. different from their parents. He referred to this phenomenon as the stimulus of heterozygosis.

Recently, a new word, 'heterobeltosis' has been used (Fonseca and Patterson, 1968) to describe the improvement of the heterozygote in relation to the better parent of the cross. In crop plants, heterosis was defined by Stebbing (1957) as 'greater adeptedness to human needs which had been obtained in a particular environment, through artificial selection followed by hybridization.

Hybrid vigour was first noticed by Koelreuter (1763) in the interspecies crosses of Nicotiana and was studied thereafter by numerous workers. Jones (1917) postulated that heterosis is due to large number of linked favorable dominant genes.

Heterosis in sorghum was observed and described in the literature before hybrid sorghum became commercially important. The existence of marked heterosis in sorghum was noted by many workers, Conner and Karper (1927) reported 66% increase in plant height over the tall parent in cross between Milo and Feterita in sorghum. However, commercial exploitation of hybrid vigour came into light only when Stephens and Holland (1954) reported for the first time, the use of cytoplasmic genetic male sterility for developing hybrids of sorghum.

A number of hypotheses have been put forward explaining heterosis, which basically differs among themselves in the role of dominant genes. Dominance hypothesis was proposed by Davenport (1908), whereas, over dominance hypothesis was given by East (1908).

The literature on heterosis for various characters in sorghum has been reviewed and given below.

Rao and Gaud (1975) reported heterosis for plant height, panicle length, days to 50 per cent blooming, number of leaves per plant, grain yield, number of grains per panicle and protein percentage in 5 x 5 diallel analysis in sorghum.

Rana and Murty (1978) recorded positive heterosis for plant height, panicle length and number of branches per panicle while negative heterosis was recorded for days to 50 per cent flowering.

Thanky *et al.* (1981) studied hybrids derived from three lines and seven testers and observed maximum heterosis for plant height and earhead length while, other characters in descending order of heterosis were seed size, days to maturity, grain yield and days to 50 per cent bloom. They further concluded that hybrids involving local parents were high yielder and early in maturity.

Shinde *et al.* (1983) reported heterosis in *rabi* sorghum and noticed that crosses between local x local parents showed maximum heterosis (40.95%) as compared to improved x improved varieties (12.96%) which might be due to more genetic diversity present in local strains. Similarly average heterosis was maximum for grain yield and 1000 grain weight, while negative heterosis for panicle length and moderate heterosis for plant height.

Ambekar and Nandanwankar (1985) observed heterosis in crosses between *kharif* and *rabi* varieties and recorded heterosis for grain yield to the extent of 59.9%.

Sahib *et al.* (1986) in their 10 x 10 diallel crosses studies observed 29% heterosis for grain yield.

Chinna and Phul (1988) observed positive and significant heterosis for grain yield, panicle weight, panicle length, and 1000 seed weight and plant height under irrigated and limited environmental conditions.

Patil and Bapat (1991) revealed that the crosses exhibiting the highest heterosis effects involved at least one parent with good general combining ability. While high SCA was not necessarily reflected in high heterosis.

Mehetre and Borikar (1992) crossed five MS lines having Maldandi cytoplasm with three restorers and reported high significant positive heterosis for grain yield, earhead length and number of primaries.

Sankarapandian *et al.* (1994) studied heterosis for yield and yield attributes in a set of 42 cross combinations evolved from three male sterile lines and fourteen testers of sorghum. Significant heterosis was recorded by all the hybrids over better parents for harvest index. While twenty hybrids showed significant and positive heterosis for grain yield.

Naik (1996) stated that, the magnitude of heterosis and heterobeltiosis in respect of dry fodder yield was remarkable in hybrids. Most of the crosses exhibited considerable heterosis for dry fodder yield, plant height, leaf length and leaf breadth.

Salunke and Deore (1998) in study of heterosis in sixty hybrids of *rabi* sorghum resulting from 5 lines x 12 testers mating design indicated higher magnitude of heterosis for grain yield, 1000-grain weight, number of grains per plant and 50 per cent flowering.

Jilani *et al.* (2000) observed 126 Sorghum hybrids developed on diverse cytoplasmic male sterile lines along with 23 parents and observed that hybrids *viz.,* MS-296A_2 x IS-3667, MS-296A x IS-3667 and VZM x IS-3667 showed best heterosis, heterobeltiosis and standard heterosis for most of the yield component traits and grain yield for both *kharif* and *rabi* seasons which indicated the proper utilization of the diverse cytoplasmic sources of sorghum for commercial hybrid seed production.

Patil (2000) reported low heterosis for days to 50 per cent flowering, low to medium heterosis for plant height and panicle length, medium heterosis for primaries per panicle and high heterosis for flag leaf area, grain yield and test weight.

Prabhakar (2001) reported heterosis was ranged from -1.41 to 11.53 per cent for days to flowering, 12.1 to 102.9 per cent for grain yield, -13.88 to 35.48 per cent for test weight over better parent in sorghum.

Ravindrababu *et al.* (2002) conducted 10 x 10 half diallel of sorghum lines and reported that heterosis ranged from -1.38 to 12.95 per cent for flowering, -65.61 to 46.67 per cent for plant height, -56.50 to 41.56 per cent for grain yield, -43.70 to 56.59 per cent for test weight and -17.91 to 29.32 per cent for dry fodder yield.

Murumkar (2002) observed 40 sorghum hybrids by crossing five cytoplasmic male sterile lines and eight testers in line x tester fashion and found that AKMS 43-3A X R 354 exhibited highest heterosis and heterobeltiosis for grain yield in the range of 140.82% and 134.13% respectively followed by hybrid AKMS 43-4A X RB 338 and MS 104 A X R 354.

Kaul *et al.* (2003) screened two MS lines with seven restorers in line x tester mating design and reported high significant positive heterosis for grain yield per plant and test weight and low to medium heterosis for time to flower, plant height, panicle length and number of branches per panicle.

Umakanth *et al.* (2003) studied 12 parents and 32 hybrids of sorghum using four lines and eight testers and observed significant positive heterosis for primaries per panicle, grain yield and test weight.

Chaudhary and Narkhede (2004) positive heterosis was reported in *rabi* sorghum for plant height, panicle length, 1000 grain weight and grain yield.

Jahagirdar and Borikar (2004) studied 121 hybrids in line x tester mating design and reported significant standard heterosis for grain yield, 1000 grain weight, plant height and fodder yield, while negative heterosis for days to 50 percent flowering.

Nirmala *et al.* (2005) studied the comparison of parents and F_1 hybrids, which revealed that, in general the hybrid has better performance than parents for panicle length, number of primary branches, grain yield per plant and 100 seed weight. *Rabi* x *kharif* types of crosses were good for days to 50 per cent flowering and plant height, while *rabi* x *rabi* type of crosses were better for 1000 seed weight. Similarly, the *kharif* x *kharif* type of hybrids have showed better performance for panicle length, panicle width, number of grain per panicle and grain yield per plant.

Rajguru *et al.* (2005) studied 30 hybrids of *rabi* sorghum resulted from three lines x ten testers mating design. They observed appreciable heterosis for days to maturity, plant height, panicle length, 1000 seed weight and fodder yield per plant in most of the crosses. The cross combinations 116A x RS-29, 36642A x SPV-489, 53A x SPV-1277 and 36642A x RSE-5 showed the highest magnitude of heterosis for grain yield and other yield contributing traits in *rabi* sorghum.

Patil *et al.* (2005) evaluated 12 hybrids sorghum along with 5 parents for grain yield and related trait. They observed that grain yield per plant exhibited heterobeltiosis in the range of 12.08 to 63.10 per cent. The cross DSV-5 x M-35-

1 recorded highest significant positive heterosis over mid parent (83.58%) and better parent (63.10%) for grain yield.

Patel *et al.* (2006) studied nine lines of sorghum in half diallel mating design and observed high value of heterobeltiosis for internodes length, number of grains per primaries and 1000 grain weight.

Desai *et al.* (2006) reported that parents and crosses differ significantly for all the characters indicating considerable amount of genetic variability in material. Parent vs. crosses comparison was found significant for all the characters except panicle length. High magnitude of relative heterosis and heterobeltiosis was observed for grain yield per plant, primaries per panicle, 1000 grain weight. The cross combinations *viz.*, AKMS-14A x GJ -41, AKMS -14A x SR-833, AKMS -14A x GJ-38, 104A x GJ -41 were the high performance for grain yield per plant and showed association with high heterotic response.

Umakanth *et al.* (2006) studied 20 hybrids of *rabi* sorghum derived from line x tester mating design. Heterosis over standard check CSH-19R and M-35-1 and better parent was studied for grain yield and its component characters. Negative heterosis over the checks for days to 50 per cent flowering and plant height was observed for most of the hybrids indicating their earliness and status for height. Heterosis for test weight over CSH-19R was significant for all hybrids. The cross 117A x PV-28 was the highest yielding, exhibiting significant heterosis over better parent and both the checks.

Khapre *et al.* (2007) studied heterosis on thirty different hybrids of sorghum resulting from 5 x 6 (line x tester) crosses which indicated pronounced hybrid vigor for plant height grain yield per plant, harvest index, earhead weight, days to maturity. Positive significant hetrobeltiosis for earhead girth (25.32%), earhead weight (65.57%), 1000 grain weight (27.87%). SPV 1500 x RSSV 8 (14.32%) hybrid recorded positive heterobeltosis for grain yield.

Jhansi Rani *et al.* (2008) evaluated ten F_1 hybrids comprising five experimental hybrids and five commercial hybrids. The heterosis was ranged from 47.3% to 78.2% for grain yield and 11.7% to 38.9% for fodder yield in experimental hybrids. Similarly it also ranged from 19.2% to 81.6% for grain yield and from 24.6% to 66.1% for fodder yield in commercial hybrids.

Boratkar (2010) studied combining ability in 50 hybrids in *kharif* sorghum obtained from 5 females and 10 males in line x tester mating design. He found that the cross AKMS 27A x AKR 456 exhibited highest average heterosis, heterobeltiosis and standard heterosis for grain yield of 45.87%, 36.43% and 18.48% respectively.

Takalkar (2010) studied combining ability in 28 hybrids in *rabi* sorghum obtained from four females and seven restorers in line x tester mating design and reported that the cross AKMS 71A x AKRB-502 exhibited highest standard heterosis (43.88%) over check PKV-Kranti in desirable direction for grain yield followed by the crosses 104A x AKR 354 (22.81%) and AKMS 71A x AKR 354 (17.16%).

Prabhakar and Raut (2010) studied a line x tester analysis involving 2 lines and 7 testers. The crosses selected for earliness based on heterosis and significant SCA effects in the desirable direction along with *per se* performance were SL-12B x SLR-10 and SL-12B x SLR-27. The crosses showed high heterosis in the desirable direction with significant SCA effects and higher *per se* performance.

Ghorade *et al.* (2014[a]) reported that hybrid SPH 1635 exhibited significant desirable standard heterosis (25.23%) over the check CSH-16 for grain yield. The hybrid SPH 1635 also recorded significant standard heterosis for fodder yield over CSH 9 by 15.35% and over SPH 840 by 16.71%.

2.2 Combining ability

One of the practical problems encountered by plant breeders has been appropriate choice of parents, which nick well in hybridization and produce superior offspring. The most useful technique that helps the plant breeder in this direction is the analysis for combining ability.

Combining ability may be defined as the ability of an individual to transmit its desirable traits to its offspring. Combining ability has been sub-divided into two categories, general and specific combining ability by Sprague and Tatum (1942). The variance of general combining ability includes additive and additive x additive genetic portion while, specific combining ability usually includes the non-additive genetic portion of the total variance arising largely from dominance and epistatic deviations and also considerable portion of genotype x environment interaction. Information on relative importance of general and specific combining ability is of value in the development of efficient breeding programme in species, which are amenable to commercial production of F_1, synthetic and composite varieties. A review on combining ability for important traits in sorghum is summarized below.

Federer and Sprague (1947) and Green (1948) suggested a single tester could efficiently test sca. They indicated that for estimation of gca more than one tester was necessary.

Handerson (1952) defined sca in terms of interactions due to the consequences of intra-allelic gene interaction (dominance) and due to inter-allelic (epistatic) gene action.

Griffing (1956[a]) presented a model to show that variance for gca involved mostly additive genetic effects whereas, sca resulted from dominance (intra-allelic) and epistatic (inter-allelic) components of genetic variance.

Griffing (1956[b]) and Carnaham *et al.* (1960) suggested that gca includes both additive genetic variance and additive x additive interactions.

Kempthorne (1957) discussed gca and sca variances in terms of covariance of half and full sibs in a random mating population.

Govil and Murty (1973) in the study of combining ability through 8 x 8 diallel in sorghum, reported high sca variance for grain yield, days to 50 per cent blooming and 1000 grain weight.

Rao *et al.* (1976) in diallel analysis for combining ability found that gca effects were more important for days to 50 per cent blooming and plant height, while sca affects were important for earhead weight and grain weight.

Rana and Murty (1978) in a study of diallel and partial diallel mating system in sorghum, reported that both gca and sca variance were significant for days to 50 per cent flowering and plant height in both the sets.

Raju *et al.* (1980) studied that, dominance and epistatis were more important than additive gene effects for the traits panicle length, number of primaries per panicle, 1000-grain weight and grain yield per plant.

Singhania (1980) studied combining ability in two separate experiments of line x tester (8 x 4 and 5 x 21) in sorghum and found that gca variance was predominant for plant height, days to flowering and number of grains per panicle. However, for grain yield sca variance was more important.

Thanky *et al.* (1981) studied three lines x seven testers in sorghum, observed predominance of additive genetic variance for grain yield and its associated characters like plant height and maturity, whereas for panicle length non-additive genetic variance was predominant.

Khidse *et al.* (1982) carried out an investigation involving thirty-two hybrids for studying combining ability. They observed predominance of non-additive gene action for panicle length, panicle weight, and 1000 grain weight and grain yield per plant, whereas plant height and days to 50 per cent flowering were largely governed by additive gene action.

Kukadia *et al.* (1983) developed twenty-four hybrids by utilizing four seed parents and six pollen parents (tester) in sorghum. They observed that both additive as well as non-additive genetic variance were important for the expression of grain yield, while days to flower and plant height were under the control of non-additive gene action. They also reported that female 2219A and male IS 370 were good combiners for yield.

Desai *et al.* (1985) observed predominance of gca variance for 1000-grain weight indicating additive gene. Further, they also concluded that non-additive gene effects were preponderant for grains per panicle.

Patil and Thombre (1986) suggested that plant height, number of leaves, days to 50 per cent flowering and 1000 seed weight were under the control of additive gene effects with high heritability, while low heritability non-additive gene action was observed for panicle girth, panicle weight and grain yield.

Kulkarni and Shinde (1987) observed six characters of yield in 42 hybrids from diallel cross with and without fertilizer and reported significant genotypic differences. Under both conditions, gca and sca mean squares were significant. For all characters except days to 50 per cent flowering, high gca variance and high heritability were noted and it was concluded that additive gene effects were most important. Parent N-13 and CK-60 B were noted as good combiners for 1000 grain weight, grain yield and dry fodder yield. The cross, CSV 18 R x 2022 B was the best specific cross under both fertility levels.

Amsalu and Bapat (1990) studied Combining ability analysis in a set of 10 x 10 diallel (without reciprocal) in sorghum and observed predominance of additive gene action for days to 50 per cent flowering, while, non-additive gene action was preponderant for plant height, panicle length, panicle weight, number of primaries per panicle, 1000 grain weight and yield per plant.

Patel *et al.* (1990) in a diallel study involving 10 varieties of grain sorghum observed sca variance was higher than gca variance for days to 50 per cent flowering, days to maturity, plant height, panicle length and grain yield per plant indicating non additive gene effects for inheritance of these characters.

Ghorade (1991) recorded additive type of gene action for days to 50 per cent flowering, plant height, leaf numbers, leaf area. The non-additive gene action was reported for panicle length, stem girth, panicle breadth, and number of whorls, grain yield and 1000 grain weight.

Jagadeshwar and Shinde (1992) reported best combining varieties (SPV-422 and SPV-438) for early flowering and plant height. Parents SPV-438, SPV-86, SPV-41 were good general combiners for grain yield, number of primaries and secondaries, 1000 grain weight and fodder yield.

Patel *et al.* (1993) while studying diallel cross of six varieties of high-energy sorghum revealed that both gca and sca variances were highly significant for plant height, panicle length, test weight and grain yield per plant which indicated the importance of both additive and non-additive gene action.

Mohamad and Prasad (1994) reported the proportion of gca/sca was wide in the case of panicle length and narrow for panicle weight. Both additive and non-additive gene actions were important while, former being predominant for panicle length, panicle weight, number of grain per panicle and grain yield per plant.

Nayakar *et al.* (1994) evaluated 24 hybrids by crossing four lines and six restorers in line x tester design. The results indicated that line 296 B possessed the highest gca effect for grain yield. Among the restorers, SPV 86 was the most promising male parent and BJ 101 and M 35-1 were the next.

Senthil and Palamisamy (1994) studied combining ability analysis through ten lines x six testers and revealed that dominant gene action was operational for 1000 grain weight, grain yield and additive gene action was operational for days to 50 per cent flowering, plant height and panicle length.

Pillai *et al.* (1995) reported that estimates of variances due to general and specific combining ability indicated the preponderance of non-additive gene action for the panicle characters *viz.,* panicle length, number of primaries per panicle and grain yield per plant while, additive gene action for 1000 grain weight. The result reveled that both gca and sca were important.

Naik (1996) reported that both gca and sca variances were significant for plant height, days to 50 per cent flowering and flag leaf area. It indicated the importance of additive and non-additive gene action in determining the expression of traits.

Salunke *et al.* (1996) reported non- additive gene action, high heritability in the inheritance of days to 50 per cent flowering, panicle girth, number of grains per plant and grain yield under both irrigated and rainfed conditions. Parents with good gca for grain yield and also had good gca for a number of other component traits.

Ambekar *et al.* (1997) reported combining ability for seed yield and its components using five lines and twelve testers. The estimates of gca and sca variance indicated the presence of non-additive gene action for all the studied characters. The parent SPV 489 was good combiner and crosses 401A x 489, 401A x SPV 655 and 296A x SPV 492 were identified for high sca for grain yield.

Bhadouriya and Saxena (1997) reported that the estimates of general and specific combining ability effects indicated the presence of both types of gene action for all the yield-attributing characters under study.

Madrap *et al.* (1997) observed both additive and non-additive gene action for all the traits studied. The parents MS 296A, MS 36642A and MS 401A were good general combiners and the crosses MS 296A x SPV 489, MS 36641A x SPV 492 and MS 401A x SPV 655 were identified for better sca in sorghum improvement.

Poor and Rezai (1997) screened, 13 MS lines and 3 testers of sorghum. They reported high gca effects for days to 50 per cent flowering, plant height, panicle length and grain yield.

Chhimpi (1998) studied eight sorghum lines in half diallel mating design. The results indicated that positive GCA as well as SCA effects for primaries per panicle and grain yield, high gca for test weight and high sca for dry fodder yield.

Karale *et al. (*1998) studied nine parental lines in diallel cross mating system. The result of study indicated that sca was higher in magnitude than gca for days to 50 per cent flowering, leaf area, dry fodder yield, panicle length, primaries per panicle, 1000 grain weight and grain yield.

Patil (2000) high gca effect was observed in his study of 8 x 8 diallel of sorghum lines for plant height, flag leaf area, panicle length and test weight.

Salunke *et al.* (2000) in study of combining ability of 60 hybrids of *rabi* sorghum resulting from line x tester (5 x 12) mating design indicated that the parents showing good general combining ability (gca) for physiological traits were consistently good combiners for grain yield. They also reported male sterile lines 42-A and 36642-A and restorers RS-67, SPV-489, SPV-927 and IS-3962 were found to be good general combiners for physiological traits, harvest index and grain yield.

Ravindrababu *et al.* (2001) reported both additive as well as non-additive gene effects were important for all characters. They reported the parents GJ-39 and CSV -15 were good combiners for grain yield. Promising hybrids for grain yield involved either high x high or high x low gca parental lines.

Siddiqui and Baig (2001) studied combining ability for seed yield and its components using five lines and twelve testers. The parents 53 B and 30 B were good general combiners and the crosses 401 B x SPV 492, 36642 B x 323 B and 90 B x SPV 492 were identified as superior crosses exhibiting high sca effects for grain yield.

Bhavsar and Borikar (2002) reported that sca variance was higher in magnitude than gca variance for days to 50% flowering, plant height, flag leaf area, fodder yield per plant, earhead length, 1000 grain weight and yield per plant.

Gaikwad *et al.* (2002) noted in their study of 4 male sterile lines and 10 restorer lines of sorghum that test weight was governed by additive effect.

Rafiq *et al.* (2002) had reported that days to 50 per cent flowering was governed by additive gene action while non-additive gene action was observed in case of grain yield, 1000-grain weight, plant height, panicle length and leaf area.

Umakanth *et al.* (2002) observed specific combining ability variance higher than the gca variance for days to 50 per cent flowering, plant height, panicle length, primaries per panicle, 1000 grain weight and seed yield.

Kaul *et al.* (2003) crossed two MS lines with seven restorers in line x tester mating design. They reported high sca variances for flowering time, plant height, panicle length and number of branches per panicle, test weight and grain yield per plant.

Chaudhary and Narkhede (2004) studied four male sterile lines and ten restorers crossed in line x tester mating design and analysis of variance for combining ability revealed highly significant differences among the treatments for all the characters indicating presence of variability among the genotypes. The interaction between parents and hybrids was significant except panicle breadth. General combining ability effects of parents exhibited that among the lines, 116A was best combiner for most of the characters. Among the testers, SPV-839, SPV-1217 was found to be best general combiners. The specific combining ability effect revealed that 116A x SPV-839 was best specific cross for most of the characters followed by 104A x SPV-727. It was also observed that the crosses showing good sca effects involved parents either good x poor or poor x poor gca type indicating prevalence of non-additive gene effects.

Jahagirdarand Borikar (2004) studied combining ability for plant height and earhead characters by using eleven male sterile lines (9 *kharif* and 2 *rabi*) and eleven testers during *kharif* and *rabi* season. The female parents were good general combiners for grain yield per plant. Amongst restorers RS-29, KR-190 and KR-191 with positive gca effect for grain yield were useful to develop hybrids suited for *kharif* season, however for *rabi* season RS-29, SPV-492 were good general combiners for grain yield per plant.

Patil *et al.* (2005) studied combining ability of newly derived restorers in *rabi* sorghum. They identified two crosses 1409A x RR-9830 and 104A x RR-9826 showing significantly high sca effects for grain yield per plant and number of grains per panicle with higher mean performance over the check CSH-19R.

Pawar (2005) observed that combining ability of *rabi* parents and revealed that the significant gca effects in desirable direction for grain yield per plant was showed by MS 104A and AKRMS-69 among female parents and AKR-351, AKR-354, AKR-377, AKR-388-1 and AKR-413 among the male parents. The line MS 104A appeared to be the good combiner showing significant gca for almost all the traits except 1000 seed weight. Among the hybrids, the hybrid 104A x AKR-354 exhibited maximum *per se* performance for yield per plant with significant sca effects for yield and yield contributing characters.

Sumalini *et al.* (2005) studied line x tester analysis for combining ability by crossing four male sterile lines with eight restorers of sorghum and reported that gca and sca variances revealed the predominant role of additive gene action for plant height, stem thickness, leaf breadth, days to 50 per cent flowering, panicle length, 1000 grain weight and dry fodder per plant and non additive genetic effects in the inheritance of number of leaves per plant, leaf length, panicle breadth, grain weight per earhead and green fodder yield per plant. The best general combiners identified for both grain and fodder yield were 18-3A and Ruchira.

Chaudhary *et al.* (2006) observed non-additive gene action for all the characters. The lines 116 A, 117A, and testers RSLG 112, SPV 1090, SPV 839 and SPV 1167 emerged as good general combiners for yield and its yield contributing characters. Considering the *per se* performance, gca and sca effects the crosses *viz.,* 104 A x SPV 839, 116 A x SPV 839, 117 A x SPV 1047 were appeared to be most promising which can be exploited for the development of the hybrids.

Premalatha *et al.* (2006) in line x tester fashion studied and reported negative gca effects for days to 50% flowering might be useful in breeding programme for earliness.

Umakant *et al.* (2006) studied 20 hybrids of *rabi* sorghum derived from line x tester mating design. Among land races, PV-28 and PV-16 proved to be better because of their good combining ability and could be utilized for commercial exploitation of heterosis.

Mukesh *et al.* (2007) studied combining ability effects in seven male sterile lines, six pollinator parents and their 42 crosses for fodder yield and components traits. The estimates of variances due to general and specific combining ability and their ratio (σ^2 sca: σ^2gca) indicated the importance of non-additive type of gene action for all the characters. Male sterile lines *viz.,* ICS 4A, ICS 79A and tester IS 3289 were found as good general combiners for most of the traits. The crosses ICS 79A x IS 3274, ICS 79A x SSG 59-3 exhibited higher sca effects for most of the studied characters.

Shelke (2007) studied combining ability and indicated that there was considerable amount of genetic variability among the parents for all characters under study. The lines MS 104 A and MS 1409 A and restorers RSLG 342, RSLG 345, RSLG 389, RSLG 322 and RSLG 484 were found to be the good general combiners for majority of characters, such as grain yield per plant, panicle length, panicle breadth, 1000 seed weight, number of grains per panicle, days to 50% flowering and dead heart per cent. The crosses MS 104A X RSLG 322, MS 1409 A X RSLG 389 and MS 1409 A X RSLG 345 exhibited good sca effects for grain yield and its components.

Yadhav and Pahuja (2007) revealed preponderance of non-additive genetic variance for plant height, leaf length, leaf breadth, stem girth, number of tillers per plant, number of leaves per plant, green fodder and dry fodder yield.

Boratkar (2010) studied combining ability in 50 hybrids in *kharif* sorghum obtained from five females and 10 males in line x tester mating design. Study indicated that the females parents AKMS 27A and AKMS 40A showed significant gca effects for days to 50% flowering, days to maturity, plant height, number of grains per panicle, grain yield per plant. He also reported that male parent AKR 496 exhibited significant gca effects for plant height, panicle length, grain yield per plant and fodder yield per plant. The cross AKMS 14A x AKR 496 recorded highly significant sca effect for grain yield per plant.

Prakash *et al.* (2010) studied 35 hybrids resulting from seven lines and five testers. They observed that the parents ISCA 693 and PKB 192 recorded high *per se* performance with positively significant gca effects for green fodder yield per plant. In addition, the crosses ISCA 547 x PKB 192, ICSA 374 x PKB 161, ICSA 403 x CSV 15-217 recorded high *per se* performance and significant sca effects for green fodder yield per plant.

Takalkar (2010) reported that line AKMS-71A exhibited significant and desirable gca effects for grain yield per plant. Further, the male AKR-354 showed significant and desirable gca effects for grain yield per plant. The cross AKMS-71A x AKRB-502, MS-104A x AKR-354, AKMS-75-1A x RS-585 and AKMS-80A x AKRB-3872 exhibited desirable sca effects for grain yield per plant.

Hariprasanna *et al.* (2012) reported that some of the crosses with positive significant sca variances for grain yield involved even low x low combination of parents.

Umakant *et al.* (2012) observed the gca and sca of 8 parents and 16 hybrids respectively at three semi arid location by following a line x tester mating design. The analysis of variance for combining ability revealed the presence of significant differences due to lines, testers, lines x testers for all the characters studied indicating the existence of variability among parents and hybrids. The variance components estimates of sca were greater than the of gca for grain yield indicating the non-additive control of genetic variation.

Tariq *et al.* (2012) observed general combining ability variances were lower than the specific combining ability variances for all the evaluated parameters, indicating greater dominant variance than the additive variance. The sorghum line V-1 indicated the highest general combining ability effects in the desired directions for plant height, TSS-9 for number of tillers per plant and CSV-13 for stem thickness.

Prabhakar *et al.* (2013) observed combining ability effects involving five females, four males and their 20 crosses for days to 50% flowering, maturity and grain yield. Analysis of variance indicated existance of variability among the parents. Female SL-9B and males SLR-57 and SLR-30 were good general combiners for grain yield. Female SL-39B and restorer SLR-66 were good general combiners for grain yield along with earliness and can be useful in developing early maturing and high yielding hybrids in *rabi* sorghum. The crosses 104B x SLR-30, SL-9 x SLR-57, SL-9B x SLR-30 and 104B x SLR-57 were identified promising for improving grain yield, while crosses SL-19B x SLR-66, SL-9B x SLR-66 and SL-39B x SLR-

57 selected for breeding for earliness. High heterotic crosses showed significant sca effects with higher *per se* performance.

Ghorade *et al.* (2014[b]) studied five lines and twelve testers by using line x tester mating design. Analysis of variance indicated presence of considerable variability among the parents selected for the study. They reported that out of five lines, the line MS 104A was good general combiner for grain yield per plant along with five drought tolerance traits. Some promising hybrids for grain yield involved high x high gca combination while some recorded high x low gca parental lines. Some of the promising crosses for grain yield were reported based on positive significant sca effects for grain yield along with mean performance and heterosis.

CHAPTER III

MATERIAL AND METHODS

The present investigation entitled, "Combining ability analysis in *rabi* sorghum [*Sorghum bicolor* (L.) Moench] was conducted at Sorghum Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri-413 722, Dist. Ahmednagar, (M.S.) India during the year 2014-15.

The details of the material used and method adopted and statistical analysis followed during the course of this investigation are described below.

3.1 Experimental material

The experimental material of the present studied comprised of three lines (females), fifteen testers (males), their resulting 45 hybrids and one hybrid check CSH-15R obtained from the Sorghum Breeder, All India Co-ordinated Sorghum Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri. The details of parents with their pedigree and silent features are presented in table 3.1.

Table 3.1 List of sorghum parents along with pedigree and silent features.

Sr.No.	Parents	Pedigree	Silent Features
Females (Lines)			
1	185 A	104A x Swati (T)	Tan pigment, semi-compact panicle, pearly white grain colour.
2	RMS 2010-10A	104B × (1543B × SP 6234B)	Non-tan pigment, medium size seed and good seed yield potential.

Sr.No.	Parents	Pedigree	Silent Features
3	RMS 2010-24A	1409B × (4111B × 7463B)	Non-tan pigment, medium plant height, longer semi compact panicle, shootfly tolerant.
Males (Testers)			
4	RSR 2231	CSV 216 x RSE 90	Round and lustrous grain colour.
5	RR 2145	RSR 3 x Sel-3	Bold grain, High yield.
6	RSV 1059	RSV 214 x RSFR 9509	Shootfly tolerant, high yield.
7	RSV 799	RSLG 888 x CSV 216	Shootfly tolerant.
8	CSV 216	Sel. from local land race	High yield, Round and lustrous grain, Non tan pigment.
9	RSV 1200	RSV 491 x RSV 273	High yield, Non lodging.
10	RSV 1093	SPV 1502 x RSFR 9509	Stay green, Shootfly tolerant.
11	RSV 912	Barshi x SPV 1359	Barshi type grain colour
12	RSV 423	RSLG 206 x SPV 1047	Good grain colour, Drought tolerant.
13	RSV 1098	CSV 216 x SPV 1502	High yield, Tall.
14	RSV 1130	CSV 216 x SPV 1543	Pearly white grain colour. Bold grains.
15	RSV 1151	RSV 491 x RSE 3-1	Shootfly tolerant.
16	RSV 1145	RSV 491 x RSE 3-1	Highly shootfly tolerant.
17	RSLG 2291	Sel. from local germplasm	Stay green, Drought and shootfly tolerant
18	RSV 1009	CSV 216 x Dudh Mogra	High yield, Tall.

3.2 Methods

3.2.1 Production of F_1 seeds

During *rabi* 2013-14, experimental material consisting three male sterile lines and fifteen testers were sown at Sorghum Improvement Project, MPKV, Rahuri and these lines and testers were crossed in line x tester design to produce 45 possible hybrids. Thus, enough quantity of seed of these 45 hybrids were produced during *rabi* 2013-14. The experiment was conducted during *rabi* 2014-15 by using eighteen parents, their 45 possible hybrids along with one standard check CSH-15R at Sorghum Improvement Project, MPKV, Rahuri. The details of experiment are given as below.

3.2.2 Experimental details

Sr.No.	Details of experiment	
1	Experimental design	Randomized Block Design
2	No. of replications	Two
3	Number of genotypes	64 (18 Parents + 45 hybrids + 1 Check)
4	Spacing	45 x 15 cm
5	Plot size	
	Gross size	3.00 x 0.45 m^2
	Net size	2.70 x 0.45 m^2
6	Date of sowing	17.09.2014
7	Fertilizer dose	100:50:50 kg NPK/ha

3.2.3 Observations recorded

Observations were recorded on five randomly selected plants from each replication.

1. Days to 50 % flowering

Days required from the date of sowing to the day when 50 % of the plants in each entry commenced flowering.

2. Plant height (cm)

Height of the plant was measured in the centimeters from ground level to the tip of the earhead of the five selected plants at the time of maturity and mean height per plant was calculated.

3. Number of internodes

Number of internodes per plant counted from selected five plants of each replications and the average was reported as number of internodes per plant.

4. Panicle length (cm)

Panicle length was measured in centimeters from the base of the panicle to the tip of the panicle.

5. Panicle girth (cm)

Panicle girth at the center of panicle was recorded in centimeter at the time of harvesting.

6. Panicle weight (g)

Weight of individual panicle was weighted in grams and average calculated.

7. 1000-seed weight (g)

A random sample of 1000-seed was taken from the bulk produce of each plant and weight was recorded in grams.

8. Days to maturity

Number of days required for maturity of grains from date of sowing was recorded at the time of harvesting.

9. Fodder yield per plant (g)

Fodder yield of each randomly selected plant was recorded after harvesting in grams.

10. Grain yield per plant (g)

The total grain weight per panicle after threshing was recorded in grams.

11. Harvest index (%)

The harvest index was determined from mean values of grain yield per plant and biological yield per plant by using formula given by Donald (1962).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

12. Dead heart (%)

Number of dead heart plants were counted and dead heart percentage was calculated after 21 days of sowing.

3.3 Statistical analysis

Combining ability analysis was carried out as per Kempthorne (1957) and modified by Arunachalam(1974).

Heterosis was calculated as per Fonesca and Patterson (1968).

3.3.1 Analysis of variance for various characters

Analysis of variance was performed to test the significance of differences between the treatments by RBD (Panse and Sukhatme 1957)

Sources of variation	D.F.	S.S.	M.S.S.	'F' value calculated
Replication	(r-1)	R.S.S.	$\frac{R.S.S.}{(r-1)}$	$\frac{R.M.S.S.}{Er\ M.S.S.}$
Treatment	(t-1)	Tr. S.S.	$\frac{Tr.\ S.S.}{t-1}$	$\frac{Tr.\ M.S.S.}{Er.\ M.S.S.}$
Error	(r-1) (t-1)	E.S.S.	$\frac{E.S.S.}{(r-1)(t-1)}$	
Total	(rt-1)	T.S.S.		

1. $C.F. = \frac{(G.T.)^2}{r \times t}$

2. Total S.S. = Total sum of squares of all observation – C.F.

3. $\text{Replication S.S.} = \frac{\text{S.S. for all replications total}}{t} - C.F.$

4. $\text{Treatment S.S.} = \frac{\text{S.S. for all treatments total}}{r} - C.F.$

5. Error S.S. = Total S.S. – (Replication S.S. + Treatment S.S.)

Where,

r = Number of replications

t = Number of treatments

G.T. = Grand total

S.S. = Sum of squares

C.F. = Correction factor

R.S.S. = Replication sum of squares

Er. S.S. = Error sum of squares

The metric traits which appeared to be significant were further subjected to Line x Tester analysis.

In order to test the significant of hybrids and parents individually, further partitioning of treatment S.S. into males, females, male vs female, hybrids and hybrids vs parents.

Sources of variation	D.F.	Mean sum of squares	'F' value calculated	'F' value Table
Replication	(r-1)			
Treatment	(t-1)			
Parents	(P-1)			
Hybrids	(h-1)			
Parents vs Hybrids	(1)			
Male	(m-1)			
Females	(f-1)			
Male vs Female	(1)			
Error	(r-1) (t-1)			
Total				

Where,

r = Number of replications

t = Number of treatments

p = Number of parents

h = Number of hybrids

m = Number of males

f = Number of females

3.3.2 Estimation of heterosis

Estimation of heterosis and testing of significance as per Fonesca and Patterson (1968).

1. Per cent heterosis over mid parent (Average heterosis)

$$= \frac{\overline{F_1} - \overline{M.P.}}{\overline{M.P.}} \times 100$$

Where,

$\overline{M.P.}$ = Mean of two parents of that particular hybrid

$$\overline{MP} = \frac{(P_1 + P_2)}{2}$$

$\overline{F_1}$ = Mean of F_1 hybrid

P_1 = Mean of first parent

P_2 = Mean of second parent

2. Per cent heterosis over better parent (Heterobeltiosis)

$$= \frac{\overline{F_1} - \overline{B.P.}}{\overline{B.P.}}$$

Where,

$\overline{F_1}$ = Mean of F_1 hybrids

$\overline{B.P.}$ = Mean of better parent of that particular hybrid

3. Per cent heterosis over standard check (Standard heterosis)

$$= \frac{\overline{F_1} - \overline{S.C.}}{\overline{S.C.}}$$

Where,

$\overline{S.C.}$ = Mean of standard check.

The significance of heterosis was tested by the least significant differences as below :

$$\text{L.S.D. for M.P.} = \sqrt{\frac{3\ Me}{r}} \times t \text{ at 5 \% and 1 \% level of significance for error d.f.}$$

$$\text{L.S.D. for B.P.} = \sqrt{\frac{2\ Me}{r}} \times t \text{ at 5 \% and 1 \% level of significance for error d.f.}$$

$$\text{L.S.D. for SH} = \sqrt{\frac{3\ Me}{r}} \times t \text{ at 5 \% and 1 \% level of significance for error d.f.}$$

Where,

Me = Error mean sum of squares.

r = Number of replications.

L.S.D. = Least square difference

3.3.3 Analysis of variance for combining ability

The combining ability analysis for 45 hybrids was carried out as per the procedure developed by Kempthorne (1957) and modified by Arunachalam (1974).

The sum of square due to different factors was partitioned as shown in table given below.

ANOVA for combining ability

Sr. No.	Sources of variation	D.F.	S.S.	M.S.S.	Expected M.S.
1	Replication	(r-1)	$\sum_{K=1}^{r} \frac{X^2..k}{mf} - \frac{X^2}{mEr}$	-	-
2	Hybrid	(mf-1)	$\sum_{j}^{f} \frac{X^2j}{mr} - \frac{X^2...}{mfr}$	-	-
3	Male	(m-1)	$\sum_{i}^{m} \frac{X^2i..}{fr} - \frac{X^2...}{mfr}$	M_1	σ^2 + r [Cov. (F.S.) – 2 Cov. (H.S.)] + rf [Cov. (H.S.)]
4	Female	(f-1)	$\sum_{j}^{f} \frac{X^2j..}{mr} - \frac{X^2...}{mfr}$	M_2	σ^2 + r [Cov. (F.S.) – 2 Cov. (H.S.)] + mr [Cov. (H.S.)]
5	Male x Female	(m-1) x (f-1)	$\sum_{ij}^{f} \frac{X^2ij..}{r} - \sum_{i}^{m} \frac{X^2i..}{fr}$ $\sum_{j}^{f} \frac{X^2j}{mr} + \frac{X^2...}{mfr}$	M_3	σ^2 + r [Cov. (F.S.) – 2 Cov. (H.S.)]
6	Error	(r-1) (mf-1)	By subtraction	M_4	σ^2e
	Total	(rfm-1)	$\sum_{k=1}^{r} X^2ijk - \frac{X^2...}{mfr}$	-	-

Where,

m = Number of male parents

f = Number of females parents

r = Number of replications

X... = Sum of all the $(ij)^{th}$ hybrid combinations

X.j. = Sum of j^{th} female parent over all males parents and replications

Xij = Sum of the $(ij)^{th}$ hybrid combination over all replications

$X_{i..}$ = Sum of the i^{th} male parent over all female parents and replications

X_{ijk} = $(ij)^{th}$ observation in k^{th} replication

M_1 = Mean sum of squares of males

M_2 = Mean sum of squares of females

M_3 = Mean sum of squares of males x females interaction

M_4 = Error mean sum of squares

From the expectation of mean square co-variance of *full sibs* [Cov. (F.S.)] and co-variance of *half sibs* [Cov. (H.S.) were estimated as follows :

$$\text{Cov. (H.S.)} = \frac{M_1 + M_2 - 3\,M_3}{r\,(m + f)}$$

Cov. (F.S.) = $1/3r - r\,(f + m)$ Cov. (H.S.) x $(M_1 - M_4) + (M_2 - M_4) + (M_3 - M_4) + 6\,r$ Cov. (H.S.)

After estimating the Cov. (H.S.) and Cov. (F.S.) by the above equations, variance due to general combining ability (σ^2gca) and variance due to specific combining ability (σ^2sca) were estimated as :

σ^2gca = Cov. (H.S.)

When the inbreeding co-efficient is 1.

σ^2sca = [Cov. (F.S.) – 2 Cov. (H.S.)]

The following formula was used to know the gene action.

$$\text{Gene action} = \frac{\sigma^2\text{gca}}{\sigma^2\text{sca}}$$

The ratio > 1 indicates the predominance of additive gene action and < 1 indicates the predominance of non-additive gene action.

3.3.4 Estimation of general and specific combining ability effects

The model used to estimate the general and specific combining ability effects of the $(ijk)^{th}$ observation was :

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

Where,

μ	=	Population mean
gi	=	gca effect of the i^{th} male parent
gj	=	gca effect of the j^{th} female parent
Sij	=	sca effect of the (ij^{th}) combination
eijk	=	Error associated with $Xijk^{th}$ observation
i	=	Number of male parents 1, 2, 3…., m
j	=	Number of females parents 1, 2, 3 …., f
k	=	Number of replications 1, 2….., r

The individual effects were estimated as follows :

a) $$\mu = \frac{X...}{mfr}$$

Where,

X…. = Grand total

b) $$g_i = \frac{\Sigma X_{i..}}{fr} - \frac{X...}{mfr}$$

Where,

ΣXi.. = Total of the i^{th} male parent over all females and replication.

c) $gi = \frac{\Sigma Xj..}{mr} - \frac{X...}{mfr}$

Where,

$\Sigma Xj..$ = Total of the j^{th} male parent over all females and replications.

d) $Sij = \frac{\Sigma Xij.}{r} - \frac{\Sigma Xi..}{fr} - \frac{\Sigma X.j.}{mr} + \frac{X...}{mfr}$

Where,

Xij.	=	$(ij)^{th}$ combination total over all replications
m	=	Number of male parents
f	=	Number of female parents
r	=	Number of replications

3.4.4 Calculation of S.E. of differences between general and specific combining ability effects of two parents

1. $$\text{Var. } (gi_1 - gi_2) \text{ males} = \frac{2 \text{ (Error variance)}}{r}$$

$$\text{S.E. } (gi_1 - gi_2) \text{ males} = \sqrt{\text{Var. } (gi_1 - gi_2) \text{ males}}$$

2. $$\text{Var. } (gi_1 - gi_2) \text{ females} = \frac{2 \text{ (Error variance)}}{r}$$

$$\text{S.E. } (gi_1 - gi_2) \text{ females} = \sqrt{\text{Var. } (gi_1 - gi_2) \text{ males}}$$

3. $$\text{Var. } (Sij_1 - Sij_2) \text{ males} = \frac{2 \text{ (Error variance)}}{r}$$

$$S.E.\ (Sij_1 - Sij_2)\ \text{males x female} = \sqrt{\frac{Var.\ (gi_1 - gi_2)}{\text{males x females}}}$$

1. S.E. gca for lines = $\sqrt{Me/rf}$

2. S.E. gca for testers = $\sqrt{Me/rm}$

3. S.E. sca for hybrids = $\sqrt{Me/r}$

CHAPTER IV

EXPERIMENTAL RESULTS

The experimental results of the present investigation "Combining ability analysis in *rabi* sorghum" for various characters obtained from the statistical analysis are presented under following subheads:

4.1 Analysis of variance.

4.2 Mean performance of parents, hybrids and standard check in *rabi* sorghum.

4.3 Estimates of heterosis over mid parent, better parent and standard check.

4.4 Analysis of variance for combining ability.

4.5 Estimates of general combining ability effects of parents.

4.6 Estimates of specific combining ability effects of crosses.

4.1 Analysis of variance

The analysis of variance for eleven characters has been presented in Table 4.1.

It is revealed from Table 4.1 mean sum of squares due to treatments were highly significant for characters *viz.,* days to 50% flowering, plant height, panicle length, panicle girth, panicle weight, 1000 seed weight, days to maturity, fodder yield per plant and grain yield per plant, while significant for number of internodes and harvest index (%). These indicated that presence of substantial amount of genetic variability for all characters.

Table 4.1. ANOVA for eleven characters in *rabi* Sorghum.

Sources of variation	D.F.	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
Replications	1	11.28	196.49	0.48	3.16	0.03	343.45	181.00	11.88	3692.63	4.31	38.81
Treatments	63	20.47**	1172.36**	1.07*	11.65**	5.20**	526.29**	29.46**	8.19**	5107.64**	217.25**	52.55*
Error	63	1.95	258.99	0.69	2.30	1.49	157.41	7.37	0.77	1909.25	104.34	32.45

Note: *, ** = Significant at 5% and 1% level of significance respectively.

4.2 Mean performance of parents, hybrids and standard check for twelve characters in *rabi* sorghum.

Mean performance of parents, hybrids and standard check *viz.,* CSH-15R for various characters are presented in Table 4.2. Higher values are desirable for all the traits under study except days to 50% flowering, days to maturity and dead heart (%) for which lower values are preferred.

1) Days to 50% flowering

The number of days to 50 percent flowering ranged from 62.50 to 76.50 days and 62.50 to 76.50 days among the parents and hybrids, respectively (Table 4.2). Among the parents, tester RSV-912 (62.50 days) took minimum days to 50% flowering followed by line 185 A (66.50 days). Three testers RSV-458, RSV-1098 and RSV-1130 (76.50 days) took maximum days to 50 percent flowering.

Among the 45 hybrids, three hybrids were found to be earlier and superior over the check CSH-15R (71.50 days) and three hybrids required similar days to 50% flowering as compared to standard check. The hybrid 185 A x RSV-458 and RMS 2010-10A x RSV-458 (62.50 days) recorded minimum days to 50% flowering followed by hybrids 185 A x RSR-2231 (67.50 days). The hybrid RMS 2010-10A x RSV-912 (76.50 days) recorded maximum days for 50% flowering.

2) Plant height (cm)

Plant height ranged from 152.50 to 278.16 cm and 193.17 to 272.38 cm among the parents and hybrids, respectively (Table 4.2). Among the parents RMS 2010-24A (152.50 cm) recorded minimum plant height, while CSV-216

Table 4.2: Mean performance of parents, hybrids and standard check for twelve characters in *rabi* sorghum.

Sr. No.	Parents/Hybrids/Check	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)	Dead heart (%)
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Females												
1	185 A	66.50*	157.29	8.80	21.02	13.42	57.00	29.86	124.50*	46.15	30.30	29.72	37.50
2	RMS 2010-10A	73.00	177.25	9.10	18.97	12.09	59.80	25.29	132.00	66.25	24.15	19.21	31.73
3	RMS 2010-24A	73.00	152.50	9.60	18.30	12.31	54.60	23.76	132.00	36.35	30.10	33.91*	18.40
	Males												
4	RSR-2231	74.50	244.70	11.20	19.91	15.02	84.40	38.34	131.50	190.55	55.50	20.35	8.85
5	RR-2145	76.00	257.20	10.90	17.35	15.90	71.00	28.57	132.50	261.75*	39.25	12.46	25.87
6	RSV-1059	75.50	229.60	10.50	16.10	12.65	52.80	31.41	132.50	103.95	34.50	22.04	39.29
7	RSV-799	75.00	244.62	11.40	16.81	14.05	80.60	28.78	133.00	181.35	38.10	14.52	31.54
8	CSV-216	76.00	278.16*	11.00	18.81	14.48	79.40	27.61	132.50	222.80	50.75	17.43	28.43
9	RSV-1093	74.50	254.94	11.90	13.45	12.31	53.40	32.03	131.50	190.25	43.30	18.18	46.15
10	RSV-1200	75.50	254.53	11.40	15.43	13.06	69.50	33.45	132.50	220.35	47.40	16.83	38.77
11	RSV-912	62.50*	258.49	11.70	18.74	14.45	73.00	34.61	127.50*	176.85	47.70	20.74	32.10
12	RSV-458	76.50	222.93	11.10	13.92	9.66	37.24	35.70	132.50	200.75	19.20	8.08	41.67
13	RSV-1098	76.50	248.47	11.70	16.40	12.32	82.20	31.61	133.50	178.30	53.70	20.47	25.76
14	RSV-1130	76.50	260.93*	11.70	15.76	12.05	62.80	30.79	132.50	129.50	43.95	26.44	25.40
15	RSV-1151	75.00	260.02	11.60	17.34	15.13	94.60	27.59	131.50	200.45	54.25	18.49	36.67
16	RSV-1145	75.00	255.11	12.40*	17.03	14.04	70.60	31.56	130.50	190.85	41.75	16.53	43.57
17	RSLG-2291	75.00	235.03	11.10	18.35	15.69	83.20	33.89	132.00	206.25	55.65	19.06	25.38
18	RSV-1009	75.00	261.48*	11.70	18.10	15.92	90.80	35.38	129.50*	216.45	57.95*	20.36	30.22
19	185 A x RSR-2231	67.50*	232.73	10.90	22.25	14.45	78.80	35.58	127.50*	211.30	48.20	17.76	39.29

Table 4.2. Contd………

Sr. No.	Parents/Hybrids/Check	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)	Dead heart (%)
		1	2	3	4	5	6	7	8	9	10	11	12
20	185 A x RR-2145	73.00	241.93	11.40	21.83	13.71	74.00	34.36	130.50	80.90	49.15	31.56*	24.35
21	185 A x RSV-1059	70.00	241.99	11.90	22.25	15.89	95.40	33.93	129.00*	96.60	43.70	22.77	26.34
22	185 A x RSV-799	69.00	243.53	10.70	21.65	16.02	81.60	35.14	127.00*	102.80	31.55	17.05	29.95
23	185 A x CSV-216	72.50	239.02	11.00	22.86	16.55	93.80	29.64	130.50	136.70	43.20	20.09	20.30
24	185 A x RSV-1093	71.00	250.31	11.70	24.44*	16.34	95.40	37.90	130.50	122.50	76.80*	35.98*	37.36
25	185 A x RSV-1200	69.00	226.97	11.70	22.04	17.54*	101.60*	32.09	128.50*	72.05	51.85	29.66	17.82
26	185 A x RSV-912	72.50	230.75	10.30	21.21	14.04	53.80	36.61	131.00	98.15	42.00	27.32	21.47
27	185 A x RSV-458	62.50*	213.49	11.30	20.81	15.72	70.60	32.01	125.00*	150.45	56.75*	26.31	46.88
28	185 A xRSV-1098	71.50	260.02	11.90	21.05	15.62	93.20	33.70	129.00*	140.65	51.20	22.03	37.05
29	185 A x RSV-1130	72.00	244.21	10.90	22.81	17.12	95.50	33.76	130.00	118.00	48.40	22.78	24.55
30	185 A x RSV-1151	71.50	236.95	10.90	21.20	15.15	80.40	34.86	130.00	88.30	44.55	27.01	41.67
31	185 A x RSV-1145	73.00	250.99	10.80	23.40	16.90	109.20*	41.90	131.00	207.15	71.50*	22.67	16.67
32	185 A x RSLG-2291	71.50	226.82	11.30	21.33	16.46	94.20	34.31	131.00	145.20	46.65	19.71	27.14
33	185 A x RSV-1009	71.00	252.38	11.30	23.12	17.37*	104.80*	33.44	130.00	155.10	50.85	19.80	20.13
34	RMS 2010-10A x RSR-2231	74.50	237.95	10.90	20.72	13.83	82.40	32.84	132.50	163.25	47.15	19.26	26.95
35	RMS 2010-10A x RR-2145	75.00	264.60*	10.60	21.84	15.54	89.40	35.87	133.50	208.25	48.85	16.46	37.09
36	RMS 2010-10A x RSV-1059	74.50	228.30	11.80	18.48	12.15	53.40	36.77	132.00	153.00	29.85	14.55	34.84
37	RMS 2010-10A x RSV-799	71.00	271.92*	11.90	20.55	12.14	72.20	34.08	129.50*	151.05	44.75	20.04	39.74
38	RMS 2010-10A x CSV-216	73.50	256.61	11.20	18.45	14.15	60.40	34.58	129.50*	180.55	34.00	14.05	28.57
39	RMS 2010-10A x RSV-1093	72.00	263.26*	11.60	20.80	13.15	54.20	32.82	127.50*	191.45	36.95	15.39	22.62
40	RMS 2010-10A x RSV-1200	74.00	271.38*	11.70	21.07	14.20	70.80	33.11	129.00*	174.50	41.00	16.32	30.38
41	RMS 2010-10A x RSV-912	76.50	244.10	10.90	23.14	15.91	98.00*	34.27	133.50	155.85	46.95	18.49	30.36
42	RMS 2010-10A x RSV-458	62.50*	234.85	10.60	21.61	16.04	93.60	32.01	126.50*	145.85	42.80	17.90	17.14
43	RMS 2010-10A x RSV-1098	74.00	272.38*	11.60	17.74	17.43*	72.00	37.28	131.00	180.15	44.45	17.57	40.00
44	RMS 2010-10A x RSV-1130	74.00	261.85*	12.40*	18.52	14.85	70.80	39.80	132.00	157.40	44.15	19.00	12.99

Table 4.2. Contd.........

Sr. No.	Parents/Hybrids/Check	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)	Dead heart (%)
		1	2	3	4	5	6	7	8	9	10	11	12
45	RMS 2010-10A x RSV-1151	74.00	253.20	11.40	19.54	13.98	62.40	38.97	131.50	161.70	36.20	16.18	29.67
46	RMS 2010-10A x RSV-1145	72.00	246.30	11.90	20.20	14.62	72.80	30.83	130.50	161.00	43.05	18.34	22.52
47	RMS2010-10A x RSLG-2291	73.50	264.39*	11.10	22.72	17.22	110.60*	39.97	130.00	206.35	61.30*	19.31	13.85
48	RMS 2010-10A x RSV-1009	74.00	244.33	11.40	20.23	15.36	94.20	38.10	131.50	171.90	55.20	20.78	26.97
49	RMS 2010-24A x RSR-2231	72.00	230.94	9.30	21.31	14.23	58.80	34.47	130.00	92.55	28.15	18.08	26.10
50	RMS 2010-24A x RR-2145	76.00	231.10	11.10	20.90	14.33	81.20	27.66	134.00	109.75	34.90	17.78	38.89
51	RMS 2010-24A x RSV-1059	74.00	238.72	11.00	20.40	16.11	77.80	31.17	132.00	102.10	44.00	24.32	38.46
52	RMS 2010-24A x RSV-799	74.50	219.15	11.30	21.52	15.66	69.40	26.27	132.00	90.75	33.80	21.12	23.38
53	RMS 2010-24A x CSV-216	75.00	203.79	10.70	22.70	15.34	94.40	28.47	132.50	90.00	54.80	29.76	26.10
54	RMS 2010-24A x RSV-1093	76.00	246.98	11.50	22.57	15.17	75.80	26.42	133.50	93.95	40.50	23.73	41.21
55	RMS 2010-24A x RSV-1200	76.00	227.71	11.10	20.72	12.64	65.60	30.18	132.00	96.40	29.70	18.27	58.49
56	RMS 2010-24A x RSV-912	74.50	193.17	9.40	21.32	15.28	66.20	29.11	130.50	54.60	30.15	24.99	46.15
57	RMS 2010-24A x RSV-458	70.50	207.15	9.60	20.20	14.26	76.80	31.71	129.50*	71.70	39.35	25.03	35.06
58	RMS 2010-24A x RSV-1098	75.00	245.63	11.10	21.15	13.05	71.40	29.83	131.00	97.95	43.20	25.61	32.14
59	RMS 2010-24A x RSV-1130	75.50	237.44	11.00	21.50	14.68	86.20	31.19	130.50	140.90	41.80	18.42	38.72
60	RMS 2010-24A x RSV-1151	73.00	226.05	10.90	20.47	15.18	89.60	27.49	129.00*	136.25	47.80	22.98	33.33
61	RMS 2010-24A x RSV-1145	74.50	243.84	11.60	23.37	15.89	99.80*	28.35	128.50*	117.75	55.00	26.04	30.68
62	RMS2010-24A x RSLG-2291	72.00	226.12	10.90	23.28	16.36	91.60	30.27	129.00*	145.40	42.60	18.02	32.17
63	RMS 2010-24A x RSV-1009	74.00	235.40	10.90	22.40	15.46	106.40*	28.77	129.50*	206.85	54.05	16.92	35.90
	Check												
64	CSH-15(R)	71.50	228.48	10.70	20.90	14.82	71.20	36.51	131.50	146.10	35.65	18.64	31.52
	SE (m) ±	0.99	11.38	0.59	1.07	0.86	8.87	1.92	0.62	30.90	7.22	4.03	8.34
	CD at 5 %	2.79	32.16	1.66	3.03	2.44	25.07	5.42	1.76	87.32	20.41	11.38	NS

(278.16 cm) recorded maximum height. Out of 18 parents, three parents were superior for more height i.e. CSV-216 (278.16 cm) followed by RSV 1009 (261.48 cm) and RSV-1130 (260.93 cm) over standard check CSH-15R.

Among the hybrids, seven hybrids exhibited superior plant height over hybrid check CSH-15R (228.48 cm). The hybrid RMS 2010-10A x RSV-1098 (272.38 cm) was tallest followed by RMS 2010-10A x RSV-799 (271.92 cm), RMS 2010-10A x RSV-1200 (271.78 cm), RMS 2010-10A x RR-2145 (264.60 cm). Whereas, among forty five hybrids, hybrid RMS 2010-24A x RSV-912 (193.17 cm) recorded minimum plant height.

3) Number of internodes

The number of internodes ranged from 8.80 to 12.40 and 9.30 to 12.40 among the parents and hybrids respectively (Table 4.2).

Among the 45 hybrids, one hybrid recorded its superiority over hybrid check CSH-15R (10.70) for number of internodes. Hybrid RMS 2010-10A x RSV-1130 (12.40) recorded highest number of internodes, whereas hybrid RMS 2010- 24A x RSR-2231 (9.30) recorded minimum number of internodes.

4) Panicle length (cm)

The panicle length ranged from 13.45 to 21.02 cm and 17.74 to 24.44 cm among the parents and hybrids, respectively (Table 4.2).

Among the hybrids, hybrid 185 A x RSV-1093 (24.44 cm) recorded the highest panicle length followed by 185 A x RSV-1145 (23.40 cm), RMS 2010-24A x RSV 1145 (23.37 cm), RMS 2010-24A x RSLG-2291 (23.28 cm), while one hybrid was found superior over the check CSH-15R (20.90 cm) for panicle length. Whereas, hybrid RMS 2010-10A x RSV-1098 (17.74 cm) recorded minimum panicle length.

5) Panicle girth (cm)

For panicle girth, parents ranged from 9.66 to 15.92 cm and hybrids ranged from 12.14 to 17.54 cm (Table 4.2).

Among the 45 hybrids, three hybrids recorded their superiority over hybrid check CSH-15R (14.82 cm) for panicle girth. Hybrid 185 A x RSV-1200 (17.54 cm) was superior for panicle girth followed by other hybrids RMS 2010-10A x RSV-1098 (17.43 cm), 185 A x RSV-1009 (17.37 cm). Whereas, the hybrid RMS 2010-10A x RSV-799 (12.14 cm) recorded minimum panicle girth.

6) Panicle weight (g)

The average panicle weight ranged from 37.24 to 94.60 g and 53.40 to 110.60 g among the parents and hybrids respectively. (Table 4.2)

Among the 45 hybrids, RMS 2010-10A x RSLG-2291 (110.60 g) recorded highest panicle weight followed by 185 A x RSV-1140 (109.20 g), RMS 2010-24A x RSV-1009 (106.40 g), 185 A x RSV-1009 (104.80 g), 185 A x RSV-1200 (101.60 g). Out of forty five hybrids, seven hybrids were found superior over the check CSH 15R (71.20 g) for panicle weight. Whereas, hybrid RMS 2010-10A x RSV-1059 (53.40 g) recorded minimum panicle weight.

7) 1000 seed weight (g)

1000 seed weight ranged between 23.76 to 38.34 g for parents and 26.27 to 41.90 g for hybrids (Table 4.2).

Among the 18 parents, highest 1000 seed weight was recorded by RSR-2231 (38.34 g). Among the 45 hybrids, hybrid 185 A x RSV 1145 (41.90 g) recorded maximum 1000 seed weight, while RMS 2010-24A x RSV 799 recorded minimum 1000 seed weight (26.27g).

8) Days to maturity

The days to maturity ranged from 124.50 to 133.50 days and 125 to 134 days among the parents and hybrids respectively. Among the parents, RSV-1098 (133.50 days) recorded the maximum days to maturity, while minimum days were recorded by the parents 185 A (124.50 days), RSV-912 (127.50 days) and RSV-1009 (129.50 days).

Among the 45 hybrids, 16 hybrids found superior for days to maturity. The hybrid 185 A x RSV-458 (125 days) took minimum days to maturity followed by RMS 2010-10A x RSV-458 (126.50 days), 185 A x RSV-799 (127 days) and 185 A x RSR- 2231 (127.50 days) found superior for this trait over the check CSH-15R (131.50 days).

9) Fodder yield per plant (g)

The average fodder yield per plant at maturity ranged from 36.35 to 261.75 g and 34.60 to 211.30 g among the parents and hybrids respectively (Table 4.2). Among the parents, tester RR 2145 (261.75 g) recorded the highest fodder yield per plant.

Among the crosses, 185 A x RSR-2231 (211.30 g) recorded maximum fodder yield per plant followed by RMS 2010-10A x RR-2145 (208.25 g) and 185 A x RSV-1145 (207.15 g).

10) Grain yield per plant (g)

The grain yield per plant ranged from 19.20 to 57.95 g and 28.15 to 76.80 g among the parents and hybrids respectively (Table 4.2). Among the parents, RSV-1009 (57.95 g) recorded the highest grain yield per plant.

Among the hybrids, hybrid 185 A x RSV-1093 (76.80 g) recorded maximum grain yield per plant followed by 185 A x RSV-1145 (71.50 g), RMS 2010-10A x RSLG-2291 (61.30 g), 185 A x RSV-458 (56.75 g). Out of 45 hybrids, four hybrids were recorded higher grain yield over hybrid check CSH-15R (36.65 g).

11) Harvest index (%)

The mean value of harvest index ranges from 8.08 to 33.9 percent and 14.05 to 35.98 percent for parents and hybrids respectively (Table 4.2).

Among the parents, line RMS 2010-24A (33.91%) superior for harvest index, while tester RSV-458 (8.08%) recorded minimum harvest index. Among the hybrids, 185 A x RSV-1093 (35.98%) recorded maximum harvest index followed by 185 A x RR-2145 (31.56%), RMS 2010-24A x CSV-216 (29.76%) and 185 A x RSV-1200 (29.66%). Among forty five hybrids, two hybrids were found superior over the check CSH - 15 R (18.64%) for harvest index. Whereas hybrid RMS 2010-10A x CSV-216 (14.05%) recorded minimum harvest index.

12) Dead heart (%)

The mean value for dead heart percent (%) ranged from 8.85 to 46.15 percent and 12.99 to 58.49 percent for parents and hybrids respectively. (Table 4.2)

Among the parents, tester RSR-2231 (8.85%) recorded minimum dead heart percent. Among the hybrids, hybrid RMS 2010-10A x RSV-1130 (12.99%) recorded minimum dead heart percentage followed by RMS 2010-10A x RSLG-2291 (13.85%).

4.3 Estimates of heterosis over mid parent, better parent and standard check.

The estimates of heterosis over mid parent (M.P.), better parent (B.P.) and standard check (CSH-15 R) are presented in table 4.3.

In sorghum, positive heterosis is desirable for all the characters except days to 50 per cent flowering and days to maturity for which negative heterosis are desirable. Character wise results of heterosis in the 45 tested hybrids are presented below.

1) Days to 50% flowering

The better parent heterosis (%) for days to 50% flowering ranged between -14.38 (RMS 2010-10A x RSV-458) to 22.40 (RMS 2010-10A x RSV-912) percent. Out of forty five hybrid combinations studied, eight hybrids exhibited negative heterosis, in which two exhibited highly significant and six had negative but non-significant values for heterobeltosis. The hybrids *viz.*, RMS 2010-10A x RSV-458 (-14.38%), 185 A x RSV-458 (-6.02%) showed highly significant negative heterobeltosis.

The range of standard heterosis (%) observed between -12.59 (185 A x RSV-458) to 6.99 (RMS 2010-10A x RSV-912) percent over standard check CSH 15 R. Out of 45

Table 4.3. Estimates of heterosis over mid parent, better parent and standard check.

Sr. No.	Hybrids	Days to 50 % flowering			Plant height (cm)			No. of internodes		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
1	185 A x RSR-2231	-4.26*	1.50	-5.59**	15.79*	-4.89	1.86	9.00	-2.68	1.87
2	185 A x RR-2145	2.46	9.77**	2.10	16.73*	-5.94	5.89	15.74*	4.59	6.54
3	185 A x RSV-1059	-1.41	5.26*	-2.10	25.09**	5.39	5.91	23.32**	13.33	11.21
4	185 A x RSV-799	-2.47	3.76	-3.50	21.18**	-0.45	6.59	5.94	-6.14	0.00
5	185 A x CSV-216	1.75	9.02**	1.40	9.78	-14.07*	4.61	11.11	0.00	2.8
6	185 A x RSV-1093	0.71	6.77**	-0.70	21.44**	-1.81	9.55	13.04	-1.68	9.35
7	185 A x RSV-1200	-2.82	3.76	-3.50	10.23	-10.83	-0.66	15.84*	2.63	9.35
8	185 A x RSV-912	12.4**	16.0**	1.40	11.0	-10.73	0.99	0.49	-11.97	-3.74
9	185 A x RSV-458	-12.59**	-6.02**	-12.59**	12.29	-4.24	-6.56	13.57	1.80	5.61
10	185 A xRSV-1098	0.00	7.52**	0.00	28.16**	4.65	13.8	16.1*	1.71	11.21
11	185 A x RSV-1130	0.70	8.27**	0.70	16.78*	-6.41	6.88	6.34	-6.84	1.87
12	185 A x RSV-1151	1.06	7.52**	0.00	13.56*	-8.87	3.71	6.86	-6.03	1.87
13	185 A x RSV-1145	3.18	9.77**	2.10	21.72**	-1.61	9.85	1.89	-12.9	0.93
14	185 A x RSLG-2291	1.06	7.52**	0.00	15.63*	-3.49	-0.72	13.57	1.80	5.61
15	185 A x RSV-1009	0.35	6.77**	-0.70	20.53**	-3.48	10.46	10.24	-3.42	5.61
16	RMS 2010-10A x RSR-2231	1.02	2.05	4.2*	12.79	-2.76	4.15	7.39	-2.68	1.87

Table 4.3. Contd………

Sr. No.	Hybrids	Days to 50 % flowering			Plant height (cm)			No. of internodes		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
17	RMS 2010-10A x RR-2145	0.67	2.74	4.90*	21.81**	2.88	15.81*	6.00	-2.75	-0.93
18	RMS 2010-10A x RSV-1059	0.34	2.05	4.20*	12.23	-0.57	-0.08	20.41**	12.38	10.28
19	RMS 2010-10A x RSV-799	-4.05*	-2.74	-0.70	28.91**	11.16	19.01*	16.10*	4.39	11.21
20	RMS 2010-10A x CSV-216	-1.34	0.68	2.80	12.69*	-7.75	12.31	11.44	1.82	4.67
21	RMS 2010-10A x RSV-1093	-2.37	-1.37	0.70	21.83**	3.27	15.22*	10.48	-2.52	8.41
22	RMS 2010-10A x RSV-1200	-0.34	1.37	3.50	25.7**	6.62	18.78*	14.15	2.63	9.35
23	RMS 2010-10A x RSV-912	12.92**	22.4**	6.99**	12.04	-5.57	6.84	4.81	-6.84	1.87
24	RMS 2010-10A x RSV-458	-16.39**	-14.38**	-12.59**	17.37*	5.35	2.79	4.95	-4.5	-0.93
25	RMS 2010-10A x RSV-1098	-1.0	1.37	3.5	27.96**	9.62	19.21**	11.54	-0.85	8.41
26	RMS 2010-10A x RSV-1130	-1.0	1.37	3.5	19.51**	0.35	14.6*	19.23**	5.98	15.89*
27	RMS 2010-10A x RSV-1151	0.00	1.37	3.5	15.81*	-2.62	10.82	10.14	-1.72	6.54
28	RMS 2010-10A x RSV-1145	-2.7	-1.37	0.7	13.93*	-3.45	7.8	10.7	-4.03	11.21
29	RMS2010-10A x RSLG-2291	-0.68	0.68	2.8	28.26**	12.49	15.72*	9.9	0.00	3.74
30	RMS 2010-10A x RSV-1009	0.00	1.37	3.5	11.38	-6.56	6.94	9.62	-2.56	6.54
31	RMS 2010-24A x RSR-2231	-2.37	-1.37	0.7	16.28*	-5.62	1.08	-10.58	-16.96*	-13.08
32	RMS 2010-24A x RR-2145	2.01	4.11*	6.29**	12.81	-10.15	1.15	8.29	1.83	3.74

Table 4.3. Contd………

Sr. No.	Hybrids	Days to 50 % flowering			Plant height (cm)			No. of internodes		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
33	RMS 2010-24A x RSV-1059	-0.34	1.37	3.5	24.95**	3.97	4.48	9.45	4.76	2.8
34	RMS 2010-24A x RSV-799	0.68	2.05	4.2*	10.37	-10.41	-4.08	7.62	-0.88	5.61
35	RMS 2010-24A x CSV-216	0.67	2.74	4.9*	-5.36	-26.74**	-10.81	3.88	-2.73	0.00
36	RMS 2010-24A x RSV-1093	3.05	4.11*	6.29**	21.23**	-3.12	8.09	6.98	-3.36	7.48
37	RMS 2010-24A x RSV-1200	2.36	4.11*	6.29**	11.88	-10.54	-0.34	5.71	-2.63	3.74
38	RMS 2010-24A x RSV-912	9.96**	19.2**	4.2*	-6.0	-25.27**	-15.45*	-11.74	-19.66**	-12.15
39	RMS 2010-24A x RSV-458	-5.69**	-3.42	-1.4	10.35	-7.08	-9.34	-7.25	-13.51	-10.28
40	RMS 2010-24A x RSV-1098	0.33	2.74	4.9*	22.52**	-1.14	7.51	4.23	-5.13	3.74
41	RMS 2010-24A x RSV-1130	1.0	3.42	5.59**	14.86*	-9.0	3.92	3.29	-5.98	2.8
42	RMS 2010-24A x RSV-1151	-1.35	0.00	2.1	9.59	-13.07*	-1.07	2.83	-6.03	1.87
43	RMS 2010-24A x RSV-1145	0.68	2.05	4.2*	19.64**	-4.42	6.72	5.45	-6.45	8.41
44	RMS 2010-24A x RSLG-2291	-2.7	-1.37	0.7	16.7*	-3.79	-1.03	5.31	-1.8	1.87
45	RMS 2010-24A x RSV-1009	0.00	1.37	3.5	13.72*	-9.97	3.03	2.35	-6.84	1.87
	SE (m) ±	1.21	1.40	1.40	13.98	16.14	16.14	0.72	0.83	0.83
	CD at 5 %	2.45	2.83	2.83	28.17	32.53	32.53	1.46	1.68	1.68
	CD at 1 %	3.27	3.78	3.78	37.63	43.46	43.46	1.95	2.25	2.25

Table 4.3.Contd………

Sr. No.	Hybrids	Panicle length (cm)			Panicle girth (cm)			Panicle weight (g)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
1	185 A x RSR-2231	8.74	5.88	6.46	1.62	-3.79	-2.5	11.46	-6.64	10.67
2	185 A x RR-2145	13.8	3.88	4.45	-6.48	-13.77	-7.49	15.63	4.23	3.93
3	185 A x RSV-1059	19.9**	5.88	6.46	21.9**	18.41*	7.22	73.77**	67.37**	33.99
4	185 A x RSV-799	14.49*	3.02	3.59	16.64*	14.02	8.1	18.6	1.24	14.61
5	185 A x CSV-216	14.8*	8.78	9.38	18.66*	14.34	11.67	37.54*	18.14	31.74
6	185 A x RSV-1093	41.83**	16.3*	16.94*	27.01**	21.76*	10.26	72.83**	67.37**	33.99
7	185 A x RSV-1200	20.94**	4.85	5.43	32.5**	30.7**	18.35*	60.63**	46.19*	42.7*
8	185 A x RSV-912	6.72	0.93	1.48	0.75	-2.84	-5.26	-17.23	-26.3	-24.44
9	185 A x RSV-458	19.15*	-0.98	-0.43	36.22**	17.14	6.07	49.84*	23.86	-0.84
10	185 A xRSV-1098	12.52	0.17	0.72	21.37*	16.39	5.4	33.91*	13.38	30.9
11	185 A x RSV-1130	24.05**	8.54	9.14	34.46**	27.57**	15.52	59.43**	52.07*	34.13
12	185 A x RSV-1151	10.56	0.88	1.44	6.13	0.13	2.23	6.07	-15.01	12.92
13	185 A x RSV-1145	23.01**	11.35	11.96	23.09**	20.37*	14.04	71.16**	54.67**	53.37**
14	185 A x RSLG-2291	8.37	1.5	2.06	13.09	4.91	11.07	34.38*	13.22	32.3
15	185 A x RSV-1009	18.22*	10.02	10.62	18.37*	9.08	17.17*	41.81**	15.42	47.19*
16	RMS 2010-10A x RSR-2231	6.56	4.04	-0.89	2.03	-7.92	-6.68	14.29	-2.37	15.73

Table 4.3.Contd.........

Sr. No.	Hybrids	Panicle length (cm)			Panicle girth (cm)			Panicle weight (g)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
17	RMS 2010-10A x RR-2145	20.24**	15.1	4.47	11.04	-2.26	4.86	36.7*	25.92	25.56
18	RMS 2010-10A x RSV-1059	5.36	-2.61	-11.6	-1.82	-3.99	-18.05*	-5.15	-10.7	-25
19	RMS 2010-10A x RSV-799	14.88	8.33	-1.67	-7.12	-13.59	-18.08*	2.85	-10.42	1.4
20	RMS 2010-10A x CSV-216	-2.36	-2.77	-11.75	6.49	-2.28	-4.55	-13.22	-23.93	-15.17
21	RMS 2010-10A x RSV-1093	28.32**	9.65	-0.48	7.79	6.82	-11.27	-4.24	-9.36	-23.88
22	RMS 2010-10A x RSV-1200	22.52**	11.07	0.81	12.94	8.77	-4.18	9.51	1.87	-0.56
23	RMS 2010-10A x RSV-912	22.72**	21.96**	10.69	19.89*	10.1	7.35	47.59**	34.25	37.64*
24	RMS 2010-10A x RSV-458	31.43**	13.92	3.4	47.49**	32.67**	8.23	92.92**	56.52*	31.46
25	RMS 2010-10A x RSV-1098	0.31	-6.48	-15.12*	42.81**	41.48**	17.61*	1.41	-12.41	1.12
26	RMS 2010-10A x RSV-1130	6.65	-2.37	-11.39	23.06*	22.83*	0.2	15.5	12.74	-0.56
27	RMS 2010-10A x RSV-1151	7.62	2.98	-6.53	2.68	-7.63	-5.7	-19.17	-34.04*	-12.36
28	RMS 2010-10A x RSV-1145	12.22	6.48	-3.35	11.9	4.13	-1.35	11.66	3.12	2.25
29	RMS2010-10A x RSLG-2291	21.76**	19.77*	8.71	23.97**	9.75	16.19	54.69**	32.93*	55.34**
30	RMS 2010-10A x RSV-1009	9.14	6.64	-3.21	9.64	-3.55	3.61	25.1	3.74	32.3
31	RMS 2010-24A x RSR-2231	11.8	7.28	2.2	4.1	-5.29	-4.01	-15.4	-30.33*	-17.42
32	RMS 2010-24A x RR-2145	17.25*	14.21	0.00	1.56	-9.91	-3.34	29.3	14.37	14.04

Table 4.3.Contd.........

Sr. No.	Hybrids	Panicle length (cm)			Panicle girth (cm)			Panicle weight (g)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
33	RMS 2010-24A x RSV-1059	18.6*	11.48	-2.39	29.09**	27.35**	8.70	44.88*	42.49	9.27
34	RMS 2010-24A x RSV-799	22.6**	17.6*	2.97	18.82*	11.46	5.67	2.66	-13.9	-2.53
35	RMS 2010-24A x CSV-216	22.34**	20.68*	8.61	14.54	5.98	3.51	40.9*	18.89	32.58
36	RMS 2010-24A x RSV-1093	42.14**	23.31**	7.97	23.19**	23.19*	2.33	40.37	38.83	6.46
37	RMS 2010-24A x RSV-1200	22.88**	13.22	-0.86	-0.34	-3.18	-14.71	5.72	-5.61	-7.87
38	RMS 2010-24A x RSV-912	15.11*	13.77	1.99	14.16	5.71	3.07	3.76	-9.32	-7.02
39	RMS 2010-24A x RSV-458	25.41**	10.38	-3.35	29.81**	15.84	-3.78	67.26**	40.66**	7.87
40	RMS 2010-24A x RSV-1098	21.9**	15.57	1.20	5.97	5.93	-11.94	4.39	-13.14	0.28
41	RMS 2010-24A x RSV-1130	26.25**	17.49*	2.87	20.51*	19.21	-0.98	46.85*	37.26	21.07
42	RMS 2010-24A x RSV-1151	14.86	11.83	-2.08	10.64	0.33	2.43	20.11	-5.29	25.84
43	RMS 2010-24A x RSV-1145	32.27**	27.68**	11.79	20.61*	13.18	7.22	59.42**	41.36*	40.17*
44	RMS 2010-24A x RSLG-2291	27.04**	26.87**	11.39	16.86*	4.27	10.39	32.95*	10.1	28.65
45	RMS 2010-24A x RSV-1009	23.08**	22.4*	7.18	9.49	-2.92	4.28	46.35**	17.18	49.44**
	SE (m) ±	1.32	1.52	1.52	1.05	1.21	1.21	10.95	12.64	12.64
	CD at 5 %	2.66	3.08	3.08	2.12	2.45	2.45	22.07	25.48	25.48
	CD at 1 %	3.56	4.11	4.11	2.84	3.28	3.28	29.48	34.04	34.04

Table 4.3.Contd.........

Sr. No.	Hybrids	1000 seed weight (g)			Days to maturity			Fodder yield per plant (g)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
1	185 A x RSR-2231	4.33	-7.21	-2.55	-0.39	2.41**	-3.04**	78.54*	10.89	44.63*
2	185 A x RR-2145	17.61*	15.07	-5.88	1.56*	4.82**	-0.76	-47.45	-69.09**	-44.63
3	185 A x RSV-1059	10.76	8.04	-7.05	0.39	3.61**	-1.9**	28.71	-7.07	-33.88
4	185 A x RSV-799	19.86*	17.68	-3.74	-1.36*	2.01**	-3.42**	-9.63	-43.31	-29.64
5	185 A x CSV-216	3.15	-0.74	-18.81*	1.56*	4.82**	-0.76	1.65	-38.64*	-6.43
6	185 A x RSV-1093	22.48**	18.33*	3.82	1.95**	4.82**	-0.76	3.64	-35.61	-16.15
7	185 A x RSV-1200	1.37	-4.07	-12.09	0.00	3.21**	-2.28**	-45.93	-67.3**	-50.68
8	185 A x RSV-912	13.57	5.78	0.29	3.97**	5.22**	-0.38	-11.97	-44.5	-32.82
9	185 A x RSV-458	-2.36	-10.34	-12.33	-2.72**	0.4	-4.94**	21.87	-25.06	2.98
10	185 A xRSV-1098	9.63	6.6	-7.7	0.00	3.61**	-1.9**	25.33	-21.12	-3.73
11	185 A x RSV-1130	11.33	9.65	-7.52	1.17	4.42**	-1.14	34.36	-8.88	-19.23
12	185 A x RSV-1151	21.37*	16.74	-4.51	1.56*	4.42**	-1.14	-28.39	-55.95*	-39.56
13	185 A x RSV-1145	36.42**	32.75**	14.77*	2.75**	5.22**	-0.38	74.81*	8.54	41.79
14	185 A x RSLG-2291	7.63	1.24	-6.03	2.14**	5.22**	-0.38	15.06	-29.6	-0.62
15	185 A x RSV-1009	2.51	-5.48	-8.4	2.36**	4.42**	-1.14	18.13	-28.34	6.16
16	RMS 2010-10A x RSR-2231	3.21	-14.36	-10.05	0.57	0.76	0.76	27.14	-14.33	11.74

Table 4.3.Contd………

Sr. No.	Hybrids	1000 seed weight (g)			Days to maturity			Fodder yield per plant (g)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
17	RMS 2010-10A x RR-2145	33.19**	25.53*	-1.75	0.95	1.14	1.52*	26.98	-20.44	42.54
18	RMS 2010-10A x RSV-1059	29.71**	17.07	0.71	-0.19	0.00	0.38	79.79	47.19**	4.72
19	RMS 2010-10A x RSV-799	26.08**	18.44	-6.64	-2.26**	-1.89**	-1.52*	22.01	-16.71	3.39
20	RMS 2010-10A x CSV-216	30.75**	25.24*	-5.27	-2.08**	-1.89**	-1.52*	24.93	-18.96	23.58
21	RMS 2010-10A x RSV-1093	14.51	2.45	-10.11	-3.23**	-3.04**	-3.04**	49.28	0.63	31.04
22	RMS 2010-10A x RSV-1200	12.74	-1.02	-9.3	-2.46**	-2.27**	-1.9**	21.77	-20.81	19.44
23	RMS 2010-10A x RSV-912	14.42	-1.0	-6.14	2.89**	4.71**	1.52*	28.22	-11.87	6.67
24	RMS 2010-10A x RSV-458	4.99	-10.32	-12.31	-4.35**	-4.17**	-3.8**	9.25	-27.35	-0.17
25	RMS 2010-10A x RSV-1098	31.05**	17.94*	2.12	-1.32*	-0.76	-0.38	47.33	1.04	23.31
26	RMS 2010-10A x RSV-1130	41.93**	29.25**	9.01	-0.19	0.00	0.38	60.82	21.54	7.73
27	RMS 2010-10A x RSV-1151	47.4**	41.25**	6.74	-0.19	0.00	0.00	21.26	-19.33	10.68
28	RMS 2010-10A x RSV-1145	8.45	-2.33	-15.56*	-0.57	0.00	-0.76	25.24	-15.64	10.2
29	RMS2010-10A x RSLG-2291	35.09**	17.94*	9.48	-1.52*	-1.52*	-1.14	51.45	0.05	41.24
30	RMS 2010-10A x RSV-1009	25.59**	7.67	4.36	0.57	1.54*	0.00	21.61	-20.58	17.66
31	RMS 2010-24A x RSR-2231	11.0	-10.11	-5.59	-1.33*	-1.14	-1.14	-18.42	-51.43*	-36.65
32	RMS 2010-24A x RR-2145	5.69	-3.2	-24.24**	1.32*	1.52*	1.9**	-26.37	-58.07**	-24.88

Table 4.3.Contd………

Sr. No.	Hybrids	1000 seed weight (g)			Days to maturity			Fodder yield per plant (g)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
33	RMS 2010-24A x RSV-1059	13.01	-0.75	-14.61	-0.19	0.00	0.38	45.55	-1.78	-30.12
34	RMS 2010-24A x RSV-799	0.01	-8.71	-28.04**	-0.38	0.00	0.38	-16.63	-49.96*	-37.89
35	RMS 2010-24A x CSV-216	10.82	3.10	-22.02**	0.19	0.38	0.76	-30.54	-59.61**	-38.4
36	RMS 2010-24A x RSV-1093	-5.29	-17.51*	-27.63**	1.33*	1.52*	1.52*	-17.08	-50.62*	-35.69
37	RMS 2010-24A x RSV-1200	5.51	-9.78	-17.33*	-0.19	0.00	0.38	-24.89	-56.25**	-34.02
38	RMS 2010-24A x RSV-912	-0.27	-15.91	-20.27**	0.58	2.35**	-0.76	-48.78	-69.13**	-62.63*
39	RMS 2010-24A x RSV-458	6.67	-11.16	-13.14	-2.08**	-1.89**	-1.52*	-39.52	-64.28**	-50.92
40	RMS 2010-24A x RSV-1098	7.73	-5.65	-18.3*	-1.32*	-0.76	-0.38	-8.74	-45.06	-32.96
41	RMS 2010-24A x RSV-1130	14.35	1.30	-14.56	-1.32*	-1.14	-0.76	69.91	8.80	-3.56
42	RMS 2010-24A x RSV-1151	7.06	-0.36	-24.71**	-2.09**	-1.9**	-1.9**	15.08	-32.03	-6.74
43	RMS 2010-24A x RSV-1145	2.48	-10.19	-22.35**	-2.1**	-1.53*	-2.28**	3.65	-38.3	-19.4
44	RMS 2010-24A x RSLG-2291	5.02	-10.67	-17.08*	-2.27**	-2.27**	-1.9**	19.87	-29.5	-0.48
45	RMS 2010-24A x RSV-1009	-2.71	-18.68*	-21.19**	-0.96	0.0	-1.52*	63.65*	-4.44	41.58
	SE (m) ±	2.36	2.73	2.73	0.76	0.88	0.88	36.53	42.18	42.18
	CD at 5 %	4.77	5.51	5.51	1.54	1.78	1.78	73.62	85.01	85.01
	CD at 1 %	6.37	7.36	7.36	2.06	2.38	2.38	98.35	113.57	113.57

Table 4.3.Contd………

Sr. No.	Hybrids	Grain yield per plant (g)			Harvest index (%)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
1	185 A x RSR-2231	12.35	-13.15	35.2	-29.05	-40.23*	-4.72
2	185 A x RR-2145	41.34	25.22	37.87	49.68*	6.21	69.31*
3	185 A x RSV-1059	34.88	26.67	22.58	-12.01	-23.37	22.16
4	185 A x RSV-799	-7.75	-17.19	-11.5	-22.9	-42.62*	-8.53
5	185 A x CSV-216	6.6	-14.88	21.18	-14.77	-32.39	7.78
6	185 A x RSV-1093	108.7**	77.37**	115.43**	50.26*	21.08	93.03**
7	185 A x RSV-1200	33.46	9.39	45.44	27.43	-0.2	59.09
8	185 A x RSV-912	7.69	-11.95	17.81	8.29	-8.06	46.57
9	185 A x RSV-458	129.29**	87.29*	59.19*	39.24	-11.46	41.15
10	185 A xRSV-1098	21.9	-4.66	43.62	-12.22	-25.88	18.16
11	185 A x RSV-1130	30.37	10.13	35.76	-18.87	-23.34	22.21
12	185 A x RSV-1151	5.38	-17.88	24.96	12.07	-9.1	44.9
13	185 A x RSV-1145	98.47**	71.26**	100.56**	-1.97	-23.73	21.59
14	185 A x RSLG-2291	8.55	-16.17	30.86	-19.18	-33.67	5.74
15	185 A x RSV-1009	15.24	-12.25	42.64	-20.92	-33.37	6.22
16	RMS 2010-10A x RSR-2231	18.39	-15.05	32.26	-2.63	-5.36	3.33

Table 4.3.Contd.........

Sr. No.	Hybrids	Grain yield per plant (g)			Harvest index (%)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
17	RMS 2010-10A x RR-2145	54.1	24.46	37.03	3.96	-14.32	-11.7
18	RMS 2010-10A x RSV-1059	1.79	-13.48	-16.27	-29.48	-34.01	-21.97
19	RMS 2010-10A x RSV-799	43.78	17.45	25.53	18.81	4.29	7.48
20	RMS 2010-10A x CSV-216	-9.21	-33.0	-4.63	-23.34	-26.89	-24.65
21	RMS 2010-10A x RSV-1093	9.56	-14.67	3.65	-17.67	-19.89	-17.44
22	RMS 2010-10A x RSV-1200	14.61	-13.5	15.01	-9.46	-15.07	-12.47
23	RMS 2010-10A x RSV-912	30.69	-1.57	31.7	-7.46	-10.87	-0.83
24	RMS 2010-10A x RSV-458	97.46*	77.23	20.06	31.21	-6.82	-3.97
25	RMS 2010-10A x RSV-1098	14.19	-17.23	24.68	-11.47	-14.19	-5.77
26	RMS 2010-10A x RSV-1130	29.66	0.46	23.84	-16.76	-28.14	1.93
27	RMS 2010-10A x RSV-1151	-7.65	-33.27	1.54	-14.18	-15.8	-13.22
28	RMS 2010-10A x RSV-1145	30.65	3.11	20.76	2.64	-4.53	-1.61
29	RMS 2010-10A x RSLG-2291	53.63*	10.15	71.95*	0.91	0.52	3.59
30	RMS 2010-10A x RSV-1009	34.47	-4.75	54.84	5.0	2.04	11.45
31	RMS 2010-24A x RSR-2231	-34.23	-49.28*	-21.04	-33.35	-46.67**	-3.0
32	RMS 2010-24A x RR-2145	0.65	-11.08	-2.1	-23.3	-47.56**	-4.61

Table 4.3.Contd………

Sr. No.	Hybrids	Grain yield per plant (g)			Harvest index (%)		
		M.P.	B.P.	S.H.	M.P.	B.P.	S.H.
33	RMS 2010-24A x RSV-1059	36.22	27.54	23.42	-13.08	-28.28	30.45
34	RMS 2010-24A x RSV-799	-0.88	-11.29	-5.19	-12.76	-37.71*	13.3
35	RMS 2010-24A x CSV-216	35.56	7.98	53.72	15.94	-12.23	59.66
36	RMS 2010-24A x RSV-1093	10.35	-6.47	13.6	-8.89	-30.03	27.28
37	RMS 2010-24A x RSV-1200	-23.35	-37.34	-16.69	-27.98	-46.11**	-1.98
38	RMS 2010-24A x RSV-912	-22.49	-36.79	-15.43	-8.54	-26.29	34.07
39	RMS 2010-24A x RSV-458	59.63	30.73	10.38	19.22	-26.19	34.25
40	RMS 2010-24A x RSV-1098	3.1	-19.55	21.18	-5.8	-24.47	37.39
41	RMS 2010-24A x RSV-1130	12.9	-4.89	17.25	-38.95*	-45.67**	-1.18
42	RMS 2010-24A x RSV-1151	13.34	-11.89	34.08	-12.27	-32.22	23.28
43	RMS 2010-24A x RSV-1145	53.1*	31.74	54.28	3.27	-23.2	39.7
44	RMS 2010-24A x RSLG-2291	-0.64	-23.45	19.5	-31.97	-46.87**	-3.35
45	RMS 2010-24A x RSV-1009	22.77	-6.73	51.61	-37.66*	-50.11**	-9.25
	SE (m) ±	8.87	10.24	10.24	4.78	5.52	5.52
	CD at 5 %	17.88	20.65	20.65	9.63	11.12	11.12
	CD at 1 %	23.89	27.58	27.58	12.87	14.86	14.86

Note: * , ** = Significant at 5% and 1% level of significance respectively.

hybrids, ten showed negative value of standard heterosis. Three hybrids showed highly significant negative standard heterosis. The cross 185 A x RSV-458 (-12.59%) showed highly significant negative heterosis followed by RMS 2010-10A x RSV 458 (-12.59%), 185 A x RSR-2231 (-5.59%) over standard check (CSH-15R).

2) Plant height (cm)

The better parent heterosis (%) ranged from -26.74 (RMS 2010-24A x CSV-216) to 12.49 (RMS 2010-10A x RSLG-2291) percent. Out of 45 hybrids, eleven showed positive better parent heterosis.

Standard heterosis (%) ranged from -15.45 (RMS 2010-24A x RSV-912) to 19.21 (RMS 2010-10A x RSV-1098) percent over check CSH-15R (Table 4.3). Out of forty five hybrids, thirty four showed positive heterosis, of which one highly significant, six showed significant positive heterosis over standard check. The hybrid RMS 2010-10A x RSV-912 showed significant positive standard heterosis (19.21%) followed by RMS 2010-10A x RSV 799 (19.01%), RMS 2010-10A x RSV 1200 (18.78%) and RMS 2010-10A x RR 2145 (15.81%) over check CSH-15R.

3) Number of internodes

Heterobeltosis (%) for number of internodes ranged between -19.66 (RMS 2010-24A x RSV 912) to 13.33 (185 A x RSV 1059) percent. None of hybrid showed positive significant heterosis over better parent.

Heterosis over standard check (%) ranged from -13.08 (RMS 2010-24A x RSR 2231) to 15.09 (RMS 2010-10A x RSV-1130) percent. Out of forty five hybrids, thirty nine showed positive heterosis over standard check. The hybrid RMS 2010-10A x RSV-1130 (15.09%) recorded significant positive heterosis over check CSH-15R.

4) Panicle length (cm)

Better parent heterosis (%) for panicle length ranged from -6.48 (RMS 2010-10A x RSV-1098) percent to 27.68 (RMS 2010-24A x RSV 1145) percent. Out of 45 hybrids, forty showed positive and five showed negative better parent heterosis. Out of forty positive hybrids, four were highly significant, six were significant better parent heterosis. The cross combinations RMS 2010-24A x RSV-1145 (27.68%), RMS 2010-10A x RSLG-2291 (26.87%), RMS 2010-24A x RSV-1093 (23.31%) were highly significant positive heterosis over better parent for panicle length.

For this character standard heterosis (%) ranged from -15.12 (RMS 2010-10A x RSV 1098) percent to 16.94 (185 A x RSV-1093) percent (Table 4.3). Thirty hybrids exhibited positive standard heterosis and fifteen exhibited negative standard heterosis for panicle length. The positive significant standard heterosis was observed by the cross 185 A x RSV-1093 (16.94 %) over check CSH-15R.

5) Panicle girth (cm)

Heterobeltosis (%) for panicle girth ranged from -13.77 (185 A x RR-2145) percent to 41.48 (RMS 2010-10A x RSV-1098) percent (Table 4.3). Among the hybrids, five hybrids showed highly significant positive heterobeltosis, while five hybrids showed significant positive heterobeltosis over better parent. Out of 45 hybrids, hybrid *viz.,* RMS 2010-10A x RSV 1098 (41.48%), RMS 2010-10A x RSV 458 (32.67%) and 185 A x RSV-1200 (30.7%) exhibited highly significant positive better parent heterosis.

The range of standard heterosis (%) over standard check CSH 15 R was observed from -18.08 (RMS 2010-10A x RSV 799) percent to 18.35 (185 A x RSV 1200) percent. Out of forty five hybrids evaluated, three hybrids observed significantly superior over standard check for panicle girth. The hybrid 185 A x RSV-1200 (18.35%) recorded significant positive standard heterosis over CSH-15R followed by RMS 2010-10A x RSV 1098 (17.61%) and 185 A x RSV 1009 (17.17%).

6) Panicle weight (g)

The better parent heterosis (%) for panicle weight ranged between -34.04 (RMS 2010-10A x RSV 1151) percent to 67.37 (185 A x RSV-1059) percent. Among the 45 hybrids, twenty nine showed positive, while sixteen showed negative heterobeltosis. The four hybrids had highly significant, five had significant positive values. The hybrids *viz.*, 185 A x RSV 1059 (67.37%), 185 A x RSV 1093 (67.37%) had highest magnitude of heterobeltosis.

The range of standard heterosis (%) for panicle weight observed between -24.44 (185 Ax RSV-912) to 55.34 (RMS 2010-10A x RSLG-2291) percent. Out of 45 hybrids, thirty three had positive and twelve had negative heterosis over check CSH 15R. Among the thirty three positive hybrids, three had highly significant, four had significant positive standard heterosis. RMS 2010-10A x RSLG 2291 (55.34%) recorded highest standard heterosis followed by 185 A x RSV-1145 (53.37%), RMS 2010-24A x RSV 1009 (49.44%) over hybrid check CSH 15R.

7) 1000 seed weight (g)

The heterobeltosis (%) for 1000 seed weight ranged between -18.68 (RMS 2010-24A x RSV-1009) to 41.25 (RMS 2010-10A x RSV-1151) percent. Three hybrids showed highly significant positive heterobeltosis, five showed significant positive heterobeltosis among the twenty two positive hybrids. The hybrid combinations *viz.*, RMS 2010-10A x RSV-1151 (41.25%), 185 A x RSV-1145 (32.75%), RMS 2010-10A x RSV-1130 (29.25%) showed highly significant positive heterobeltosis for 1000 seed weight.

Standard heterosis (%) over standard check CSH-15R ranged between -28.04 (RMS 2010-24A x RSV-799) to 14.77 (185 A x RSV-1145) percent. Among the 45 hybrids, nine hybrids showed positive while thirty six hybrids showed negative standard heterosis. The hybrid 185 A x RSV-1145 showed positive significant standard heterosis over hybrid check.

8) Days to maturity

For days to maturity, negative heterosis is desirable and preferred in sorghum breeding.

The better parent heterosis (%) for days to maturity ranged between –4.17 (RMS 2010-10A x RSV-458) to 5.22 (185 Ax RSV-912) percent. Out of forty five hybrid combinations studied eight crosses exhibited highly significant negative heterobeltosis and two showed significant negative heterobeltosis. The hybrid combinations *viz.*, RMS 2010-10A x RSV-458 (-4.17%), RMS 2010-10A x RSV-1093 (-3.04%), RMS 2010-10A x RSV-1200 (-2.27%) and RMS 2010-24A x RSLG-

2291 (-2.27%) showed highly significant negative heterobeltosis for days to maturity.

The range of standard heterosis (%) was observed between -4.94 (185 A x RSV 458) to 1.90 (RMS 2010-24A x RR-2145) percent. Out of 45 hybrids, thirty two showed negative value of standard heterosis. Twelve hybrids were highly significant, four were significant negative standard heterosis. The cross 185 A x RSV-458 (-4.94%) showed superior significant negative standard heterosis followed by RMS 2010-10A x RSV 458 (-3.8%), 185 A x RSV-799(-3.42%) over check CSH 15R.

9) Fodder yield per plant (g)

Heterobeltosis (%) for fodder yield per plant ranged from -69.13 (RMS 2010-24A x RSV 912) to 47.19 (RMS 2010-10A x RSV-1059) percent. Among the 45 hybrids, eight hybrids showed positive better parent heterotic effect. The hybrid RMS 2010-10A x RSV-1059 (47.19%) showed positive significant better parent heterosis.

Standard heterosis (%) for fodder yield per plant ranged from -62.63 percent (RMS 2010-24A x RSV 912) to 44.63 (185A x RSR-2231) percent. Among the 45 hybrids, nineteen showed positive significant, while twenty six showed negative standard heterosis. The hybrid 185 A x RSR-2231 (44.63%) showed positive significant standard heterosis for fodder yield per plant over the standard check CSH 15R.

10) Grain yield per plant (g)

The better parent heterosis (%) ranged between -49.28 (RMS 2010-24A x RSR-2231) to 87.29 (185 A x RSV-458) percent. Out of 45 hybrids, three were positively significant over better parent heterosis. The hybrid 185 A x RSV-458 (87.29%) showed highest magnitude of heterobeltosis followed by 185 A x RSV-1093 (77.37%) and 185 A x RSV 1145 (71.26%).

Standard heterosis (%) for grain yield among the available hybrids ranged from -21.04 (RMS 2010-24A x RSR-2231) percent to 115.43 (185 A x RSV-1093) per cent (Table 4.3). Out of 45 hybrids, 37 hybrids showed positive standard heterosis. The hybrid 185 A x RSV 1093 (115.43%) recorded highest magnitude of standard heterosis followed by 185 A x RSV-1145 (100.56%) and RMS 2010-10A x RSLG 2291 (71.95%). Four hybrids were observed significantly superior over the standard check for grain yield per plant.

11) Harvest index (%)

The range of heterobeltosis (%) for harvest index observed between -50.11 (RMS 2010-24A x RSV 1009) to 21.08 (185 A x RSV-1093) percent. None of hybrid combinations showed positive significant heterobeltosis.

Standard heterosis (%) ranged between -24.65 (RMS 2010-10A x CSV-216) to 93.03 (185 A x RSV 1093) percent. Among the 45 hybrids, twenty seven were positive significant. Among the hybrids, two were positive significant standard heterosis over standard check. The hybrid 185A x RSV 1093 (93.03%) showed highest magnitude of standard heterosis followed by 185 A x RR 2145 (69.31%) over standard check CSH 15R.

4.4 Analysis of variance for combining ability for eleven characters in *rabi* sorghum.

The analysis of variance for combining ability for various characters has been presented in Table 4.4.

It is revealed from Table 4.4 that mean sum of squares due to treatments were highly significant for characters *viz.,* days to 50 % flowering, plant height , panicle length, panicle girth, panicle weight, 1000 seed weight, days to maturity, fodder yield per plant and grain yield per plant, while significant for number of internodes and harvest index. These indicated that presence of substantial amount of genetic variability for all characters.

From the table 4.4, it was observed that the mean sum of square due to females were significant for days to 50% flowering, days to maturity and harvest index. Mean sum of square due to males were significant for all characters except plant height, number of internodes, fodder yield per plant and harvest index.

The magnitude of mean sum of squares due to female vs. male interaction were significant for days to 50 percent flowering, plant height, number of internodes, panicle length, panicle weight, 1000 seed weight, days to maturity, fodder yield per plant, harvest index and panicle girth. This indicated that substantial degree of variation.

Mean sum of square due to parent vs. crosses were highly significant for days to 50% flowering, panicle length, panicle girth, panicle weight, 1000 seed weight, days to maturity and fodder yield per plant. This indicated that the

Table 4.4. ANOVA for combining ability for eleven characters in *rabi* Sorghum (L x T design).

Sources of variation	D.F	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
Replications	1	10.86	152.08	0.50	2.89	0.0004	338.33	175.91	11.46	5293.64	1.14	59.87
Treatments	62	20.73**	1187.57**	1.084*	11.82**	5.28**	533.07**	29.44**	8.29**	5190**	218.29**	53.24*
Parents	17	26.73**	2680.11**	1.89**	7.67**	5.61**	468.94**	28.76**	9.70**	8290.89**	263.80**	70.34**
Females	2	28.16**	344.487	0.32	4.00	1.01	13.54	20.15	37.50**	464.68	24.42	114.61*
Males	14	23.37**	393.46	0.44	6.45**	6.17**	484.59**	20.10**	4.70**	2822.33	209.37*	36.95
Female vs Male	1	70.93**	39364.47**	25.38**	32.00**	6.89*	1160.63**	167.31**	24.20**	100503.11**	1504.53**	449.35**
Parents vs Crosses	1	51.60**	446.73	0.14	421.84**	65.27**	3815.65**	105.80**	26.86**	25348.77**	165.17	62.54
Crosses	44	17.70**	627.75**	0.79	4.10*	3.79**	483.24**	27.97**	7.32**	3533.78**	201.91**	46.43
Error	62	1.97	260.60	0.70	2.33	1.48	159.94	7.47	0.78	1779.59	105.01	30.47
σ^2 gca		3.65	155.07	0.08	0.66	0.35	31.32	8.65	0.77	791.68	17.91	8.34
σ^2 sca		1.63	-2.59	-0.14	0.26	1.13	140.44	4.75	2.43	160.74	34.97	3.87
σ^2 gca/σ^2sca		2.23	-59.87	-0.57	2.53	0.31	0.22	1.82	0.31	4.92	0.51	2.15
σ^2 A		7.30	310.14	0.16	1.31	0.69	62.64	17.29	1.54	1583.37	35.83	16.68
σ^2 D		1.63	-2.59	-0.14	0.26	1.13	140.44	4.75	2.43	160.74	34.97	3.87
σ^2 A/σ^2 D		4.48	-119.74	-1.14	5.03	0.61	0.45	3.65	0.63	9.85	1.02	4.31

Note: * , ** = Significant at 5% and 1% level of significance respectively.

substantial degree of heterosis and variation for these characters.

Means sum of square due to crosses were significant for all characters except number of internodes and harvest index indicating substantial degree of variation.

The ratio of GCA variance to SCA variance less than unity for grain yield per plant, days to maturity, panicle girth, panicle weight and number of internodes indicating presence of non-additive gene action, whereas more than unity for days to 50% flowering, plant height, panicle length, 1000 seed weight, fodder yield per plant and harvest index indicating presence of additive type of gene action.

4.5. Estimates of general combining ability effects of parents for eleven characters.

The estimates of general combining ability effects of lines and testers are presented in Table 4.5. In sorghum, positive gca effects are desirable for all the studied traits except days to 50% flowering and days to maturity for which negative gca effects are desirable.

1) Days to 50% flowering

The significant negative gca effects are desirable for days to 50% flowering. The present investigation revealed that among the lines, line 185 A (-2.05) showed highly significant negative gca effects for days to 50% flowering.

Among the testers, tester RSV-458 (-7.38) showed highly significant negative gca effects for days to 50% flowering and hence it was the best general combiner among the testers followed by RSR-2231 (-1.22).

Table 4.5. Estimates of GCA effects of parents for eleven characters in *rabi* sorghum.

Sr. No.	Parents	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	Females											
1	185 A	-2.05**	-0.98	0.08	0.77**	0.74**	6.14*	1.46**	-0.94**	-7.94	5.25**	2.89**
2	RMS201O-10A	0.44	13.90**	0.28	-0.99**	-0.47*	-4.86*	2.26**	0.35*	34.48**	-1.39	-3.69**
3	RMS2010-24A	1.61**	-12.91**	-0.36*	0.21	-0.27	-1.27	-3.72**	0.58**	-26.54**	-3.85*	0.8
	SE (m) ±	0.25	2.94	0.15	0.27	0.22	2.30	0.49	0.16	7.70	1.87	1.00
	CD at 5%	0.51	5.94	0.30	0.56	0.44	4.65	1.00	0.32	15.52	3.77	2.03
	CD at 1%	0.69	7.93	0.41	0.75	0.59	6.21	1.34	0.43	20.73	5.03	2.71
	Males											
4	RSR-2231	-1.22*	-6.58	-0.75*	0.07	-1.01*	-8.67	1.14	-0.31	19.36	-4.00	-2.90
5	RR-2145	2.11**	5.41	-0.08	0.15	-0.65	-0.47	-0.52	2.35**	-3.36	-0.87	0.66
6	RSV-1059	0.27	-4.12	0.44	-0.99	-0.46	-6.47	0.80	0.68	-19.10	-5.99	-0.72
7	RSV-799	-1.05	4.40	0.18	-0.13	-0.57	-7.61	-1.32	-0.81*	-21.46	-8.47*	-1.86
8	CSV-216	1.11	-7.32	-0.15	-0.03	0.16	0.85	-2.25*	0.52	-0.58	-1.17	0.02
9	RSV-1093	0.44	13.05	0.48	1.23	-0.29	-6.87	-0.77	0.18	-0.36	6.24	3.76

Table 4.5.Contd........

Sr. No.	Parents	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
		1	2	3	4	5	6	7	8	9	10	11
10	RSV-1200	0.44	1.55	0.38	-0.09	-0.38	-2.67	-1.35	-0.47	-22.01	-4.32	0.14
11	RSV-912	1.94**	-17.78**	-0.92**	0.51	-0.10	-9.34	0.17	1.35**	-33.46	-5.47	2.32
12	RSV-458	-7.38**	-21.96**	-0.62	-0.49	0.16	-1.67	-1.24	-3.31**	-13.66	1.12	1.80
13	RSV-1098	0.94	18.88**	0.41	-1.39*	0.18	-3.14	0.44	0.02	3.25	1.11	0.46
14	RSV-1130	1.27*	7.37	0.31	-0.42	0.37	2.15	1.76	0.52	2.43	-0.39	-1.20
15	RSV-1151	0.27	-1.72	-0.05	-0.97	-0.41	-4.54	0.61	-0.14	-7.58	-2.32	0.78
16	RSV-1145	0.61	6.58	0.31	0.95	0.62	11.92*	0.53	-0.31	25.63	11.34**	1.07
17	RSLG-2291	-0.22	-1.34	-0.02	1.07	1.50**	16.78**	1.69	-0.31	29.31	5.01	-2.25
18	RSV-1009	0.44	3.57	0.08	0.54	0.88	19.78**	0.28	0.02	41.61*	8.19	-2.10
	SE (m) ±	0.57	6.59	0.34	0.62	0.49	5.16	1.11	0.36	17.22	4.18	2.25
	CD at 5 %	1.15	13.28	0.68	1.25	1.00	10.40	2.24	0.72	34.70	8.43	4.54
	CD at 1 %	1.54	17.74	0.92	1.68	1.33	13.9	3.00	0.97	46.36	11.26	6.06

Note: * , ** = Significant at 5% and 1% level of significance respectively.

2) Plant height (cm)

Among the lines, line RMS 2010-10A (13.90) showed highly significant positive gca effect for plant height. Among the testers, tester RSV 1098 (18.88) showed highly significant positive gca effects for plant height.

3) Number of internodes

Among the lines and testers neither line nor tester observed positively significant gca for number of internodes per plant.

4) Panicle length (cm)

Among the lines, line 185 A (0.77) revealed highly significant positive gca effects. Among the testers, none of the tester showed significant positive gca effects for panicle length.

5) Panicle girth (cm)

Among the lines, line 185 A (0.74) showed highly significant positive general combining ability for panicle girth, while among the testers, tester RSLG-2291 (1.50) showed highly significant positive gca effects for panicle girth.

6) Panicle weight (g)

Among the lines, line 185 A (6.14) exhibited significant positive gca effects, while among the testers, tester RSV 1009 (19.78) showed highly significant positive gca effects followed by RSLG 2291 (16.78) and RSV 1145 (11.92) for panicle weight.

7) 1000 seed weight (g)

Among three lines, two lines *viz.,* 185 A and RMS 2010-10A showed highly significant positive gca effects for 1000 seed weight. The line RMS 2010-10A (2.26) was best general combiner followed by 185 A (1.46).

8) Days to maturity

The significant negative gca effects is desirable for days to maturity as earliness is always important in rainfed agriculture.

Among the lines, line 185 A (-0.94) showed highly significant positive gca effects for days to maturity, while among the testers, two tester exhibited highly significant negative gca effects. Highest significant negative gca effects was exhibited by tester RSV-458 (-3.31) followed by RSV-799 (-0.81).

9) Fodder yield per plant (g)

Among the lines, line RMS 2010-10A (34.48) showed highly significant positive gca effects, whereas among the testers, tester RSV 1009 (41.61) exhibited significant positive gca effects fodder yield per plant.

10) Grain yield per plant (g)

The study revealed that among the lines, line 185 A (5.25) observed highly significant positive gca effects, while among the testers, tester RSV 1145 (11.34) recorded highly significant positive gca effects for grain yield per plant.

11) Harvest index (%)

Among the lines, line 185 A (2.89) exhibited highly significant positive gca effects, whereas among the testers, none of the tester showed significant positive gca effect for harvest index (%).

4.6. Estimates of specific combining ability effects of hybrids.

The estimates of specific combining ability effects of 45 crosses are presented in Table 4.6. Positive and significant

Table 4.6. Estimates of SCA effects of hybrids for eleven characters in *rabi* sorghum.

Sr. No.	Hybrids	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
		1	2	3	4	5	6	7	8	9	10	11
1	185 A x RSR-2231	-1.778	-0.158	0.453	0.029	-0.465	-0.676	-0.18	-1.556*	63.543*	1.783	-3.503
2	185 A x RR-2145	0.389	-2.96	0.287	-0.471	-1.561	-13.676	0.27	-1.222	-44.123	-0.4	6.731
3	185 A x RSV-1059	-0.778	6.638	0.253	1.096	0.429	13.724	-1.488	-1.056	-12.69	-0.733	-0.669
4	185 A x RSV-799	-0.444	-0.35	-0.68	-0.369	0.667	1.058	1.847	-1.556*	-4.123	-10.4	-5.248
5	185 A x CSV-216	0.889	6.867	-0.047	0.746	0.459	4.791	-2.718	0.611	8.893	-6.05	-4.104
6	185 A x RSV-1093	0.056	-2.218	0.02	1.059	0.709	14.124	4.059*	0.944	-5.523	20.133**	8.052*
7	185 A x RSV-1200	-1.944	-14.062	0.12	-0.019	2.000*	16.124	-1.166	-0.389	-34.323	5.75	5.346
8	185 A x RSV-912	0.056	9.063	0.02	-1.456	-1.781*	-25.009**	1.82	0.278	3.227	-2.95	0.826
9	185 A x RSV-458	-0.611	-4.022	0.72	-0.843	-0.366	-15.876	-1.366	-1.056	35.727	5.2	0.336
10	185 A xRSV-1098	0.056	1.665	0.287	0.291	-0.493	8.191	-1.368	-0.389	9.01	-0.333	-2.604
11	185 A x RSV-1130	0.222	-2.637	-0.613	1.087	0.825	5.191	-2.618	0.111	-12.823	-1.633	-0.183
12	185 A x RSV-1151	0.722	-0.792	-0.247	0.021	-0.365	-3.209	-0.373	0.778	-32.507	-3.55	2.059

Table 4.6.Contd..........

Sr. No.	Hybrids	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
		1	2	3	4	5	6	7	8	9	10	11
13	185 A x RSV-1145	1.889	4.937	-0.713	0.299	0.35	9.124	6.744**	1.944**	53.127	9.733	-2.579
14	185 A x RSLG-2291	1.222	-11.3	0.12	-1.893	-0.966	-10.742	-2.005	1.944**	-12.507	-8.783	-2.198
15	185 A x RSV-1009	0.056	9.33	0.02	0.424	0.56	-3.142	-1.458	0.611	-14.907	-7.767	-2.259
16	RMS 2010-10A x RSR-2231	2.722**	-9.821	0.253	0.272	0.137	13.931	-3.723	2.144**	-26.933	7.38	4.59
17	RMS 2010-10A x RR-2145	-0.111	4.822	-0.713	1.312	1.49	12.731	0.972	0.478	40.8	5.947	-1.777
18	RMS 2010-10A x RSV-1059	1.222	-21.935	-0.047	-0.902	-2.095*	-17.269	0.544	0.644	1.283	-7.937	-2.302
19	RMS 2010-10A x RSV-799	-0.944	13.152	0.32	0.308	-1.991*	2.664	-0.016	-0.356	1.7	9.447	4.33
20	RMS 2010-10A x CSV-216	-0.611	9.569	-0.047	-1.892	-0.725	-17.602	1.419	-1.689**	10.317	-8.603	-3.557
21	RMS 2010-10A x RSV-1093	-1.444	-4.156	-0.28	-0.803	-1.26	-16.069	-1.829	-3.356**	21	-13.07	-5.945
22	RMS 2010-10A x RSV-1200	0.556	15.46	-0.08	0.793	-0.118	-3.669	-0.949	-1.189	25.7	1.547	-1.402
23	RMS 2010-10A x RSV-912	1.556	7.525	0.42	2.247*	1.31	30.198**	-1.328	1.478*	18.5	8.647	-1.417
24	RMS 2010-10A x RSV-458	-3.111**	2.455	-0.18	1.735	1.175	18.131*	-2.164	-0.856	-11.3	-2.103	-1.482

Table 4.6.Contd……….

Sr. No.	Hybrids	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
		1	2	3	4	5	6	7	8	9	10	11
25	RMS 2010-10A x RSV-1098	0.056	-0.868	-0.213	-1.242	2.539**	-2.002	1.414	0.311	6.083	-0.437	-0.472
26	RMS 2010-10A x RSV-1130	-0.278	0.11	0.687	-1.425	-0.223	-8.502	2.614	0.811	-15.85	0.763	2.63
27	RMS 2010-10A x RSV-1151	0.722	0.565	0.053	0.133	-0.318	-10.202	2.929	0.978	-1.533	-5.253	-2.184
28	RMS 2010-10A x RSV-1145	-1.611	-14.646	0.187	-1.123	-0.708	-16.269	-5.129*	0.144	-35.45	-12.07	-0.312
29	RMS 2010-10A x RSLG-2291	0.722	11.377	-0.28	1.275	1.015	16.664	2.852	-0.356	6.217	12.513	3.995
30	RMS 2010-10A x RSV-1009	0.556	-13.608	-0.08	-0.688	-0.228	-2.736	2.394	0.811	-40.533	3.23	5.308
31	RMS 2010-24A x RSR-2231	-0.944	9.98	-0.707	-0.301	0.328	-13.256	3.902*	-0.589	-36.61	-9.163	-1.087
32	RMS 2010-24A x RR-2145	-0.278	-1.862	0.427	-0.841	0.071	0.944	-1.243	0.744	3.323	-5.547	-4.953
33	RMS 2010-24A x RSV-1059	-0.444	15.297	-0.207	-0.194	1.666	3.544	0.944	0.411	11.407	8.67	2.972
34	RMS 2010-24A x RSV-799	1.389	-12.802	0.36	0.061	1.325	-3.722	-1.831	1.911**	2.423	0.953	0.918
35	RMS 2010-24A x CSV-216	-0.278	-16.435	0.093	1.146	0.266	12.811	1.299	1.078	-19.21	14.653*	7.662
36	RMS 2010-24A x RSV-1093	1.389	6.375	0.26	-0.256	0.551	1.944	-2.229	2.411**	-15.477	-7.063	-2.107
37	RMS 2010-24A x RSV-1200	1.389	-1.398	-0.04	-0.774	-1.882*	-12.456	2.116	1.578*	8.623	-7.297	-3.943

Table 4.6.Contd..........

Sr. No.	Hybrids	Days to 50% flowering	Plant height (cm)	No. of internodes	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g)	1000 Seed weight (g)	Days to maturity	Fodder yield per plant (g)	Grain yield/ Plant (g)	Harvest index (%)
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
38	RMS 2010-24A x RSV-912	-1.611	-16.588	-0.440	-0.791	0.471	-5.189	-0.493	-1.756**	-21.727	-5.697	0.592
39	RMS 2010-24A x RSV-458	3.722**	1.567	-0.540	-0.892	-0.809	-2.256	3.531	1.911**	-24.427	-3.097	1.147
40	RMS 2010-24A x RSV-1098	-0.111	-0.797	-0.073	0.951	-2.045*	-6.189	-0.046	0.078	-15.093	0.770	3.077
41	RMS 2010-24A x RSV-1130	0.056	2.527	-0.073	0.338	-0.602	3.311	0.004	-0.922	28.673	0.870	-2.447
42	RMS 2010-24A x RSV-1151	-1.444	0.227	0.193	-0.154	0.683	13.411	-2.556	-1.756**	34.040	8.803	0.125
43	RMS 2010-24A x RSV-1145	-0.278	9.710	0.527	0.824	0.358	7.144	-1.614	-2.089**	-17.677	2.337	2.892
44	RMS 2010-24A x RSLG-2291	-1.944	-0.077	0.160	0.618	-0.049	-5.922	-0.848	-1.589*	6.290	-3.730	-1.797
45	RMS 2010-24A x RSV-1009	-0.611	4.278	0.06	0.264	-0.332	5.878	-0.936	-1.422**	55.44	4.537	-3.048
	SE (m) ±	0.99	11.41	0.59	1.08	0.86	8.94	1.93	0.62	29.82	7.24	3.90
	CD at 5 %	2.00	23.00	1.19	2.17	1.73	18.02	3.89	1.26	60.11	14.60	7.86
	CD at 1 %	2.67	30.73	1.59	2.90	2.31	24.07	5.20	1.68	80.30	19.50	10.50

Note: * , ** = Significant at 5% and 1% level of significance respectively.

sca effects are desirable for all studied traits except days to 50% flowering and days to maturity for which negative significant sca effects are desirable.

1) Days to 50% flowering

Out of 45 hybrid combinations evaluated, one cross exhibited highly significant negative sca effects. The cross RMS 2010-10A x RSV-458 (-3.111) exhibited highly significant negative sca effects.

2) Plant height (cm)

Out of 45 hybrids, twenty three hybrids registered positive non-significant sca effects. None of hybrid recorded positive significant sca effects for plant height.

3) Number of internodes

Among the 45 hybrids, none of the hybrid registered as a significant positive sca effects for number of internodes.

4) Panicle length (cm)

Out of the 45 crosses, twenty four hybrids were observed positive sca effects for panicle length. The cross combination RMS 2010-10A x RSV 912 (2.247) observed significant positive sca effects.

5) Panicle girth (cm)

Out of the 45 hybrids, two hybrids showed significant positive sca effects for panicle girth. The cross combination RMS 2010-10A x RSV-1098 (2.539) showed highly significant positive sca effects for panicle girth followed by 185 A x RSV 1200 (2.00).

6) Panicle weight (g)

Out of 45 hybrids, twenty two were observed positive sca effects. The hybrid RMS 2010-10A x RSV-912 (30.198) recorded highly significant positive sca effects followed by RMS 2010-10A x RSV-458 (18.131) for panicle weight.

7) 1000 seed weight (g)

Out of 45 hybrids, three hybrids recorded positive significant sca effects for 1000 seed weight. The hybrid 185 A x RSV-1145 (6.744) was recorded highly significant positive sca effects for 1000 seed weight. The hybrid 185 A x RSV 1093 (4.059) and RMS 2010-24A x RSR 2231 (3.902) were observed significant positive sca effects.

8) Days to maturity

Out of 45 hybrids, six hybrids had highly significant, three had significant negative sca effects. The hybrid RMS 2010-10A x RSV-1093 (-3.356) recorded highly significant negative sca effects for days to maturity followed by RMS 2010-24A x RSV 1145 (-2.089), RMS 2010-24A x RSV 912 (-1.756), RMS 2010-24A x RSV-1151 (-1.756), RMS 2010-10A x CSV-216 (-1.689), RMS 2010-24A x RSV 1009 (-1.422).

9) Fodder yield per plant (g)

Out of 45 hybrids, twenty three were recorded positive sca effects for fodder yield per plant. The hybrid 185 A x RSR-2231 (63.543) was recorded significant positive sca effects.

10) Grain yield per plant (g)

Among the hybrids, twenty one hybrids showed positive sca effects. The hybrid 185 A x RSV 1093 (20.133) showed highly significant positive sca effects, while hybrid RMS 2010-24A x CSV 216 (14.653) showed significant positive sca effects for grain yield per plant.

11) Harvest index (%)

Out of 45 hybrids, hybrid 185 A x RSV 1093 (8.052) revealed significant positive sca effects, while other eighteen were positive but non-significant sca effects.

The ratio of GCA variance to SCA variance less than unity for grain yield per plant, days to maturity, panicle girth, panicle weight and number of internodes indicating presence of non additive type of gene action, whereas more than unity for days to 50% flowering, plant height, panicle length, 1000 seed weight, fodder yield per plant and harvest index indicating presence of additive type of gene action.

CHAPTER V

DISCUSSION

Since the discovery of cytoplasmic genetic male sterility system in sorghum by Stephens and Holland (1954), heterosis breeding has been recognized as the most suitable breeding methodology, for boosting up yield in sorghum. Which could be achieved by properly utilizing the genetic variability available in sorghum cultivars, land races and other populations in appropriate breeding programmes.

The concept of combining ability in relation to diallel crossing system proposed by Griffing (1956[a]) is considered as a landmark in the development of breeding procedure since it helps in selection of potential parents and to know the magnitude of gene action in terms of general and specific combining ability variances.

Thus, a critical examination of relative magnitude of g.c.a. and s.c.a. variances and g.c.a. and s.c.a. effects of parents and their crosses, respectively provides valuable guidelines for choice of parents and for planning suitable breeding methodology. So the selection of parents is almost important for successful improvement of these characters during hybridization and selection programme.

The present study was therefore undertaken to generate information in respect of promising inbreds for desirable characters. A summarized account of best parents and hybrids selected on the basis of their *per se* performance, gca effects, sca effect and heterosis response over standard check and better parent are presented in Table 5.1

Table 5.1. A summarized account of best parents and hybrids selected on the basis of their *per se* performance gca effects, sca effects and heterosis response over standard check and better parent.

Name of character	***Per se* performance**		Best gca parents	Best *sca* crosses	Best heterotic crosses over better parent	Best heterotic crosses over standard check
	Best parents	**Best crosses**				
Days to 50% flowering	185 A RSV 912	185 A x RSV 458 RMS 2010-10A x RSV 458 185 A x RSR 2231	185 A RSV 458	RMS 2010-10A x RSV 458	RMS 2010-10A x RSV 458 185 A x RSV 458	185 A x RSV 458 RMS 2010-10A x RSV 458 185 A x RSR 2231
Plant height (cm)	CSV 216 RSV 1009 RSV 1130	RMS 2010-10A x RSV 1098 RMS 2010 -10A x RSV 1200 RMS 2010-10A x RSV 799	RMS2010-10A RSV 1098			RMS 2010-10A x RSV 912 RMS 2010-10A x RSV 799 RMS 2010-10A x RSV 1200
No. of internodes	RMS 2010-24A RSV 1145	RMS 2010-10A x RSV 1130				RMS 2010-10A x RSV 1130
Panicle length (cm)		185 A x RSV 1093	185 A	RMS 2010-10A x RSV 912	RMS 2010-24A x RSV 1145 RMS 2010-24A x RSLG 2291 RMS 2010-24A x RSV 1093	185 A x RSV 1093
Panicle girth (cm)		185 A x RSV 1200 RMS 2010-10A x RSV 1098 185 A x RSV 1009	185 A RSLG 2291	RMS 2010-10A x RSV 1098 185 A x RSV 1200	RMS 2010-10A x RSV 1098 RMS 2010-10A x RSV 458 185 A x RSV 1200	185 A x RSV 1200 RMS 2010-10A x RSV 1098 185 A x RSV 1009
Panicle weight (g)		RMS 2010-10A x RSLG 2291 185 A x RSV 1145 RMS 2010-24A x RSV 1009	185 A RSV 1009 RSLG 2291 RSV 1145	RMS 2010-10A x RSV 912 RMS 2010-10A x RSV 458	185 A x RSV 1059 185 A x RSV 1093 185 A x RSV 1145	RMS 2010-10A x RSLG 2291 185 A x RSV 1145 RMS 2010-24A x RSV 1009

Table 5.1 Contd……..

Name of character	*Per se* performance		Best gca parents	Best sca crosses	Best heterotic crosses over better parent	Best heterotic crosses over standard check
	Best parents	Best crosses				
1000 seed weight (g)			RMS 2010-10A 185 A	185 A x RSV 1145 RMS 2010-24A x RSR 2231 185 A x RSV 1093	RMS 2010-10A x RSV 1151 185 A x RSV 1145 RMS 2010-10A x RSV 1130	185 A x RSV 1145
Days to maturity	185 A RSV 912 RSV 1009	185 A x RSV 458 RMS 2010-10A x RSV458 185 A x RSV 799 185 A x RSR 2231	185 A RSV 458 RSV 799	RMS 2010-10A x RSV 1093 RMS 2010-24A x RSV 1145 RMS 2010-24A x RSV 912	RMS 2010-10A x RSV 458 RMS 2010-10A x RSV 1093 RMS 2010-10A x RSV 1200	185 A x RSV 458 RMS 2010-10A x RSV 458 185 A x RSV 799
Fodder yield per plant (g)	RR 2145		RMS 2010-10A RSV 1009	185 A x RSR 2231	RMS 2010-10A x RSV 1059	185 A x RSR 2231
Grain yield per plant (g)	RSV 1009	185 A x RSV 1093 185 A x RSV 1145 RMS 2010-10A x RSLG 2291 185 A x RSV 458	185 A RSV 1145	185 A x RSV 1093 RMS 2010-24A x CSV 216	185 A x RSV 458 185 A x RSV 1093 185 A x RSV 1145	185 A x RSV 1093 185 A x RSV 1145 RMS 2010-10A x RSLG 2291 185 A x RSV 458
Harvet index (%)	RMS 2010-24A	185 A x RSV 1093 185 A x RR 2145	185 A	185 A x RSV 1093		185 A x RSV 1093 185 A x RR 2145

The results obtained are discussed under the following subheads.

5.1 Mean performance of parents and hybrids

5.2 Heterosis

5.3 General combining ability

5.4 Specific combining ability

5.1 Mean performance of parents and hybrids

Among the female parents, female line 185 A exhibited the lowest mean value for days to 50% flowering and days to maturity. The female line RMS 2010-24A exhibited highest mean value for harvest index percentage over standard check.

Among the male parents, tester RSV 912 superior for days to 50% flowering and days to maturity over standard check. The tester RSV 1009 showed highest mean values for grain yield per plant and superior for plant height and days to maturity over standard check. The tester RR 2145 showed highest mean value for fodder yield per plant. The male parent CSV 216 recorded the highest plant height, RSV 1145 showed highest mean value for number of internodes, tester RSV 1130 superior for plant height over standard check.

Considering *per se* performance of parents, it was found that the 185A, RMS 2010-24A, RSV 1009, RR 2145, CSV-216, RSV 1130, RSV 1145 and RSV 912 were the most promising parents so can be used in future breeding programme.

Among the crosses 185 A x RSV 1093 for panicle length, harvest index, grain yield per plant, hybrid 185 A x RSV 458 for days to 50 % flowering, days to maturity, grain yield per plant, hybrid RMS 2010-10A x RSV 1098 for plant height, panicle girth, hybrid 185 A x RSV 1200 for panicle girth, panicle weight, days to maturity, hybrid RMS 2010-10A x RSLG 2291 for panicle weight, plant height, grain yield, hybrid 185 A x RSV 1145 for grain yield per plant, panicle weight superior over standard check CSH-15R.

The hybrids 185 A x RSV 1093, 185 A x RSV 458, RMS 2010-10A x RSV 1151, RMS 2010-10A x RSV 1098, 185 A x RSV 1145 and RMS 2010-10A x RSLG 2291 were observed to be the most promising and could be exploited in future breeding programme and for development of hybrid.

5.2 Heterosis

5.2.1 Days to 50 % flowering

Out of 45 cross combinations evaluated, the hybrids RMS 2010-10A x RSV 458 and 185 A x RSV 458 exhibited highly significant negative heterobeltiosis for days to 50% flowering. The cross combinations, 185 A x RSV 458, RMS 2010-10A x RSV 458 and 185 A x RSR 2231 showed negative, but highly significant standard heterosis over hybrid check CSH-15R.

Among the cross combinations, cross 185 A x RSV 458, RMS 2010-10A x RSV 912, RMS 2010-24A x RSV 912 and RMS 2010-10A x RSV 458 showed negatively significant better parent and standard heterosis for days to 50 % flowering, so these crosses could be used for exploitation of hybrids.

The significant negative heterosis for days to 50% flowering was observed by Rao and Gaud (1975), Rana and Murty (1978), Salunke and Deore (1998), Maheshwari *et al.* (1993), Veerabadhiran *et al.* (1994), Khapre *et al.* (2000[b]), Patil

(2000), Prabhakar (2001), Ravindrababu *et al.* (2002), Kaul *et al.* (2003), Jahangirdar and Borikar (2004), Rajguru *et al.* (2005), Umakant *et al.* (2006) and Premalata *et al* (2006).

5.2.2 Plant height (cm)

The cross combinations *viz.,* RMS 2010-10A x RSV 912, RMS 2010-10A x RSV 799, RMS 2010-10A x RSV 1200 recorded significant standard heterosis over hybrid check CSH-15R.

Rao and Gaud (1975), Rana and Murty (1978), Chinna and Phul (1988), Maheshwari *et al.* (1993), Naik (1996), Khapre *et al.* (2000), Patil (2000), Ravindrababu *et al.* (2002), Kaul *et al.* (2003), Chaudhary and Narkhede (2004), Jahangirdar and Borikar (2004) and Rajguru *et al.* (2005) also reported positive and significant heterosis for plant height.

5.2.3 Panicle length (cm)

The hybrid RMS 2010-24A x RSV 1093 recorded positive highly significant better parent heterosis followed by RMS 2010-24A x RSV 1145 and RMS 2010-24A x RSLG 2291. The cross 185 A x RSV 1093 recorded the significant standard heterosis over hybrid check CSH-15R.

Similar results were obtained by Rao and Gaud (1975), Rana and Murty (1978), Desai *et al.* (1985), Patel *et al.* (1987), Chinna and Phul (1988), Mehetre and Borikar (1992), Maheshwari *et al.* (1993), Salunke and Deore (1998), Patil (2000), Kaul *et al.* (2003), Chaudhary and Narkhede (2004), Nirmala (2005) and Rajguru *et al.* (2005).

5.2.4 Panicle girth (cm)

The cross combinations 185 A x RSV 1200 and RMS 2010-10A x RSV 1098 expressed substantial amount of heterosis for panicle girth. The hybrids RMS 2010-10A x RSV 1098, RMS 2010-10A x RSV 458 and 185 A x RSV 1200 showed positive highly significant heterosis over better parent. The hybrids 185 A x RSV 1200, RMS 2010-10A x RSV 1098 and 185 A x RSV 1009 showed highest magnitude of standard heterosis over hybrid check CSH 15 R.

These results are in confirmation with those shown by Salunke and Deore (1998), Chaudhary *et al.* (2006) and Sharma and Sharma (2006).

5.2.5 Panicle weight (g)

The crosses 185 A x RSV 1059, 185 A x RSV 1093, 185 A x RSV 1145, RMS 2010-24A x RSV 458 exhibited the most promising heterobeltiosis. The hybrid combinations RMS 2010-10A x RSLG 2291, 185 A x RSV 1145, RMS 2010-24A x RSV 1009 had the highest magnitude of standard heterosis over CSH-15-R.

The cross combinations 185 A x RSV 1145, RMS 2010-10A x RSLG 2291, RMS 2010-24A x RSV 1145 and 185 A x RSV 1200 expressed substantial amount of better parent heterosis and standard heterosis for panicle weight.

Positive and highly significant heterosis for this trait had been reported by Chinna and Phul (1988), Nandanwankar (1990), Desai and Shukla (1997), Gite *et al.* (1997), Patil and Biradar (2005) and Khapre *et al.* (2007).

5.2.6 1000-seed weight (g)

The crosses exhibiting most promising heterobeltiosis were RMS 2010-10A x RSV 1151, 185 A x RSV 1145, RMS 2010-10A x RSV 1130. The hybrid 185A x RSV

1145 exhibited positive significant standard heterosis over hybrid check CSH-15R.

Deasi *et al.* (1985), Chinna and Phul (1988), Kulkarni (1997), Salunke and Deore (1998), Patil (2000), Prabhakar (2001), Ravindrababu *et al.* (2002), Kaul *et al* (2003), Umakanth *et al.* (2003), Chaudhary and Narkhede (2004), Jahangirdar and Borikar (2004), Rajguru *et al.* (2005), Patel *et al.* (2006), Premalata *et al.* (2006) and Umakanth *et al.* (2006) observed positive heterosis for 1000-seed weight.

5.2.7 Days for maturity

The hybrid combinations *viz.*, RMS 2010-10A x RSV 458, RMS 2010-10A x RSV 1093, RMS 2010-10A x RSV 1200, RMS 2010-24A x RSLG 2291 showed most promising heterobeltosis. The hybrid combinations *viz.*, 185 A x RSV 458, RMS 2010-10A x RSV 458, 185 A x RSV 799 and RMS 2010-10A x RSV 1093 had exhibited highly significant negative standard heterosis over check CSH 15R.

The hybrid RMS 2010-10A x RSV 458 and RMS 2010-10A x RSV 1093, RMS 2010-10A x RSV 799 showed highly significant negative heterosis over better parent and standard check, these three crosses could be used to develop early mature hybrids. The significant negative heterosis for days to maturity was observed by Rajguru *et al.* (2005), Salunke and Deore (1998) and Khapre *et al.* (2007).

5.2.8 Fodder yield per plant (g)

The hybrid RMS 2010-10A x RSV 1059 showed positive significant heterobeltosis. The hybrid 185 A x RSR 2231 observed significant positive standard heterosis over check CSH 15R.

Similar result obtained by Naik (1996), Desai (2002), Ravindrababu *et al.* (2002), Jahangidar and Borikar (2004), Patil and Biradar (2005), Rajguru *et al.* (2005), Jhansi Rani *et al.* (2008) and Ghorade *et al.* (2014[a]).

5.2.9 Grain yield per plant (g)

The positively significant heterobeltiosis for grain yield per plant was exhibited by the crosses 185 A x RSV 458, 185 A x RSV 1093 and 185 A x RSV 1145. The highest magnitude of standard heterosis was exhibited by hybrids *viz.,* 185 A x RSV 1093, 185 A x RSV 1145, RMS 2010-10A x RSLG 2291 over the hybrid check CSH-15R. The hybrid 185 A x RSV 1145 showed highest magnitude of better parent and standard heterosis for grain yield per plant.

Rao and Gaud (1975), Ambekar and Nandanwankar (1985), Desai *et al.* (1985), Patel *et al.* (1987), Chinna and Phul (1988), Mehetre And Borikar (1992), Maheshwari *et al.* (1993), Shankarapandian *et al.* (1994), Naik *et al.* (1994), Gite *et al.* (1997), Salunke and Deore (1998), Jilani *et al.* (2000), Patil (2000), Thawari *et al.* (2000), Prabhakar (2001), Ravindrababu *et al.* (2002), Murumkar (2002), Kaul *et al.* (2003), Umakanth *et al.* (2003), Chaudhary and Narkhede (2004), Jahangirdar and Borikar (2004), Nirmala *et al.* (2005), Patel *et al.* (2006), Boratkar (2010), Takalkar (2010), Mahdy *et al.* (2011) and Ghorade *et at* (2014[a]) reported similar result for heterosis for grain yield per plant in sorghum.

5.2.10 Harvest index (%)

Two hybrids were recorded positively significant standard heterosis over hybrid check for harvest index percentage. The hybrids 185 A x RSV 1093 and 185 A x RR

2145 showed positive significant standard heterosis over CSH-15R.

The present results were agreement with those of Sankarapandian *et al.* (1994) and Khapre *et al.* (2007).

5.3 General combining ability

The general combiner parents for different characters are presented in table 5.2

It is revealed that, line 185 A was the best general combiner for eight characters i.e. grain yield per plant, days to 50% flowering, panicle length, panicle girth, panicle weight, days to maturity, thousand seed weight and harvest index. The second preference given to line RMS 2010-10A which had given highly significant positive gca effects for plant height, fodder yield per plant and thousand seed weight. For characters like days to 50% flowering and days to maturity negative gca values are desirable. The line 185 A was found to be suitable for developing high yielding and early maturing hybrids in *rabi* sorghum.

Premalatha *et al.* (2006) also reported negative gca effects for days to 50% flowering might be useful in breeding programme for earliness.

Prabhakar *et al.* (2013) also identified one line SL-39B with positive significant gca for grain yield and negative significant gca for days to flowering and reported the use of this line in developing high yielding early maturing hybrids in *rabi* sorghum.

Among the testers, RSV 458 exhibited significant negative gca effects for two characters like days to 50% flowering and days to maturity. The tester RSLG 2291 showed

Table 5.2 General combiner parents for different characters

Sr. No.	Genotypes	Characters
1	185 A	Grain yield per plant, days to 50% flowering, days to maturity, panicle length, panicle girth, panicle weight, 1000 seed weight, harvest index.
2	RMS 2010-10A	Plant height, fodder yield per plant, 1000 seed weight
3	RSV 1145	Grain yield per plant, panicle weight
4	RSV 458	Days to 50 % flowering, days to maturity
5	RSV 1009	Panicle weight, fodder yield per plant.
6	RSLG 2291	Panicle girth, panicle weight
7	RSV 1098	Plant height
8	RSV 799	Days to maturity
9	RSR 2231	Days to 50 % flowering

Significant desirable gca effects for two characters *viz.*, panicle girth and panicle weight. The tester RSV 1145 showed significant positive gca effects for grain yield per plant and panicle weight, while tester RSV 1009 best general combiner for panicle weight and fodder yield per plant. Thus these four testers can be used in new hybrid development programme.

Prabhakar *et al.* (2013) also reported the tester SLR-66 with significant desirable gca effects for grain yield per plant along with days to 50% flowering and reported the usefulness of this tester in developing high yielding and early maturing hybrids in *rabi* sorghum.

In general good combiners for grain yield also had good or average combining ability for one or more yield components. In most of the parents high GCA effects were associated with high *per se* mean for yield and yield components. Similar results reported by Patel *et al.* (1990), Pillai *et al.* (1995), Barhate (1996), Badhe and Patil (1997), Khapre *et al.* (2000a) and Vaidya (2000).

5.4. Specific combining ability

5.4.1 Days to 50% flowering

The hybrid RMS 2010-10A x RSV 458 (average x high) observed best specific combiner for days to 50 % flowering. The data revealed that the hybrid showing significantly high SCA effects having average x high GCA effects of parents.

5.4.2 Panicle length (cm)

For character panicle length the hybrid RMS 2010-10A x RSV 912 (low x average) showed the higher magnitude of positive specific combining ability effects. This hybrid showed significantly high SCA effects involves low x average GCA effects of parents.

5.4.3 Panicle girth (cm)

Among the hybrids, two hybrids showed significant positive specific combining ability effects. The hybrid combinations RMS 2010-10A x RSV 1098 (low x average) and 185 A x RSV 1200 (high x average) exhibited the higher magnitude of positive specific combining ability effects. From the data it was observed that hybrids with positive significant SCA involved low x average, high x average GCA effects of parents.

5.4.4 Panicle weight (g)

Two crosses *viz.*, RMS 2010-10A x RSV 912 and RMS 2010-10A x RSV 458 best specific combiners involved low x low GCA effects of parents.

5.4.5 1000 seed weight (g)

The hybrid combinations *viz.,* 185 A x RSV 1145 (high x average), 185 A x RSV 1093 (high x average) and RMS 2010-24A x RSR 2231 (low x average) observed best specific combiners for 1000 seed weight involved high x average and low x average GCA effects of parents.

5.4.6 Days to maturity

Six hybrids showed highly significant negative SCA effects for days to maturity. The hybrid combinations RMS 2010-10A x RSV 1093 exhibited highly significant negative SCA effects followed by RMS 2010-24A x RSV 1145, RMS 2010-24A x RSV 912, RMS 2010-24A x RSV 1151, RMS 2010-10A x CSV 216 and RMS 2010-24A x RSV 1009 for days to maturity. These hybrids showed highly significant SCA effects involving low x average, low x low GCA effects of parents.

5.4.7 Fodder yield per plant (g)

The hybrid 185 A x RSR 2231 (average x average) recorded positively significant SCA effects for fodder yield per plant. The data revealed that the hybrid showed significantly SCA effects having average x average GCA effects of parents.

5.4.8 Grain yield per plant (g)

Two hybrids showed positively significant SCA effects for grain yield per plant. The hybrid combinations *viz.*, 185 A x RSV 1093 (high x average), RMS 2010-24A x CSV 216 (low x average) were best specific combiners. The data revealed that the hybrids showing high magnitude of specific combining ability effects having high x average and low x average GCA effects indicated the presence of non additive gene action.

Similar result also obtained by Desai *et al.* (1985), Wadikar *et al.* (2006), Vaidya (2000), Patel *et al.* (1990), Khapre *et al.* (2000), Ravindrababu *et al.* (2001), Hariprasanna *et al.* (2012) and Ghorade *et al.* (2014[b]).

5.4.9 Harvest index (%)

The hybrid 185 A x RSV 1093 (high x average) showed positively significant SCA effects. The data revealed that hybrid showing high magnitude of positive SCA effects involved high x average GCA effects of parents.

The ratio of GCA variance to SCA variance less than unity for grain yield per plant, days to maturity, panicle girth, panicle weight and number of internodes indicating presence of non additive gene action, whereas more than unity for days to 50% flowering, plant height, panicle length, 1000 seed weight, fodder yield per plant and harvest index indicating presence of additive type of gene action.

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Summary

The present investigation entitled, "Combining ability analysis in *rabi* sorghum (*Sorghum bicolor* L. Monench)" was undertaken at Sorghum Improvement Project, Department of Botany, Mahatma Phule Krishi Vidyapeeth, Rahuri during *rabi* 2013-2014. The eighteen parents crossed in line x tester mating design involving three cytoplasmic genetic male sterile lines and fifteen testers to study the amount of heterosis for grain yield and yield components, general combing ability effects of parents and specific combining ability effects of the crosses.

The observations on five randomly selected plants per replication in each treatment were recorded on twelve characters viz., days to 50 % flowering, plant height, number of internodes, panicle length, panicle girth, panicle weight, 1000-seed weight, days for maturity, fodder yield per plant, grain yield per plant, harvest index and dead heart. The data was subjected to the analysis of heterosis over better parent and standard check as per Fonesca and Patterson (1968) and combining ability analysis as per Kempthorne (1957) and modified by Arunachalam (1974).

6.2 Conclusions

1. The hybrid combinations *viz.*, 185 A x RSV 458, 185 A x RSV 1093, 185 A x RSV 1145, RMS 2010-10A X RSLG 2291 showed significant heterosis over better parent and

standard check CSH 15R for grain yield. So these hybrids can be exploited for hybrid development.

2. The female parent 185 A observed as a good general combiners for grain yield per plant, days to 50% flowering, days to maturity, panicle length, panicle girth, panicle weight, 1000 seed weight and harvest index. Among the testers, tester RSV 1145 recorded positively significant superior gca for grain yield and panicle weight, while tester RSV 458 took minimum days to 50% flowering and days to maturity.

3. The hybrids which exhibited higher SCA for grain yield having average or good general combiner for other traits. From the studies it was observed that the hybrids 185A x RSV 1093, RMS 2010-24A x CSV 216 were observed to be the best specific combiners for grain yield per plant.

4. The higher magnitude of SCA variance over GCA variance was observed in grain yield per plant, days to maturity, panicle weight and panicle girth which indicate the importance of non additive gene action.

6.3 Future breeding strategy

Considering *per se* performance, general and specific combining ability and heterosis, the hybrid 185 A x RSV 1093, 185 A x RSV 458, RMS 2010-10A x RSLG 2291, RMS 2010-24A x CSV 216, 185A x RSV 1145 were observed most promising and could be exploited for further hybrid development in *rabi* sorghum.

CHAPTER VII

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