"GENETIC STUDIES AND MOLECULAR ANALYSIS FOR FORAGE YIELD IN PEARL MILLET (*Pennisetum glaucum* L.) R. Br "

A

THESIS

SUBMITTED TO THE

MAHATMA PHULE KRISHI VIDYAPEETH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

DOCTOR OF PHILOSOPHY (AGRICULTURE)

IN

AGRICULTURAL BOTANY

(CYTOGENETICS AND PLANT BREEDING)

BY

Shinde Gorakshanath Changdeo

(Reg. No. 07/029)

DEPARTMENT OF AGRICULTURAL BOTANY
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA

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Approved by

Dr. S.S. Mehetre
(Chairman and Research Guide)

Prof. A.H. Sonone
(Committee Member)

Dr. A.A. Kale
(Committee Member)

Prof. S.V. Damame
(Committee Member)

DEPARTMENT OF AGRICULTURAL BOTANY
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413722, DIST.AHMEDNAGAR,
MAHARASHTRA, INDIA
2011

CANDIDATE'S DECLARATION

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

Place : MPKV, Rahuri **(G. C. Shinde)**

Date: / /2011

Dr. S. S. Mehetre
Director of Research,
Mahatma Phule Krishi Vidyapeeth,
Rahuri- 413 722, Dist: Ahmednagar, Maharashtra State
(INDIA)

CERTIFICATE

This is to certify that the thesis entitled "**GENETIC STUDIES AND MOLECULAR ANALYSIS FOR FORAGE YIELD IN PEARL MILLET (*Pennisetum glaucum*, L) R. Br.]"** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri Dist. Ahmednagar, M. S. for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRICULTURAL BOTANY (CYTOGENETICS AND PLANT BREEDING)**, embodies the results of a bona fide research carried out by **MR. GORAKSHANATH CHANGDEO SHINDE,** under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Place : MPKV, Rahuri **(S. S. Mehetre)**
Date: / /2011 Research Guide

Dr. R. S. Patil
Associate Dean,
Post Graduate Institute,
Mahatma Phule Krishi Vidyapeeth,
Rahuri- 413 722, Dist: Ahmednagar, Maharashtra State
(INDIA)

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Place : MPKV, Rahuri **(R. S. Patil)**

Date: / /2011

ACKNOWLEDGEMENT

This memorable occasion provides me a unique privilege to express my deep sense of gratitude and indebtedness to my Research guide ***Dr. S. S. Mehetre,*** *Director of Research, Mahatma Phule Krishi Vidyapeeth, Rahuri for his valuable guidance, ever willing help and talented guidance, constructive criticism and judicious supervision throughout the course of this investigation and scrutinizing the manuscript right from the selection of my research problem up to the final shaping of the thesis in the present form.*

I extend my sincere thanks to Dr. J.V. Patil, Ex. Head, Department of Agricultural Botany and Dr. R. W. Bharud, Head, Department of Botany, Mahatma Phule Krishi Vidyapeeth, Rahuri for their constant encouragement, sustained interest, and talented guidance in breeding work.

I am equally thankful to the members of Advisory committee Dr. A. H. Sonone, Forage Breeder, AICRP on Forage Crops, Dr. A. A. Kale, Associate Professor of Biochemistry, Biotechnology Centre and Prof. S. V. Damame, Asstt. Professor of Biochemistry, AICRP on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri for their valuable suggestions and crirical review of the manuscript.

I am also grateful to Dr. C. B. Gaikwad, Ex. Associate Dean and Head, Department of Agronomy and Dr. R. S. Patil, Associate Dean (PGI), MPKV, Rahuri for their useful guidance and cooperation during my Ph. D. degree programme.

In many ways Dr. P. A. Navale, Ex. Cotton Breeder, has contributed to the fulfillment of my objectives. I am greatly indebted to him.

I express my heartful thanks to Dr. A. S. Jadhav, Professor & I/c Biotechnology centre, Dr. S. N. Mate, Dr. D. V. Kusalkar, Professor of Botany, Dr. V. P. Chimute, Dr. A. P. Padhye, Dr.. N. S. Kute, Associate Professor of Botany and Dr. S. V. Pawar, Asstt. Professor of Botany, MPKV, Rahuri for their cooperation during my Ph. D. degree programme.

I make mention of Shri. Balu Jadhav, Gorakh Shirsath, Raju Pawar, Bhusan Sonawane and Gorakh Kanase for their help in field experiments and molecular work.

The valuable help extendended by the technical staff of Forage and Grass Project especially, Prof. P. P. Surana, Research Officer, Prof. A. B. Tambe, Shri. A. V. Awari, Shri. R. S. Bagul, Shri. Ravi Bhingarde, Shri. S. A. Anarase and Shri. Tarate will be always remembered.

I express my deep sense of appreciation to my friends and colleagues especially, Dr. Ajit Mokate, Shri. Sunil Rajmane and Shri. Adhir Aher for their encouragement and kind cooperation during my Ph. D studies.

I would like to extend my gratitude to Shri Nitin Bagal for accurate typing of the manuscript and editing plates and figures.

Words are not enough to express my heartiest gratitude to my parents and brother Raghunath and Bhabi Chandrakala for their love, patience, constant inspiration and support of building up my educational career.

I offer my apologies to my wife Sau.Nanda and Daughters Jayashree and Rajashree which were not fully attended during the course of this investigation. I am also thankful to them for showing great patience, under standing and for extending moral support during my studies.

Lastly, I am thankful to Mahatma Phule Krishi Vidyapeeth, Rahuri for providing me this opportunity to undertake higher studies leading to Ph. D (Agri.) degree.

Place: MPKV, Rahuri
Date : / /2011 **(Gorakshanath C. Shinde)**

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List of Abbreviations

%	Per cent
@	At the rate of
°C	Degree Celsius
µg	Microgram
µl	Micro litre
bp	Base pair
BP	Better parent
BPH	Better parent heterosis
C. D.	Critical difference
cm	Centimeter
C. V.	Coefficient of variation
d.f.	Degree of freedom
e.g.	For example
et al.	et allii :and others
etc.	Etcetera
Fig.	Figure
g	Gram
GD_R	Genetic distance of RAPD
GS	Genetic distance
ha	Hactare
hr	Hours
i.e.	That is
Kb	Kilo bases
Kg	kilogram
M	Molar
mM	Milimolar
Max.	Maximum
MP	Mid parent value
MPH	Mid parent heterosis
Min.	Minimum
ml	Millilitre
ng	Nanogram
No.	Number
NS	Non-significant
rpm	Revolution per minutes
S. E	Standard Error
Sr.	Serial
TBE	Tris Borate EDTA
viz.	Namely

ABSTRACT

"GENETIC STUDIES AND MOLECULAR ANALYSIS FOR FORAGE YIELD IN PEARL MILLET (*Pennisetum glaucum* L.) R. Br."

By

SHINDE GORAKSHANATH CHAGDEO

A

Candidate for the Degree

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CYTOGENETICS AND PLANT BREEDING

2011

Research Guide	**:**	**Dr. S. S. Mehetre**
Major Descipline	**:**	**Agricultural Botany**

The present investigation entitled "Genetic studies and molecular analysis for forage yield in Pearl millet [*Pennisetum glaucum* (L.) R Br.]" was conducted at AICRP on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri. The experimental material was developed by crossing eight parental lines in a half diallel mating design and resulting 28 hybrids along with 8 parents were grown in a randomized block design, with three replications in kharif 2008 and summer 2009 seasons. The observations were recorded on eighteen characters, comprising of green forage yield, its components and fodder quality characters. The objectives of the field level investigation were to study the combining ability of various genotypes, nature of gene action and magnitude of heterosis, under two seasons. Molecular studies were also

conducted to distinguish parental lines by using genomic DNA polymorphism revealed by RAPD molecular markers and to know the association of genetic distance revealed by molecular markers with mean hybrid performance , MP value, sca effects, mid parent and better parent heterosis for forage yield and yield components .

The pooled analysis of variance revealed that the environments (seasons) differed significantly for all the characters except L:S ratio, oxalic acid and IVDMD (%) suggesting sufficient diversity among the test environments. The significant differences among treatments , parents and hybrids were also observed for of the characters suggesting substantial diversity among them. The significant mean squares due to parents Vs. hybrids for most of the characters except number of tillers/plant, number of leaves/plant, leaf width, leaf weight, ADF, NDF and IVDMD (%) indicated presence of heterosis in hybrids for the traits.

A pooled analysis of variances by the interactions of treatments x environments, parents x environments, hybrids x environments and parents vs. hybrids x environments were found significant for majority of the characters, except for number of tillers in case of treatments x environment and hybrids x environment; number of tillers, leaves per plant and oxalic acid (%) in case of parents x environment and except number of tillers, L:S ratio, crude protein, crude fibre, ADF, NDF, oxalic acid and IVDMD (%) in case of parents vs. hybrids x environments.

Among the parents, Giant bajra and RHRB-282 showed high mean performance for green forage, dry matter yield and for majority of the yield contributing characters in kharif, 2008 as well

as summer, 2009 seasons. Among the hybrids, Giant bajra x RHRB-282, PMFT-907 x RHRB-278 and Giant bajra x RHRB-278 had high *per se* performance for green forage yield and other important yield contributing characters.

Analysis of combining ability revealed that mean squares due GCA and SCA were highly significant for all the characters in both the seasons and across the seasons revealing importance of both additive and non additive type of gene effects for expression of these traits. Significant GCA x environment for all the characters except number of tillers per plant, L:S ratio, crude protein, NDF, oxalic acid and IVDMD percent, while significant SCA x environment interaction for all the characters except number of tillers per plant indicated importance of experimentation over environment to assess the genetic worth of genotypes. The magnitude of GCA mean sum of squares was higher than SCA for all the characters in both the environments except for number of leaves/plant and IVDMD percent in E_1, ADF and IVDMD percent in E_2 and except for IVDMD percent in pooled over environments.

The general combining ability effects and *per se* performance for various characters under both the seasons revealed that, Giant bajra, RHRB-282, PMFT-904 were found to be a good and consistent general combiner for green forage yield and most of the forage traits

The hybrids *viz.,* Giant bajra x RHRB-282 in kharif, 2008 ; PMFT-907 x RHRB-278, in summer 2009 and Giant bajra x RHRB-282 in pooled analysis exhibited highest significant sca effect for green forage yield and most of the yield contributing and quality

characters. However, the cross combination viz., RHRB-259 x RHRB-260 of low x low performing parents also exhibited high positive and significant sca effect for green forage yield and most of the other yield contributing and quality traits in both the seasons and pooled over seasons. The ratio of gca/sca variance indicated predominant role of non-additive gene action in the genetic expression of most of the characters under study.

The hybrids PMFT- 907 x RHRB-278 and RHRB-259 X RHRB-260 exhibited high heterobeltiosis for green forage yield and other yield contributing characters in both the seasons and in pooled analysis. The hybrids PMFT-907 x RHRB-259 and PMFT-907 x RHRB-278 were most heterobeltiotic for crude protein percent in both the seasons and in pooled analysis. Similarly, for IVDMD the heterotic combinations were Giant bajra x RHRB-259 in kharif 2008 and PMFT-905 x RHRB-259 and PMFT-905 x RHRB-278 in summer 2009 season and in pooled analysis. The superior heterobeltiotic hybrid for oxalic acid, was PMFT-907 x RHRB-278 in kharif 2008 and PMFT-907 x RHRB-259 in summer 2009 season and in pooled analysis.

The significant sca effects, heterobeltiosis and high *per se* performance for green forage yield and at least one or more yield contributing characters in both the seasons as well as across the seasons were exhibited by the hybrids Giant bajra x RHRB-282, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260, Giant bajra x PMFT-905 and PMFT-905 x PMFT-907 .

Genetic diversity studied by using Mahalanobis D^2 statistic indicated that material studied was genetically diverse. The genotypes were grouped in six clusters each in Kharif, 2008 (E_1) and Summer, 2009 (E_2) environment. The genotypes RHRB-260, RHRB-282 and Giant bajra showed same clustering pattern in both the seasons.

Abstract contd..... **Mr. Shinde G.C.**

Pooled RAPD analysis of all twenty arbitrary oligonucleotide primers of three primer series *viz.,* OPA, OPC and OPE generated total 806 scorable bands with 171 loci, among them 136 loci were found polymorphic, showing 79.53% polymorphism.

Dendrogram based on unbiased measures of genetic distance by UPGMA method formed two major clusters which grouped all the 8 genotypes. The first major cluster contains parent Giant bajra only, where as second major cluster divides other parental lines into four minor clusters.

The results obtained from cluster analysis through RAPD and D^2 indicated that Giant bajra, RHRB-260 and RHRB-282 formed distinct cluster in both the analysis and proving that Giant bajra was the most diverse line among all parental genotypes.

Correlation studies for molecular divergence and hybrid performance for green forage yield and yield imparting traits indicated that GD_R exhibited significant positive correlation with F_1 mean values for some yield contributing characters but non-significant for green fodder yield, dry matter yield and almost all quality traits and non significant association of GD_R with SCA, MPH and BPH for almost all the characters in both the seasons and across the seasons. However, some cross combinations had high mean performance, SCA effects, BPH and mid parent heterosis involving the parents of moderate to high genetic distance Hence, genetic distance estimates based on the RAPDs may be useful for the grouping of genetically diverse parents, which may result heterotic combinations in forage pearl millet.

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1. INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R Br.) is a monocot species belonging to the family Poaceae and sub family Penicedae, having relatively small diploid genome (2n = 2x = 14) with DNA content of 1C = 2.36 pg (Budak *et al.*, 2003). Pearl millet locally known as Bajra, is also known as bulrush millet, cat tail or spiked millet. Pearl millet spikelets are markedly protogynous, most of the styles having started to dry up before pollen shed, so that the crop is mostly highly cross pollinated. It demonstrates highest level of tolerance to drought and heat amongst domesticated cereals. Consequently it is grown on more than 26 million hectares in arid and semiarid regions of Africa and India (Budak *et al.*, 2003).

In India, principal states under pearl millet cultivation are Rajasthan, Maharastra, Gujarat and Punjab. In the eastern side of the Western Ghats and in Tamilnadu, it is sown as winter crop (George *et al.*, 2005).

India is the largest producer of pearl millet both in terms of area (9.43 million ha) and production (8.01 million t), with an average productivity of 850 kg/ha (Anonymous, 2010). This grain crop contributes significantly to food and nutritional security of the rural and urban poor people in drier areas where it is valued equally for both its grain and fodder. Although demand for pearl millet grain as human food in India is currently decreasing, it is emerging as forerunner in the form of alternative food, feed and industrial products. Being a C_4 species, it has tremendous potential for biomass production, most of which is accumulated in its vegetative parts (Appa Rao ,1999).

In Maharashtra, pearl millet is grown either as *kharif* or summer crop in 7.70 lakh hectares with production of 10.89 tones,

which contributes 11.34% and 19.57% to India's total area and production under pearl millet, respectively. Productivity of pearl millet was found to be 1414 kg/ha for Gujarat, whereas 972 kg/ha for India (Anonymous, 2010).

Pearl millet is an excellent forage crop because of its low hydrocyanic acid content. The green fodder which is rich in protein, calcium, phosphorus and other minerals contains oxalic acid within a safe limit (Chowdari *et al.*, 1998a).

Because of its tolerance to high temperature, ability to withstand drought and grow even in low soil fertility conditions, pearl millet is best suited for arid and semi-arid regions of the country. The major thrust is to improve yield potential which may be achieved either through direct selection of landraces/ germplasm lines or by developing populations/hybrids that are adapted to diverse environments and provide higher yield of both grain and fodder. With increasing demand for livestock products and a realization of the impact of livestock in improving rural livelihood, the value of fodder (both green forage and dry stover) has considerably increased in recent years. It is a water-use-efficient crop and having high photosynthetic efficiency and dry matter accumulation rates, making it especially attractive for forage production. Generally, good quality forage is high in protein and digestible nutrients, and low in fiber and lignin.

Results from All India Coordinated Forage Project trials showed that pearl millet forage had 8.7% of crude protein, which was 45% more than that in sorghum and 58% more than that in maize (Rai *et al.*, 2004). Further, Choi *et al.* (1993) showed that the digestibility of pearl millet hybrid *Chungaecho* varied from 63.4% (one cut) to 57.6% (four cut) as compared to 57.6% and 47.3%, respectively, for the sorghum-sudan grass hybrid.

The d_2 dwarfing gene in pearl millet that reduces plant height by 50% and total plant dry matter by 22%, has been shown to increase the proportion of leaves by 50% and protein content by 15%, and reduce lignin by 17%, thus leading to 21% more forage consumption and 40% more body gain in 51-d cattle feeding trials (Johnson *et al.,* 1968). Similarly, a brown mid-rib (*bmr*) mutant reported in pearl millet (Cherney *et al.* 1991) that increases forage palatability and its digestibility by 10% can have a great impact on forage quality improvement provided its adverse effect related to reduced dry matter production and lodging can be resolved.

The basic material for population improvement or hybrid breeding could be derived from well adapted genotypes to stress environments or from improved elite breeding populations with high yield potential and high levels of disease resistance. Large genetic variability for several highly heritable traits (e.g. plant height, tiller number, leaf number and leaf length, photosensitivity) that show significant and positive association with forage yield provides opportunities to develop forage hybrids or populations with higher yield potential.

It is a well-established fact that the progress in improvement of a crop depends on the degree of variability in the desired traits in the base material vis-à-vis germplasm (Sharma *et al.* 2003). Phenotypic performance of a genotype will depend on its genetic make up and environment under which it is tested. The information on the magnitude and nature of the prevalent genetic variation is essentially needed to draw conclusion about the genetic potential of a particular population. Moreover, genetic variances are also found to be interacting with environments in many crops including pearl millet.

An ideal variety that performs fairly well under average or poor environments and also responds better under favourable environments. The evaluation of genotype x environment interactions gives an idea about buffering ability of the population under study. Genotype x environment interactions are of common occurrence and often create manifold difficulties in interpreting results and thus hampers the progress of breeding programme aiming at further genetic improvement in crop plants. Hence, the knowledge of magnitude and nature of genotype x environment interaction is very useful to a breeder for proper understanding and assessment of material with response to seasons.

Combining ability studies are very important for the breeders of any crop as it helps them in the selection of parents and crosses which give highest improvement for the character under consideration and also furnish the information on additive and non-additive portion of genetic variance present in the material under study. An environment plays an important role in the expression of a character and greatly influences the combining ability estimates, a single environment may not provide reliable information.

The information about combining ability and heterotic pattern of the current breeding material generated in kharif and summer seasons can be used to create new source populations for hybrid and population breeding with increased genetic variability and to combine adaptation with forage yield potential.

Genetic diversity in the species is distributed both within and among cultivars, due to its highly out crossing behaviour. Pearl millet exhibits tremendous amount of phenotypic and genotypic polymorphism (George *et al.*, 2005). D^2 statistic is a useful analysis technique employed for the assessment of genetic

divergence depicted by cluster diagram (Singh and Narayan, 2000). DNA markers data have been used to study genetic diversity among the cultivars and within the cultivars, by constructing the dendrogram using the UPGMA cluster algorithm (Chandra Shekara *et al.,* 2005).

However, the application of molecular markers in hybrid breeding has been investigated for assigning inbreds to heterotic groups. A heterotic group is collection of germplasm, that when crossed to germplasm external to group, tends to exhibit a higher degree of heterosis than crossed to a member of its own group. An essential assumption underlying the use of DNA markers for predicting hybrid performance is that a strong linear correlation exists between heterozygosity and heterosis (Singh *et al.,* 2006).

An implicit purpose for establishing and using heterotic group has been desired to predict the performance of hybrids, created by inter group crosses. Traditionally, the prediction of hybrid performance made on the basis of the morphological traits requires large number of crosses to be made, which have several associated problems. This is where molecular markers will be handy in determining genetic diversity and this will help in predicting hybrid performance. This would help to overcome the extremely labor intensive, time consuming and tedious process of making large number of crosses (Singh *et al.,* 2006).

In all crop species, phenotypic estimates of genetic diversity are biased by the environment in which they occur (George *et al.*, 2005), same is the case of isozyme markers which are affected by environmental conditions and different stages of development (Chowdari *et al.*,1998a).

Thus, for genetic diversity assessment in cross pollinated species molecular markers offer considerable advantage over other methods. The development of RAPD markers by Williams *et al.* (1990) is a cost effective and efficient method for genotype identification, pedigree analysis and genome mapping.

Hence, the present investigation of " Genetic studies and molecular analysis for forage yield in pearl millet (*Pennisetum glaucum*, L) R. Br.]" was undertaken in two environments *viz.* Kharif and Summer with following objectives;

1. To study gca of parents and sca of crosses for different forage and quality characters during kharif and summer seasons.
2. To study the extent of heterosis for different quantitative and fodder quality characters.
3. To study molecular diversity among parents by RAPD markers and study of its relation with hybrid performance for forage yield.

2. REVIEW OF LITERATURE

The available literature and information pertaining to present investigation is briefly reviewed and presented in this chapter under the following sub headings.

2.1 Combining ability and gene action

2.2 Heterosis

2.3 Genetic divergence (D^2)

2.4 Molecular studies

2.5 Correlation studies between Genetic distance, Heterosis and Combining ability

2.1 Combining ability and gene action:

The concept of combining ability has become very popular in the discipline of plant breeding since Davis (1927) suggested the use of inbred-variety cross (top cross) as a method of evaluating inbred lines of maize. General combining ability is the average performance of a parental line in a series of hybrid combinations with other lines and is controlled by additive genetic variance including additive x additive interaction variance. The concept of general and specific combining ability variances as a measure of gene action was proposed by Sprague and Tatum (1942). Specific combining ability is the deviation in the performance of a specific cross from the performance predicted on the basis of general combining ability. The F_1 performance between two parents may not be the true indication of the potentialities of the parents but performance of F_1 crosses involving a common parent may be good indication of the potentialities of a particular

parent to transmit favourable genes to the progenies. Therefore, general and specific combining ability estimates are likely to be quite useful in self as well as cross-pollinated crops. In general combining ability, therefore, genes with additive effects are more important, while specific combining ability is more dependent on genes with dominance and epistatic effects.

The choice of parental material in a breeding programme is very important, since it puts a limitation on the possibility of isolating the genotypes outside the framework of the genetic makeup of the parents. No amount of manipulation later on would compensate for the genes not present in parental material. The knowledge of combining ability of the parents and crosses is important to achieve this goal.

Several methods have been developed to estimate the general and specific combining ability of different genetic materials *viz.,* inbred- variety cross or top cross technique (Jenkins and Brunson, 1932), poly cross (Tysdal, *et al.* 1942), diallel cross (Griffing, 1956), line x tester analysis (Kempthorne, 1957), partial diallel cross (Kempthorne and Curnow, 1961) and triallel cross (Rawling and Cockerham, 1962).

Many characters of economic importance with which the plant breeders work, exhibit continuous variation of phenotypes, as many genes with small and cumulative effect govern them. The effect of these individual genes cannot be measured separately, hence they must be considered as together and appropriate statistical procedures are used to obtain the genetic information. The inferences on magnitude and nature of gene effects are usually drawn from the estimates of different genetic variances.

The review pertaining to combining ability studies and gene effects for various characters related to present investigation is as follows:

Badwal (1970) in diallel analysis study of pearl millet observed significant SCA for grain yield and GCA for plant height, number of tillers, number of internodes, ear length, ear girth and 1000 grain weight.

Gupta and Gupta (1971) studied combining ability for green fodder characters in pearl millet and observed that eight out of 54 crosses had high sca for green fodder yield. They concluded that combining ability of parents can be successfully be used in predicting the performance of cross combinations.

Upadhyay and Murthy (1971) studied 20 populations of diverse origin and reported that the nature of gene action was predominantly non additive for days to 50 per cent flowering, number of tillers, plant height, ear length and number of seeds and it was considerable for number of tillers and ear head girth.

Badwal *et al.* (1973) crossed five male sterile lines with 10 inbreds in line x tester design and reported that an estimate of GCA was significant and higher than SCA for most of characters except ear girth and days to 50 per cent flowering, indicating thereby the importance of additive gene effects for these yield components.

Phule *et al.* (1973) reported from their study of 9 x 9 diallel of pearl millet that magnitude of gca variance was larger than sca variance for days to flowering, plant height, number of ears, ear girth, ear length and grain yield. The crosses between the two general combiners were not always good for sca of the hybrids.

Gill *et al.* (1974) crossed 55 inbred lines of pearl millet with each of the four male sterile lines to ascertain their combining ability, using line x tester analysis and revealed that non additive gene effects were more important for grain yield, ear number, ear length, ear girth, plant height and earliness. The best cross combination generally involved either both or one of the best general combining parents.

Singh et al. (1974) analyzed combining ability of five male sterile lines and 10 inbreds of pearl millet in line x tester and reported that the lines and testers with high gca effects for yield proved to be high general combiners for other characters too. They also suggested to give more emphasis on *per se* performance of crosses instead of estimates of sca for correct choice of hybrid combination.

Observations of Pokhriyal *et al.* (1976) in pearl millet indicated that the best cross combinations generally involved either both or one of the best combining parents, while the parents with low gca effect in general, made poor crosses.

Kumar *et al.* (1977) carried out genetic analysis in a 15 parent diallel cross and reported that both additive and non additive genetic variances were present with predominance of later one for head weight, head length and head number per plant.

Yadav (1977) in combining ability studies of pearl millet revealed additive gene action for plant height, number of ear bearing tillers/plant and mainly non additive gene action for number of tillers/plant and fodder weight/plant.

Hooda *et al.* (1978) studied genetic architecture of quantitative as well as qualitative characters in 6 x 6 diallel set of pearl millet and observed predominance of non additive genetic

variance for the characters green fodder yield, dry fodder yield, leaf length and width, protein content and IVDMD .

Tyagi *et al.* (1978) studied combining ability in a 16 x 16 diallel set and observed that estimates of both general and specific combining ability effects were highly significant for days to ear emergence, plant height, number of tillers per plant, ear length and grain yield except for ear diameter, with preponderance of additive genetic variance for almost all the characters.

A study was undertaken by Singh *et al.* (1979) with a view to characterize the nature of gene action in F_1 generation of a 12 parent diallel cross. Both additive and non additive components were significant for days to 50 per cent flowering, number of effective tillers, plant height, ear length, ear girth, 1000 grain weight and grain yield in both generations.

A line x tester analysis was carried out by Basavaraju *et al.* (1980) in pearl millet and they stated that variance due to sca was pronounced for days to 50 per cent flowering, number of tillers, number of leaves, plant height, ear girth and 250 grain weight but not for ear length, while, variance due to gca was also considerable for days to flowering, number of leaves and plant height.

Singh *et al.* (1980) in their study of diallel analysis of pearl millet reported significant gca, sca variances and large additive effects for plant height, number of tillers/plant and number of internodes/main shoot.

Sreenivasulu and Sreeramulu (1980) reported that both gca and sca mean sum of squares were significant indicating the importance of both additive and non additive gene effects for days to 50 per cent flowering, plant height, number of leaves per main

shoot, ear length, ear girth and grain yield. However, additive gene action was predominant for height, number of days to 50% flowering, stem girth and grain yield.

Indu and Gupta (1981) reported predominance of gca variances and additive gene effects for both soluble protein and crude protein in stem of pearl millet and sca variance and non additive gene effects for both contents in leaves.

In 8 x 8 diallel, involving five Indian and three exotic pearl millet inbreds, Mukherji *et al.* (1981) reported over dominance for ear length and grain yield per plant and partial dominance for effective tillers per plant. Variances due to sca and gca revealed that both additive and non additive gene actions were important with a preponderance of non additive gene effects.

Chawla and Gupta (1982) studied combining ability in a 12 × 12 diallel cross set in pearl millet in different seasons with respect to fodder quality characteristics such as oxalic acid, calcium, sodium, potassium besides green fodder yield. The relative proportions of general and specific combining variances indicated the preponderance of non-additive genetic variance. Parents possessing desirable fodder quality characteristics were identified on the basis of combining ability and *per se* performance, and selection criterion for crosses was discussed. They recommended that leaf portion should be biochemically analyzed and manipulated in an environment when the genes are expressed.

In the study of genetics of some forage attributes in pearl millet, Prakash kumar *et al.* (1982) reported significant gca and sca mean squares and higher magnitude of non additive genetic component for stover yield, plant height and number of tillers/plant.

Chawla and Gupta (1983) studied combining ability from 12 x 12 diallel cross set of pearl millet and found preponderance of non additive gene action for leaf number, leaf length, leaf width, number of tillers and plant height.

From a line x tester analysis, Mathur and Mathur (1983) reported that both gca and sca variances were important for expression of grain yield per plant, number of effective tillers, ear length, ear girth and 1000 grain weight.

Dass *et al.* (1984) in the study of combining ability in pearl millet observed non additive type of gene action predominant for all the traits *viz.,* grain weight, ear weight, number of effective tillers, plant height and days to 50 per cent flowering except for 500 grain weight where additive type of gene action was noticed.

In study of combining ability in pearl millet Dass *et al.* (1985) found that variance due to gca and sca were significant for head weight, number of effective tillers, head length and plant height. They stated that both additive and non additive gene action were important for the expression of all the yield attributing characters.

Navale *et al.* (1985) in their study of diallel analysis of five maintainers of pearl millet, proved that *per se* performance and gca of parents were found to be related for total tillers, ear length and plant height and were found to be unrelated in case of grain yield. Similarly, they also observed that sca effects and mean performance of hybrids were not related for effective tillers and 50 per cent flowering.

Patel and Kukadiya (1986) studied combining ability in 5 lines x 10 testers set and found that the sca variance was significant for chlorophyll content and early growth, whereas for

flag leaf area, plant height, and days to heading gca variance was predominant. They indicated that crosses with high sca had not exhibited high performance. Further, hybrids showing high sca did not always involve the parents with high gca effects.

Pethani (1987) in line x tester analysis study of pearl millet, reported greater role of additive gene action for days to ear emergence, number of nodes, peduncle length, ear length and ear diameter, non additive gene action for grain yield and both for number of effective tillers, plant height and grain weight.

In a combining ability study using line x tester design, Kunjir *et al.* (1988) found additive effects for days to 50 per cent flowering and effective tillers, whereas for ear weight and length, variance due to sca was of greater magnitude than variance due to gca.

Gopalan and Sree Rangasamy (1989) reported higher magnitude of sca variances for plant height, number of tillers/plant, number of leaves, stem weight, leaf weight, green fodder yield, dry matter yield and crude protein content while gca variance was higher than sca variance for leaf length, leaf breath and leaf weight in their L x T analysis study of pearl millet in four environments and two locations.

Combining ability was estimated by Satija and Thukral (1989) with respect to grain yield and other quantitative traits in a complete diallel set of 12 pearl millet lines. The relative proportion of gca and sca variances indicated the preponderance of gca variance for grain yield, days to 50 per cent heading, heading duration, days to maturity, plant height, ear length and grain size.

Harer *et al.* (1990) from line x tester analysis of pearl millet, observed predominant non additive gene action for days to

50 per cent flowering, plant height, number of leaves per plant and total tillers.

Patil (1990) in his studies on line x tester analysis of pearl millet, indicated that the additive gene action was found to be predominant for days to flowering, ear length and ear girth while, non additive gene action was predominant for plant height , total tillers per plant and grain yield per plant.

Ashwini kumar and Dahiya (1991) in an analysis of nine parent diallel of pearl millet reported non additive gene action for dry fodder yield, plant height and number of tillers/plant.

From 14 lines x 8 testers, Navale *et al.* (1991) studied combining ability for five traits. General combining ability effects indicated that additive gene action was important for grain yield, days to 50 per cent flowering and production of tillers, while sca effects revealed importance of dominant gene action for ear length and plant height. From gca analysis it was observed that parents with high mean values showed high gca effects. Crosses between good x good, poor x average and poor x poor combiners produced high sca effects, which appeared due to dominance and epistasis gene effects.

Navale and Harinarayana (1992) assessed combining ability from 12 x 12 full diallel in pearl millet. The mean sum of squares due to gca was significant for all the six traits. Significant reciprocal combining ability mean squares for grain yield and ear length indicated role of cytoplasm in expression of both of these traits. The preponderance of dominant components for grain yield and additive component for plant height, days to 50 per cent flowering and maturity was observed. It was also revealed that

presence of at least one good general combiner is essential in producing high sca effects for yield in pearl millet.

Rasal (1992) from combining ability study of pearl millet observed the predominance of additive gene action for days to 50 per cent flowering, number of leaves per main shoot, flag leaf area, number of productive tillers per plant and non additive gene action for grain yield, fodder yield and harvest index.

Quendeba *et al.* (1993) studied combining ability from five populations and their 10 inter population crosses of African pearl millet land races. The variance due to gca was found significant, indicating importance of additive gene effects for plant height, flowering time, spike length, grain yield and 1000 grain weight.

Combining ability effects were estimated by Chavan and Nerkar (1994) in a line x tester crossing programme involving 105 pearl millet hybrids produced by crossing five lines with 21 restorers. Specific combining ability variance was predominant indicating importance of non additive gene effects for days to 50 per cent flowering, days to maturity, leaves per plant, plant height, number of effective tillers per plant, spike length, spike girth and grain yield per plant.

A diallel analysis involving eight parents carried out by Aher and Ugale (1995) in F_1 and F_2 for plant height, total number of tillers, effective tillers, ear head length and girth, grain weight and grain yield per plant. In both generations, variance for gca and sca were highly significant which indicated the role of additive as well as non additive gene effects for expression of these traits. However, non additive gene effects were predominant for all the traits except ear head girth in F_1 generation.

Balakrishnan and Das (1996) estimated the combining ability in crosses involving six male sterile lines and five restorers of pearl millet in line x tester manner. An estimate of sca variance was predominant for all traits. Thus, the traits like plant height, leaf area, effective tillers, ear head length, ear head thickness, earliness and grain yield were predominantly governed by non additive gene action.

Devanand and Das (1996) studied combining ability in six pearl millet varieties and reported predominance of gca variance for days to 50 % flowering, green fodder yield, dry matter yield, crude protein and oxalic acid content while predominance of sca variance for plant height, number of tillers/plant, stem girth, number of leaves , leaf area and calcium content.

Naik *et al.* (1996) studied line x tester analysis involving five male sterile lines and eight inbreds. They observed importance of non additive gene action over additive gene action for ear length, plant height, days to 50 % flowering and maturity.

Azhaguvel *et al.* (1998) investigated line x tester study including nine male sterile lines and 10 testers. They observed preponderance of non additive gene action for expression of plant height, days to 50 % flowering, number of effective tillers, panicle length, panicle girth, 100 grain weight and grain yield per plant.

Karale *et al.* (1998) in combining ability studies of pearl millet revealed that non additive genetic variance predominantly governed the expression of yield, 1000 grain weight, and effective tillers per plant and leaves per main shoot. Additive gene action was found important for days to 50 per cent flowering, plant height, ear length and ear girth. The parents showing good gca

also displayed good sca for one or other important attributes in hybrid combination.

Combining ability estimates in pearl millet were obtained by Latha and Shanmugasundaram (1998) from line x tester analysis of crosses involving 10 male sterile lines and six restorers. They found predominant non additive gene action for all traits like plant height, number of effective tillers, ear thickness, 1000 grain weight and grain yield per plant except ear length in which additive type of gene action was noticed.

Gandhi *et al.* (1999) crossed six male sterile lines with 10 restorers in line x tester design to study the combining ability in pearl millet and observed significant gca for days to 50 per cent flowering, grain yield, effective tillers and ear length.

The results of combining ability obtained by Mohan *et al.* (1999) from data on five yield related traits in the parents and 30 progeny of five lines x six testers of pearl millet crosses indicated role of additive gene action for number of effective tillers, ear head length, ear head girth and 1000 grain weight, whereas non additive gene action for grain yield per plant.

Yadav *et al.* (2000 a) determined the combining ability of sixteen land races of pearl millet (*Pennisetum glaucum* (L.,) R. Br.), originating from the arid area of western Rajasthan, for four traits by evaluating their crosses in 12 environments grouped into three zones. The results indicated that general combining ability (gca) effects were more important in the genetic control of grain yield and stover yield, while both gca and specific combining ability (sca) effects were important for time to flower and 100-seed weight. Environments influenced the gca effects. General combining ability effects of most pollinators varied substantially across three

production zones. None of the pollinators exhibited desirable gca effects for all traits simultaneously. The existence of rather high magnitude of additive genetic effects could be a characteristic feature of pearl millet land races and this variation can be utilized by placing more emphasis on inter-population breeding through recurrent selection. Thus, a rather higher importance of additive gene effects than non-additive gene effects was found in the genetic control of most traits among the land race material originating from arid areas of Rajasthan. The results showed that gca effects of land race pollinators varied considerably across zones; and specific pollinators need to be utilized for a particular zone. The local land races proved better combiners for grain yield than the control pollinators in ND zone.

Ali *et al.* (2001) derived information on heterosis and combining ability of direct open cultivars, breeding populations and gene pools. Data for grain and biomass yield, time to flowering, plant height, panicle length and productive tillers were collected from an eleven parent diallel cross. Populations ICMV 91059, SenPop, ICMP 91715 and ICMP 929451 constitute a genetically diverse subset of the parents that consistently had the best ranks for grain yield gca across test environments.

Singh and Sagar (2001) undertook genetic analysis of grain yield and its components in pearl millet in rainfed and irrigated condition. They reported that dominance variance exceeded the additive variance, thereby indicating preponderance of dominance gene action for number of productive tillers per plant, ear length, days to maturity, ear head weight per plant and grain yield per plant of all the crosses in both the environments.

Yadav *et al.* (2002) studied the combining ability of seven newly developed male sterile lines and eleven testers of forage pearl

millet. They found sca estimates were higher for dry fodder yield and effective tillers indicating the predominance of non additive gene effect for these traits.

Bidinger *et al.* (2003 b) identified the requirement for simultaneous increase in stover as well as grain yields in arid zone environments. General combining cbility (gca) estimates for seven land race-derived populations / varieties, derived from multi-environment tests in arid zone environments indicated that selection history played a large role in determining gca for both biomass and HI, with prior selection (for grain yield) favoring gca for HI, at the expense of gca for biomass. It was, however, possible to identify several parental lines with a positive gca for biomass, achieved by a positive gca for growth rate, and neutral gca for HI, resulting in positive / neutral gca for both stover and grain yields. Also, the ability of parental gca to predict heterosis in TCH indicated that heterosis for stover yield was closely related to pollinator gca for stover yield, and heterosis for grain yield was related to both pollinator and A line gca for HI. Hence, they confirmed the hypothesis that parents with positive gca for biomass and neutral gca for HI could produce TCH with positive heterosis for grain yield without an offsetting negative heterosis for stover yield.

Rasal and Patil (2003) found that there was involvement of non additive gene action for the inheritance of grain yield per plant and additive gene action for plant height, days to flower, tillers per plant, ear girth and ear length in line x tester analysis involving 13 parents.

Lakshamana *et al.* (2003) reported significant gca among parents for plant height, ear length, days to 50 per cent flowering and maturity.

Rathore *et al.* (2004) studied diallel mating design involving 11 diverse restorer lines and reported that variance due to both sca and gca were significant for days to flowering, plant height, productive tillers per plants, 500 grain test weight and grain yield per plant indicating importance of both additive and non additive gene action for panicle girth.

Shanmuganathan *et al.* (2005) evaluated the 55 F_1 and 11 parents during rabi 2003 in Coimbatore for grain and stover yield and associated characters (days to 50% flowering, plant height, number of tillers per plant, number of productive tillers, number of leaves, leaf length and breadth, panicle length and width, stem diameter, and 1000-grain weight). The variances due to general combining ability (gca) and specific combining ability (sca) were significant. General comining ability variances were higher in magnitude than sca variances for all characters except leaf breadth, indicating the preponderance of additive gene action. For leaf breadth, both gca and sca variances were equal, indicating the prevalence of both additive and non-additive gene action. The *per se* performance of the parents provided a fairly good indication of their combining ability in most cases, except for panicle width and in general, hybrids having high sca effects have high *per se* performance.

Sushir *et al.* (2005) studied combining ability in pearl millet and observed higher gca effects than sca for number of tillers/plant and ear length and higher sca for days to 50 % flowering, ear girth and grain yield /plant.

Pachade (2006) reported predominance of non additive gene action for leaf length and additive gene action for plant height, number of tillers/plant, dry matter yield, green fodder yield, L:S ratio and oxalic acid content in pearl millet.

Haussmann *et al.* (2006) evaluated the medium-maturity, high-tillering population diallel derived from crossing 12 diverse pearl millet populations in all possible combinations without reciprocals at the ICRISAT research station, Sadoré, Niger in the rainy season of 2005. The variance of general combining ability (*gca*) effects was highly significant for days to 50% flowering, head yield, grain yield, plant height, panicle length panicle circumference, panicle exertion and tillers per hill. Variance of specific combining ability (*sca*) effects was significant for days to 50% flowering, head and grain yield, panicle length and circumference and number of tillers per hill.

Rohitashwa *et al.* (2006) studied combining ability for dry fodder yield in pearl millet in a 10 x 10 diallel cross without reciprocals in 3 environments (sowing dates viz. 23 June, and 8 and 25 July). The variances due to general combining ability (gca) and specific combining ability (sca) were highly significant, indicating the importance of additive and non-additive gene action. The estimates of sca components were higher in magnitude than that of gca component, indicating the pre-dominance of non-additive gene action for the trait.

Izge *et al.* (2007) observed that fair general parallelism existed in most cases between the gca effects and the performance of the parental lines per se in pearl millet. Similar general parallelism also existed between sca effects and per se performance of hybrids and between sca effects of hybrids and levels of higher parent heterosis. The preponderance of non-additive genetic effect and the tremendous levels of higher parent heterosis observed among the traits in the parents and the hybrids studied would be a great asset in choosing pearl millet cultivars for

inter crossing and development of cultivars and hybrids for commercial production.

Kumar and Singhania (2007) reported significant estimates of σ^2gca and σ^2sca variances for most of the characters in pearl millet in both the environments indicating the importance of both additive and non-additive gene actions in the inheritance. The nine hybrid combinations showed consistence mean performance across the environments with average to high sca effects for grain yield per plant, component characters and downy mildew [*Sclerospora graminicola*] resistance (at Jodhpur).

Suthamathi *et al.* (2007) studied the combining ability of quality characters in interspecific hybrids of *P. glaucum x P. purpureum*. The variance due to lines was high for crude protein content whereas it was high for the other traits in the testers. The contribution by the interaction component of lines x testers was more than that of lines for ash content, crude fibre and oxalic acid contents, and it was more than testers for none of the traits. The sca variances were higher than the gca variances for all characters.

Patel *et al.* (2008) in combining ability analysis of pearl millet indicated that only non additive gene action governed most of the fodder yield attributes. For the expression of days to maturity, both additive and non additive gene action were responsible. The estimates of general combining ability effects indicated that none of the parents was good general combiner for fodder yield.

2.2 Heterosis

Heterosis or hybrid vigour indicates the superiority of hybrid over its parents. It was first reported in plants by Koelreuter (1766). He noted that vigour in crosses increased with the increase

in dissimilarity of parents. The term "heterosis" as is now widely used, was first coined by Shull (1908). It refers to the phenomenon in which the F_1 hybrid obtained by crossing two genetically dissimilar individuals shows the increased or decreased vigour over the better or mid-parent value. Later on, Fonseca and Patterson (1968) used the new term "heterobeltiosis" to describe improvement of heterozygotes in relation to better parent.

Heterosis being a complex phenomenon, no conclusive or clear cut explanation is available to account for its manifestation. However, several theories have been postulated to explain heterosis, like dominance of genes (Davenport, 1908; Keeble and Pellew, 1910; Bruce, 1910 and Jones, 1917), over dominance of genes (East, 1908; Shull, 1908; and Hull, 1945), gene dispersion in parental lines, epistatic interaction, linkages of genes, maternal effect and genotype x environment interaction (Mather and Jinks, 1971) and mitochondrial complementation (Hanson *et al.,* 1960 and Srivastava and Balyan, 1977). There is no evidence however, to attribute a single cause responsible for heterosis (Strickberger, 1976). Thus, observed heterosis might result from the combined interactions of several above mention causes.

Using diallel mating design in pearl millet, Pokhriyal *et al.* (1967) observed heterosis for grain yield, days to flowering, plant height, thickness of main culm, leaf area, main spike girth, thickness of peduncle and 1000 grain weight.

Singh (1970) studied heterotic effects in crosses of Tifton 23 A with nine inbreds. The maximum heterobeltiosis was observed for number of nodal heads (190.00 %) followed by plant height (132.21 %), leaf width (48.30 %), number of nodes (46.80 %), seed size (42.42 %), yield per plant (37.49 %) and days to flowering (9.09).

Gupta and Gupta (1971) reported higher magnitude of heterosis for green fodder characters in pearl millet when high x high, medium x high combinations were evolved and all top combinations involved parents of different eco geographic origin.

Significant and positive heterosis was observed by Singh and Singh (1972) for plant height, number of spike-bearing tillers and for grain yield and significant negative for spike length in a cross involving two inbred lines of pearl millet.

Hira Chand *et al.* (1973) reported very low magnitude of heterosis in pearl millet for number of internodes, leaf length, leaf width, 1000 grain weight and also negative heterosis for leaf length, leaf width and number of internodes in three crosses.

Yadav (1977) in heterosis studies of pearl millet hybrids revealed significant heterosis for plant height, number of tillers per plant, number of ear-bearing tillers per plant, grain weight per plant, fodder weight per plant 1000-grain weight, number of days to flowering and number of leaves per main tiller.

Pandey and Katiyar (1978) reported that internal cancellation of heterotic components was the cause of absence of heterosis in number of tillers.

Subramaniam and Rathinam (1980) reported significant relative heterosis in pearl millet for plant height, number of tillers, peduncle length, 1000 grain weight and grain yield in 6 x 6 diallel analysis.

Mukherji *et al.* (1981) carried out heterosis study in 8 x 8 diallel involving 5 Indian and 3 exotic cultivars of pearl millet. They observed over dominance for ear length, ear girth and yield per plant and partial dominance for effective tillers per plant.

Reddy and Arunachalam(1981) performed diallel analysis on F_1 and F_2 data from derived populations obtained from a world germplasm collection through selfing (T), biparental matings (A) and irradiation (R) and populations from exotic collections (W). On the basis of general combining ability estimates, with respect to yield components, parents of type biparental matings and selfing were classified as High (H) and type irradiation and populations from exotic collections as Low (L) general combiners. Heterotic crosses were more frequently obtained with H x L than H x H or L x L combinations. Evidence for heterosis without dominance was obtained.

During the study of heterosis in pearl millet Vaidya *et al.* (1983) recorded very high heterosis over the better parent which was 134%, 44.5% and 38.8% for grain yield per plant, 1000 grain weight and protein content, respectively.

From analysis of data, using Mahalanobis D^2 statistic, Raveendran and Appadurai (1984) placed 53 inbreds in 19 divergent clusters and reported heterosis for plant height, number of effective tillers, ear length and grain size in some hybrid combinations involving genetically distinct parents.

Shinde and Desale (1985) studied heterosis in pearl millet for forage yield per plant and other yield-related traits from four male-sterile *Pennisetum americanum* lines, 10 male testers and their 40 F_1 hybrids. They observed highest heterosis for fodder yield (93.92% in MS5141A X CN74-1).

Gartan *et al.* (1988) carried out heterosis study in pearl millet hybrids derived from 9 x 9 diallel and reported positive heterosis for seed yield, 1000 grain weight and ear girth, while,

negative heterosis for number of tillers, ears per plant and ear length.

Hapse (1989) reported high magnitude of heterosis for grain yield, plant height, pancle length, panicle girth, leaf length and breadth and appreciable amout of heterosis for days to flower and number of tillers per plant.

In a complete diallel set of 12 pearl millet lines characterized by differences in downy mildew resistance, Satija and Thukral (1989) reported significant heterosis for grain yield, days to 50 per cent heading, heading duration, days to maturity, plant height and ear length.

In a partial diallel involving twelve inbred lines (three each of Indian and African origin and six derivatives of indigenous x exotic crosses) of pearl millet, Kushwah and Singh (1992) observed heterosis for days to 50 per cent flowering, plant height, leaf length, leaf width, number of nodes on main tiller, length of first internode, number of tillers, spike length, spike girth, grain density, 1000 grain weight and grain yield. Plant height, length and width of leaf, number of nodes on main tiller and earliness showed undesirable heterosis. The magnitude of heterosis was highest for grain yield (397.00 %) and lowest for days to 50 per cent flowering (-5.00 %).

Kulkarni *et al.* (1993) in a 8 x 8 full diallel of pearl millet reported more than 50 % hybrids derived from Indian x Exotic were significantly maximum heterotic for number of tillers/plant (61.0%), days to 50 % flowering (-16.4 %) and leaf area (103.3 %).

By using line x tester crossing programme involving five lines and 21 restorers, Chavan and Nerkar (1994) reported high heterobeltiosis for grain yield per plant (109.26%), leaves per plant

(50.14 %) and moderate heterobeltiosis for number of effective tillers per plant (48.00 %), plant height (26.03 %), spike length (23.87 %), days to 50 per cent flowering (-16.44 %) and days to maturity (-4.17 %).

Patil *et al.* (1994) reported high range of heterosis over better parent for days to 50 % flowering (-11.92 to 4.O %), Plant height (-1.82 to 32.65) and number of tillers/plant (-26.66 to 30.33).

In a study on heterosis in thirty hybrids derived from six male sterile lines and five restorer testers, Balakrishnan and Das (1996) reported heterosis for leaf area, effective tillers, earhead length, earhead thickness and yield.

Quendeba *et al* (1996) recorded highly significant difference between crosses (9.94 t ha^{-1}) and parents (8.50 t ha^{-1}), or average heterosis, well as general combining ability was observed in the combined analyses for dry weight forage yield in pearl millet. No other partitions of entries for either trait were significant. Year x entries was significant for forage yield but not for IVDMD. All mid parent and high-parent heterosis values were positive for forage yield but were non significant. Heterosis for forage yield did not affect IVDMD.

Devanand and Das (1997) observed high heterosis for fodder yield and crude protein and calcium content in pearl millet.

Comparative expression of heterosis for physiological traits and grain yield was examined in 21 F_1 hybrids of pearl millet by Deore *et al.* (1997). Significant heterosis for grain yield, harvest index and leaf area index was obtained. In case of grain yield 73.38, 63.36 and 28.50 percent heterosis was observed over mid parent, superior parent and standard check, respectively.

Karale *et al.* (1997) while adopting line x tester analysis (5 x 8), observed positive heterosis for plant height, number of leaves per main shoot, ear length, ear girth, 1000 grain weight, grain yield per plant and number of effective tillers per plant and negative heterosis for days to 50 per cent flowering.

Gandhi *et al.* (1999) crossed six male sterile lines with 10 testers in line x tester design and observed heterosis for grain yield, plant height, ear length and earliness.

Yadav (1999) undertook an investigation to quantify magnitude of heterosis in hybrids based on different cytoplasmic male sterility sources. Magnitude of heterosis varied considerably within the hybrids retaining a particular cytoplasm. Manifestation of cytoplasmic effects was higher for heterosis for grain yield and plant height than heterosis for days to flowering (negative) and ear length.

Sheoran *et al.* (2000) reported heterobeltiosis for plant height, ear head girth, ear head length, 1000 grain weight and grain yield per plant but not for tillers per plant and days to flowering.

Yadav *et al.* (2000 b) quantified the magnitude of heterosis under water stress environments in pearl millet top cross hybrids produced by crossing 16 diverse land races and three high yielding open pollinating varieties on two male sterile lines. The hybrids showed conspicuous heterosis for earliness and grain yield but not for straw yield. The level and direction of heterosis for time to flowering depended strongly on the earliness of male sterile line. Heterosis for biomass yield and biomass yield per day was also positive in all three zones over water stress environments. They further revealed that the significant amounts of heterosis observed

in land race based top cross hybrids for grain yield and other productivity related traits suggested that substantial improvement in pearl millet productivity in water stress environments can be obtained by top crossing locally adopted land races on suitable male sterile lines.

Singh and Sagar (2001) undertook genetic analysis of grain yield and its components in pearl millet in rainfed and irrigated condition. They indicated prevalence of heterobeltiosis due to over dominance of completely or incompletely dominant genes. The positive heterosis was observed for number of productive tillers per plant, ear length, days to maturity, ear head weight per plant and grain yield per plant but negative heterosis for days to flowering.

Dutt and Bainiwal (2002) studied the ten pearl millet genotypes crossed in a diallel manner and observed high heterosis for green fodder yield and grain yield.

Jindal and Sagar (2003) studied genetics and heterotic relationship in ten early maturing pearl millet populations and observed that for days to 50 % flowering accounted for 55.57 % variances out of which 85 % was due to specific heterosis.

Bidinger *et al.* (2003 b) identified the requirement for simultaneous increase in stover as well as grain yields in arid zone environments. From the heterosis study they concluded that the ability of parental gca to predict heterosis in TCH indicated that heterosis for stover yield was closely related to pollinator gca for stover yield, and heterosis for grain yield was related to both pollinator and A line gca for HI. Hence, they confirmed the hypothesis that parents with positive gca for biomass and neutral

gca for HI could produce TCH with positive heterosis for grain yield without an offsetting negative heterosis for stover yield.

Presterl and Weltzien (2003) evaluated the performance of six elite breeding populations and three land races and determined the heterotic pattern among the 36-diallel crosses of those populations and land races under different water stress environments. They observed that mean grain yields under favourable growing conditions were two to three folds higher than those in the water stress conditions. The elite populations generally showed higher grain yield than land races; stover yield was similar in both population types. Mean level of mid parent heterosis was generally low, ranging from 0.85% for time to flowering to 6.57% for stover yield. They further suggested that the elite x land race population crosses with high mean grain yield and high levels of heterosis under drought stress could be beneficial to widen the germplasm base and to combine the high yield potential of elite materials with good adaptation of the land races.

Manga and Dubey (2004) in their study of diallel analysis involving nine restorer lines found good amount of heterosis for grain yield, earliness, productive tillers per plant, ear head length, ears per ha., ear head weight, 1000 grain weight, harvest index and biomass.

Blummel and Rai (2004) studied 42 top cross hybrids obtained from crossing seven populations of diverse origin on each of six fodder type male sterile lines. They observed significant positive as well as negative heterotic effects for grain yield and stover yield. Positive heterosis trends were observed in 32 hybrids for grain yield and 12 hybrids for stover yield.

By using line x tester programme in pearl millet, Pachade (2006) revealed significant higher magnitude of heterosis over better parent in favourable direction for days to 50 % flowering followed by leaf length, L:S ratio, dry forage yield, number of leaves, plant height, green forage yield and oxalic acid content.

Kumar and Singhania (2007) evaluated eight male sterile lines each in A_4 and A_1 CMS sources, nine diverse restorers and their 144 crosses in line x tester design in pearl millet for grain yield and component characters to study the magnitude of heterosis, mean performance and combining ability variance and effects. Analysis of variance indicated significant differences among genotypes for all the characters on pooled as well as in individual environments. Mean sum of squares due to parents vs. hybrids were significant for all the characters indicating presence of heterosis.

Patel *et al.* (2008) studied heterosis and combining ability in pearl millet hybrids and revealed that 5 hybrids (JMSA 101 A x 217 SB, JMSA 98222 x 98 SB, ICMA 92777 x 59 SB, ICMA 92777 x 74 SB and JMSA 20005 x 9 SB) exhibited higher relative heterosis, heterobeltiosis and standard heterosis for most of the fodder yield attributes, indicating their importance for commercial exploitation of heterosis.

Vetriventhan *et al.* (2008) evaluated five male sterile lines and 30 inbred testers of pearl millet and their 150 hybrids for studying the extent of hybrid vigour in F_1 for grain yield and its components. Highest and significant negative relative heterosis, heterobeltiosis and standard heterosis was observed in the cross ICMA 94111A x PT 5259 and the same combination showed negative relative heterosis, heterobeltiosis and standard heterosis for the trait plant height.

Vagadiya *et al.* (2010) crossed four cytoplasmic genic male sterile lines with 12 diverse pollinators in line x tester design and observed high magnitude of heterosis for grain yield per plant, fodder yield per plant and ear heads weight per plant; medium level of heterosis was exhibited for days to 50 % flowering, days to maturity, node number per plant and 1000-grain weight.

2.3 Genetic Divergence (D^2)

The variability present among the different genotypes of a species is known as genetic diversity. Genetic diversity arises due to geographical separation or due to genetic barrier to cross ability. One of the potent techniques of assessing genetic divergence is the D^2 statistic proposed by Mahalanobis (1936). This technique measures the forces of differentiation at two level, namely, inter cluster and intra cluster level, and thus helps in the selection of genetically divergent parents for exploitation in hybridization programme.

Allard (1961) concluded that the genetic diversity and productivity were complexly related, while divergence and stability appeared to be more simply related. Wallace (1963) pointed out the importance of geographical barrier in changing breeding structure, while Jain *et al.* (1981) concluded that geographical barriers preventing gene flow or intense natural or human selection for diverse, adaptive gene complexes may be responsible for the genetic diversity.

Mahalanobi's D^2 statistic is a proven powerful tool in quantifying the degree of divergence between biological populations at the genotypic level and to access relative contribution of different components to the total divergence (Singh and

Choudhary, 1979; Arunachalam, 1981; Jatasera and Paroda, 1983)

Murthy and Arunachalam (1966) reported that D^2 was not related to eco-geographical diversity in wheat, sorghum, and soybean, and stated that in different environments genetic drift and selection cause more diversity among genotypes.

Murthy and Tiwari (1967) studied genetic diversity in a population of 64-dwarf pearl millet and reported that geographical diversity is not related to genetic diversity. He further indicated that the most potent factor for divergence in the dwarf derivation appeared to be tiller number at inter and intra cluster level of differentiation.

Joshi (1979) stated that the genetic diversity involving genetically diverse parent in crossing would be advantageous as it would provide an opportunity for bringing together gene constellations of divergent origin. Isolation in space and time result in locking up genes in different constellations and these should be brought together in hybridization.

Singh and Gupta (1979) estimated that the genetic diversity among 34 pearl millet strains in two different environments varying in level of fertilizer application. They pointed out that diversity was more fully expressed in normal environment without fertilizer and also indicated that some characters like number of leaves per plant, leaf length, 1000-seed weight and tiller number were very potent in contributing to diversity.

Mukherji *et al.* (1981) studied the genetic divergence in fifty-one inbreds of pearl millet and reported that geographical distance was not related to genetic divergence. The inbred were grouped into 14 different clusters. Plant height, ear length, ear

girth and test weight were significantly and positively associated with grain yield per plant.

Singh *et al.* (1981) also studied the genetic divergence in 9 pearl millet inbred and their 36 F_1 hybrids, and observed that genetic divergence is not essentially related to geographic diversity.

Thete and Bapat (1986) analyzed data on yield per plant and 13 related traits in 45 diverse varieties using D^2 statistic. The varieties were grouped into 12 clusters with substantial genetic divergence between them. Geographical diversity was not related to genetic diversity. The main traits contributing towards diversity were internodes number, stem girth, leaf length, ear length, number of fertile tillers, total leaf number, grain yield/main clum, grain yield/plant and especially height and ear length.

Joshi *et al.* (1988) carried out D^2 and canonical analysis from data on 13 yield components in 92 entries (Pennisetum americanum) derived from Indian X Indian and Indian x African crosses. Eleven clusters were identified, with the largest containing 32 entries. No relationship was found between genetic and geographical diversity.

Singh (1988) examined 34 *Pennisetum typhoides* strains for genetic diversity for 13 quantitative characters under four environments. Data was analyzed sing Mahalanobi's D^2 statistic. Considerable diversity was present between the strains and up to 13 clusters were identified. An environment with high soil fertility and a late sowing expressed the most diversity.

Biwas and Sasmal (1990) studied genetic diversity in seven rice varieties and their twenty-one hybrids. The twenty-eight genotypes were grouped into six clusters. Shoot fresh weight was identified as the main factor contributing the genetic diversity.

Yadav (1994) studied 50 accessions of pearl millet (*Pennisetum glaucum*), 17 from India and 33 from seven African countries. Based on D^2 analysis, the genotypes were grouped into ten clusters. Of the 14 accessions from Ghana, all but one was grouped together in a single cluster, whereas the 17 accessions from India were spread over seven clusters. Likewise, four accessions of Nigerian origin fell into four different clusters. The results indicated that geographical diversity could not be taken as the sole criterion of genetic diversity.

Yadav (1994) evaluated fifty two pearl millet accessions of Indian and exotic origin for genetic divergence. The accessions were grouped in ten clusters. Cluster I had approximately half of all the accessions. The genotypes in cluster I were early and had higher threshing ratio and seed weight, while those in clusters IV and V showed quick early growth. The clustering pattern indicated that the geographic diversity was not necessarily related with genetic diversity. Seedling vigour, productive tillers and plant height have been identified as potent variables which can be used as parameters while selecting diverse parents for hybridization programmes.

Dave and Joshi (1995) observed no relationship between geographic and genetic divergence in pearl millet. The clustering pattern was affected by environment and the role of different characters varied with shift in season. The size of D^2 statistic had no effect on the magnitude of heterosis for the attributes studied.

Hepziba *et al.* (1995) evaluated ninety-five pearl millet genotypes (48 from India, 23 from Ghana,19 from Togo,2 from Burkhina Faso and one each from UAS,Nigeria and Mexico) for seven yield related traits. The genotypes were grouped into twenty-seven clusters using canonical and metro glyph analysis and into

twenty-six clusters via D^2 analysis with the distribution of genotypes amongst clusters being similar. There was no significant association between genetic diversity and geographic diversity. The grain yield contributed most to the genetic divergence.

Quendeba *et al.* (1995) evaluated ten and race populations, widely grown in African countries, and two experimental F_1 hybrids of pearl millet for thirteen characters. They observed that the days to flowering, plant height, stem diameter, primary spike length and grain and spike yield per plant were the major contributors to diversity among the land race populations.

Suthamathi and Dorai raj (1995) estimated genetic divergence using Mahalanobi's D^2 from data on twelve-fodder yield and six fodder quality characters in twenty-eight *Pennisetum glaucum* genotypes evaluated at Coimbatore. The genotypes were grouped into five distinct clusters. Crude protein content of the fodder contributed greatest to genetic divergence. Nine genotypes were identified for further breeding programme.

Tomar *et al.* (1995) carrier out clusters analysis of data on ten agro morphological traits in twenty-one *Pennisetum typhoides* genotypes and assigned the genotypes to four clusters, which were unrelated to geographical origin.

Berwal and Khairwal (1997) evaluated forty-two diverse accessions of pearl millet at Hissar for ten yield related traits and were grouped into nine clusters.

Hendre (1998) studied genetic diversity of seventy-five genotypes in pearl millet. The genotypes were grouped into nine clusters. Plant height, panicle width, 1000-grain weight and grain

yield were the main characters contributing to the genetic divergence.

Shanmuganathan *et al.* (2006) studied genetic variability and diversity in pearl millet with 104 germplasm accessions of different origin. Based on the D^2 analysis all the accessions were grouped into twelve clusters. Based on the relative contribution, plant height contributed more towards genetic divergence.

Lakshmana *et al.* (2010) studied one hundred and five genotypes of pearl millet representing different countries for genetic divergence analysis utilizing Mahalanobis D^2 technique. Based on the genetic distance (D^2 value), the 105 accessions were grouped into 22 clusters. Of the 22 clusters formed, cluster II was the largest with 63 genotypes followed by cluster III with 10 accessions.

4. Molecular studies

Random amplified polymorphic DNA [RAPD] analysis, a PCR based molecular marker technique, was first developed independently by Williams *et al.* [1990] and Welsh and McClelland [1990]. These markers are, as a result of PCR amplification [Saiki *et al.* 1985, 1988] of random genomic DNA segments with single primers [usually 10 nucleotide long] of arbitrary sequence. RAPD are usually dominant markers with polymorphisms between individuals defined as the presence or absence of a particular RAPD band (Stuab *et al.* 1996). Tingey and del-Tufo (1993) reported RAPD markers to be 4-6 times more efficient than screening for the same polymorphisms using RFLP technology and over 10-fold more efficient in terms of time and labour involved. RAPD overcomes many of the technical limitations of RFLP analysis. It neither requires previous knowledge of any genomic

sequence such as general PCR nor tedious procedure such as RFLP analysis. A brief review on RAPD analysis in pearl millet is presented here.

The first molecular marker-based genetic linkage map of pearl millet [*Pennisetum glaucum* (L.) R. Br.] was built with restriction fragment-length polymorphisms (RFLPs), the marker system of choice in the early 1990s (Liu *et al.* 1994).

Autunes *et al.* (1997) used the RAPD markers to distinguish 11 pearl millet (*Pennisetum glaucum* L.) cultivars. Thirty-two randomly selected oligonucleotide primers produced 158 amplification products, of which 75 were polymorphic. Amplification products were used to estimate genetic distances among the accessions. Genetic distances ranged from 9 to 76%. The accessions were clustered into three groups on the basis of their genetic distances. The results indicated the importance of knowing not only the origin, but also similarities among cultivars, to be used as parents in a breeding programme.

Chowdari *et al.* (1998a) investigated the potential of DNA markers such as microsatellites, minisatellites and RAPDs in pearl millet (*Pennisetum glaucum* L.) with respect to their abundance and variability. The clustering patterns of pearl millet cultivars and land races based on (GATA)4 and RAPD (randomly amplified polymorphic DNA) markers differed. RAPD analysis revealed a high degree of genetic diversity among the cultivars and land races employed in this study and suggested that microsatellite such as (GATA)4 and RAPDs are useful tools for genotype identification and for the assessment of genetic relationships in pearl millet.

Chowdari *et al.* (1998b) determined the genetic diversity in five cytoplasmically male-sterile and seven restorer lines of pearl

millet (*Pennisetum glaucum*) by DNA fingerprinting using a (GATA)4 microsatellite and randomly amplified polymorphic DNAs. A total of 160 polymorphic loci were generated and based on the polymorphism data, similarity index values ranged from 0.50 to 0.81. Cluster analysis was performed and relationships among these lines revealed that they were not in agreement with the available pedigree data. The *per se* performance of parents and hybrids was analysed for days to 50 percent flowering, plant height, productive tillers, ear length, ear width, 1000- grain weight and grain yield per plot. Their results indicated that genetic distance measures based on the (GATA)4, microsatellite and RAPDs may be useful for the grouping of parents, but not for predicting heterotic combinations in pearl millet.

Rao *et al.* (2001) compared RAPD analysis of genomic DNA for identification of 24 genotypes of pearl millet including seven hybrids and their A, B and R lines. Thirty-one arbitrary primers from A, B and C series of Operon kit were screened to identify suitable primers for RAPD analysis. A combination of four primers (OPA4, OPA18, OPB12 and OPB18) could differentiate all 24 genotypes. RAPD analysis could also establish hybridity of four of the hybrids. The probability of identical match by chance between two genotypes was more with RAPD analysis (6.76 x 10-13) suggesting that RAPDs were more polymorphic. A dendogram obtained with RAPDs revealed that many of the genotypes were grouped into the same cluster. There was a positive and significant correlation (r=0.44**) between the genetic distances estimated by RAPD profiles. They also advocated that RAPD technique could identify all the genotypes examined in this study, its possible uses for grant of plant variety protection and genetic purity testing.

Srivastava *et al.* (2002) performed molecular characterization of sixteen hybrids along with their parental lines. It was observed that the genetic diversity in parental lines is related to yield performance. A total of 94 amplification products were obtained in thirty genotypes with 15 primers, out of which 89% were polymorphic. The average numbers of amplification products were 6.2 with a maximum of 11 in OPD 11, OPE 19 and minimum of 3 in OPF 13 and the size of amplification product ranged form 0.3 kb to 3 kb. The Jaccard's similarity coefficient values ranged from 0.22 to 0.84 indicating high diversity in the material under investigation.

Agrama and Tuinstra (2003) applied two DNA-based fingerprinting techniques; simple sequence repeats (SSR) and random amplified polymorphic DNA (RAPD) analysis in sorghum germplasm analysis to compare suitability for quantifying genetic diversity. Twenty-two sorghum genotypes were assayed for polymorphism using 32 RAPD primers and 28 sets of sorghum SSR primers. The results indicated that SSR markers were highly polymorphic with an average of 4.5 alleles per primer. The RAPD primers were less polymorphic with nearly 40% of the fragments being monomorphic.

Budak *et al.* (2003) developed and utilized SSR markers to evaluate the degree of genetic relationship in collection of pearl millet germplasm by assessing the genetic diversity of 53 lines of pearl millet. Cluster analysis by UPGMA showed two major and eight minor clusters; average coefficient of genetic distance among germplasm lines was high with value D = 0.60 (range 0.28-0.92).

Qi *et al.* (2004) developed integrated genetic map and a new set of simple sequence repeat markers for pearl millet, *Pennisetum glaucum*. Genetic maps produced in four different

crosses have been integrated to develop a consensus map of 353 RFLP and 65 SSR markers. They have also described the generation of 44 SSR markers from a (CA)n –enriched small-insert genomic library.

Chandra Shekara *et al.* (2005) analyzed the mitochondrial DNA (mt-DNA) polymorphism among five pearl millet CMS lines and a male fertile maintainer (B) lines, all in an isonuclear background. They revealed that two RAPD primers, OPG 12 and OPG 19 in combination, were able to distinguish all the male sterile and male fertile cytoplasms. Cluster analysis, followed by bootstrap analysis of the mt DNA data set, revealed two distinct clusters: Cluster I comprising the A1, A2, A3, CMS lines and the male fertile lines, and cluster II comprising the A4 and A5 CMS lines.

Patil *et al.* (2006) revealed genetic diversity of commercial pearl millet hybrids based on RAPD markers. Primer OPD-07 gave minimum four amplicons, and maximum 12 amplicons were amplified with OPD-19 across seven varieties. The similarity index value ranged from 0.10 to 0.56 and consensus tree exhibited two distinct groups. The late and midlate maturing hybrids each formed a separate cluster whereas early maturing and drought tolerant hybrids formed another cluster. Hybrid GHB 577 was found to be most divergent.

Chandra Shekara *et al.* (2007) studied genetic diversity of elite pearl millet inbred lines using 20 RAPD and 21 SSR markers. They found that six RAPD primers *viz.,* OPD12, OPA16, OPB6, OPA19, OPB5 and OPB1 and three SSR markers *viz., Xpsmp*2208, *Xpsmp*2223 and *Xpsmp*2220, were found to be highly discriminative. The PIC value ranged from 0.28 to 0.48 for RAPD and from 0.24 to 0.60 for the SSR markers. Cluster analysis and

principal component analysis of combined data set of RAPD and SSR markers indicated moderate genetic divergence in elite pearl millet germplasm.

Yadav *et al.* (2007) developed new simple sequence repeat markers for pearl millet from the 6788 sequence retrieved database for a total sequence length of 3716878 bp; 162 sequence contained simple sequence repeats and designed primer to amplify 19 new SSR loci. When tested in Tift 23A, alleles were amplified in 11 of 19 SSR loci and eight loci failed to amplify. When fractioned on high resolution agarose gel, four of the 11 loci amplified in the test DNA.

Kapila *et al.* (2008) studied genetic diversity among 70 maintainers and two pollinators of sub-Saharan and Indian origin by using SSR markers and found sufficient diversity among the maintainer and pollinator lines. The 72 lines fell in five clusters, and the clustering pattern corroborated with their pedigree and characteristic traits.

Govindaraj *et al.,* (2009) carried out Random amplified polymorphic DNA (RAPD) analysis in 20 genotypes of pearl millet genotypes using 30 different 10-mer primers of arbitrary sequence and observed that most of the primers did not reveal any polymorphism; however 12 primers revealed scorable polymorphism between genotypes of pearl millet. The associations among the 20 genotypes were also examined with Principle components analysis (PCA) from Jaccard's similarity co-efficient and it is more informative to analyze the extreme genotypes.

Kadri Karim *et al.,* (2010) observed a high level of polymorphism with both RAPD and SSR markers and the mean polymorphism information content (PIC) values were 0.477 and 0.533 for RAPD and SSR markers, respectively in barley genotypes.

A poor correlation (r = 0.193) was found between both sets of genetic similarity data, suggesting that both sets of markers revealed unrelated estimates of genetic relationships.

2.5 Correlation of genetic distance with hybrid performance and heterosis

The relationship between GD (genetic distance) and heterosis was reported before the development of genetic markers (Moll *et al.,* 1965). Genetic distance has been used to predict hybrid performance and the efficiency of prediction was greater with cross between inbred line from the same heterotic group then cross between inbred lines from different heterotic groups (Melchinger, 1999). Linkage disequilibrium between DNA markers and genes involved in the expression of target traits is required for GD and hybrid performance to be correlated (Betran *et al.,* 2003). Genetically diverse parents are, to a certain extent more likely to give heterotic hybrids than those genetically related. From a plant breeder's viewpoint, increase over better parent (heterobeltosis) and standard variety (standard heterosis) is more relevant. It is reported that a positive correlation exists between genetic distance and heterosis.

Ghaderi *et al.* (1984) investigated the association of genetic distance and heterosis in dry edible bean (*Phaseolus vulgaris* L.) and faba bean (*Vicia faba* L.). Mahalanobis' D^2 was used to estimate genetic distance between parents. Correlations in dry beans between heterotic effects and parental distances were positive and highly significant for yield at harvest and for two of the three yield components, namely, number pods/plant and number seeds/pod. No relationship was found for 100-seed weight. A highly significant positive correlation was obtained for leaf weight. Both significantly positive and negative correlations were found in

faba beans for an array of "number" traits related to yield, but heterosis for yield of seed per se in faba beans was not associated with the Mahalanobis D^2.

Sarawat *et al.* (1993) investigated the relationship between the genetic distance of parents and both the heterosis of F_1 hybrids and the variance of F_5 lines in 72 crosses of pea (*Pisum sativum* L.). The genetic distance between each pair of parents was estimated, using isozyme (GD*i*), morphological (GD*m*) or quantitative (GD*q*) markers and finally a combination of isozyme and morphological markers (GD*i*+*m*). GD was not significantly correlated with heterosis for yield over the better or best parent but it was significantly correlated with all three measures of heterosis for pods per plant and hundred seed weight. There was no correlation between genetic distance and the level of heterosis for yield and total dry matter in the F_2 generation, but GD*i*, GD*i*+*m* and GD*q* were predictive for the level of inbreeding depression in grain yield and total dry matter.

Cerna *et al.* (1997) in soybean found that correlations of GDs revealed by RFLP analysis with MPH and HPH values on an entry-mean basis were low and not significant indicating that heterosis in yield may not be associated with genetic diversity at the molecular level as determined by RFLPs.

Dias and Kageyama (1997) calculated genetic distances among cacao cultivars through multivariate analysis, using the D^2 and found that genetic distance of parents by D^2 was to be linearly related to average performance of hybrids for wet seed weight per plant and per fruit.

Maroof *et al.* (1997) studied the relationship between molecular marker polymorphism of the parents and performance of

the F_1 hybrids in rice. Marker F1 heterozygosity was highly correlated with rough rice yield (0.79**) and head rice yield (0.82**), and was also significantly correlated with heterosis of these two traits (0.47*, 0.58**, respectively).

Fabrizius *et al.* (1998) observed that genetic diversity between parents may contribute positively to both heterosis and transgressive segregation. No linear relationship between genetic distance and F_2 bulk heterosis was detected. However, when crosses were divided into related and unrelated groups, crosses with parents unrelated by pedigree or morphology expressed greater heterosis than crosses with related parents.

Sant *et al.* (1999) used molecular markers such as RAPDs and microsatellites to study genetic diversity in 29 elite Indian chickpea genotypes. The F_1s and their parents in the diallel set were analysed for agronomic traits for better parent and midparent heterosis. The study indicated that although molecular marker-based genetic distance did not linearly correlate to heterosis, two heterotic groups could be identified on the basis of the molecular marker heterozygosity.

Cheres *et al.* (2000) estimated correlations between genetic distance, heterosis, and hybrid performance for seed yield in sunflower. Genetic distances were significantly correlated with hybrid seed yield when estimated from AFLP fingerprints (*G* D- genetic distance) (r = 0.63 for A × R and 0.79 for A × B hybrids), but not from co ancestries (*G* C- genetic co ancestries) (r = -0.02 for A × R and 0.54 for A × B hybrids). *G* D (R 2 = 0.4) was a poor predictor of hybrid seed yield.

Betran *et al.* (2003) studied (i) heterosis and specific combining ability (SCA) for grain yield under stress and non-stress

environments; (ii) genetic diversity for restriction fragment length polymorphisms (RFLPs) within a set of tropical lines; (iii) GD and classify the lines according to their GD; and (iv) correlation between the GD and hybrid performance, heterosis, and SCA in tropical maize. Positive correlation was found between GD and F_1 performance, sca, midparent heterosis (MPH) and high-parent heterosis (HPH). Specific combining ability had the strongest correlation with GD.

Dias *et al.* (2003) assessed the genetic distance among five clones of cacao with RAPD data (GD) and with yield component data (Mahalanobis -MD). Both distances were related to heterotic performance of hybrids for wet seed weight/plant and wet seed weight/fruit. The average hybrid performance for the same two yield components was correlated with only MD. Hence, genetic distances measured by RAPD and yield components can be used as a guide to the choice of the superior crosses.

Riday *et al.* (2003) calculated genetic distances among nine sativa and five falcata genotypes based on amplified fragment length polymorphism (AFLP) and simple sequence repeat (SSR) DNA markers. Genetic distance did not correlate with specific combining ability (sca) or mid-parent heterosis. In contrast, a morphological distance matrix based on seventeen agronomic and forage quality traits was significantly correlated with heterosis; the agronomic traits of maturity, midseason regrowth, and autumn regrowth showed strong association with heterosis. Heterosis was also correlated with subspecies.

Dias *et al.* (2004) focused on *a priori* choice based on parental distances by means of agronomic and molecular data. A total of 139 articles on genetic divergence were sampled to examine aspects such as type and number of markers utilized which

suggested that the mean number of 160, 281 and 25 for RAPD and RFLP markers, and SSR loci, respectively found in these papers, should be increased for accurate analysis. A second sample composed of 54 articles was used to evaluate the divergence-heterosis association. Most of them (28) detected positive divergence-heterosis association, whereas 26 revealed negative or inconclusive results.

Góral *et al.* (2005) measured phenotypic diversity for eight agronomic traits in 10 parents and 27 F_1 hybrids of winter triticale. Genotypic diversity was measured by 91 AFLP markers. Coefficients of correlation of genetic similarity (AFLP-GS) with both Euclidean distances and mean values of the traits were generally not significant. A correction of the preliminary binary matrix into trait-specific derived matrices increased the values of five correlation coefficients to a significant level. The correlation of AFLP-GS with mid-parent heterosis of grain weight per plant was low but significant (r = –0.452). Study confirmed the effectiveness of marker preselection for obtaining AFLP-GS better correlated with heterosis.

Shahnejat-Bhshehari *et al.*, (2005) surveyed the genetic divergence among 12 genotypes of barley using seven primers of a 10-mer arbitrary sequence. Experimental results showed that the 12 barley genotypes were divided into several groups. Although the genetic distance based on RAPD markers has not been significantly correlated with hybrid performance and heterosis in all of the traits, the genetic distance was used to predict hybrid performance with mixed results. It appears to be impossible to predict the hybrid performance from the genetic distance itself. Comparisons of genetic and morphological distance were studied with RAPD and

morphometric approaches and results showed that there was not significant correlation between them.

Pradhan *et al.* (2007) studied genetic diversity among basmati lines including maintainers of sterile lines utilizing Mahalanobis D^2 statistic. A wide diversity was observed having ten clusters with high intra- and inter-cluster distance. Heterosis was estimated utilizing the cytoplasmic male sterile lines from the clusters having high intra- and inter-cluster distance. And positive association of intra-cluster distance with heterosis was observed.

Immanuel Selvaraj *et al.*, (2010) examined 20 parents along with the other six rice varieties for DNA polymorphism using 53 random decamer oligonucleotide primers of which 36 primers generated clear banding profiles. Heterosis was observed in hybrids for most of the traits and yield exhibited the highest heterosis among the nine traits examined. The correlation values of GDs with F_1 performance were mostly non-significant, except for days to 50% flowering and test weight. The correlations of GDs with mid parent, better-parent heterosis and standard heterosis were not significant enough to be of predictive value. However, when specific combining ability (sca) value was correlated with GD values of a group of hybrid (BPT 5204), there was high significance pertaining to a particular hybrid with relatively higher yield. These results indicated that GDs based on the random amplified polymorphic DNA (RAPD) markers may be useful for predicting heterotic combinations in rice and support the idea that the level of correlation between hybrid performance and genetic divergence is dependent on the germplasm used.

3. MATERIALS AND METHODS

The present investigation on "Genetic studies and molecular analysis for forage yield in Pearl millet [*Pennisetum glaucum* (L.) R Br.]" was conducted during Kharif 2008 and Summer 2009 at All India Coordinated Research Project on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri. The details of the materials used and the methods adopted during the course of study are given below.

3.1 Experimental Material

The experimental material for this study comprised of 8 forage genotypes obtained from Forage Breeder, All India Coordinated Research Project on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri. The details of theses genotypes is given below

S.N.	Genotype	Pedigree	Salient features
1	Giant Bajra	Australian bajra x Dhule local	Tall, profuse tillering, high palatable, high protein content (9-11 %) at flowering, high green fodder yield in kharif and summer seasons.
2	PMFT-904	K 96768 x96795	Early, mid-tall, profuse tillering, bold grains
3	PMFT-905	K 96752 x 96382	Late, midtall, long ear head & girth, bold grain, downy mildew resistant.
4	PMFT-907	S 98-2087 x 1190	Early, mid tall, profuse tillering.
5	RHRB-259	(1630 x 628) x 1630	Early, dwarf, profuse synchronous tillering, downy mildew resistant.
6	RHRB-260	K 94412 x 708-2	Early, Mid tall, stay green, more leaf: stem ratio, synchronous tillering, downy mildew resistant.
7	RHRB-282	S 1630 x 885	Tall, more leaf length and width, long ear head, stay green.
8	RHRB-278	S 8681 x AMPCI-6ER	Late, Tall, profuse tillering, more leaf length and width, stay green.

These parental lines were grown during summer, 2008 at All India Coordinated Research Project on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri. Parents were crossed in diallel fashion to obtain F_1's excluding reciprocals. Sufficient quantity of seed for 28 cross combinations was obtained.

Thus, the experimental material, consisting 36 entries including 8 parents and 28 crosses was evaluated during Kharif, 2008 and summer, 2009.

3.2 Methods

3.2.1 Experimental details

The details of field experiments were as follow

Seasons	: Kharif, 2008 and Summer, 2009
Location	: All India Coordinated Research Project on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri
Treatments	: 36 (28 F_1S+ 8 parents)
Design	: RBD
Replication	: Three
Plot size	: Gross: Two row of 3 m length
	: Net: Two row of 2.80 m length
Spacing	: 30 x 10 cm
Fertilizers applied	: 40 kg N + 40 kg P2O5 kg/ha , at sowing
	40 kg N at 30 DAS
Date of sowing (s)	: Kharif, 2008 - 11.07.2008
	: Summer, 2009 - 16.02.2009
Harvesting	: At 50 % flowering of respective entry

Normal agronomic practices were adopted to raise the crop. The weather parameters for the cropping season are presented in Appendix A.

3.2.2 Procedure of recording the experimental data

Fifteen competitive plants of each genotype / replication / environment were randomly selected for the purpose of recording observations of following different morphological, yield and quality characters and their averages were used in the statistical analysis.

3.2.2.1 Morphological and yield characters

1. Days to 50 per cent flowering

The number of days required for emergence of stigma on the earhead of the main shoot of 50 per cent plants per plot was noted.

2. Plant height (cm)

Length of the plant from soil to the tip of the ear head of the main tiller was measured in cm and average plant height was computed.

3. Number of tillers/plant

The total number of tillers per plant was recorded at 50 % flowering stage of entry i.e. at harvest.

4. Number of leaves/plant

The number of leaves on main tiller for fifteen selected plants were recorded and average was reported as number of leaves per plant.

5. Leaf length (cm)

Length of leaf blade from its base to the tip of fifth leaf observational plants was recorded in cm and average leaf length was reported.

6. Leaf breadth (cm)

Breadth of the fifth leaf blade of observational plants at its widest point was measured in cm and average leaf breath was reported.

7. Leaf area per plant (cm^2)

Leaf area was measured as the product of the length and maximum width. Leaves obtained from fifteen randomly selected observational plants from each entry were collected and area of each was measured using the formula suggested by Singh (1970)

Leaf area= Leaf length (cm) x leaf breadth (cm) x 0.72

8. Leaf weight (g)

Fresh leaves weight of fifteen observational plants was recorded separately in gram at harvesting and average leaf weight was reported.

9. Stem weight (g)

Fresh stem weight of fifteen observational plants was recorded separately in gram at harvesting and average stem weight was reported.

10. Leaf: Stem ratio

Weight of leaves divided by weight of stem was recorded as leaf: stem ratio.

11. Green fodder yield (q/ha)

The total plants in net plot per replication were cut at 50 % flowering stage and total green fodder yield was recorded in kilogram. Then this per plot yield was converted into q/ha by multiplying hectare factor.

12. Dry matter yield (q/ha)

250 g green fodder sample of each entry from each replication was taken, chaffed and mixed thoroughly. The sample was dried in an electric oven at 65 ± 5 ^{0}c for 72 hrs. After drying, dry weight per entry was recorded in gram by using an electronic balance and dry matter percent was recorded. Dry matter yield (q/ha) was estimated as follows.

Dry matter yield (q/ha) = Green fodder yield (q/ha) x Dry matter (%)

3.2.2.2 Quality characters

1. Crude Protein

Nitrogen content was determined by Kjeldahl method (A.O.A.C., 1995).

The dried plant sample was grind into powder form and 0.2 g sample was taken in Micro-Kjeldhal flask. Then 5 ml concentrated sulphuric acid + 5 ml hydrogen peroxide (30%) +1.0 g digestion mixture was added to it. This Kjeldahl flask was kept in digestic heater. The flask was heated gently first and then to more strongly till the solution in the flask become clear. Then the content of the flask was transferred to 50 ml volumetric flask and the volume was made upto 50 ml. The distillation was carried out in Micro-Kjeldahl system (KELPLUS) by taking an aliquots (10 ml) of the diluted sample in distillation tube. 10 ml of 40% NaOH solution was automatically added to the tube. After this steam was allowed to pass through the solution and distillate was collected in 20 ml of 2% boric acid solution in conical flask with the tube of condenser immersed in boric acid solution. 50 ml of distillate was collected. The content of the flask was titrate with standard 0.02N H_2SO_4 upto the end point when colour was changed from blue to pink.

N (%) = BR x 0.02 N H_2SO_4 x 0.014 x 50/10 x 100/ sample (g)

Crude protein (%)= Nitrogen % x 6.25

2. Crude fibre (CF %)

The dried fodder was analyzed for crude fibre content (AOAC, 1995).

2.0 g of the dried sample was refluxed first with 200 ml 1.25 percent sodium hydroxide solution for 30 minutes and subsequently with 200 ml 1.25 percent H_2SO_4 for another 3 minutes to dissolve alkali soluble carbohydrates, minerals and proteins. The residue was dried and its weight was recorded. The dried residue was ignited in muffle furnace and the weight of ash was recorded. Crude fibre was calculated as under

$$\text{Crude Fibre (CF \%)} = \frac{\text{Weight of dried residue-weight of ash}}{\text{Weight of dried sample (g)}} \times 100$$

3.Acid detergent fibre (ADF %)

Acid detergent solution was prepared by taking following composition (AOAC, 1995).

Reagent:

1. Sulphuric acid 1 N = 27.2 ml per litre of distilled water
2. Cetyl trimethyl ammonium bromide (CTAB) = 20g + 1 litre of 1N H_2SO_4.
3. Acetone

Procedure

One gram of sample was taken in a conical flask and 100ml of ADF reagent was added. The contents were boiled for one hour and filtered. The residue was washed with hot distilled

water and then with acetone. The residue was placed in the china dish and dried at 100^{0}C for 8 hours. Weight of the residue was recorded and ADF percentage was worked out by the formula

$$\text{ADF (\%)} = \frac{\text{Weight of residue}}{\text{Weight of dried sample (g)}} \times 100$$

4. Neutral detergent fibre (NDF %)

Neutral detergent solution was prepared by taking following composition (AOAC, 1995).

Reagents:

Sodium luryl sulphate	= 30.00 g
EDTA (Disodium dihydrogen)	= 18.61 g
Sodium borate	= 06.81 g
Disodium hydrogen phosphate	= 05.72 g
2-ethoxy ethanol	=10.00 ml

Procedure:

One gram of sample was taken in a conical flask and 100ml NDF solution and 0.5 g Sodium sulphite (NA_2SO_4) was added. The contents were boiled for one hour, cooled and filtered. The residue was washed 5-6 times with hot distilled water at 80^{0}C and then with acetone. The residue was oven dried at 100^{0}C for 8 hour. Weight of the residue was recorded after cooling and NDF percentage was worked out by the formula

$$\text{NDF (\%)} = \frac{\text{Weight of residue}}{\text{Weight of dried sample}} \times 100$$

5. Oxalic acid determination:-

Oxalic acid content of the dried sample was estimated according to the method given by Abaza *et al.* (1968). The detailed procedure was as under:

Reagents

1. HCL (6N)
2. Methyl red indicator
3. Calcium chloride 5% (w/v)
4. Sulphuric acid (1:4)
5. $KMNO_4$ (0.05N)
6. Liquier Ammonia
7. Filter paper (Whatman No.41)

Procedure

1. 2 g of sample of each entry from each replication was taken separately in 250 ml volumetric flasks and 190 ml of water and 10 ml of 6 N HCl was added and digested for 1 hour on boiling water bath. Allowed cooling, diluted and made volume and filterered the supernatant.
2. 50 ml of filtrate was taken in a beaker and 20 ml of 6 N HCl was added. The mixture was evaporated to about half of its volume and then washed and filtered the volume about 125 ml.
3. 3-4 drops of methyl red indicator was added to the filtrate followed by concentrated ammonia (step 2) till the solution turned faint yellow and then heated to 90-100^{0}C, cooled and filtered (Whatman No.1) for removing the precipitated ferrous impurities.

4. The filtrate was boiled and 10 ml of 5 per cent $CaCl_2$ was added with constant stirring and kept overnight (step 3).
5. Filtered through filter paper (Whatman No.41), washed the precipitate 4 times with hot water to make it free of calcium ions.
6. The precipitate was transferred to the original beaker by washing with distilled water and then sulphuric acid solution (1:4) was added till the precipitate was completely dissolved.
7. The content was warmed (70^0C) and titrated against 0.05N $KMnO_4$ to the end point (Given the colour change) and then the filter paper was added to the contents, stirred it thoroughly and completed the titration.

Oxalic acid (%) =0.05N $KMnO_4$ used (ml) X 0.0025 X250/50 X 100/ weight of sample (g)

6. In Vitro dry matter digestibility (IVDMD)

a. Rumen liquor sampling

The well mixed samples of rumen liquor were directly collected from goat rumen in one litre bottle covered with dark cloth and immediately taken to laboratory. The rumen liquor was strained through four layer muslin cloth. This strained rumen liquor (SRL) was used for *in vitro* study.

b. Composition of McDougall's buffer solution (Artificial saliva)

The McDougall's buffer solution was prepared with following ingredients.

Sr.No.	Chemical	g/lit
1.	Na_2CO_3	9.80
2.	Na_2HPO_4	3.39
3.	KCl	0.57
4.	NaCl	0.47
5.	$CaCl_2$	0.04
6.	$MgSO_4$	0.12

All ingredients, except $CaCl_2$ were weighed, mixed and dissolved in 1 litre glass distilled water. $CaCl_2$ was added just before using the solution. The pH of the buffer solution was adjusted to 6.7 ± 0.1 as suggested by Baumgardt *et al.* (1962).

c. Experimental procedure

The *in vitro* techniques recommended by Baumgardt *et al.* (1962), Tilley and Terry (1963) and Van Soest *et al. (*1971) was followed in the present investigations.

One gram test sample from each treatment was taken separately in 150 ml Erlenmeyer flasks containing 40 ml artificial saliva. Ten ml SRL was added to each flask and immediately flushed with carbon-dioxide gas for 30 seconds to create anaerobic condition and closed tightly with rubber cork fitted with Bunsen gas release valve. The sample was incubated at 39^0C temperature for 48 hours. Simultaneously two blank flasks with 40 ml artificial salvia and 10 ml SRL were also incubated along with the test sample. At the end of the incubation, 2 ml of 6N HCl was added to each Erlenmeyer flask.

The content in the flasks were transferred to centrifuge tubes and centrifuged at 1500 rpm for 15 minutes. The supernatant was discarded and insoluble solid portion was washed with water and transferred to preweighed 100 ml beaker. The

beaker containing undigested feed residues was dried into oven to constant weight and final weight was recorded.

DM disappearance= Wt. of sample- [Wt. of residue of test- Wt. of residue of blank]

$$\text{DM Digestibility (\%)} = \frac{\text{DM disappearance}}{\text{Wt of sample}} \times 100$$

3.2.2.3 Molecular observations:-

DNA extraction

Reagents/chemicals

a) Extraction Buffer: (Formulation of 100 ml)

Stock solution	**Required as per protocol**	**Working for 100 ml**
CTAB 10 %	2 %	20 ml
Tris HCL pH 8 (1 M)	100 mM	10 ml
EDTA (0.5 M)	5 mM	10 ml
NaCl (5 M)	1.4M	28 ml
β-Mercaptoethanol (1.0 %)	(1.0 % v/v)	1 ml
PVP (1 %)	(1.0 % v/v)	10 ml
Sterile distilled water		21 ml

b) Chloroform

c) Isoamyl alcohol

d) Ethanol (Absolute)

e) Liquid nitrogen

Procedure

Plant material

The seeds of eight pearl millet parental lines were aseptically germinated at 30°C for 7 days. The tissue used is fresh leaves.

DNA isolation protocol

Total DNA was extracted from the leaves by Cetyl trimethyl ammonium bromide (CTAB) method (Zidani *et al.* 2005) with some modifications. A 0.3 g of leaf sample of each genotype was ground in liquid nitrogen using a mortar and pestle. The pulverized leaves were quickly transferred to liquid nitrogen. 2% of CTAB buffer (1 ml) containing 1% (v/v) mercaptoethanol and 1% PVP was quickly added to the micro centrifuge tube (2 ml) and stirred with a glass to mix. The tube was incubated at 60°C for 30 min with frequent swirling. An equal volume of chloroform: isoamylalcohol (24:1) was added and centrifuged at 10 000 rpm and 4°C for 15 min to separate the phases. The supernatant was carefully decanted and transferred to a new tube. The above steps, beginning with the addition of chloroform: isoamylalcohol (24:1) and ending with decanting of supernatant, were repeated twice. The supernatant was precipitated with 2/3 volume of ethanol. The precipitated nucleic acids were collected and washed twice with the buffer (75% ethanol, 3 M sodium acetate, TE). The pellets were air dried and resuspended in TE. The dissolved nucleic acids were brought to 1.4 M NaCl and reprecipitated using 2 volumes of 75%. The pellets were washed twice using 100% ethanol, dried and re-suspended in 100 µl of TE buffer. The pellet was not allowed to dry excessively. The tube was incubated at 37°C for 30 min to dissolve genomic DNA, and RNase was then added. DNA concentration was determined using a UV spectrophotometer at 260 mm and 280mm (Sambrook *et al.*, 1989).

Randomly Amplified Polymorphic DNA (RAPD):

Chemicals:

a) PCR buffer (10 x)

b) Primers

c) d NTPs (2.5 mM) Banglore genei, India.

d) Taq DNA polymerase

The genomic DNA as amplified using random primers of OPA, OPC and OPE series. PCR reactions for RAPD were carried out in a reaction volume of 25 µl .

The PCR mix consisted of:

PCR buffer (10 x)	2.5 µl
25 mM $MgCl_2$	2.5 µl
Primer (10 p moles/ml)	5.0 µl
dNTPs mix (2.5 mM each)	2.0 µl
Taq DNA polymerase (3U/µl)	0.3 µl
Template DNA	3.0 µl
Sterile distilled water	9.7 µl

All the PCR reactions were carried out in 200 µl thin walled PCR tubes. PCR tubes containing reaction mixture were tapped gently. The amplification carried out in eppendorf master cycle (PCR) and subjected to following DNA Protocol:

PCR conditions for (RAPD) thermo cycle:-

	Step	**Temperature (ºC)**	**Duration**
1	Initial Denaturation	95	5 min.
2	Denaturation	94	1 min.
3	Annealing	37	1 min.
4	Extension	72	1 min.
		(45 times to step 2)	
5	Final extension	72	5 min.
6	Hold	4	3 min.

Agarose gel electrophoresis:

Agarose (low EEO type)

10 x Tris Borate EDTA (TBE) buffer pH 8.0

10 mM Tris – HCL

1 mM EDTA

55 gm Boric acid

Gel loading dye (6x)

Ethidium bromide (1 mg/ml)

100bp DNA ladder (Banglore Genie, India)

All the PCR products were run on 1.2% agarose gel containing 5 µl of ethidium bromide (1 mg/ml). 25 µl of PCR product was mixed with 4 µl of 6x tracking dye and loaded onto the well. The gel was run at 60 V (Constant) to separate the amplified bands. The standard DNA marker (100 bp) was also run along with the samples. The separated bands were seen under UV and photographed by Gel documentation system and analyzed by Gene tool.

Bands sharing and similarity index:

The presence or absence of band in RAPD patterns scored as one or zero respectively were used to estimate bands sharing between the genotypes. The genetic similarity estimates between each pair of inbred lines were obtained using Dice similarity coefficients (Nei and Lu, 1979).

$$(GS) = a/ (b+c),$$

Where

a = Number of bands present in both parents,

b = Number of bands present in first parent and

c= Number of bands present in the second parent.

Genetic distance between pair of inbred lines were estimated as

$$GD = 1-GS.$$

Dendrograms:

A dendrogram was constructed based on similarity coefficient using the marker data for eight parental lines of pearl millet following the unweighted paired group method with arithmetic averages (UPGMA), using NTSYS-pc version 2.02 (Sokal and Michener, 1958).

3.3 Statistical analysis

The following calculations were made using average of fifteen plants of each genotype / replication in both the environments.

1. The analysis of variance for experimental design (Fisher,1950)
2. Estimation of relative heterosis and heterobeltiosis (Fonesca and Patterson, 1968)
3. Analysis of variance for combining ability in individual environment (Griffing, 1956)
4. Pooled analysis of variance for combining ability (Singh,1979).
5. D^2 analysis of parents (Rao,1952)
6. Estimation of similarity index, polymorphism percentage and RAPD-dendrogram among the parental lines and selected hybrids.
7. Correlation between genetic distance and F_1 mean, Mid parent value (MP), specific combining ability effects (sca), mid parent heterosis (MBP) and better parent heterosis (BPH) for forage yield and yield contributing characters.

3.3.1 Analysis of variance for experimental design

The analysis of variance was performed to test the significance of differences between the treatments (progenies) for all the characters under study separately for individual environment (Fisher, 1950).

$Y_{ijk} = \mu + g_{ij} + r_k + e_{ijk}$

Where,

Y_{ijk} = Phenotypic performance of ij^{th} genotype in k^{th} replication.

μ = General mean

g_{ij} = The effect of ij^{th} phenotype

r_k = The effect of k^{th} replication

e_{ijk} = The environmental effect

The analysis of variance based on this model is as under

ANOVA

Sources of variation	**d.f.**	**Sum of squares**	**Mean sum of squares**	
			Observed	**Expected**
Replications	[r-1]	SS_r	M_1	$\sigma^2e + \sigma^2r$
Genotypes	[g-1]	SS_g	M_2	$\sigma^2e + r\sigma^2g$
Parents	[p-1]	SS_p	M_3	-
Hybrids	[h-1]	SS_h	M_4	-
Parents *vs.* Hybrids	1	$SS_{p/h}$	M_5	-
Error	[r-1][g-1]	SS_e	M_e	σ^2e

Where, r = Number of replications

g = Number of genotypes

p = Number of parents

h = Number of hybrids

The mean squares were tested against error variance (Me) by usual 'F' test. The standard error for comparing any two progenies means was estimated by the formula.

SE (diff.) $= (2M_e/r)^{½}$

The critical difference was computed by multiplying the standard error of difference with table 't' value for (r-1) (g-1) error degrees of freedom at 5 and 1 per cent level of significance.

The orthogonal partitioning of the analysis of variance was done as below:-Pooled analysis of variance over the two seasons was also done to test the interaction of treatments and sub-divisions with environments.

The sum of squares for genotypes and its sub divisions were obtained as usual and their interaction sum of squares were worked out using two-way tables. The mean sum of squares due to treatments and its sub-divisions were tested against their respective interaction mean squares where interaction was significant. The structure of analysis of variance table is given below

Sources of variation	**d.f.**	**MS**
Environments	[e-1]	M_1
Replication in environments	e[r-1]	M_2
Parents (P)	[p-1]	M_3
Hybrids (H)	[h-1]	M_4
Parents *vs.* Hybrids	1	M_5
Parents x Environments	[p-1] [e-1]	M_6
Hybrids x Environments	[e-1][h-1]	M_7
(Parents *vs.* Hybrids) x Environments	[e-1]	M_8
Pooled error	e[r-1[[t-1]	M_9

3.3.2 Estimation of Heterosis

Heterosis is the superiority of F_1 hybrid over both the parents in terms of yield or some other characters and is expressed as per cent. In the present investigation heterosis has been estimated over mid parent (Average/Relative heterosis) and better parent (heterobeltiosis) as per Fonesca and Patterson (1968).

a. Average heterosis (H_1) $= \dfrac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$

Where,

$$\overline{MP} = \frac{\overline{P1} + \overline{P2}}{2}$$

F_1= Mean performance of F_1

P_1= Mean performance of parent 1

P_2= Mean performance of parent 2

MP= Mean performance of both the parents

b. Heterobeltiosis (H_2) $= \dfrac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$

F1= Mean performance of F_1

BP1= Mean performance of better parent

Standard error of differences of heterosis effect was calculated by the following formulae.

SE (diff.) H_1 $= (3M_e/2r)^{½}$

SE (diff.) H_2 $= (2M_e/r)^{½}$

Where,

Me - Error mean square

r - Number of replications

The critical difference was calculated by multiplying the standard error difference with respective table 't' value for error degree of freedom at 5 and 1 per cent level of significance.

To work out heterosis over mid parent and better parent (heterobeltiosis) over the environments following formula were used:

$$\text{Average heterosis } (H_1\ \%) = \frac{\overline{F_1}' - \overline{MP}'}{\overline{MP}'} \times 100$$

$$\text{Heterobeltiosis } (H_2\ \%) = \frac{\overline{F_1}' - \overline{BP}'}{\overline{BP}'} \times 100$$

Where,

$\overline{F_1}'$ = Average performance of a hybrid over locations

MP' = Mid parent value involved in a cross after averaging over locations and replications

$\overline{BP}'$ = Better parent value involved in a cross after averaging over locations and replications

The test of significance was done by standard usual 't' test for over environments.

3.3.3 Analysis of variance for combining ability an individual environment

The combining ability analysis was carried out according to following Method II and Model I suggested by Griffing (1956). The mathematical model for combining ability analysis assumed as followed

$Y_{ij} = \mu + g_i + g_j + s_{ij} + r_k + \in_{ijk}$

ij = 1,....., p

k = 1,.....,r

Where,

μ = General mean

r = Number of replications

p = Number of parents

$g_i(g_j)$ = gca effect of i(j)th parent

S_{ij} = Sca cross between ith and jth parents

$\in_{ijk}$ = Mean error effects associated with I, j and kth observation

The restriction imposed to the model are:

$\sum_i g_i = 0$ and

$\sum_i S_{ij} \# S_{ij} = 0$ (for each i)

On the basis of this model, the analysis of variance and exploitation of mean sum of squares was set up as under.

ANOVA for combining ability

Source	**d.f.**	**S.S**	**Mean squares**	
			Observed	**Expected**
gca	(p-1)	Sg	Mg	$\sigma^2 e + \frac{n+2}{n-1} \sum_i \sigma^2 g_i$
sca	p(p-1)/2	Ss	Ms	$\sigma^2 e + \frac{2}{n(n-1)} \sum_{i<j} \sigma^2 s_{ij}$
Error	M	SE	Me	$\sigma^2 e$

Where,

P = Number of parents

M = (r-1) (g-1)

Me = Error mean squares

The sum of squares were calculated as:

$$S_g = \frac{1}{P+2} \left[\sum (X_{i.}+X_{ii})^2 - 4/p \times X^2..\right]$$

$$S_s = \sum_{i \leq j} \sum X_{ij}^2 - \frac{1}{P+2} \sum (X_{i.}+X_{ij})^2 + \frac{2}{(P+1)(P+2)} \times X^2....$$

Where,

S_g = S. S. due to gca

S_s = S. S. due to sca

P = Number of parents

X_i = Total of assay involving i^{th} parent

X_{ij} = Mean value of ij^{th} cross

X = Total number of combination

n = Difference for error mean square

The mean sum of square for gca and sca were computed by dividing sum of squares with respective degree of freedom.

The following 'F' ratios were used for testing the significance of gca and sca effects.

1. To test the significance of gca

$$F\left[(P-1),\ m\right] = Mg/Me$$

2. To test the significance of sca

$$F\left[\frac{P(P-1)}{2}, m\right] = Ms/Me$$

3.3.3.1 Estimates of general and specific combining ability effects

The individual effects were estimated as follows.

1. Population mean $\hat{\mu} = \frac{2}{P(P-1)} \times X....$

2. General Combining ability effect

$$\hat{g}_i = \frac{1}{P+2} [\sum (X_{i.}+X_{ii})\ 2/P \times X..]$$

3. Special combining ability effect

$$\hat{S}_{ij} = X_{ij} \frac{1}{P+2} [X_{i.}+X_{ii}+X_{j.}+X_{ij.}) + \frac{2}{(P+1)(P+2)} \times X...$$

3.3.3.2 Standard error for estimates

Standard error of effect was calculated as a square root of the variance of the effect. The variance of various effects were calculated as follows.

$$\text{SE for gca effects } (\hat{g}i) = \left[\frac{(P-1)}{P(P+2)} \times \hat{\sigma}^2\right]^{1/2}$$

$$\text{SE for sca effects } (\hat{S}ij) = \left[\frac{P2+P+2}{(P+1)(P+2)} \times \hat{\sigma}^2\right]^{1/2} \quad (i\#1)$$

Where,

P = Number of parents, $\sigma^2 = M'_e$

3.3.3.3 Standard error of difference between two effects

Standard error of difference between two effects was taken as a square root of the variance of the two estimates. The variance for difference between two estimates was computed as :

$$\text{SE for } (\hat{g}_i - \hat{g}_j) = \left(\frac{2}{(P+2)} \times \hat{\sigma}^2 \right)^{1/2} \qquad (i \# 1)$$

$$\text{SE for } (\hat{S}_{ij} - \hat{S}_{jk}) = \left(\frac{2(P+1)}{(P+2)} \times \hat{\sigma}^2 \right)^{1/2} \qquad (i \# j, k; j \# k)$$

$$\text{SE for } (\hat{S}_{ij} - \hat{S}_{kl}) = \left(\frac{2P}{(P+2)} \times \hat{\sigma}^2 \right)^{1/2} \qquad (i \# j, k, i; j \# k, l; k \# l)$$

3.3.4 Analysis of variance for combining ability over environments

In order to have information concerning the influence of genotype-environment interactions on combining ability estimates, pooled analysis of combining ability over the environments was conducted. The statistical model in this case would be as follows :

$$Y_{ijkl} = \mu + g_{i.} + g_j + S_{ij} + E_l + r_{kl} + (GE)_{i.l} + (GE)_{.jl} + (SE)_{ijl} + e_{ijkl}$$

ij = 1,....., p

k = 1,.....,r

l = 1, ..., e (Environments)

Where,

μ = General mean

r = Number of replications

p = Number of parents

$g_i(g_j)$ = gca effect of i(j)th parent

S_{ij} = sca cross between i^{th} and j^{th} parents

$\in_{ijk}$ = Mean error effects associated with I, j and k^{th} observation

The term,

Y_{ijkl} = The value of l^{th} environment in k^{th} replication of progeny of the cross between $i(j)^{th}$ parent

μ = An effect common to all hybrids over the replication

$g_i(g_j)$ = An effect common to all progenies of the $i(j)^{th}$ parent

S_{ij} = An effect specific to the progenies of the i^{th} and j^{th} parents

E_l = The average effect of l^{th} environment

r_{kl} = The effect of k^{th} replication effect over the environment

$(GE)_{i.l}$ = Interaction effect of i^{th} parent with l^{th} environment

$(GE)_{.jl}$ = Interaction effect of j^{th} parent with l^{th} environment

$(SE)_{ijl}$ = Interaction effect of hybrid of i^{th} and j^{th} parents with l^{th} environment

e_{ijkl} =Uncontrolled variation associated in the l^{th} environment in the k^{th} replication with progenies of i^{th} and j^{th} parents and assumed to be homogeneous for all the genotypes and all environments.

The structure of ANOVA used for the estimation of general and specific combining ability variance components and their interaction with environments for various characters is given as below:

ANOVA for method 2, model I over environments (Singh, 1973b, 1979)

Source	**df**	**SS**	**MS**	**EMS**
GCA (G)	(p-1)	SS_g	M_g	$\sigma^2 + \frac{(p+2)l}{(p-1)} \sum_i g_i^2$
SCA (S)	$\frac{p(p-1)}{2}$	SS_s	M_s	$\sigma^2 + \frac{2l}{p(p-1)} \sum_{i \le j} \sum s^2_{ij}$
Environments (L)	(l-1)	SS_l	M_l	$\sigma^2 + \frac{p(p+1)}{2(l-1)} \sum_k l_k^2$
G x L	(p-l)(l-1)	SS_{gl}	M_{gl}	$\sigma^2 + \frac{P+2}{(p-1)(l-1)} \sum_k \sum_i (gl)^2_{ik}$
S X L	p (p-l)\2 (l-1)	SS_{sl}	M_{sl}	$\sigma^2 + \frac{2}{p(p-1)(l-1)} \sum_k \sum_{i \le j} \sum (sl)^2_{ijk}$
Error l	(v-1) (r-1)*		Me'	σ^2

Where, v= p(p+1)/2

Various sums of squares are calculated as shown below.

$$SS_g = \frac{1}{(p+2)l} \sum_i (X_{i..} + X_{ii.})^2 - \frac{4X^2}{p(p+2)l}$$

$$SS_s = \frac{1}{l} \sum_{i \le j} \sum x^2_{ij} - \frac{1}{(p+2)l} \sum_i (Xi.. + xii.)^2 + \frac{2\,\Psi^2_{...}}{(\pi+1)(\pi+2)\lambda}$$

$$SS_l = \frac{2\sum_k X^2_{..k}}{p(p+1)} - \frac{2X^2_{...}}{p(p+1)l}$$

$$SS_{gl} = \frac{1}{(p+2)}\sum_k\sum_i (X_{i.k}+x_{i.i.k})^2 + \frac{4\sum_k X^2_{..k}}{p(p+2)} - \frac{1}{(p+2)l}\sum_i (x_{i.}+x_{il..})^2 + \frac{4X^2_{...}}{p(p+2)l}$$

In this expression $\sum_K\sum_i (X_{i.k}+x_{iik})^2$ is the sum over environments of the

item $\sum_i (X_{i.}+x_{ii})^2$, and $4\sum X^2_{..k}\backslash p(p+2)$ is sum of items $4X^2_{..}\backslash p(p+2)$ over environments

As shown by Singh (1979) sums of squares for interaction of g.c.a or s.c.a.effects with environments could be obtained as:

$$SS\,(A_{x\,l}) = \sum_{l=1}^{k} SS_l\,(A) - SS(A),$$

where SS(A) is the sums of squares for factor A (in this case either g.c.a or s.c.a) calculated from the total of means over k environments and

$\sum_{l=1}^{k} SS_l(A)$ is the total of sums of squares of A factor at each of the environments and hence the SS(sl) is computed as:

$$\sum_k\sum_{i\le j}\sum x^2_{ijk} - \frac{1}{P+2}\sum_k\sum_i (X_{i.k}+x_{ijk})^2 + \frac{2\sum_k \Psi^2_{..k}}{(\pi+1)(\pi+2)} - \sum_{I\le j}\sum\frac{x^2_{ij.}}{l}$$

$$+\frac{1}{P+2)l}\sum_i (X_{i..}+x_{ii.})^2 - \frac{2X^2_{...}}{(p+1)(p+2)l}$$

Significance of various mean squares is then tested in usual fashion i.e. F test using error mean square as denominator. When the mean squares for general and specific combining ability effects are significant, estimates of g.c.a and s.c.a are calculated and tested for significance. The g.c.a (g_i) and s.c.a (s_{ij}) effects are got as:

3.3.4.1 Estimates of general and specific combining ability effects

1. General Combining ability effect

$$\hat{g}_i = \frac{1}{(P+2)l}\left[(X_{i..}+x_{ii.}) - \frac{2}{p}X...\right]$$

2. Special combining ability effect

$$\hat{S}_{ij} = \frac{1}{l}x_{ij.} - \frac{1}{(p+2)l}(X_{i..}+x_{ii.}+Y_{j..}+y_{ij.}) + \frac{2\,\Psi...}{((\pi+1)(\pi+2)\lambda}$$

3. Interaction of General Combining ability effect with environments

$$\hat{(gl)}_{ik} = \frac{1}{(P+2)}\left[(X_{i.k}+x_{ijk.}) - \frac{2X..K}{p}\right] - \frac{1}{(P+2)l}\left[(X_{i..}+x_{ii.}) - \frac{2}{p}X...\right]$$

4. Interaction of Specific Combining ability effect with environments

$$\hat{(Sl)}_{ijk} = y_{ijk} - \frac{1}{p+2}[X_{ik}+x_{iik}+X_{jk}+x_{ijk}) + \frac{2X..K}{(p+1)(p+2)} + \frac{x_{ij.}}{l} + \frac{1}{(p+2)l}(X_{i..}+x_{ii.}+X_{j..}+x_{jj}) - \frac{2X...}{(p+1)(p+2)l}$$

3.3.4.2 Standard error for estimates

Standard error of effect was calculated as a square root of the variance of the effect. The variance of various effects were calculated as follows.

$$\text{SE for gca effects } (\hat{g}i) = \left[\frac{(P-1)}{P\,(P+2)l} \times \hat{\sigma}^2 \right]^{1/2}$$

$$\text{SE for sca effects } (\hat{S}ij) = \left[\frac{P^2+P+2}{(P+1)\,(P+2)l} \times \hat{\sigma}^2 \right]^{1/2}$$

Where,

P = Number of parents

l = Number of environments

σ^2 = M'_e

3.3.4.3 Standard error of difference between two effects

Standard error of difference between two effects was taken as a square root of the variance of the two estimates. The variance for difference between two estimates was computed as :

$$\text{SE for } (\hat{g}_i - \hat{g}_j) = \left[\frac{2}{(P+2)l} \times \hat{\sigma}^2 \right]^{1/2}$$

$$\text{SE for } (\hat{S}_{ij} - \hat{g}_{ik}) = \left[\frac{2\,(P+1)}{(P+2)l} \times \hat{\sigma}^2 \right]^{1/2}$$

$$\text{SE for } (\hat{S}_{ij} - \hat{S}_{kl}) = \left[\frac{2P}{(P+2)l} \times \hat{\sigma}^2 \right]^{1/2}$$

3.3.5 Mahalanobi's generalized distance (D^2)

Mahalanobis (1936) D^2 Statistics was used for assessing the genetic divergence among the genotypes and the generalized distance between any two populations as given in the following formula,

$$\triangle^2 = \sum\sum \lambda^{ij} \delta_i \delta_j$$

Where,

$\triangle^2$ = Square of generalized distance

λ^{ij} = The reciprocal matrix o the common dispersion matrix

δ_i = The difference between the mean values of the two populations for i^{th} character.

This quantity is estimated by the D^2 statistic as:

$$D^2 = \sum\sum s^{ij} d_i d_j$$

Where,

s^{ij} is the sample estimate of λ^{ij} and di of δ_i.

Since, the formula for computation requires inversion of higher order determinant, transformation of original correlated unstandardized character means (XS) into standardized uncorrelated variables (YS) was done to simplify the computational

procedures. The D^2 values were obtained as sum of squares of differences between the pairs of corresponding uncorrelated (YS) values of any two genotypes (Rao, 1952).

3.3.5.1 Clustering of D^2 values

All the n (n-1)/2 D^2 values were clustered using Tocher's method as described by Rao (1952)

3.3.5.2 Intra and inter cluster distances

The intra and inter cluster distances were calculated by the formula given by Singh and Chaudhary (1979)

Intra cluster distance $=\sum D_i^2 \backslash n$

Where,

$\sum D_i^2$ is the sum of distance between all possible combinations of the genotypes included in cluster.

n=number of all possible combinations

Inter cluster distance $=\sum D_i^2 \backslash ninj$

Where,

$\sum D_i^2$ is the sum of distance between all possible combinations ($n_i n_j$) of the genotypes included in the clusters i and j

n_i =number of genotypes in cluster i

n_j =number of genotypes in cluster j

3.3.6 Correlation

In order to understand association between genetic distance and hybrid mean performance, Mid parent value, SCA effects, mid parent and better parent heterosis, simple correlation coefficients were calculated by following Singh and Chaudhary (1985).

$$r_{x1\,x2} = \frac{\text{Cov. } x_1\, x_2}{\sqrt{\text{Variance } x_1 . \text{ Variance } x_2}}$$

Where,

$r_{x1\,x2}$ = Correlation coefficient between variables x_1 and x_2.

Cov. $x_1\, x_2$ = Covariance between x_1 and x_2.

Variance x_1 = Variance of the variable x_1

Variance x_2 = Variance of the variable x_2

Significance of correlation coefficient was determined by comparing with table 'r' value at n-2 d. f.

3.3.7 Polymorphic Information Content (PIC):

The PIC value for each locus of RAPD was calculated on the basis of allele frequency (Budak *et al.*, 2003).

$$PIC_i = 1 - \Sigma\, Pij^2$$

Where Pij is the frequency of jth allele for marker i, and summation extends over n alleles. This referred to as heterozygosity and gene diversity.

4. EXPERIMENTAL RESULTS

The results obtained of the present investigation entitled "Genetic studies and molecular analysis for forage yield in pearl millet (*Pennisetum glaucum*, L) R.Br.)" for green fodder yield and its components in two seasons viz., Kharif- 2008 and summer-2009 are presented character wise under the following headings:

4.1 Mean performance of parents and hybrids

4.2 Analysis of variance

- 4.2. 1 Combined analysis of variance
- 4.2. 2 Pooled analysis of variance

4.3 Combining ability studies

- 4.3.1 Analysis of variance for combining ability in individual environment and pooled over environments.
- 4.3.2 General combining ability effects
- 4.3.3 Specific combining ability effects
- 4.3.4 Gene action

4.4 Heterosis

4.5 Clustering of genotypes through D^2 analysis

4.6 Molecular studies through RAPD markers

4.7 Comparison of grouping of genotypes through RAPD and D^2 analysis.

4.8 Correlation studies for molecular divergence and hybrid performance for forage yield and yield characters.

4.1 Mean performance of parents and hybrids

The results obtained on the mean performance of parents and hybrids along with the range for different character under kharif 2008 (E_1), summer 2009 (E_2) and pooled over environments are presented in Tables 4.1.1 to 4.1.6.

4.1.1 Days to 50 % flowering (Table 4.1.1)

The variation in days to 50% flowering among parents ranged between 47.33 (RHRB-259) to 56.33 (Giant bajra) with 50.87 as general parent mean in the Kharif, 2008 (E_1). While it ranged from 50.00 (PMFT-907) to Giant bajra (60.00) with 55.54 as a parent mean in summer, 2009 (E_2). On the basis of pooled mean, RHRB-259 (48.33) was the earliest flowering parent.

Among the hybrids, minimum number of days to 50 % flowering was recorded by the cross Giant bajra x RHRB 259 in E_1 (42.67) and PMFT-905 x PMFT-907 in E_2 (44.67). On the basis of pooled mean the cross PMFT-905 x PMFT-907 was the earliest to 50 % flowering (43.67). The hybrids in the E_1 recorded the least number of mean days to 50% flowering (46.77) as compared to the E_2 (50.65). Fourteen hybrids flowered earlier than hybrid mean in E_1, E_2 and over pooled mean.

4.1.2 Plant height (cm) (Table 4.1.1)

The plant height for parents ranged from 147.57 (RHRB-260) to 196.83 (Giant bajra) with 167.72 as the parental mean in E_1 and from 116.60 (RHRB 259) to 189.30 (Giant bajra) with 139.95 as the parental mean in E_2. On the basis of pooled mean Giant bajra recorded the highest plant height (193.07) whereas RHRB-260 had the lowest (134.35).Among the hybrids, the range for plant height was 164.30 (PMFT-904 x RHRB-260) to 224.97 (Giant bajra x PMFT-905) and 113.00 (PMFT-905 x RHRB-259) to 163.83 (Giant bajra x PMFT-905) in E_1 and E_2, respectively. On the

Table.4.1.1: Mean performance of parents and hybrids for Days to 50 % flowering, Plant height (cm) and Number of tillers/plant in Kharif, 2008 (E_1), summer, 2009 (E_2) environments and over seasons (pooled).

S. N	Cross	Days to 50 % flowering			Plant height (cm)			No. of tillers/plant		
Parents		**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**
1	Giant Bajra	56.33	60.00	58.17	196.83	189.30	193.07	3.07	3.37	3.22
2	PMFT 904	49.67	52.00	50.83	156.90	128.20	142.55	3.20	3.00	3.10
3	PMFT 905	53.67	57.67	55.67	163.77	143.33	153.55	3.70	3.30	3.50
4	PMFT 907	48.00	50.00	49.00	175.07	127.03	151.05	2.67	2.93	2.80
5	RHRB 259	47.33	50.33	48.83	156.50	116.60	136.55	2.87	2.60	2.73
6	RHRB 260	48.33	56.67	52.50	147.57	121.13	134.35	2.67	2.40	2.53
7	RHRB 282	51.33	58.67	55.00	180.83	153.83	167.33	3.27	3.10	3.18
8	RHRB 278	52.33	59.00	55.67	164.30	140.13	152.22	3.87	3.43	3.65
Parent mean		**50.87**	**55.54**	**53.21**	**167.72**	**139.95**	**153.83**	**3.16**	**3.02**	**3.09**
F_1s										
1	1 x 2	48.67	61.33	55.00	179.03	139.97	159.50	2.90	2.60	2.75
2	1 x 3	50.67	49.33	50.00	224.97	163.83	194.40	3.70	3.30	3.50
3	1 x 4	51.00	50.67	50.83	204.83	153.83	179.33	2.77	2.67	2.72
4	1 x 5	42.67	51.00	46.83	165.77	138.27	152.02	3.63	3.30	3.47
5	1 x 6	48.67	53.00	50.83	166.53	161.80	164.17	3.43	3.10	3.27
6	1 x 7	49.67	53.67	51.67	208.93	156.20	182.57	3.27	3.07	3.17
7	1 x 8	51.67	55.00	53.33	184.47	149.57	167.02	4.00	3.50	3.75
8	2 x 3	43.67	47.67	45.67	167.20	146.30	156.75	5.10	2.87	3.98
9	2 x 4	44.00	47.67	45.83	172.10	145.23	158.67	3.53	3.10	3.32
10	2 x 5	43.67	46.67	45.17	177.20	113.27	145.23	3.50	2.93	3.22
11	2 x 6	44.00	49.00	46.50	164.30	140.13	152.22	3.17	3.03	3.10
12	2 x 7	46.67	50.33	48.50	182.23	140.20	161.22	3.37	3.13	3.25
13	2 x 8	50.00	54.33	52.17	174.13	131.47	152.80	2.90	2.93	2.92
14	3 x 4	42.67	44.67	43.67	191.23	161.47	176.35	3.27	2.87	3.07
15	3 x 5	43.00	45.00	44.00	179.13	113.00	146.07	2.93	2.60	2.77
16	3 x 6	44.67	48.33	46.50	175.40	137.53	156.47	2.73	2.63	2.68
17	3 x 7	47.33	49.00	48.17	210.70	147.67	179.18	3.93	3.30	3.62
18	3 x 8	50.33	49.00	49.67	207.00	154.17	180.58	2.97	2.83	2.90
19	4 x 5	43.67	48.00	45.83	175.80	126.90	151.35	3.00	2.73	2.87
20	4 x 6	45.33	49.00	47.17	173.23	140.37	156.80	2.87	2.70	2.78
21	4 x 7	46.67	53.00	49.83	182.70	130.00	156.35	3.73	3.30	3.52
22	4 x 8	48.67	51.33	50.00	183.27	134.80	159.03	3.90	3.40	3.65
23	5 x 6	46.67	47.00	46.83	168.30	142.50	155.40	2.90	2.80	2.85
24	5 x 7	44.33	52.00	48.17	175.63	128.53	152.08	3.27	3.10	3.18
25	5 x 8	48.00	54.00	51.00	186.60	133.93	160.27	3.63	3.27	3.45
26	6 x 7	47.33	53.00	50.17	185.13	129.87	157.50	3.20	3.03	3.12
27	6 x 8	48.67	52.00	50.33	187.27	135.17	161.22	3.23	3.03	3.13
28	7 x 8	47.33	53.33	50.33	187.70	160.43	174.07	3.13	3.00	3.07
Hybrid mean		**46.77**	**50.65**	**48.71**	**183.60**	**141.30**	**162.45**	**3.36**	**3.00**	**3.18**
General Mean		**47.69**	**51.74**	**49.71**	**180.07**	**141.00**	**160.54**	**3.31**	**3.01**	**3.16**
Range Parents		47.33-56.33	50.00-60.00	48.83-58.17	147.57-196.83	116.60-189.30	134.35-193.07	2.67-3.87	2.40-3.43	2.53-3.65
Range Hybrids		42.67-51-67	44.67-61.33	43.67-55.00	164.30-224.97	113.00-163.83	145.23-194.40	2.73-5.10	2.60-3.50	2.68-3.98
SE ±		0.74	0.78	0.54	2.85	2.80	2.00	0.14	0.10	0.18
CD at 5 %		2.09	2.19	1.50	8.05	7.90	5.59	0.39	0.27	0.50
C.V. %		2.69	2.60	2.64	2.74	3.44	3.05	18.07	5.52	14.15

basis of pooled mean, the hybrid Giant bajra x PMFT-905 recorded the highest plant height (194.40) whereas PMFT-904x RHRB-259 had the lowest Plant height (145.23). Eleven hybrids each in E_1 and E_2 and nine hybrids on the basis of pooled mean measured higher plant height than the hybrid mean.

4.1.3 Number of tillers per plant (Table 4.1.1)

The mean number of tillers per plant for parents exhibited a range from 2.67 (PMFT-907, RHRB-260) to 3.87 (RHRB-278) with a parental mean of 3.16 in E_1 and 2.40 (RHRB-260) to 3.43 (RHRB-278) with a parental mean of 3.02 in E_2, where as on the basis of pooled over seasons, it ranged from 2.53 (RHRB-260) to 3.65 (RHRB-278) with a parental mean of 3.09.

For hybrids the range for number of tillers per plant was 2.73 (PMFT-905 x RHRB-260) to 5.10 (PMFT-904 x PMFT-905) and 2.60 (Giant bajra x PMFT-904 and PMFT-905 x RHRB-259) to 3.50 (Giant bajra x RHRB-278) in E_1 and E_2, respectively. On the basis of pooled mean the hybrid PMFT-904 x PMFT-905 recorded the highest number of tillers (3.98), whereas PMFT-905 x RHRB-260 had the lowest number of tillers (2.68). Twelve hybrids each in E_1 and on the basis of pooled mean and fifteen hybrids in E_2 had higher number of tillers per plant than the hybrid mean.

4.1.4 Number of leaves per plant (Table 4.1.2)

It was observed that the parent Giant bajra had maximum number of leaves in E_1 (9.93), E_2 (10.10) and over pooled (10.02), while lowest number of leaves was recorded by RHRB-259 in E_1 (7.47), E_2 (6.37) and over pooled (6.92).

The hybrid combination which recorded the highest number of leaves was Giant bajra x PMFT-905 and Giant bajra x PMFT-904 (10.70 and 8.03 in E_1 and E_2, respectively). On the basis of pooled mean the hybrid Giant bajra x PMFT-905 recorded the

highest number of leaves (9.32). Twelve, fifteen and eleven hybrids had higher number of leaves per plant than the hybrid mean in E_1, E_2 and over environments, respectively.

4.1.5 Leaf length (cm) (Table 4.1.2)

The parent, Giant bajra recorded the highest value for this trait in E_1 (84.13) and E_2 (80.87) and the parent RHRB-260 recorded the lowest leaf length (53.93) in E_1 and RHRB-259 (41.30) in E_2. On the basis of pooled mean the highest and lowest leaf length was recorded by Giant bajra (82.50) and RHRB-260 (51.52), respectively.

The hybrid Giant bajra x PMFT-905 that exhibited high mean values for leaf length in E_1 (82.13), E_2 (60.37) and over pooled (71.25), respectively. Fourteen hybrids each in E_1 and E_2 and twelve hybrids on the basis of pooled mean measured higher leaf length than the hybrid mean.

4.1.6 Leaf width (cm) (Table 4.1.2)

The highest leaf width was recorded by the parent Giant bajra in E_1 (3.87), E_2 (4.07) and over pooled means (3.97). The hybrid combinations which excelled in leaf width were PMFT-905 x PMFT-907 (4.37) in E_1, Giant bajra x RHRB-278 (3.60) in E_2 and Giant bajra x PMFT-905(3.85) over pooled mean. Thirteen hybrids each in E_1 and E_2 and eleven hybrids on the basis of pooled mean measured higher leaf width than the hybrid mean.

4.1.7 Leaf area (cm^2) (Table 4.1.3)

Among the parents, Giant bajra was the superior for leaf area per plant in E_1 (235.42), E_2 (237.04) and over pooled means (236.23) whereas RHRB-260 and RHRB-259 had recorded lowest leaf area (106.53, 87.24) in E_1 and E_2 , respectively.

Among hybrids, Giant bajra x PMFT-905 was the superior cross combination for this trait in the environments E_1

Table 4.1.2: Mean performance of parents and hybrids for Number of leaves/plant, Leaf length (cm) and Leaf width in Kharif, 2008 (E_1), summer, 2009 (E_2) environments and over seasons (Pooled).

S. N	Cross	No. of leaves/plant			Leaf length (cm)			Leaf width (cm)		
Parents		**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**
1	Giant Bajra	9.93	10.10	10.02	84.13	80.87	82.50	3.87	4.07	3.97
2	PMFT 904	8.37	7.60	7.98	75.73	52.07	63.90	3.33	3.03	3.18
3	PMFT 905	8.63	7.47	8.05	72.30	53.70	63.00	3.60	2.83	3.22
4	PMFT 907	7.93	7.03	7.48	61.23	54.10	57.67	3.00	2.70	2.85
5	RHRB 259	7.47	6.37	6.92	65.77	41.30	53.53	3.10	2.93	3.02
6	RHRB 260	8.20	7.40	7.80	53.93	49.10	51.52	2.60	2.43	2.52
7	RHRB 282	9.17	8.20	8.68	62.17	62.03	62.10	2.80	2.60	2.70
8	RHRB 278	7.93	7.73	7.83	77.57	60.90	69.23	3.73	2.93	3.33
Parent mean		**8.45**	**7.74**	**8.10**	**69.10**	**56.76**	**62.93**	**3.25**	**2.94**	**3.10**
F_1s										
1	1 x 2	8.23	8.03	8.13	67.20	57.77	62.48	3.47	3.00	3.23
2	1 x 3	10.70	7.93	9.32	82.13	60.37	71.25	4.13	3.57	3.85
3	1 x 4	10.13	7.43	8.78	75.60	52.87	64.23	3.87	2.80	3.33
4	1 x 5	8.27	7.37	7.82	64.30	50.90	57.60	3.33	2.63	2.98
5	1 x 6	7.57	7.57	7.57	63.37	58.50	60.93	2.63	2.57	2.60
6	1 x 7	9.53	7.93	8.73	76.37	59.23	67.80	3.70	3.17	3.43
7	1 x 8	8.40	7.57	7.98	81.33	57.97	69.65	3.70	3.60	3.65
8	2 x 3	7.80	6.93	7.37	65.43	49.23	57.33	3.63	2.43	3.03
9	2 x 4	9.33	7.67	8.50	69.53	49.27	59.40	4.03	2.90	3.47
10	2 x 5	8.83	7.50	8.17	63.83	51.90	57.87	3.70	2.90	3.30
11	2 x 6	8.67	7.17	7.92	68.20	51.87	60.03	3.10	2.80	2.95
12	2 x 7	8.27	7.53	7.90	69.57	53.87	61.72	3.73	2.83	3.28
13	2 x 8	8.87	7.20	8.03	66.67	52.27	59.47	2.77	2.73	2.75
14	3 x 4	8.23	7.53	7.88	69.67	50.43	60.05	4.37	2.57	3.47
15	3 x 5	8.73	6.80	7.77	66.40	42.83	54.62	3.47	2.33	2.90
16	3 x 6	9.03	6.70	7.87	70.97	44.83	57.90	3.57	2.53	3.05
17	3 x 7	9.47	7.07	8.27	69.17	49.03	59.10	3.33	2.60	2.97
18	3 x 8	8.17	7.33	7.75	69.03	54.10	61.57	3.23	3.00	3.12
19	4 x 5	8.57	6.60	7.58	62.87	47.47	55.17	3.20	2.77	2.98
20	4 x 6	8.50	7.33	7.92	64.87	51.23	58.05	3.40	2.67	3.03
21	4 x 7	8.60	6.73	7.67	71.43	52.40	61.92	3.50	2.80	3.15
22	4 x 8	9.70	7.03	8.37	73.53	53.73	63.63	3.87	2.77	3.32
23	5 x 6	8.50	6.93	7.72	63.87	47.80	55.83	2.87	2.87	2.87
24	5 x 7	9.00	7.10	8.05	71.83	48.30	60.07	3.43	2.83	3.13
25	5 x 8	9.43	7.67	8.55	70.77	55.30	63.03	3.27	2.60	2.93
26	6 x 7	8.43	6.97	7.70	71.70	47.40	59.55	3.67	2.57	3.12
27	6 x 8	9.03	7.17	8.10	63.63	54.47	59.05	3.07	2.53	2.80
28	7 x 8	8.30	7.07	7.68	70.73	57.77	64.25	3.30	2.77	3.03
Hybrid mean		**8.80**	**7.28**	**8.04**	**69.43**	**52.25**	**60.84**	**3.48**	**2.79**	**3.13**
General Mean		**8.72**	**7.38**	**8.05**	**69.36**	**53.25**	**61.31**	**3.43**	**2.82**	**3.13**
Range Parents		7.47-9.93	6.37-10.10	6.92-10.02	53.93-84.13	41.30-80.87	51.52-82.50	2.60-3.87	2.43-4.07	2.52-3.97
Range Hybrids		7.57-10.70	6.60-8.03	7.37-9.32	62.87-82.13	42.83-60.37	54.62-71.25	2.63-4.37	2.33-3.60	2.60-3.85
SE ±		0.25	0.24	0.17	1.60	1.76	1.19	0.09	0.12	0.08
CD at 5 %		0.69	0.67	0.48	4.50	4.98	3.33	0.25	0.35	0.21
C.V. %		4.87	5.57	5.12	3.99	5.74	4.75	4.47	7.59	5.54

(245.45) and E_2 (154.62). Twelve, thirteen and ten hybrids had more leaf area than the hybrid mean in E_1, E_2 and over environments, respectively.

4.1.8 Leaf weight (g) (Table 4.1.3)

The range of leaf weight among parents ranged from 17.64 (PMFT-907) to 47.87 (Giant bajra) in E_1 , 18.33 (RHRB-259) to 40.67 (Giant bajra) in E_2 and 19.32 (PMFT-907) to 44.27 (Giant bajra) in pooled over seasons.

Among hybrids, Giant bajra x PMFT-907 and Giant bajra x RHRB-282 was the superior cross combination for this trait in the environments E_1 (38.53) and E_2 (30.67), respectively. On the basis of pooled mean the cross Giant bajra x PMFT-907 also recorded the highest leaf weight (32.10). Fifteen, thirteen and twelve hybrids had more leaf weight than the hybrid mean in E_1, E_2 and over environments, respectively.

4.1.9 Stem weight (g) (Table 4.1.3)

Among the parents Giant bajra recorded the highest stem weight in E_1 (219.78), E_2 (171.90) and over pooled mean (195.84) whereas, the lowest stem weight was recorded by PMFT-907 (69.22) in E_1, RHRB-259 (69.00) in E_2 and RHRB-259 (76.28) over pooled mean.

Among the crosses, Giant bajra x PMFT-905 recorded the highest stem weight of 184.33 in E_1, 157.33 in E_2 and 170.83 over pooled men while, the lowest stem weight was observed in Giant bajra x RHRB-260 (72.45) in E_1, PMFT-905 x RHRB-260 (70.33) in E_2 and RHRB-259 x RHRB-260 (85.72) over pooled mean.

Table 4.1.3: Mean performance of parents and hybrids for Leaf area (cm^2), Leaf weight (g) and Stem weight (g) in Kharif, 2008 (E_1), summer, 2009 (E_2) environments and over seasons (Pooled).

S. N	Cross	Leaf area (cm^2)			Leaf weight (g)			Stem weight (g)		
Parents		**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**
1	Giant Bajra	235.42	237.04	236.23	47.87	40.67	44.27	219.78	171.90	195.84
2	PMFT 904	181.65	114.87	148.26	20.11	27.67	23.89	95.00	125.33	110.17
3	PMFT 905	187.17	108.63	147.90	20.02	24.20	22.11	82.47	102.33	92.40
4	PMFT 907	132.95	105.03	118.99	17.64	21.00	19.32	69.22	94.67	81.95
5	RHRB 259	147.35	87.24	117.29	21.56	18.33	19.95	83.56	69.00	76.28
6	RHRB 260	101.53	87.98	94.75	20.89	22.56	21.72	86.13	94.33	90.23
7	RHRB 282	126.88	115.72	121.30	22.89	22.33	22.61	116.62	158.67	137.64
8	RHRB 278	210.22	129.47	169.85	26.64	25.33	25.99	99.42	106.00	102.71
Parent mean		**165.40**	**123.25**	**144.32**	**24.70**	**25.25**	**24.97**	**106.53**	**115.28**	**110.90**
F_1s										
1	1 x 2	168.50	125.81	147.16	23.33	26.44	24.89	103.11	128.33	115.72
2	1 x 3	245.45	154.62	200.04	32.76	30.00	31.38	184.33	157.33	170.83
3	1 x 4	211.54	107.00	159.27	38.53	25.67	32.10	173.00	137.67	155.33
4	1 x 5	155.91	97.75	126.83	28.89	24.00	26.45	130.13	107.67	118.90
5	1 x 6	120.95	109.67	115.31	19.38	26.33	22.86	72.45	142.67	107.56
6	1 x 7	204.90	136.26	170.58	32.33	30.67	31.50	142.89	139.33	141.11
7	1 x 8	218.46	150.26	184.36	30.20	30.33	30.27	144.44	120.67	132.56
8	2 x 3	171.62	86.16	128.89	18.31	18.00	18.16	98.36	98.00	98.18
9	2 x 4	202.80	102.83	152.81	29.49	22.33	25.91	135.18	100.67	117.92
10	2 x 5	170.12	108.89	139.50	24.62	27.67	26.15	109.11	123.67	116.39
11	2 x 6	154.70	106.25	130.48	24.11	23.00	23.56	103.60	105.33	104.47
12	2 x 7	188.04	110.41	149.22	34.33	21.33	27.83	142.20	92.00	117.10
13	2 x 8	134.21	103.28	118.75	22.60	24.27	23.43	110.60	113.00	111.80
14	3 x 4	218.99	93.52	156.25	29.02	23.67	26.35	140.82	121.33	131.08
15	3 x 5	166.19	72.93	119.56	29.18	23.33	26.26	125.07	113.00	119.03
16	3 x 6	183.53	83.00	133.27	34.89	16.00	25.45	144.56	70.33	107.45
17	3 x 7	166.73	91.24	128.99	24.67	21.20	22.93	126.78	97.00	111.89
18	3 x 8	160.04	117.15	138.59	16.09	24.00	20.05	97.82	129.00	113.41
19	4 x 5	145.59	94.65	120.12	24.22	21.00	22.61	95.20	94.67	94.93
20	4 x 6	159.60	99.45	129.53	28.33	24.33	26.33	129.49	101.67	115.58
21	4 x 7	181.28	107.82	144.55	27.33	25.22	26.28	99.78	102.67	101.22
22	4 x 8	207.39	107.25	157.32	30.71	19.00	24.86	129.38	80.00	104.69
23	5 x 6	131.57	98.91	115.24	21.58	23.00	22.29	82.11	89.33	85.72
24	5 x 7	178.12	99.25	138.69	32.60	25.33	28.97	125.80	104.33	115.07
25	5 x 8	168.55	103.36	135.96	29.04	26.00	27.52	128.62	115.33	121.98
26	6 x 7	189.22	88.04	138.63	36.76	23.33	30.05	130.36	105.67	118.01
27	6 x 8	140.86	98.59	119.73	30.00	21.67	25.83	119.33	99.33	109.33
28	7 x 8	169.52	115.23	142.37	22.56	28.89	25.72	84.96	123.67	104.31
Hybrid mean		**175.51**	**106.06**	**140.78**	**28.42**	**24.14**	**26.28**	**121.77**	**111.20**	**116.48**
General Mean		**173.26**	**109.88**	**141.57**	**27.60**	**24.95**	**26.27**	**118.38**	**112.11**	**115.24**
Range Parents		101.53-235.42	87.24-237.04	94.75-236.23	17.64-47.87	18.33-42.33	19.32-44.27	69.22-219.78	69.00-171.90	76.28-195.84
Range Hybrids		120.95-245.45	72.93-154.62	115.24-200.04	16.09-56.76	16.00-30.67	18.16-40.05	72.45-184.33	70.33-157.33	85.72-170.83
SE ±		6.02	6.44	4.41	2.67	1.66	1.57	8.08	7.88	5.64
CD at 5 %		16.97	18.17	12.32	7.53	4.68	4.39	22.79	22.21	15.78
C.V. %		6.02	10.16	7.64	16.75	11.52	14.65	11.82	12.17	11.99

4.1.10 Leaf : stem ratio (Table 4.1.4)

The range for leaf: stem ratio for parents ranged from 0.20 (RHRB-282) to 0.27 (RHRB-278) in E1, 0.22 (PMFT-904, RPMFT-907) to 0.27 (RHRB-282) in E2 and 0.22 (PMFT-904) to 0.26 (RHRB-259) over pooled mean.

Among the crosses, the highest leaf: stem ratio was recorded by Giant bajra x RHRB-260, PMFT-907 x RHRB-282 and RHRB-260 x RHRB-282 (0.27) in E1, RHRB-259 x RHRB-260 (0.26) in E2 and by PMFT-907 x RHRB-282 and RHRB-259 x RHRB-260 (0.26) over pooled mean. Eleven, twelve and fifteen hybrids measured higher leaf: stem ratio than the hybrid mean in E_1 , E_2 and over pooled mean.

4.1.11 Green forage yield (q/ha) (Table 4.1.4)

The green forage yield for parents ranged from 415.63 (RHRB-260) to 662.55 (Giant bajra) with 520.98 as the parental mean in E_1 and from 270.08 (RHRB 259) to 630.65 (Giant bajra) with 400.99 as the parental mean in E_2. On the basis of pooled mean Giant bajra recorded the highest green forage yield (646.60) whereas lowest green forage yield was produced by RHRB-260 (350.82).

Among the hybrids, the range for green forage yield was 456.79 (Giant bajra x RHRB-259) to 853.90 (Giant bajra x RHRB-282) and 325.10 (PMFT-905 x RHRB-260) to 632.82 (Giant bajra x RHRB-282) in E_1 and E_2, respectively. On the basis of pooled mean the hybrid Giant bajra x RHRB-282 recorded the highest green forage yield (743.36) whereas Giant bajra x RHRB-259 had the lowest green forage yield (391.97). Nine, fifteen and ten hybrids recorded higher green forage yield than the hybrid mean in E_1, E_2 and over pooled means, respectively.

Table 4.1.4: Mean performance of parents and hybrids for Leaf: stem ratio, Green fodder yield (kg/ha) and Dry matter yield (kg/ha) in Kharif, 2008 (E_1) , Summer, 2009 (E_2) environments and over seasons (Pooled).

S. N	Cross	Leaf: stem ratio			Green fodder yield (q/ha)			Dry matter yield (q/ha)		
Parents		**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**
1	Giant Bajra	0.22	0.24	0.23	662.55	630.65	646.60	136.29	124.61	130.45
2	PMFT 904	0.21	0.22	0.22	473.25	446.50	459.87	93.92	87.37	90.65
3	PMFT 905	0.24	0.24	0.24	592.59	304.53	448.56	117.61	66.76	92.19
4	PMFT 907	0.26	0.22	0.24	479.42	420.37	449.89	96.85	81.43	89.14
5	RHRB 259	0.26	0.27	0.26	446.50	270.08	358.29	80.88	49.49	65.18
6	RHRB 260	0.24	0.24	0.24	415.63	286.01	350.82	75.06	54.74	64.90
7	RHRB 282	0.20	0.27	0.23	593.82	460.90	527.36	134.98	87.44	111.21
8	RHRB 278	0.27	0.24	0.25	504.11	388.89	446.50	96.20	75.26	85.73
Parent mean		**0.24**	**0.24**	**0.24**	**520.98**	**400.99**	**460.99**	**103.98**	**78.39**	**91.18**
F_1s										
1	1 x 2	0.23	0.21	0.22	588.47	475.30	531.89	108.15	91.30	99.73
2	1 x 3	0.18	0.19	0.19	755.14	489.71	622.42	145.21	92.33	118.77
3	1 x 4	0.22	0.19	0.21	576.13	370.37	473.25	112.43	69.98	91.20
4	1 x 5	0.22	0.22	0.22	456.79	327.16	391.97	82.55	59.86	71.20
5	1 x 6	0.27	0.18	0.23	490.94	547.32	519.13	97.76	116.74	107.25
6	1 x 7	0.23	0.22	0.22	853.90	632.82	743.36	166.35	93.42	129.88
7	1 x 8	0.21	0.25	0.23	646.09	561.31	603.70	133.69	90.18	111.93
8	2 x 3	0.19	0.19	0.19	568.93	380.66	474.79	121.05	74.18	97.62
9	2 x 4	0.22	0.22	0.22	517.49	504.11	510.80	94.59	94.26	94.43
10	2 x 5	0.22	0.22	0.22	596.70	423.87	510.29	113.71	84.29	99.00
11	2 x 6	0.23	0.22	0.23	567.08	423.87	495.47	112.20	83.96	98.08
12	2 x 7	0.24	0.23	0.24	697.53	500.00	598.76	124.92	108.07	116.50
13	2 x 8	0.21	0.21	0.21	477.77	454.73	466.25	94.37	88.49	91.43
14	3 x 4	0.21	0.20	0.20	681.07	453.70	567.38	133.99	90.08	112.03
15	3 x 5	0.24	0.21	0.22	582.30	334.36	458.33	112.75	60.55	86.65
16	3 x 6	0.24	0.23	0.24	504.11	325.10	414.61	95.84	64.93	80.39
17	3 x 7	0.19	0.22	0.21	740.74	333.33	537.03	170.63	71.43	121.03
18	3 x 8	0.16	0.19	0.18	551.44	341.56	446.50	128.49	75.83	102.16
19	4 x 5	0.25	0.22	0.24	570.16	355.14	462.65	97.78	73.89	85.84
20	4 x 6	0.21	0.24	0.23	510.90	481.48	496.19	91.72	83.87	87.79
21	4 x 7	0.27	0.25	0.26	640.94	560.49	600.72	113.42	88.95	101.19
22	4 x 8	0.24	0.24	0.24	726.33	564.61	645.47	159.70	103.79	131.75
23	5 x 6	0.26	0.26	0.26	596.70	434.15	515.43	129.18	106.31	117.75
24	5 x 7	0.26	0.24	0.25	594.85	430.04	512.45	112.91	76.32	94.61
25	5 x 8	0.23	0.23	0.23	581.27	434.15	507.71	119.35	91.01	105.18
26	6 x 7	0.27	0.22	0.25	488.06	497.94	493.00	101.79	93.23	97.51
27	6 x 8	0.25	0.22	0.23	568.93	477.36	523.15	126.99	108.83	117.91
28	7 x 8	0.26	0.24	0.25	636.21	556.99	596.60	125.13	104..80	114.97
Hybrid mean		**0.23**	**0.22**	**0.22**	**598.82**	**452.56**	**525.69**	**118.81**	**87.17**	**102.99**
General Mean		**0.23**	**0.22**	**0.23**	**581.52**	**441.10**	**511.31**	**115.51**	**85.22**	**100.37**
Range Parents		0.20-0.27	0.22-0.27	0.22-0.26	415.63-662.55	270.08-630.65	350.82-646.60	75.06-136.29	49.48-124.60	64.90-130.45
Range Hybrids		0.16-0.27	0.18-0.26	0.18-0.26	456.79-853.90	325.10-632.82	391.97-743.36	82.55-170.63	59.86-116.73	71.21-131.75
SE ±		0.02	0.01	0.01	30.49	26.57	20.22	6.27	5.78	4.26
CD at 5 %		0.04	0.03	0.03	86.01	74.95	56.54	17.69	16.29	11.92
C.V. %		11.33	9.03	9.82	9.08	10.43	9.68	9.41	11.74	10.45

4.1.12 Dry matter yield (q/ha) (Table 4.1.4)

Among the parents the range for dry matter yield was 75.06 (RHRB-260) to 136.29 (Giant bajra) with 103.98 as the parental mean in E_1 and from 49.49 (RHRB 259) to 124.61 (Giant bajra) with 78.39 as the parental mean in E_2. On the basis of pooled mean Giant bajra recorded the highest dry matter yield (130.45) whereas RHRB-260 had the lowest (64.90) dry matter yield.

Among the hybrids, the range for dry matter yield was 82.55 (Giant bajra x RHRB-259) to 170.63 (PMFT-905 x RHRB-282) and 59.86 (Giant bajra x RHRB-259) to 116.73 (Giant bajra x RHRB-260) in E_1 and E_2, respectively. On the basis of pooled mean the hybrid PMFT-907 x RHRB-278 recorded the highest dry matter yield (131.75) whereas Giant bajra x RHRB-259 had the lowest dry matter yield (71.20). Thirteen, sixteen and twelve hybrids recorded higher dry matter yield than the hybrid mean in E_1, E_2 and over pooled means, respectively.

4.1.13 Crude Protein content (%) (Table 4.1.5)

The range for crude protein percent in parents was 6.56 (RHRB-259) to 9.04 (Giant bajra) in E_1, 7.00 (PMFT-907) to 8.70 (RHRB-282) in E_2 .On the bais of pooled mean it ranged from 7.07 (RHRB-259) to 8.83 (Giant bajra).

Among the hybrids, PMFT-907 x RHRB-278 in E_1 and PMFT-907 x RHRB-259 in E_2 recorded the highest crude protein percent of 9.77 and 10.06, respectively, while, the hybrid RHRB-260 x RHRB-278 had the lowest crude protein percent of 7.15, 7.44 and 7.29 in E_1, E_2 and over pooled mean, respectively. Thirteen, fifteen and twelve hybrids had higher crude protein content than the hybrid mean in E_1 , E_2 and over pooled mean.

4.1.14 Crude fibre content (%) (Table 4.1.5)

The range for crude fibre percent for parents ranged from 30.97 (Giant bajra) to 33.53 (RHRB-278) in E_1, 32.18 (RHRB-278) to 32.85 (RHRB-259) in E_2 and 31.64 (Giant bajra) to 33.00 (RHRB-259) over pooled mean.

Among the crosses, the range for crude fibre percent was from 30.03 (Giant bajra x PMFT-905) to 33.75 (RHRB-260 x RHRB-278) in E_1, 30.87 (Giant bajra x PMFT-905) to 33.11 (Giant bajra x RHRB-259) in E_2. On the basis of pooled mean the lowest crude fibre content was observed in cross Giant bajra x PMFT-905 (30.45). Fifteen, thirteen and fourteen hybrids had lower crude fibre content than the hybrid mean in E_1 , E_2 and over pooled mean.

4.1.15 Acid Detergent Fibre (%) (Table 4.1.5)

The range for ADF percent in parents was 42.38 (RHRB-260) to 45.48 (RHRB-278) in E_1, 43.02 (RHRB-278) to 46.32 (RHRB-259) in E_2 .On the basis of pooled mean it ranged from 43.17 (RHRB-260) to 45.68 (RHRB-259).

Among the hybrids, Giant bajra x RHRB-282 in E_1 and RHRB-260 x RHRB-278 in E_2 recorded the lowest ADF percent of 42.04 and 42.89, respectively, while, the hybrids PMFT-905 x RHRB-260 and PMFT-905 x RHRB-278 had the highest ADF percent of 46.48 and 46.85 in E_1 and E2, respectively. However, on the basis of pooled mean the lowest ADF percent was observed in cross Giant bajra x PMFT-905 (42.97). Fourteen, thirteen and sixteen hybrids had lower ADF content than the hybrid mean in E_1, E_2 and over pooled mean.

Table 4.1.5: Mean performance of parents and hybrids for Crude protein (%), Crude fibre (%) and ADF (%) in Kharif, 2008 (E_1), summer, 2009 (E_2) environments and over seasons (Pooled).

S. N	Cross	Crude protein (%)			Crude fibre (%)			ADF (%)		
Parents		**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**
1	Giant Bajra	9.04	8.61	8.83	30.97	32.30	31.64	44.89	44.14	44.51
2	PMFT 904	8.75	8.46	8.60	32.17	32.80	32.49	43.04	44.69	43.87
3	PMFT 905	8.75	7.81	8.28	31.62	32.47	32.04	43.06	44.50	43.78
4	PMFT 907	8.46	7.00	7.73	31.73	32.75	32.24	45.35	44.37	44.86
5	RHRB 259	6.56	7.58	7.07	33.15	32.85	33.00	45.04	46.32	45.68
6	RHRB 260	8.17	7.88	8.02	32.06	32.73	32.40	42.38	43.97	43.17
7	RHRB 282	8.46	8.70	8.58	31.15	32.34	31.75	44.19	44.20	44.20
8	RHRB 278	7.44	7.73	7.59	33.53	32.18	32.86	45.48	43.02	44.25
Parent mean		**8.20**	**7.97**	**8.09**	**32.05**	**32.55**	**32.30**	**44.18**	**44.40**	**44.29**
F_1s										
1	1 x 2	9.19	9.04	9.12	30.82	31.55	31.18	43.17	45.09	44.13
2	1 x 3	9.63	8.99	9.31	30.03	30.87	30.45	42.42	43.52	42.97
3	1 x 4	8.31	8.02	8.17	33.10	32.78	32.94	42.20	45.64	43.92
4	1 x 5	9.34	8.17	8.75	31.62	33.11	32.37	44.35	43.58	43.97
5	1 x 6	9.48	8.31	8.90	30.94	32.22	31.58	42.92	43.75	43.34
6	1 x 7	9.63	9.19	9.41	32.09	31.75	31.92	42.04	44.44	43.24
7	1 x 8	7.88	8.31	8.10	32.68	32.86	32.77	44.15	43.61	43.88
8	2 x 3	8.61	8.90	8.75	32.42	31.84	32.13	43.80	44.61	44.20
9	2 x 4	7.88	8.31	8.10	32.96	31.63	32.29	44.39	43.05	43.72
10	2 x 5	9.34	9.19	9.26	31.03	32.49	31.76	43.27	44.85	44.06
11	2 x 6	8.75	8.60	8.68	31.65	32.60	32.13	43.95	44.58	44.26
12	2 x 7	9.34	9.19	9.26	31.90	30.90	31.40	43.63	45.29	44.46
13	2 x 8	8.75	7.44	8.10	33.18	32.31	32.75	42.93	44.82	43.88
14	3 x 4	9.04	8.31	8.68	31.65	32.35	32.00	43.25	44.01	43.63
15	3 x 5	9.19	8.75	8.97	31.73	32.93	32.33	44.42	44.81	44.61
16	3 x 6	8.61	8.46	8.53	33.02	32.95	32.99	46.48	45.83	46.16
17	3 x 7	9.19	9.04	9.12	31.82	31.47	31.65	43.10	44.34	43.72
18	3 x 8	7.59	8.46	8.02	32.13	32.95	32.54	45.82	46.85	46.33
19	4 x 5	9.48	10.06	9.77	31.62	32.34	31.98	44.39	44.62	44.50
20	4 x 6	7.88	8.90	8.39	32.72	31.71	32.21	43.77	46.21	44.99
21	4 x 7	9.19	9.00	9.10	30.98	31.61	31.30	44.75	45.00	44.88
22	4 x 8	9.77	8.90	9.34	30.07	31.65	30.86	43.97	45.27	44.62
23	5 x 6	9.04	8.61	8.83	31.63	32.19	31.91	44.14	45.35	44.75
24	5 x 7	8.75	8.61	8.68	31.43	32.19	31.81	45.75	46.06	45.91
25	5 x 8	7.29	8.31	7.80	33.54	32.91	33.23	45.35	45.86	45.61
26	6 x 7	8.75	9.04	8.90	32.44	33.03	32.74	45.42	44.99	45.21
27	6 x 8	7.15	7.44	7.29	33.75	33.03	33.39	45.91	42.89	44.40
28	7 x 8	9.29	9.04	9.17	32.15	31.62	31.89	44.91	43.76	44.34
Hybrid mean		**8.80**	**8.66**	**8.73**	**31.97**	**32.21**	**32.09**	**44.10**	**44.74**	**44.42**
General Mean		**8.67**	**8.51**	**8.59**	**31.99**	**32.29**	**32.14**	**44.11**	**44.66**	**44.39**
Range Parents		6.56-9.04	7.00-8.70	7.07-8.83	30.97-33.53	32.18-32.85	31.64-33.00	42.38-45.48	43.02-46.32	43.17-45.68
Range Hybrids		7.15-9.77	7.44-10.06	7.29-9.77	30.03-33.75	30.87-33.11	30.45-33.39	42.04-46.48	42.89-46.85	42.97-46.33
SE ±		0.27	0.33	0.22	0.48	0.37	0.30	0.64	0.52	0.42
CD at 5 %		0.76	0.96	0.6	1.36	1.06	0.85	1.82	1.49	1.16
C.V. %		5.37	6.92	6.16	2.61	2.01	2.32	2.53	2.04	2.30

4.1.16 Neutral Detergent Fibre (%) (Table 4.1.6)

The range for NDF percent for parents ranged from 65.00 (Giant bajra) to 70.10 (RHRB-259) in E1, 66.40 (Giant bajra) to 70.72 (RHRB-278) in E2 and 65.70 (Giant bajra) to 69.85 (PMFT-907, RHRB-278) over pooled mean.

Among the crosses, the range for NDF was from 65.81 (RHRB-259 x RHRB-260) to 71.84 (PMFT-905 x RHRB-260) in E1, 66.75 (Giant bajra x PMFT-905) to 71.21 (RHRB-260 x RHRB-278) in E2 . On the basis of pooled mean the lowest NDF content was observed in cross Giant bajra x PMFT-905 (66.35). Fourteen, fifteen and fourteen hybrids had lower NDF content than the hybrid mean in E_1 , E_2 and over pooled mean.

4.1.17 Oxalic acid content (%) (Table 4.1.6)

The range for oxalic acid percent in parents was 1.46 (RHRB-282) to 1.67 (RHRB-259) in E_1, 1.38 (RHRB-282) to 1.75 (PMFT-907) in E_2 .On the basis of pooled mean it ranged from 1.42 (RHRB-282) to 1.65 (RHRB-278 and PMFT-907).

Among the hybrids, PMFT-907 x RHRB-278 and Giant bajra x PMFT-905 in E_1 and PMFT-904 x RHRB-259 in E_2 recorded the lowest oxalic acid percent of 1.17 and 1.25, respectively, while, the hybrids RHRB-259 x RHRB-278, PMFT-905-RHRB-278 and RHRB-260 x RHRB-278 had the highest oxalic acid percent in E_1 wheras the hyrid RHRB-260xRHRB-278 recorded 1.69 % in E_2. However, on the basis of pooled mean the lowest percent of this trait was observed in cross PMFT-904 x RHRB-259 and PMFT-907 x RHRB-282 (1.27). Sixteen, fifteen and thirteen hybrids recorded lower oxalic content than the hybrid mean in E_1, E_2 and over pooled mean.

Table 4.1.6: Mean performance of parents and hybrids for NDF, Oxalic acid and IVDMD (%) in Kharif, 2008 (E_1) , Summer, 2009 (E_2) environments and over seasons (Pooled).

S. N	Cross	NDF (%)			Oxalic Acid (%)			IVDMD (%)		
	Parents	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**	**Kh.08**	**Sum.09**	**Pooled**
1	Giant Bajra	65.00	66.40	65.70	1.50	1.42	1.46	62.90	61.85	62.38
2	PMFT 904	67.42	70.18	68.80	1.50	1.46	1.48	60.60	62.00	61.30
3	PMFT 905	66.05	68.04	67.04	1.54	1.63	1.58	57.70	58.40	58.05
4	PMFT 907	69.93	69.77	69.85	1.54	1.75	1.65	60.75	58.50	59.63
5	RHRB 259	70.10	69.38	69.74	1.67	1.59	1.63	60.00	57.60	58.80
6	RHRB 260	66.81	68.61	67.71	1.63	1.63	1.63	61.40	59.50	60.45
7	RHRB 282	68.95	67.61	68.28	1.46	1.38	1.42	60.75	60.20	60.48
8	RHRB 278	68.98	70.72	69.85	1.59	1.71	1.65	58.20	59.60	58.90
Parent mean		**67.91**	**68.84**	**68.37**	**1.55**	**1.57**	**1.56**	**60.29**	**59.71**	**60.00**
	F_1s									
1	1 x 2	67.74	66.95	67.35	1.54	1.38	1.46	61.10	60.30	60.70
2	1 x 3	65.94	66.75	66.35	1.17	1.50	1.34	65.20	63.70	64.45
3	1 x 4	70.21	69.39	69.80	1.63	1.46	1.54	57.40	59.60	58.50
4	1 x 5	67.83	69.60	68.71	1.34	1.63	1.48	63.10	60.70	61.90
5	1 x 6	68.34	67.29	67.81	1.29	1.50	1.40	61.10	58.90	60.00
6	1 x 7	67.21	68.51	67.86	1.38	1.29	1.33	60.90	61.10	61.00
7	1 x 8	68.85	68.25	68.55	1.59	1.46	1.52	57.80	59.10	58.45
8	2 x 3	66.47	67.03	66.75	1.46	1.34	1.40	60.80	57.90	59.35
9	2 x 4	66.84	67.99	67.41	1.59	1.54	1.56	58.40	60.00	59.20
10	2 x 5	67.23	68.34	67.78	1.30	1.25	1.27	57.60	60.30	58.95
11	2 x 6	68.50	69.35	68.93	1.55	1.46	1.50	61.30	62.30	61.80
12	2 x 7	66.39	67.21	66.80	1.34	1.29	1.31	63.10	62.75	62.93
13	2 x 8	67.45	68.10	67.78	1.50	1.63	1.56	56.90	58.50	57.70
14	3 x 4	66.00	67.57	66.79	1.34	1.46	1.40	61.20	61.20	61.20
15	3 x 5	67.20	68.22	67.71	1.54	1.34	1.44	61.70	62.20	61.95
16	3 x 6	71.84	69.83	70.84	1.63	1.46	1.54	56.60	60.10	58.35
17	3 x 7	66.47	67.51	66.99	1.38	1.29	1.34	60.70	61.85	61.28
18	3 x 8	67.50	70.03	68.77	1.71	1.50	1.61	61.30	62.70	62.00
19	4 x 5	68.17	69.33	68.75	1.46	1.25	1.36	58.60	60.15	59.38
20	4 x 6	69.36	70.07	69.72	1.63	1.46	1.54	59.60	58.80	59.20
21	4 x 7	70.03	68.76	69.39	1.21	1.34	1.27	57.80	59.90	58.85
22	4 x 8	69.66	68.74	69.20	1.17	1.46	1.31	61.20	61.90	61.55
23	5 x 6	65.81	67.24	66.53	1.50	1.34	1.44	58.85	58.00	58.43
24	5 x 7	69.81	70.34	70.07	1.42	1.50	1.46	60.20	60.10	60.15
25	5 x 8	69.80	68.80	69.30	1.71	1.42	1.56	60.60	58.40	59.50
26	6 x 7	68.46	69.53	69.00	1.46	1.38	1.42	61.80	59.50	60.65
27	6 x 8	68.68	71.21	69.94	1.71	1.67	1.69	62.15	60.70	61.43
28	7 x 8	68.51	67.70	68.11	1.25	1.38	1.31	61.25	60.70	60.98
Hybrid mean		**68.08**	**68.56**	**68.32**	**1.46**	**1.43**	**1.44**	**60.29**	**60.41**	**60.35**
General Mean		**68.04**	**68.62**	**68.33**	**1.48**	**1.46**	**1.47**	**60.29**	**60.25**	**60.27**
Range Parents		65.00-70.10	66.40-70.72	65.70-69.85	1.460 1.670	1.38-1.75	1.42 1.65	57.70-62.90	57.60-62.00	58.05-62.38
Range Hybrids		65.81-71.84	66.75-71.21	66.35-70.84	1.17-1.71	1.25-1.67	1.27-1.69	56.60-65.20	57.90-63.70	57.70-64.45
SE ±		0.48	0.81	0.47	0.07	0.08	0.06	0.67	0.87	0.55
CD at 5 %		1.35	2.29	1.32	0.21	0.24	0.16	1.91	2.50	1.55
C.V. %		1.22	2.05	1.70	8.68	9.99	9.62	1.56	2.05	1.81

4.1.18 *In vitro* dry matter digestibility (%) (Table 4.1.6)

The IVDMD percent for parents ranged from 57.70 (PMFT-905) to 62.90 (Giant bajra) with 60.29 as the parental mean in E_1 and from 57.60 (RHRB 259) to 62.00 (PMFT-904) with 59.71 as the parental mean in E_2. On the basis of pooled mean Giant bajra recorded the highest IVDMD percent (62.38) whereas PMFT-905 had the lowest (58.05) IVDMD percent.

Among the hybrids, the range for this trait was 56.60 (PMFT-905 x RHRB-260) to 65.20 (Giant bajra x PMFT-905) and 57.90 (PMFT-904 x PMFT-905) to 63.70 (Giant bajra x PMFT-905) in E_1 and E_2, respectively. On the basis of pooled mean the hybrid Giant bajra x PMFT-905 recorded the highest IVDMD percent (64.45) whereas the lowest was observed in PMFT-904 x RHRB-278 (57.70).

4.2 Analysis of variance

The analysis of variance for eighteen characters studied in this investigation for two diverse environments are presented in Table 4.2.1.1. The analysis of variance revealed significant differences among treatments (parents and hybrids) for all the characters in Kharif 2008 (E_1) and summer 2009 (E_2).

4.2.1 Combined analysis of variance

A combined analysis of variance in diallel set for eighteen characters in kharif 2008 (E_1) and summer 2009 (E_2) environments is presented in Tables 4.2.1.2 and 4.2.1.3, respectively. The mean sum of squares due to treatments, parents and crosses were significant for all characters in both the environments except mean sum of squares due to parents for number of tillers/plant and oxalic acid in E_1 and for crude fibre content in E_2 and except mean sum of squares due to hybrids for number of tillers in E_1.

Table :4.2.1.1 Analysis of variance for eighteen characters of pearl millet during Kharif, 2008 (E_1) and Summer, 2009 (E_2) seasons.

Sr. No.	Characters	Mean Sum of Squares(MSS)					
		Kharif, 2008 (E_1)			Summer, 2009 (E_2)		
		Repl.	Treatments	Error	Repl.	Treatments	Error
	DF	2	35	70	2	35	70
1	Days to 50 % flowering	0.06	32.86**	1.65	0.48	51.52**	1.80
2	Plant height (cm)	11.33	822.48**	24.41	152.48**	747.98**	23.51
3	Number of tillers/plant	0.33	0.72**	0.33	0.04	0.23**	0.03
4	Number of leaves/plant	0.93**	1.55**	0.18	0.81	1.17**	0.17
5	Leaf length (cm)	6.33	119.40**	7.65	9.97	138.76**	9.34
6	Leaf width (cm)	0.05	0.52**	0.02	0.18	0.35**	0.05
7	Leaf area (cm^2)	89.80	3307.63**	108.62	350.14	2318.92**	124.52
8	Leaf weight /plant (g)	11.84	200.32**	21.38	10.55	83.98**	8.26
9	Stem weight /plant (g)	176.37	3038.55**	195.92	1.57	1626.78**	186.09
10	Leaf: Stem ratio	0.06	0.09**	0.03	0.03	0.05**	0.02
11	Green forage yield (q/ha)	4949.32	27948.01**	2789.78	5232.58	26622.41**	2118.20
12	Dry matter yield (q/ha)	382.36	1587.37**	118.07	234.79	889.80**	100.07
13	Crude protein (%)	0.10	1.83**	0.21	0.34	1.15**	0.34
14	Crude fibre (%)	0.43	2.60**	0.70	0.27	1.11**	0.42
15	Acid detergent fibre (%)	0.53	4.00**	1.24	0.45	2.80**	0.83
16	Neutral detergent fibre (%)	0.45	7.33**	0.69	1.43	4.49**	1.97
17	Oxalic acid (%)	0.01	0.07**	0.02	0.01	0.05**	0.02
	DF	1	35	35	1	35	35
18	IVDMD (%)	1.67	7.98**	0.89	3.92	4.76**	1.52

*,** significant at 5 and 1 % level, respectively.

Table 4.2.1.2 : Combined Analysis of variance in Kharif, 2008 (E_1) for 18 characters in a 8 x 8 diallel set of pearl millet.

Sr. No.	Characters	Mean Sum of Squares(MSS)				
		Treatments	Parents	Hybrids	Parent Vs. Hybrids	Error
	DF	35	7	27	1	70
1	Days to 50 % flowering	32.86**	29.42**	23.33**	313.97**	1.64
2	Plant height (cm)	822.48**	7493.98**	697.41**	4706.76**	24.41
3	Number of tillers/plant	0.72**	0.59	0.75	0.70	0.50
4	Number of leaves/plant	1.55**	1.85**	1.44**	2.19**	0.18
5	Leaf length (cm)	119.40**	301.29**	76.59**	1.96	7.64
6	Leaf width (cm)	0.52**	0.62**	0.47**	0.92**	0.02
7	Leaf area (cm^2)	3307.63**	6253.70**	2595.57**	1910.74**	108.63
8	Leaf weight /plant (g)	200.32**	283.22**	176.68**	258.40**	21.38
9	Stem weight /plant (g)	3038.55**	6867.72**	1997.74**	4336.35**	195.92
10	Leaf: Stem ratio	0.08**	0.06*	0.09**	0.05	0.02
11	Green forage yield (q/ha)	27948.01**	22033.18**	26327.95**	113093.39**	2789.77
12	Dry matter yield (q/ha)	1587.37**	1616.92**	1486.38**	4107.48**	118.07
13	Crude protein (%)	1.83**	2.20**	1.60**	6.57**	0.22
14	Crude fibre (%)	2.60**	2.43**	2.73**	1.12	0.70
15	Acid detergent fibre (%)	4.00**	4.32**	4.06**	0.13	1.24
16	Neutral detergent fibre (%)	7.33**	10.49**	6.76**	0.58	0.68
17	Oxalic acid (%)	0.07**	0.01	0.08**	0.18**	0.01
	DF	35	7	27	1	35
18	IVDMD (%)	7.88**	5.63**	8.63**	0.001	0.89

*,** significant at 5 and 1 % level, respectively.

Table 4.2.1.3 : Combined Analysis of variance in Summer, 2009 (E_2) for 18 characters in a 8 x 8 diallel set of pearl millet.

Sr. No.	Characters	Mean Sum of Squares (MSS)				
		Treatments	Parents	Hybrids	Parent Vs. Hybrids	Error
		35	7	27	1	70
1	Days to 50 % flowering	51.53**	50.47**	37.20**	445.79**	1.80**
2	Plant height (cm)	747.98**	1647.36**	541.24**	34.23	23.51
3	Number of tillers/plant	0.23**	0.40**	0.19**	0.03	0.02
4	Number of leaves/plant	1.17**	3.59**	0.44**	3.89**	0.17
5	Leaf length (cm)	138.76**	412.38**	58.93**	378.80**	9.34
6	Leaf width (cm)	0.35**	0.74**	0.25**	0.43**	0.04
7	Leaf area(cm^2)	2318.92**	6942.90**	1001.65**	5517.30**	124.53
8	Leaf weight /plant (g)	83.98**	239.64**	37.68**	244.29**	8.26
9	Stem weight /plant (g)	1626.78**	3620.80**	1158.57**	310.24	186.09
10	Leaf: Stem ratio	0.05**	0.03*	0.05**	0.32**	0.01
11	Green forage yield (q/ha)	26622.41**	42253.60**	21717.42**	49638.87**	2118.15
12	Dry matter yield (q/ha)	889.80**	1648.85**	672.57**	1441.54**	100.07
13	Crude protein (%)	1.15**	1.01*	0.90**	8.98**	0.35
14	Crude fibre (%)	1.11**	0.20	1.31**	2.22*	0.42
15	Acid detergent fibre (%)	2.80**	2.56**	2.89**	2.11	0.83
16	Neutral detergent fibre (%)	4.49**	6.29**	4.14**	1.46	1.97
17	Oxalic acid (%)	0.05**	0.05*	0.04*	0.37**	0.02
	DF	35	7	27	1	35
18	IVDMD (%)	4.76**	5.07**	4.43**	6.10*	1.52

*,** significant at 5 and 1 % level, respectively.

The analysis of variance further revealed that the parents Vs. hybrids differed significantly for all the characters in both the seasons except number of tillers/plant, leaf length, L:S ratio, crude fibre (%), ADF (%), NDF (%) and IVDMD in kharif, 2008 (E_1), and except plant height, number of tillers, stem weight, ADF and NDF (%) in summer, 2009 (E_2).

4.2.2 Pooled analysis of variance

The pooled analysis of variance (Table 4.2.2) revealed that the environments differed significantly for all the characters except L:S ratio, oxalic acid and IVDMD (%). The mean sum of squares due to treatments, parents and hybrids were significant for of the characters. The mean sum of squares for parents Vs. hybrids were significant for days to 50 % flowering, plant height, leaf: stem ratio, green forage yield, dry matter yield, crude protein, oxalic acid (%), leaf area, stem weight and crude fibre (%) while non significant for number of tillers/plant, number of leaves/plant, leaf width, leaf weight, ADF, NDF and IVDMD (%).

The mean sum of squares due to the interactions of treatments x environments, parents x environments, hybrids x environments and parents vs. hybrids x environments were found significant for majority of the characters, except for number of tillers in case of treatments x environment and hybrids x environment; number of tillers, leaves per plant and oxalic acid (%) in case of parents x environment and except number of tillers, L:S ratio, crude protein, crude fibre, ADF, NDF, oxalic acid and IVDMD (%) in case of parents vs. hybrids x environments.

Table 4.2.2 : Pooled analysis of variance for 18 characters over two environments in a 8 x 8 diallel set of pearl millet.

Source of variation	DF	Mean Sum of Squares (MSS)								
		Days to 50 % flowering	Plant height (cm)	No. of tillers/ plant	No.of leaves/ plant	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Leaf weight / plant (g)	Stem weight/ plant (g)
Environments	1	888.16**	82434.48**	5.04**	96.66**	14000.56**	19.62**	216975.73**	379.08**	2123.71**
Blocks within environments	4	0.27	81.90	0.18	0.88**	8.15	0.07	219.96	11.20	88.97
Treatments	35	72.54**	1204.66**	0.72**	1.88**	193.87**	0.60**	4268.75**	167.63**	3302.52**
Parents	7	71.03**	2175.06**	0.88**	5.11**	574.81**	1.20**	11559.22**	425.21**	9260.33**
Hybrids	27	47.69**	895.03**	0.70**	1.11**	96.25**	0.46**	2519.42**	107.05**	1837.14**
Parent Vs. Hybrid	1	754.00**	2771.88**	0.31	0.12	163.10**	0.04	467.15*	0.10	1163.41*
Treatment x Environments	35	11.84**	365.79**	0.22	0.83**	64.29**	0.27**	1357.81**	116.66**	1362.81**
Parent x Environments	7	8.86**	222.28**	0.12	0.32	138.86**	0.16**	1637.38**	97.65**	1228.19**
Hybrid x Environments	27	12.84**	343.62**	0.24	0.77**	39.27**	0.26**	1077.80**	107.30**	1319.18**
P vs. hybrids x environments	1	5.76**	1969.10**	0.39	5.95**	217.66**	1.30**	6960.89**	502.58**	3483.18**
Error	140	1.72	23.96	0.19	0.17	8.49	0.03	116.58	14.82	191.01

*,** significant at 5 and 1 % level, respectively.

4.3 Combining ability analysis

4.3.1 Analysis of variance for combining ability

The combining ability ANOVA for individual environment and pooled over environments is presented in Table 4.3.1.1 and 4.3.1.2, respectively. Mean squares due to gca and sca were highly significant for all the characters in both the environments and over pooled and in pooled analysis. Further, pooled combining ability ANOVA revealed that mean squares due to gca x environment were found significant for all the characters except plant height, number of tillers, L:S ratio, crude protein, NDF, oxalic acid and IVDMD percent, while sca x environment mean of squares were significant for all the characters except number of tillers per plant. The magnitude of gca mean sum of squares was higher than sca for all the characters in both the environments except for IVDMD percent in E_1 and ADF and IVDMD percent in E_2 and except for plant height, number of leaves, leaf weight, stem weight, L:S ratio, crude protein, NDF, oxalic acid and IVDMD percent in pooled analysis.

4.3.2 General combining ability effects

General combining ability effects of the eight parents were determined separately for each environment and pooled over environments. The results of gca effect are presented character wise in Table 4.3.2.1.

4.3.2.1 Days to 50 % flowering

Genotypes which flower early, with negative gca values for this character are preferred, so that it can fit into different cropping patterns. Under the Kharif-2008 environment (E_1), the parents *viz.*, RHRB-259 (-2.25), PMFT- 907 (-1.12), PMFT-904 (-0.92) and RHRB-260 (-0.72) showed significant gca effects in the desirable direction.

In E_2, RHRB-259, PMFT- 907 (-2.13), PMFT-905 (-1.73) and PMFT-904 (-0.47) recorded significant GCA effects. The parents *viz.*, RHRB-259 (-2.19), PMFT- 907 (-1.63), PMFT-905 (-0.84) and PMFT-904 (-0.69) registered high negative gca effects in pooled analysis while, RHRB-259, PMFT- 904 and PMFT-907 displayed significant gca effects in desirable direction under both the environments.

4.3.2.2. Plant height (cm)

The parents viz., Giant bajra (10.76, 17.31), RHRB-282 (7.41, 3.16) and PMFT-905 (6.25, 4.15) displayed significant and positive gca effects in E_1 and E_2, respectively. In pooled analysis, Giant bajra (14.03), RHRB-282 (5.28), PMFT-905 (5.21) and RHRB-278 (1.46) proved to be good general combiners. The parents Giant bajra, RHRB-282 and PMFT-905 displayed the highest positive significant gca effects under both the environments.

4.3.2.3 Number of tillers per plant

More number of tillers is a desirable feature in pearl millet, since it is related to yield. Therefore, parents with positive gca values are preferable for this trait. Among parents, PMFT-905 (0.22) in the E_1, Giant bajra (6.12), RHRB-278 (0.18) and RHRB-282 (0.11) in E_2 and RHRB-278 (0.17) and PMFT-905 (0.11) in pooled analysis recorded significant positive gca effect for this trait.

4.3.2.4 Number of leaves per plant

In E_1, Giant bajra (0.42) and RHRB-282 (0.15) were found to have positive gca effects. In E_2, and pooled analysis only Giant bajra registered significantly positive gca effects of 0.76 and 0.59, respectively.

Table 4.3.1.1 : Combining ability ANOVA for 18 characters of pearl millet in kharif, 2008 (E_1) and summer, 2009 (E_2) seasons..

Characters	Mean sum of squares (MSS)											
	Kharif, 2008 (E_1)						Summer, 2009 (E_2)					
	GCA	SCA	Error	σ^2gca	σ^2sca	σ^2gca/ σ^2sca	GCA	SCA	Error	σ^2gca	σ^2sca	σ^2gca/ σ^2sca
df	7	28	70				7	28	70			
Days to 50 % flowering	26.91**	6.96**	0.55	2.64	6.41	0.41	39.25**	11.66**	0.60	3.86	11.05	0.35
Plant height (cm)	672.11**	174.67	8.14	66.40	166.53	0.40	820.27**	106.59**	7.84	81.24	98.75	0.82
No. of tillers/plant	0.31*	0.22*	0.12	0.02	0.10	0.18	0.16**	0.06**	0.01	0.01	0.05	0.32
No. of leaves/plant	0.50**	0.52**	0.06	0.04	0.46	0.10	1.61**	0.20**	0.05	0.11	0.41	0.78
Leaf length (cm)	105.01**	23.50**	2.55	10.25	20.95	0.49	163.15**	17.03**	3.11	16.00	13.92	1.15
Leaf width (cm)	0.32**	0.13**	0.01	0.03	0.13	0.25	0.32**	0.07**	0.01	0.03	0.05	0.60
Leaf area (cm^2)	2518.30**	748.60**	36.21	248.21	712.03	0.35	2636.33**	307.13**	41.51	259.48	265.63	0.98
Leaf weight / plant (g)	80.33**	63.38**	7.12	7.32	56.26	0.13	78.55**	15.35**	2.75	7.58	15.60	0.60
Stem weight / plant (g)	1963.48**	775.19	65.31	189.82	709.88	0.27	1584.69**	281.65**	62.03	152.26	219.62	0.69
Leaf: Stem ratio	0.05**	0.02**	0.01	0.004	0.014	0.30	0.03**	0.01**	0.005	0.003	0.008	0.34
Green forage yield (q/ha)	19381.16*	6799.72**	929.90	1845.14	5869.79	0.31	25515.88*	4713.70**	706.00	2480.98	4007.65	0.62
Dry matter yield (q/ha)	1120.18**	381.36**	39.56	108.08	342.00	0.32	551.65**	232.84**	33.36	51.83	199.48	0.26
Crude protein (%)	0.93**	0.53**	0.07	0.08	0.46	0.19	0.44**	0.37**	0.11	0.03	0.25	0.12
Crude fibre (%)	1.23**	0.77**	0.23	0.10	0.54	0.18	0.49**	0.34**	0.14	0.03	0.19	0.17
Acid detergent fibre (%)	2.06**	1.15**	0.41	0.16	0.73	0.22	0.86**	0.95**	0.28	0.06	0.67	0.08
Neutral detergent fibre	4.08**	2.03**	0.23	0.38	1.80	0.21	2.63**	1.21**	0.66	0.20	0.55	0.35
Oxalic acid (%)	0.03**	0.02**	0.005	0.002	0.016	0.13	0.03**	0.01*	0.007	0.002	0.007	0.29
IVDMD (%)+	2.88**	4.15**	0.44	0.24	3.70	0.06	2.33*	2.39**	0.76	0.16	1.63	0.10

*,** significant at 5 and 1 % level, respectively

Error df= 35 in case of IVDMD (%)

Table 4.3.1.2 : Pooled combining ability ANOVA over seasons for 18 characters of pearl millet.

Characters	Mean sum of squares (MSS)								
	GCA	SCA	Envir.	GCA x Env.	SCA x Env.	Error	σ^2gca	σ^2sca	σ^2gca/ σ^2sca
	7	28	1	7	28	140			
Days to 50 % flowering	61.44**	14.86**	444.08**	4.70**	3.75**	0.57	3.04	7.14	0.42
Plant height (cm)	1371.03**	159.18**	41219.24**	121.35	122.08**	7.98	68.15	75.60	0.90
No. of tillers/plant	0.38**	0.20**	2.52**	0.08	0.07	0.06	0.01	0.07	0.22
No. of leaves/plant	1.42**	0.43**	48.33**	0.23**	0.29**	0.05	0.07	0.18	0.36
Leaf length (cm)	245.44**	19.42**	7000.28**	22.71**	21.11**	2.83	12.13	8.29	1.46
Leaf width (cm)	0.50**	0.12**	9.81**	0.14**	0.08**	0.01	0.02	0.05	0.43
Leaf area (cm^2)	4518.33**	649.06**	108487.86**	636.31**	406.67**	38.86	223.97	305.10	0.73
Leaf weight / plant (g)	143.95**	33.85**	189.54**	14.92**	44.87**	4.94	6.95	14.46	0.48
Stem weight / plant (g)	3420.58**	520.91**	1061.85**	127.60*	535.93**	63.67	167.84	228.62	0.73
Leaf: Stem ratio	0.08**	0.02**	0.03*	0.008	0.01**	0.006	0.003	0.007	0.48
Green forage yield (q/ha)	32703.12**	9037.90**	532417.17**	12193.92**	2475.50**	817.99	1594.26	4109.96	0.39
Dry matter yield (q/ha)	1050.92**	460.92**	24774.79**	620.91**	153.27**	36.35	50.73	212.28	0.24
Crude protein (%)	1.18**	0.69**	0.64**	0.18	0.21**	0.09	0.05	0.30	0.18
Crude fibre (%)	1.31**	0.75**	2.43**	0.41*	0.36**	0.18	0.05	0.28	0.20
Acid detergent fibre (%)	1.92**	1.18**	8.14**	1.00**	0.91**	0.35	0.08	0.42	0.19
Neutral detergent fibre (%)	6.07**	2.44**	9.00**	0.65	0.80*	0.44	0.28	1.00	0.28
Oxalic acid (%)	0.05**	0.02**	0.01	0.006	0.01**	0.006	0.002	0.008	0.26
IVDMD (%)+	3.97**	5.07**	0.03	1.23	1.46**	0.60	0.17	2.23	0.07

*,** significant at 5 and 1 % level, respectively, + Error df= 70, in case of IVDMD (%)

An overall appraisal of the gca effects revealed that Giant bajra and RHRB-278 showed highest gca effects in E_1, E_2 and pooled analysis.

4.3.2.5 Leaf length (cm)

Significant and positive gca effects were recorded by the parents viz., Giant bajra (5.44), RHRB-278 (2.66) and PMFT-905 (1.32) in (E_1). In E_2, Giant bajra (8.00), RHRB-278 (2.81) and RHRB-282 (1.28) recorded positively significant gca effects. In pooled analysis, parent *viz.*, Giant bajra (6.72) and RHRB-278 (2.74) were found to be good general combiners.

4.3.2.6 Leaf width (cm)

The parents viz., Giant bajra (0.17), PMFT-905 (0.21) and PMFT-905 (0.14) in E_1 and Giant bajra (0.41 in E_2 displayed significant and positive gca effects. In pooled analysis, Giant bajra (0.29) and PMFT-905 (0.07) proved to be good general combiners.

4.3.2.7 Leaf area (cm^2)

Among parents, Giant bajra (23.72, 30.19), PMFT-905 (12.75, 2.73) and RHRB-278 (6.01, 6.26) recorded the significant and positive gca effects in the kharif, 2008 (E_1) and pooled analysis, respectively. While only Giant bajra (36.66) and RHRB-278 (6.52) had positive and significant gca effects in E_2.

4.3.2.8 Leaf weight (g)

More leaf weight is a desirable feature in fodder pearl millet; therefore, parents with positive gca values are preferable for this trait. Among parents, Giant bajra (5.28, 5.03, 5.15) and RHRB-282 (2.80, 3.61, 3.21) recorded significant positive gca effect for this trait in E_1 , E_2 and pooled analysis, respectively.

Table 4.3.2.1: General ability effects (gcs) of eight parents for different characters of pearl millet in Kharif-2008 (E_1) , Summer-2009 (E_2) and pooled over seasons.

Sr. No	Parents	Days to 50 % flowering			Plant height (cm)			Number of tillers/plant		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant Bajra	2.65**	2.83**	2.74**	10.76**	17.31**	14.03**	0.01	0.12**	0.06
2	PMFT-904	- 0.92**	- 0.47*	- 0.69**	- 9.06**	-5.60**	-7.33**	0.11	-0.05	0.03
3	PMFT-905	0.05	- 1.73**	- 0.84**	6.25**	4.16**	5.21**	0.22*	-0.01	0.11*
4	PMFT-907	- 1.12**	- 2.13**	- 1.63**	1.27	-2.23**	-0.48	-0.14	-0.04	-0.09
5	RHRB-259	- 2.25**	- 2.13**	- 2.19**	- 7.92**	-13.94**	-10.93**	-0.12	-0.11**	-0.12*
6	RHRB-260	- 0.72**	- 0.10	- 0.41	-10.53**	-3.94**	-7.24**	-0.30**	-0.19**	-0.24**
7	RHRB-282	0.28	1.60**	0.94**	7.41**	3.16**	5.28**	0.06	0.11**	0.08
8	RHRB-278	2.02**	2.13**	2.08**	1.84*	1.08	1.46*	0.17	0.18**	0.17**
	SE ±	0.22	0.23	0.15	0.84	0.83	0.59	0.10	0.03	0.05

Sr. No.	Parents	Number of leaves/plant			Leaf length (cm)			Leaf width (cm)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant Bajra	0.42**	0.76**	0.59**	5.44**	8.00**	6.72**	0.17**	0.41**	0.29**
2	PMFT-904	-0.18**	0.08	-0.05	-0.23	-0.90	-0.57	0.03	0.03	0.03
3	PMFT-905	0.09	-0.12	-0.02	1.32**	-2.11**	-0.39	0.21**	-0.07	0.07**
4	PMFT-907	0.05	-0.20**	-0.08	-1.42**	-1.37**	-1.40**	0.14**	-0.08*	0.03
5	RHRB-259	-0.22**	-0.37**	-0.30**	-2.88**	-5.22**	-4.05**	-0.14**	-0.06	-0.10**
6	RHRB-260	-0.24**	-0.18**	-0.21**	-4.97**	-2.50**	-3.74**	-0.33**	-0.20**	-0.27**
7	RHRB-282	0.15*	0.04	0.09	0.09	1.28*	0.69	-0.06**	-0.07	-0.06**
8	RHRB-278	-0.07	0.01	-0.03	2.66**	2.81**	2.74**	-0.02	0.05	0.01
	SE ±	0.07	0.07	0.05	0.47	0.52	0.35	0.02	0.04	0.02

Table 4.3.2.1 contd. : General ability effects (gcs) of eight parents for different characters of pearl millet in Kharif-2008 (E_1) , Summer-2009 (E_2) and pooled over seasons.

Sr. No.	Parents	Leaf area (cm^2)			Leaf weight (g)			Stem weight (g)		
A	gca	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant Bajra	23.72**	36.66**	30.19**	5.28**	5.03**	5.15**	32.45**	26.85**	29.65**
2	PMFT-904	-0.61	-1.55	-1.08	-3.14**	-0.62	-1.88**	-7.33**	0.27	-3.53*
3	PMFT-905	12.75**	-7.30**	2.73*	-2.34**	-1.99**	-2.17**	1.73	- 1.83	-0.05
4	PMFT-907	3.37	-6.63**	-1.63	-0.54	-2.13**	-1.34**	-2.41	- 8.10**	-5.26**
5	RHRB-259	-14.87**	-13.87**	-14.37**	-1.51	-1.75**	-1.63**	-10.23**	-12.30**	-11.20**
6	RHRB-260	-27.59**	-12.90**	-20.25**	0.85	-2.18**	- 0.67	-11.13**	10.60**	-10.80**
7	RHRB-282	-2.78**	-0.92	-1.85	2.80**	3.61**	3.21**	2.06	7.30**	4.68**
8	RHRB-278	6.01**	6.52**	6.26**	-1.39	0.03	-0.68	-5.14*	- 1.60	-3.37*
	SE ±	1.77	1.90	1.30	0.79	0.49	0.46	2.39	2.33	1.66

Sr. No.	Parents	Leaf: stem ratio			Green fodder yield (q/ha)			Dry matter yield (q/ha)		
A	gca	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant Bajra	-0.01**	-0.01**	-0.01**	45.88**	69.54**	57.71**	7.91**	9.60**	8.76**
2	PMFT-904	-0.01**	-0.01**	-0.01**	-27.33**	8.56	- 9.38	- 8.28**	3.23*	-2.52*
3	PMFT-905	-0.02**	-0.01**	-0.02**	33.52**	-70.20**	- 18.36**	10.36**	-10.40**	-0.03
4	PMFT-907	0.01**	0.00	0.00	-5.19	16.08*	5.45	-4.23*	0.07	-2.08*
5	RHRB-259	0.01**	0.01**	0.01**	-36.19**	-69.10**	- 52.64**	-10.90**	-11.60**	-11.30**
6	RHRB-260	0.01**	0.00	0.01**	-67.57**	-21.10**	- 44.32**	-13.40**	0.04	-6.70**
7	RHRB-282	0.01**	0.01**	0.01**	60.62**	46.35**	53.49**	14.55**	4.41*	9.48**
8	RHRB-278	0.00	0.00	0.00	-3.75	19.86**	8.06	4.05*	4.65**	4.35**
	SE ±	0.002	0.003	0.002	9.02	7.85	5.98	1.85	1.70	1.26

Table 4.3.2.1 contd.: General ability effects (gcs) of eight parents for different characters of pearl millet in Kharif-2008 (E_1) , Summer-2009 (E_2) and pooled over seasons.

Sr. No.	Parent	Crude protein (%)			Crude fibre (%)			Acid detergent fibre (%)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant Bajra	0.36**	0.07	0.21**	-0.47**	-0.08	-0.27**	- 0.60**	-0.40*	-0.50**
2	PMFT-904	0.14	0.10	0.12*	0.04	-0.16	-0.60	0.58**	-0.03	-0.31*
3	PMFT-905	0.14	-0.01	0.07	-0.18	-0.03	-0.10	0.16	0.09	-0.03
4	PMFT-907	0.05	-0.11	-0.03	-0.13	-0.10	-0.12	- 0.04	0.05	0.05
5	RHRB-259	-0.24**	0.03	-0.11	0.10	0.33**	0.22*	0.47*	0.58**	0.52**
6	RHRB-260	-0.20*	-0.15	-0.17**	0.24	0.26*	0.25**	0.03	-0.04	-0.05
7	RHRB-282	0.31**	0.39**	0.35**	-0.28*	-0.33**	-0.30**	0.09	0.03	0.06
8	RHRB-278	-0.54**	-0.32**	-0.43**	0.67**	0.11	0.39**	0.69**	-0.29	0.20
	SE ±	0.08	0.10	0.06	0.14	0.11	0.09	0.19	0.16	0.12

Sr.No.	Parents	NDF (%)			Oxalic Acid (%)			IVDMD (%)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant Bajra	-0.63**	-0.81**	-0.72**	-0.03	-0.08**	-0.02*	0.98**	0.48	0.73**
2	PMFT-904	-0.69**	-0.22	-0.46**	-0.02	-0.03	-0.01	-0.22	0.38	0.08
3	PMFT-905	-0.89**	-0.46	-0.67**	0.01	0.00	0.01	0.02	0.42	0.22
4	PMFT-907	0.77**	0.38	0.58**	-0.02	0.03	0.06**	-0.69**	-0.37	-0.53**
5	RHRB-259	0.37*	0.30	0.34*	0.03	-0.02	0.05**	-0.19	-0.72**	-0.46**
6	RHRB-260	0.22	0.42	0.32*	0.07**	0.04*	0.05**	0.15	-0.50	-0.17
7	RHRB-282	0.24	-0.28	-0.02	-0.09**	-0.09**	-0.09**	0.46*	0.40	0.43**
8	RHRB-278	0.60**	0.67**	0.64**	0.05*	0.08	0.06**	-0.50*	-0.10	-0.30
	SE ±	0.14	0.24	0.14	0.02	0.02	0.01	0.20	0.26	0.16

4.3.2.9 Stem weight (g)

In E_1, Giant bajra (32.45) was found to have positive gca effects. In E_2, Giant bajra (26.85), RHRB-260 (10.60) and RHRB-282 (7.30) and in pooled analysis only Giant bajra (29.65) and RHRB-282 (4.68) registered significantly positive gca effects. An overall appraisal of the gca effects revealed that only Giant bajra showed highest gca effects under both the environments.

4.3.2.10 Leaf : stem ratio

More L:S is a desirable feature in forage pearl millet. Among parents, PMFT-907, RHRB-259, RHRB-260 and RHRB-282 (0.01) in the E_1, RHRB-259 and RHRB-282 (0.01) in E_2 and RHRB-259 and RHRB-260 and RHRB-282 (0.01) in pooled analysis recorded significant positive gca effect for this trait. However, only RHRB-259 and RHRB-282 had positive and significant gca effect under both the environments.

4.3.2.11 Green fodder yield (q/ha)

Green fodder yield is of the utmost economic importance and of main interest in a pearl millet for fodder purpose.

Under the Kharif, 2008 (E_1), RHRB-282 (60.62), Giant bajra (45.88) and PMFT-905 (33.52) showed significant positive gca effects. In E_2, significant positive gca effects were exhibited by Giant bajra (69.54), RHRB-282 (46.35), RHRB-278 (19.86) and PMFT-907 (16.08). In pooled analysis, the desirable parents identified were Giant bajra (57.71) and RHRB-282 (53.49). Under both the environments Giant bajra and RHRB-282 exhibited significant positive gca for this trait.

4.3.2.12 Dry matter yield (q/ha)

In E_1, four parents *viz.*, RHRB-282 (14.55), PMFT-905 (10.36). Giant bajra (7.91) and RHRB-278 (4.05) displayed significant positive gca effects for this trait. In E_2, Giant bajra (9.06), RHRB-278 (4.65), RHRB-282 (4.41), and PMFT-904 (3.23) and in pooled analysis RHRB-282 (9.48), Giant bajra (8.76) and RHRB-278 (4.35) were the superior genotypes for gca effects. The parents Giant bajra, RHRB-282 and RHRB-278 expressed the significant positive gca effects, in both the environmental conditions.

4.3.2.13 Crude protein content (%)

High crude protein content is desirable fodder quality trait in pearl millet. In E_1, Giant bajra (0.36) and RHRB-282 (0.31) recorded significant positive gca effects. In E_2, only RHRB-282 (0.39) displayed significant gca effects. In pooled analysis, RHRB-282 (0.35), Giant bajra (0.21) and PMFT-904 (0.12) showed desirable and significant gca effects. The parent RHRB-282 expressed the significant positive gca effects, in both the environmental conditions.

4.3.2.14 Crude fibre (%)

Low crude fibre content is a desirable quality feature in forage pearl millet. Among parents, Giant bajra (-0.47) and RHRB-282 (-0.28) in the E_1, RHRB-282 (-0.33) in E_2 and RHRB-282 (-0.30) and Giant bajra (-0.27) in pooled analysis recorded significant negative gca effect for this trait. However, only RHRB-282 had negative and significant gca effect under both the environments.

4.3.2.15 Acid detergent fibre (%)

Low acid detergent fibre content is a desirable quality feature in forage pearl millet. Among parents, only Giant bajra had significant negative gca effect for this trait of -0.60, -0.40 and -0.50 in E_1, E_2 and pooled analysis.

4.3.2.16 Neutral detergent fibre (%)

Low neutral detergent fibre content is a desirable quality feature in forage pearl millet. Among parents, RHRB-905 (-0.89), RHRB-904 (-0.69) Giant bajra (-0.63) and in the E_1, Giant bajra (-0.81) in E_2 and Giant bajra (-0.71), RHRB-905 (-0.67) and RHRB-904 (-0.46) in pooled analysis recorded significant negative gca effect for this trait. However, only Giant bajra had negative and significant gca effect under both the environments.

4.3.2.17 Oxalic acid (%)

Low oxalic acid content is a desirable quality feature in forage pearl millet. Among parents, RHRB-282 (-0.09) in the E_1, and in E_2 and pooled analysis RHRB-282 (-0.09, -0.09), and Giant bajra (-0.08, -0.02) recorded significant negative gca effect for this trait. However, only RHRB-282 had negative and significant gca effect under both the environments.

4.3.2.18 *In vitro* dry matter digestibility (%)

High *In vitro* dry matter digestibility is desirable fodder quality trait in pearl millet. In E_1, Giant bajra (0.98) and RHRB-282 (0.46) recorded significant positive gca effects. In E_2, none of the parent displayed significant positive gca effect. In pooled analysis, both RHRB-282 and Giant bajra showed desirable and significant gca effects.

4.3.3 Specific combining ability effects

Specific combining ability effects of crosses for different characters were determined separately for each environment and results are presented character wise in Tables 4.3.3.1 to 4.3.3.6.

4.3.3.1 Days to 50 % flowering (Table 4.3.3.1)

For days to 50 % flowering nine combinations in kharif 2008 (E_1), nineteen in summer, 2009 (E_2) and seventeen from pooled analysis exhibited significant negative sca effects which is desirable direction. The sca effects ranged from – 5.42 (Giant bajra x RHRB-259) to 1.95 (RHRB-259 x RHRB-260) in E_1, -3.51 (Giant bajra x PMFT-905) to 7.23 (Giant bajra x PMFT-904) in E_2, and – 3.58 (PMFT-905 x PMFT-907) to 3.24 (Giant bajra x PMFT-904) in pooled analysis. The eight crosses viz., Giant bajra x RHRB-259, PMFT-904 x PMFT-905, PMFT-904 x RHRB-260, PMFT-905 x PMFT-907, PMFT-905 x RHRB-259, PMFT-905 x RHRB-260, PMFT-905 x RHRB-282 and RHRB-282 x RHRB-278 showed significant negative sca effects under both the environments.

4.3.3.2. Plant height (cm) (Table 4.3.3.1)

Significant sca effects were observed for this trait and the range for the same was –17.14 (Giant bajra x RHRB-259) to 27.89 (Giant bajra x PMFT-905) in E_1, –18.22 (PMFT-905 x RHRB-259) to 19.38 (RHRB-259 x RHRB-260) in E_2 and –11.62 (Giant bajra x RHRB-259) to 14.63 (Giant bajra x PMFT-905) in pooled analysis. The number of crosses, which recorded significant positive sca effects for this trait, where ten, ten and twelve in E_1, E_2 and pooled analysis, respectively. The crosses PMFT-905 x RHRB-278, RHRB-259 x RHRB-260 and RHRB-259 x RHRB-278 displayed the positive significant sca effects under both the environments.

4.3.3.3 Number of tillers per plant (Table 4.3.3.1)

For number of tillers per plant, the significant positive sca effects were noted in one, ten and five crosses in E_1, E_2 and pooled analysis, respectively. The highest magnitude of positive sca effects was observed in the cross PMFT-904 x PMFT-905 (1.46) in E_1, PMFT-904 x RHRB-260 (0.27) in E_2 and PMFT-904 x PMFT-905 (0.69) in pooled analysis. None of the same cross displayed the positive significant sca effects under both the environments.

4.3.3.4 Number of leaves per plant (Table 4.3.3.2)

The number of crosses which recorded significant positive sca effects for number of leaves per plant were ten, two and five in E_1, E_2 and pooled analysis, respectively. The highest and significant positive sca effect was noticed in the cross Giant bajra x PMFT-905 (1.47) in E_1 and RHRB-259 x RHRB- 278 in E_2 (0.65) and in pooled analysis (0.83). The cross RHRB-259 x RHRB-278 displayed the positive significant sca effects under both the environments.

4.3.3.5 Leaf length (cm) (Table 4.3.3.2)

The highest positive and significant sca effect for leaf length was recorded by the cross combination RHRB-260 x RHRB-282 (7.23) in E_1, PMFT-904 x RHRB-259 (4.76) in E_2 and Giant bajra x PMFT-905 (3.62) in pooled analysis. The significant and high positive sca effects were recorded in E_1, E_2 and pooled analysis, were recorded by eight, two and four crosses, respectively. None of the same cross displayed the positive significant sca effects under both the environments.

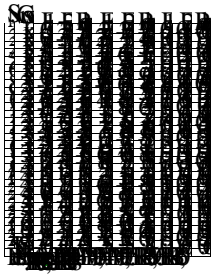


Table 4.3.3.1: Specific combining ability (SCA) for 28 crosses for days to 50 % flowering, plant height and number of tillers/plant in Kharif-2008 (E_1) , Summer-2009 (E_2) and over seasons.

	Days to 50 % flowering	Plant height (cm)	No. of tillers/plant

4.3.3.6 Leaf width (cm) (Table 4.3.3.2)

It is revealed from the data presented in Table 4.3.3.2 that the cross combination RHRB-260 x RHRB-282 (0.63) expressed highest significant positive sca effect in E_1 and Giant bajra x PMFT-905 in E2 (0.41) and in pooled analysis (0.37). The number of crosses, which recorded significant positive sca effects for this trait, were ten, two and eleven in E_1, E_2 and pooled analysis, respectively. The cross combination Giant bajra x PMFT-905 displayed the positive significant sca effects under both the environments.

4.3.3.7 Leaf area (cm^2) (Table 4.3.3.3)

For leaf area the significant positive sca effects were recorded by fifteen, three and twelve crosses in E_1, E_2 and pooled analysis, respectively. The cross combination RHRB-260 x RHRB-282 (46.33) expressed highest significant positive sca effect in E_1, RHRB-259 x RHRB-260 (15.80) in E_2 and Giant bajra x PMFT-905 (25.55) in pooled analysis. The cross combinations Giant bajra x PMFT-905 and PMFT-904 x RHRB-259 displayed the positive significant sca effects for this trait under both the environments.

4.3.3.8 Leaf weight (g) (Table 4.3.3.3)

The values of the sca effects were recorded to be significant positive in seven, two and six crosses in E_1, E_2 and pooled analysis, respectively. The cross combination RHRB-260 x RHRB-282 (15.52) expressed highest significant positive sca effect in E_1, PMFT-904 x RHRB-259 (5.09) in E_2 and RHRB-260 x RHRB-282 (6.23) in pooled analysis. None of the same cross displayed the positive significant sca effects under both the environments.

Table 4.3.3.2: Specific combining ability (SCA) for 28 crosses for number of leaves/plant, leaf length and leaf width in Kharif-2008 (E_1) , Summer-2009 (E_2) and over seasons.

S. N	Crosses	No. of leaves/plant			Leaf length (cm)			Leaf width (cm)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	1 x 2	-0.73**	-0.19	-0.46**	-7.36**	-2.59	-4.98**	-0.16*	-0.25*	-0.21**
2	1 x 3	1.47**	-0.09	0.69**	6.02**	1.21	3.62**	0.33**	0.41**	0.37**
3	1 x 4	0.95**	-0.50*	0.22	2.23	-7.02**	-2.40*	0.13	-0.35**	-0.11
4	1 x 5	-0.65**	-0.40	-0.53**	-7.61**	-5.14**	-6.38**	-0.13	-0.53**	-0.33**
5	1 x 6	-1.34**	-0.39	-0.87**	-6.45**	-0.26	-3.36**	-0.63**	-0.46**	-0.55**
6	1 x 7	0.25	-0.24	0.00	1.48	-3.30*	-0.91	0.16*	0.00	0.08
7	1 x 8	-0.60**	-0.58**	-0.63**	3.88**	-6.10**	-1.11	0.12	0.33**	0.22**
8	2 x 3	-0.84**	-0.41	-0.62**	-5.01**	-1.02	-3.01**	-0.03	-0.34**	-0.19**
9	2 x 4	0.74**	0.41	0.58**	1.83	-1.72	0.06	0.44**	0.13	0.28**
10	2 x 5	0.51*	0.41	0.46**	-2.41	4.76**	1.18	0.39**	0.11	0.25**
11	2 x 6	0.36	-0.11	0.12	4.05**	2.01	3.03**	-0.02	0.15	0.07
12	2 x 7	-0.42	0.04	-0.19	0.35	0.23	0.29	0.34**	0.05	0.19**
13	2 x 8	0.39	-0.27	0.06	-5.12**	-2.90	-4.01**	-0.67**	-0.16	-0.42**
14	3 x 4	-0.62**	0.48*	-0.07	0.42	0.65	0.53	0.59**	-0.11	0.24**
15	3 x 5	0.14	-0.09	0.03	-1.40	-3.10	-2.25*	-0.03	-0.36**	-0.20**
16	3 x 6	0.46*	-0.38	0.04	5.27**	-3.82*	0.72	0.27**	-0.02	0.12*
17	3 x 7	0.51*	-0.23	0.14	-1.60	-3.39*	-2.50*	-0.25**	-0.09	-0.17**
18	3 x 8	-0.57*	0.07	-0.25	-4.31**	0.14	-2.08	-0.39**	0.20	-0.09
19	4 x 5	0.02	-0.20	-0.09	-2.19	0.80	-0.69	-0.23**	0.08	-0.08
20	4 x 6	-0.03	0.34	0.15	1.91	1.85	1.88	0.17*	0.12	0.14*
21	4 x 7	-0.31	-0.48*	-0.40**	3.41*	-0.76	1.32	-0.01	0.12	0.05
22	4 x 8	1.01**	-0.15	0.43**	2.94*	-0.96	0.99	0.32**	-0.03	0.15*
23	5 x 6	0.24	0.11	0.17	2.37	2.26	2.31*	-0.09	0.31**	0.11
24	5 x 7	0.36*	0.06	0.21	5.27**	-1.01	2.13	0.20*	0.14	0.17**
25	5 x 8	1.01**	0.65**	0.83**	1.63	4.45**	3.04**	-0.01	-0.21	-0.11
26	6 x 7	-0.20	-0.27	-0.23	7.23**	-4.63**	1.30	0.63**	0.01	0.32**
27	6 x 8	0.62**	-0.04	0.29	-3.41**	0.90	-1.26	-0.01	-0.13	-0.07
28	7 x 8	-0.49*	-0.36*	-0.43**	-1.38	0.42	-0.48	-0.05	-0.04	-0.05
SE (Sij) ±		0.22	0.21	0.15	1.44	1.60	1.07	0.08	0.11	0.06

Parents: 1: Giant bajra, 2. PMFT-904, 3. PMFT-905, 4. PMFT-907, 5. RHRB-259, 6. RHRB-260, 7. RHRB-282, 8. RHRB-278

4.3.3.9 Stem weight (g) (Table 4.3.3.3)

The sca effects for stem weight ranged from –67.26 to 35.58 in E_1, -29.35 to 23.59 in E_2 and -26.48 to 25.99 in pooled analysis. The significant and high positive sca effects were recorded in E_1, E_2 and pooled analysis, by twelve, seven and eight crosses, respectively. The cross combination PMFT-905 x RHRB-260 (35.58) expressed highest significant positive sca effect in E_1, PMFT-904 x RHRB-259 (23.59) in E_2 and Giant bajra x PMFT-905 (25.99) in pooled analysis. The four cross combinations viz., Giant bajra x PMFT-907, PMFT-905 x PMFT-907, PMFT-905 x RHRB-259 and RHRB-259 x RHRB-278 displayed the positive significant sca effects under both the environments.

4.3.3.10 Leaf : stem ratio (Table 4.3.3.4)

Significant and positive sca effects for leaf : stem ratio were recorded by ten, one and one crosses in E_1, E_2 and pooled analysis, respectively. The highest significant positive sca effect was recorded by cross combinations Giant bajra x RHRB-260 and PMFT-907 x RHRB-278 (0.03) in E_1, RHRB-259 x RHRB-260 (0.02) in E_2 and PMFT-907 x RHRB-282 (0.02) in pooled analysis.

4.3.3.11 Green fodder yield (q/ha) (Table 4.3.3.4)

The significant and positive sca effects for green fodder yield were recorded in eight crosses in E_1 and E_2 while ten in pooled analysis. The highest magnitude of sca effect was exhibited by Giant bajra x RHRB-282 in E_1 (165.88) and in pooled analysis (120.85) while, PMFT-907 x RHRB-278 (87.57) in E_2. The five cross combinations *viz.,* Giant bajra x PMFT-905, Giant bajra x RHRB-282 PMFT-905 x PMFT-907, PMFT-907 x RHRB-278 and RHRB-259 x RHRB-260 expressed the positive significant sca effects under both the environments.

Table 4.3.3.3 : Specific combining ability (SCA) for 28 crosses for leaf area, leaf weight and stem weight in Kharif-2008 (E_1) , Summer-2009 (E_2) and over seasons.

S. N	Crosses	Leaf area (cm^2)			Leaf weight (g)			Stem weight (g)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	1 x 2	-27.87**	-19.17**	-23.52**	-6.41*	-2.91	-4.66**	-40.39**	-10.89	-25.64**
2	1 x 3	35.72**	15.39*	25.55**	2.22	2.02	2.12	31.78**	20.21**	25.99**
3	1 x 4	11.19**	-32.90**	-10.85**	6.20*	-2.18	2.01	24.58**	6.81	15.70**
4	1 x 5	-26.21**	-34.92**	-30.56**	-2.47	-4.22**	-3.35*	-10.47	-18.99**	-14.73**
5	1 x 6	-48.44**	-23.96**	-36.20**	-14.34**	-1.46	-7.90**	-67.26**	14.31*	-26.48**
6	1 x 7	10.70**	-9.36	0.67	-3.34	-2.92	-3.13*	-10.00	-6.93	-8.46
7	1 x 8	15.47**	-2.79	6.34	-1.29	0.33	-0.48	-1.24	-16.69*	-8.97
8	2 x 3	-13.78**	-14.87*	-14.32**	-3.81	-4.34	-4.08*	-14.42	-12.55	-13.49**
9	2 x 4	26.77**	1.14	13.95**	5.57*	0.13	2.85*	26.54**	-3.61	11.46*
10	2 x 5	12.33**	14.43*	13.38**	1.67	5.09**	3.38*	8.29	23.59**	15.94**
11	2 x 6	9.63**	10.83	10.23*	-1.20	0.84	-0.18	3.68	3.55	3.61
12	2 x 7	18.17**	3.00	10.59*	7.07**	-6.61**	0.23	29.09**	-27.68**	0.70
13	2 x 8	-44.45**	-11.56	-28.01**	-0.47	-0.10	-0.28	4.69	2.22	3.45
14	3 x 4	29.60**	-2.43	13.59**	4.31	2.84	3.58*	23.13**	19.15**	21.14**
15	3 x 5	-4.96*	-15.78**	-10.37*	5.43*	2.13	3.78**	15.19*	15.02*	15.10**
16	3 x 6	25.11**	-6.67	9.22*	8.79**	-4.78**	2.01	35.58**	-29.35**	3.12
17	3 x 7	-16.51**	-10.41	-13.46**	-3.39	-5.37**	-4.38**	4.61	-20.58**	-7.98
18	3 x 8	-31.99**	8.06	-11.97**	-7.78**	1.02	-3.38*	-17.14*	20.32**	1.59
19	4 x 5	-16.18**	5.27	-5.46	-1.32	-0.06	-0.69	-10.54	2.95	-3.79
20	4 x 6	10.56**	9.11	9.83*	0.44	3.69*	2.06	24.65**	8.25	16.45**
21	4 x 7	7.43**	5.50	6.46	-2.52	-1.21	-1.86	-18.25*	-8.65	-13.45*
22	4 x 8	24.75**	-2.51	11.12**	5.05*	-3.85*	0.60	18.55*	-22.41**	-1.93
23	5 x 6	0.76	15.80**	8.28*	-5.35*	1.98	-1.69	-14.92*	0.12	-7.40
24	5 x 7	22.51**	4.16	13.33**	3.72	-1.47	1.12	15.59*	-2.78	6.40
25	5 x 8	4.15	0.83	2.49	4.35	2.78	3.56*	25.61**	17.12*	21.36**
26	6 x 7	46.33**	-8.02	19.16**	15.52**	-3.05*	6.23**	21.05**	-3.15	8.95
27	6 x 8	-10.82**	-4.90	-7.86	2.95	-1.14	0.91	17.22*	-0.58	8.32
28	7 x 8	-6.98**	-0.25	-3.61	-6.45**	0.30	-3.08*	-30.34**	5.85	-12.24*
SE (Sij) ±		2.45	5.84	3.99	2.42	1.50	1.42	7.32	7.14	5.11

Parents: 1: Giant bajra, 2. PMFT-904, 3. PMFT-905, 4. PMFT-907, 5. RHRB-259, 6. RHRB-260, 7. RHRB-282, 8. RHRB-278

4.3.3.12 Dry matter yield (q/ha) (Table 4.3.3.4)

For dry matter yield, the highest and positive signicant sca effect was recorded by PMFT-907 x RHRB-278 (44.36) in E_1 and RHRB-259 x RHRB-260 in E_2 (32.63) and pooled analysis (35.33). In E_1 and pooled analysis nine and eight crosses each and in E_2 seven crosses registered significant sca effects. However, only four crosses *viz.,* PMFT905 x PMFT-907, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260 and RHRB-260 x RHRB-278 exhibited significant and positive sca effects under both the environments.

4.3.3.13 Crude protein content (%) (Table 4.3.3.5)

High crude protein content is desirable fodder quality trait in pearl millet. The frequency of crosses recording significant positive sca effects were nine, four and seven in E_1, E_2 and pooled analysis, respectively. Among them, the cross combinations PMFT-907 x RHRB-278 (1.60 in E_1)and PMFT-907 x RHRB-259 E_2(1.63) and pooled analysis (1.32). The crosses PMFT-907 x RHRB-259 and PMFT-907 x RHRB-278 expressed the significant positive sca effects, in both the environmental conditions

4.3.3.14 Crude fibre (%) (Table 4.3.3.5)

Low crude fibre content is desirable fodder quality trait in pearl millet. Significant negative sca effects were recorded by eleven crosses in E_1 and five in E_2 and six in pooled analysis. The highest significant negative sca effects was observed in cross combination PMF-907 x RHRB-278 in E_1 (–2.45) and pooled analysis (–1.55) and Giant bajra x PMFT-905 (–1.31) in E_2. The two crosses PMFT-907 x RHRB-278 and RHRB-259 x RHRB-278 expressed the significant negative sca effects, in both the environmental conditions.

Table 4.3.3.4: Specific combining ability (SCA) for 28 crosses for L:S ratio, green fodder yield and dry matter yield in Kharif-2008 (E_1) , Summer-2009 (E_2) and over seasons.

S. N	Cross	Leaf: stem ratio			Green fodder yield (q/ha)			Dry matter yield (q/ha)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	1 x 2	0.020**	-0.002**	0.008	-11.61	-43.90	-27.76	-7.00	-6.75	-6.88
2	1 x 3	-0.020**	-0.013**	-0.019*	94.21**	49.31*	71.76**	11.43*	7.92	9.68*
3	1 x 4	0.000	-0.027**	-0.015	-46.10	-156.34**	-101.22**	-6.77	-24.92**	-15.84**
4	1 x 5	-0.010**	-0.006**	-0.010	-134.43**	-114.39**	-124.41**	-29.91**	-23.39**	-26.65**
5	1 x 6	0.030**	-0.036**	-0.002	-68.89*	57.75*	-5.57	-12.26*	21.88**	4.81
6	1 x 7	0.000	-0.009**	-0.005	165.88**	75.83**	120.85**	28.38**	-5.82	11.28**
7	1 x 8	-0.010**	0.034**	0.010	22.42	30.81	26.62	6.21	-9.29	-1.54
8	2 x 3	-0.020**	-0.018**	-0.016*	-18.79	1.24	-8.78	3.46	-3.86	-0.20
9	2 x 4	-0.010**	0.009**	0.000	-31.53	38.38	3.43	-8.42	5.74	-1.34
10	2 x 5	-0.010**	-0.007**	-0.007	78.70**	43.29	60.99**	17.44**	7.42	12.43**
11	2 x 6	0.000	-0.003**	-0.002	80.45**	-4.73	37.86*	18.36**	-4.53	6.92
12	2 x 7	0.020**	0.000	0.009	82.71**	3.98	43.35*	3.14	15.20**	9.17
13	2 x 8	-0.020**	-0.007**	-0.011	-72.68*	-14.80	-43.74*	-16.92**	-4.61	-10.76**
14	3 x 4	-0.010**	-0.012**	-0.012	71.21*	66.77**	68.99**	12.35*	15.20**	13.78
15	3 x 5	0.010**	-0.014**	-0.001	3.45	32.59	18.02	-2.16	-2.68	-2.42
16	3 x 6	0.020**	0.012**	0.015	-43.36	-24.69	-34.03	-16.64**	-9.91	-13.27**
17	3 x 7	-0.030**	-0.005**	-0.015	65.08*	-83.88**	-9.40	30.21**	-7.79	11.21**
18	3 x 8	-0.050**	-0.028**	-0.039**	-59.86	-49.15*	-54.51**	-1.43	-3.63	-2.53
19	4 x 5	0.010**	-0.014**	-0.004	30.02	-32.95	-1.47	-2.55	0.18	-1.18
20	4 x 6	-0.040**	0.016**	-0.011	2.13	45.37	23.75	-6.16	-1.46	-3.81
21	4 x 7	0.030**	0.012**	0.020*	3.99	56.97*	30.48	-12.41*	-0.75	-6.58
22	4 x 8	0.000	0.012**	0.006	153.74	87.57**	120.66**	44.36**	13.86*	29.11**
23	5 x 6	0.000	0.020**	0.012	118.95	83.21**	101.08**	38.03**	32.63**	35.33**
24	5 x 7	0.010**	-0.007**	0.003	-11.09	11.67	0.29	-6.20	-1.73	-3.97
25	5 x 8	-0.020**	-0.013**	-0.015	39.69	42.28	40.98*	10.75	12.72	11.73**
26	6 x 7	0.020**	-0.020**	0.002	-86.51**	31.55	-27.48	-14.87*	3.56	-5.65
27	6 x 8	0.000	-0.010**	-0.005	58.72*	37.47	48.10*	20.83**	18.93**	19.88**
28	7 x 8	0.030**	-0.004**	0.011	-2.19	49.68*	23.75	-8.98	10.52*	0.77
SE (Sij) ±		0.001	0.001	0.008	27.65	24.09	18.33	5.68	5.24	3.86

Parents: 1: Giant bajra, 2. PMFT-904, 3. PMFT-905, 4. PMFT-907, 5. RHRB-259, 6. RHRB-260, 7. RHRB-282, 8. RHRB-278

4.3.3.15 Acid detergent fibre (%) (Table 4.3.3.5)

Low ADF content is desirable fodder quality trait in pearl millet. The the highest values of the sca effects were recorded to be significant negative in three crosses in E_1 and four crosses each in E_2 and pooled analysis. The cross combination Giant bajra x RHRB-282 (-1.57) expressed highest significant negatve sca effect in E_1, PMFT-904 x PMFT-907 (-1.64) in E_2 and Giant bajra x PMFT-905 (-0.89) in pooled analysis.

4.3.3.16 Neutral detergent fibre (%) (Table 4.3.3.6)

Low NDF content is desirable fodder quality trait in pearl millet. The significant negative sca effects were recorded by six, two and seven crosses in E_1, E_2 and pooled analysis, respectively. The cross combination RHRB-259 x RHRB-260 recorded the highest significant negative sca effect for NDF per cent (–2.82, –2.09, 2.46) in E_1, E_2 and pooled analysis, respectively.

4.3.3.17 Oxalic acid (%) (Table 4.3.3.6)

Low oxalic acid content is a desirable quality feature in forage pearl millet. Significant negative sca effects were recorded by eight, three and seven crosses in E_1, E_2 and pooled analysis, respectively. The highest significant negative sca effects was observed in PMFT-904 x RHRB-278 (-0.34) in E_1, PMFT-904 x RHRB-260 (–1.08) in E_2 and PMFT-904 x RHRB-259 (-0.18) in pooled analysis. The cross PMFT-904 x RHRB-259 exhibited significant negative sca effects, in both the environmental conditions.

Table 4.3.3.5: Specific combining ability (SCA) for 28 crosses for crude protein, crude fibre and acid detergent fibre content in Kharif-2008 (E_1), Summer-2009 (E_2) and over seasons.

S. N	Crosses	Crude protein (%)			Crude Fibre (%)			ADF (%)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	1 x 2	0.03	0.37	0.20	-0.75**	-0.49	-0.62*	0.23	0.86*	0.55
2	1 x 3	0.47	0.42	0.45*	-1.30**	-1.31**	-1.31**	-0.94	-0.84*	-0.89**
3	1 x 4	-0.76**	-0.45	-0.60**	1.70**	0.68*	1.20**	-1.35**	1.33**	-0.01
4	1 x 5	0.56*	-0.43	0.06	-0.01	0.58	0.29	0.36	-1.26**	-0.44
5	1 x 6	0.66**	-0.12	0.27	-0.82**	-0.25	-0.54*	-0.62	-0.47	-0.54
6	1 x 7	0.30	0.22	0.26	0.85**	-0.12	0.36	-1.57**	0.15	-0.71*
7	1 x 8	-0.61**	0.06	-0.27	0.49**	0.54	0.52*	-0.05	-0.36	-0.21
8	2 x 3	-0.33	0.29	-0.02	0.58**	-0.25	0.16	0.42	-0.12	0.15
9	2 x 4	-0.97**	-0.19	-0.58**	1.06**	-0.39	0.34	0.82	-1.64**	-0.41
10	2 x 5	0.78**	0.55*	0.67**	-1.10**	0.04	-0.53*	-0.73	-0.36	-0.55
11	2 x 6	0.15	0.14	0.15	-0.65**	0.22	-0.20	0.38	-0.01	0.19
12	2 x 7	0.23	0.19	0.21	0.14	-0.89**	-0.37	-0.04	0.63	0.31
13	2 x 8	0.49*	-0.85*	-0.18	0.48**	0.07	0.28	-1.30*	0.47	-0.41
14	3 x 4	0.19	-0.08	0.06	-0.02	0.20	0.09	-0.74	-0.81	-0.77*
15	3 x 5	0.63*	0.22	0.43*	-0.17	0.34	0.08	-0.01	-0.54	-.27
16	3 x 6	0.00	0.10	0.05	0.97**	0.43	0.70**	2.52**	1.11*	1.80**
17	3 x 7	0.08	0.15	0.11	0.29*	-0.45	-0.08	-0.9	-0.45	-0.70*
18	3 x 8	-0.68**	0.28	-0.20	-0.34*	0.58	0.12	1.16**	2.38**	1.77**
19	4 x 5	1.01**	1.63**	1.32**	-0.34*	-0.18	-0.26	-0.24	-0.68	-0.46
20	4 x 6	-0.64**	0.64*	0.00	0.62**	-0.74*	-0.06	-0.42	1.53**	0.56
21	4 x 7	0.17	0.21	0.19	-0.60**	-.24	-0.42	0.50	0.24	0.37
22	4 x 8	1.60**	0.82**	1.21**	-2.45**	-0.65*	-1.55**	-0.88	0.83	-0.02
23	5 x 6	0.82**	0.22	0.52**	-0.70**	-0.69*	-0.69**	-0.48	0.15	-0.16
24	5 x 7	0.02	-0.32	-0.15	-0.38*	-0.09	-0.24	1.07*	0.79	0.93**
25	5 x 8	-0.59*	0.10	-0.25	0.78**	0.18	0.48*	0.10	0.90	0.49
26	6 x 7	-0.02	0.29	0.13	0.49**	0.82**	0.65**	1.18*	0.33	0.76*
27	6 x 8	-0.78**	-0.60*	-0.69**	0.86**	0.37	0.61*	1.06*	-1.44**	-0.19
28	7 x 8	0.85**	0.46	0.66**	-0.23	-0.45	-0.34	0.04	-0.65	-0.32
SE (Sij) ±		0.24	0.30	0.19	0.14	0.30	0.24	0.51	0.42	0.33

Parents: 1: Giant bajra, 2. PMFT-904, 3. PMFT-905, 4. PMFT-907, 5. RHRB-259, 6. RHRB-260, 7. RHRB-282, 8. RHRB-278

Table 4.3.3.6: Specific combining ability (SCA) for 28 crosses for neutral detergent fibre, oxalic acid and IVDMD percent in Kharif-2008 (E_1) , Summer-2009 (E_2) and over seasons.

S. N	Crosses	NDF (%)			Oxalic Acid (%)			IVDMD (%)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	1 x 2	1.02**	-0.64	0.19	0.10	-0.04	0.03	0.05	-0.82	-0.38
2	1 x 3	-0.59	-0.61	-0.60	-0.27**	0.05	-0.11**	3.90**	2.54**	3.22**
3	1 x 4	2.01**	1.20	1.60**	0.21**	-0.02	0.09*	-3.17**	-0.77	-1.97**
4	1 x 5	0.04	1.48**	0.76*	-0.14*	0.019	0.03	2.03**	0.68	1.36***
5	1 x 6	0.69	-0.94	-0.12	-0.22**	0.09	-0.10*	-0.33	-1.34	-0.83
6	1 x 7	-0.45	0.98	0.26	0.03	-0.07	-0.01	-0.83	-0.04	-0.44
7	1 x 8	0.83*	-0.24	0.30	0.09	-0.07	0.01	-2.97**	-1.53*	-2.25**
8	2 x 3	0.03	-0.91	-0.45	-0.01	-0.09	-0.05	0.70	-3.15**	-1.22**
9	2 x 4	-1.29**	-0.79	-1.03**	0.13*	0.08	0.10*	-0.98	-0.26	-0.62
10	2 x 5	-0.49	-0.36	-0.42	-0.21**	-0.15*	-0.18**	-2.27**	0.39	-0.94*
11	2 x 6	0.93*	0.54	0.73	-0.01	-1.08	-0.05	1.07*	2.17**	1.62**
12	2 x 7	-1.19**	-0.90	-1.05**	-0.04	-0.04	-0.04	2.57**	1.71**	2.14**
13	2 x 8	-0.50	-0.96	-0.73	-0.02	0.12*	0.04	-2.67**	-2.03**	-2.35**
14	3 x 4	-1.92**	-0.97	-1.50**	-0.12*	-0.03	-0.07	1.57*	0.90	1.24*
15	3 x 5	-0.32	-0.25	-0.28	0.03	-0.10	-0.03	1.57*	2.25**	1.92**
16	3 x 6	4.46**	1.25	2.85**	0.08	-0.04	0.01	-3.88**	-0.07	-1.98**
17	3 x 7	-0.93*	-0.37	-0.62	-0.04	-0.07	-0.04	-0.08	0.77	0.35
18	3 x 8	-0.26	1.20	0.47	0.18**	-0.03	0.07	1.48*	2.13**	1.81**
19	4 x 5	-1.01*	0.02	-0.49	-0.03	-0.22*	-0.12**	-0.80	0.99	0.09
20	4 x 6	0.32	0.66	0.49	0.09	-0.07	0.01	-0.16	-0.59	-0.37
21	4 x 7	0.97*	0.03	0.50	-0.15*	-0.06	-0.10*	-2.26**	-0.38	-1.32*
22	4 x 8	0.24	-0.93	-0.34	-0.34**	-0.11*	-0.22**	2.10**	2.12**	2.12**
23	5 x 6	-2.82**	-2.09**	-2.46**	-0.08	-0.10	-0.09*	-1.40*	-1.03	-1.22**
24	5 x 7	1.16**	1.69**	1.42**	0.03	0.15*	0.08*	-0.36	0.16	-0.09
25	5 x 8	0.79*	-0.80	-0.04	0.15**	-0.10	0.02	1.09*	-1.02	-0.08
26	6 x 7	-0.04	0.78	0.36	0.05	-0.03	-0.01	0.89	-0.66	0.12
27	6 x 8	-0.19	1.50*	0.65	0.11	0.08	0.09*	2.20**	1.05	1.62**
28	7 x 8	-0.38	-1.31*	-0.84*	-0.18**	-0.07	-0.12**	0.99	0.15	0.58
SE (Sij) ±		0.38	0.64	0.37	0.06	0.06	0.04	0.53	0.69	0.43

Parents: 1: Giant bajra, 2. PMFT-904, 3. PMFT-905, 4. PMFT-907, 5. RHRB-259, 6. RHRB-260, 7. RHRB-282, 8. RHRB-278

4.3.3.18 *In vitro* dry matter digestibility (%) (Table 4.3.3.6)

High *in vitro* dry matter digestibility is desirable fodder quality trait in pearl millet. The frequency of crosses recording significant sca effects were ten, six and nine in E_1, E_2 and pooled analysis, respectively. Among the crosses, Giant bajra x PMFT- 905 exhibited the highest significant positive sca effect (3.90, 2.54, 3.22) in E_1, E_2 and and pooled analysis, respectively. However,the five crosses viz., Giant bajra x MFT-905, PMFT-904 x RHRB-282, PMFT-905 x RHRB-259, PMFT-905 x RHRB-278 and PMFT-907 x RHRB-278 expressed the significant positive sca effects, in both the environmental conditions.

4.3.4 Gene action

The estimates of variance components (σ^2gca and σ^2sca) and their ratio for different characters are presented in Table 4.3.1.1 (kharif 2008 (E_1) and summer 2009 (E_2)) and Table 4.3.1.2 (pooled analysis).

From Table 4.3.1.1 and 4.3.1.2, it is observed that the genetic variance due to σ^2sca were of higher magnitude than that of σ^2gca for all the characters in kharif 2008 (E1), summer, 2009 (E2) seasons and in pooled analysis except for leaf length in summer, 2009 (E2) season and in pooled analysis in which σ^2gca is of higher magnitude than σ^2sca.

4.4. Heterosis (%)

In the present study, most of the hybrids showed the existence of considerable heterosis for yield and its component characters. The degree and magnitude of heterosis varied from cross to cross for all the characters studied.

The extent of per cent increase or decrease of F_1 over mid parent (MP) i.e. relative heterosis and better parent *i.e.*

heterobeltiosis (BP) was estimated for all the characters in kharif-2008 (E_1), summer-2009 (E_2) environments and pooled analysis. The results are presented below in Tables 4.4.1 to 4.4.9

Days to 50 per cent flowering (Table 4.4.1)

Since earliness in flowering is desirable, the hybrids showing negative heterosis are of immense value in breeding.

The range of relative heterosis was -17.68 (Giant bajra x RHRB-259) to -1.96 (PMFT-904 x RHRB-278) in E_1, –17.03 (PMFT-905 x PMFT-907) to 9.52 (Giant bajra x PMFT-904) in E_2 environments and –16.56 (PMFT-905 x PMFT-907) to 0.92 (Giant bajra x PMFT-904) in pooled analysis. The number of crosses that registered significant negative relative heterosis were twenty three in E_1, twenty four in E_2 and twenty five in pooled analysis.

The range of heterobeltiosis was -12.08 (PMFT-904 x PMFT-905) to 1.41 (RHRB-259 x RHRB-278) in E_1, –15.03 (PMFT-905 x RHRB-282, PMFT-905 x RHRB-278) to 17.95 (Giant bajra x PMFT-904) in E_2 environments and -12.42 (PMFT-905 x RHRB-282) to 8.20 (Giant bajra x PMFT-904) in pooled analysis. The number of crosses that registered significant negative heterobeltiosis were fifteen in E_1 and sixteen each E2 and in pooled analysis.

Plant height (cm) (Table 4.4.1)

The positive heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -6.17 (Giant bajra x RHRB-259) to 26.19 (PMFT-905 X RHRB-278) in E_1, –13.05 (PMFT-905 x RHRB-259) to 19.88 (RHRB-259x RHRB-260) in E_2 environments and –7.76 (Giant bajra X RHRB-259) to 18.11 (PMFT-905 X RHRB-278) in pooled analysis. The number of crosses that registered significant positive relative heterosis were

Table 4.4.1: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for days to 50 per cent flowering and plant height (cm) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Days to 50 per cent flowering						Plant height (cm)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	-8.18**	9.52**	0.92	-2.01	17.95**	8.20**	1.23	-11.83**	-4.95*	-9.04*	-26.06**	-17.39**
2	Giant bajra X PMFT-905	-7.88**	-16.15**	-12.16**	-5.59**	-14.45**	-10.19**	24.77**	-1.49	12.17**	14.29**	-13.45**	0.69
3	Giant bajra X PMFT-907	-2.24	-7.88**	-5.14**	6.25**	1.33	3.73	10.16**	-2.74	4.23*	4.06	-18.74**	-7.12**
4	Giant bajra X RHRB-259	-17.68**	-7.55**	-12.47**	-9.86**	1.32	-4.10	-6.17	-9.60**	-7.76**	-15.78**	-26.96**	-21.26**
5	Giant bajra X RHRB-260	-7.01**	-9.14**	-8.14**	0.69	-6.47**	-3.18	-3.29	4.24	0.28	-15.39**	-14.53**	-14.97**
6	Giant bajra X RHRB-282	-7.74**	-9.55**	-8.69**	-3.25	-8.52**	-6.05**	10.64**	-8.96**	1.32	6.15	-17.49**	-5.44**
7	Giant bajra X RHRB-278	-4.91**	-7.56**	-6.31**	1.27	-6.78**	-4.20**	2.16	-9.20**	-3.26*	-6.28	-20.99**	-13.49**
8	PMFT-904 X PMFT-905	-15.48**	-13.07**	-14.23**	-12.08**	-8.33**	-10.15**	4.28	7.76**	5.88**	2.10	2.07	2.08
9	PMFT-904 X PMFT-907	-9.90**	-6.54**	-8.18**	-8.33**	-4.67*	-6.47**	3.69	13.80**	8.09	-1.69	13.29**	5.04
10	PMFT-904 X RHRB-259	-9.97**	-8.79**	-9.35**	-7.75**	-7.28**	-7.50**	13.08**	-7.46**	4.07**	12.94**	-11.65**	1.88
11	PMFT-904 X RHRB-260	-10.20**	-9.82**	-10.00**	-8.97**	-5.77**	-8.52**	7.93*	12.41**	9.95	4.72	9.31**	6.78*
12	PMFT-904 X RHRB-282	-7.59**	-9.04**	-8.34**	-6.04**	-3.21	-4.58**	7.92**	-0.58	4.05**	0.77	-8.86**	-3.65
13	PMFT-904 X RHRB-278	-1.96	-2.10	-2.03	0.67	4.49*	2.64	8.43*	-2.01	3.67	5.98	-6.18*	0.38
14	PMFT-905 X PMFT-907	-16.07**	-17.03**	-16.56**	-11.11**	-10.67**	-10.88**	12.88**	19.44**	15.79**	9.23*	12.65**	14.85*
15	PMFT-905 X RHRB-259	-14.85**	-16.67**	-15.79**	-9.15**	-10.60**	-9.89**	11.87**	-13.05**	0.70**	9.38*	-21.16**	-4.87
16	PMFT-905 X RHRB-260	-12.42**	-15.45**	-14.02**	-7.59**	-14.71**	-11.43**	12.68**	4.01	8.70**	7.10**	-4.05	1.90
17	PMFT-905 X RHRB-282	-9.84**	-15.76**	-12.95**	-7.79**	-15.03**	-12.42**	22.29**	-0.62	11.68*	16.52**	-4.01	7.08**
18	PMFT-905 X RHRB-278	-5.03***	-16.00**	-10.78**	-3.82	-15.03**	-10.78**	26.19**	8.77**	18.11**	25.99**	7.56**	17.60**
19	PMFT-907 X RHRB-259	-8.39**	-4.32*	-6.31**	-7.75**	-4.00	-6.14**	6.04	4.17	5.25*	0.42	-0.10	0.20
20	PMFT-907 X RHRB-260	-5.88**	-8.13**	-7.05**	-5.56*	-2.00	-3.73	7.39*	13.12**	9.88**	-1.05	10.50**	3.81
21	PMFT-907 X RHRB-282	-6.04**	-2.45	-4.17*	-2.78	6.00**	1.69	2.67	-7.43	-1.78	1.03	-15.49**	-6.56**
22	PMFT-907 X RHRB-278	-2.99	-5.81**	-4.46*	1.39	2.67	2.04	8.01*	0.91	4.88*	4.68	-3.81	4.47
23	RHRB-259 X RHRB-260	-2.44	-12.15**	-7.57**	-1.41	-6.62**	-4.10	10.70**	19.88**	14.73**	7.54**	17.64**	13.80**
24	RHRB-259 X RHRB-282	-10.14**	-4.59*	-7.21**	-6.34**	3.31	-1.35*	4.13	-4.94	0.09	-2.88	-16.45**	-9.11**
25	RHRB-259 X RHRB-278	-3.68*	-1.22	-2.39	1.41	7.28**	4.44*	16.33**	4.34	11.00**	13.57**	-4.42	5.29*
26	RHRB-260 X RHRB-282	-5.02**	-8.09**	-6.66**	-2.07	-6.47**	-4.44*	12.75**	-5.54*	4.42	2.38	-15.58**	-5.87*
27	RHRB-260 X RHRB-278	-3.31	-10.09**	-6.94**	0.69	-8.24**	-4.13**	20.09**	3.47	12.52**	13.98**	-3.54	5.91*
28	RHRB-282 X RHRB-278	-8.68**	-9.35**	-9.04**	-7.79**	-9.09	-8.49	8.77*	9.15**	8.95**	3.80	4.29	4.03
	SED	0.90	0.95	0.93	1.05	1.10	1.07	3.49	3.42	3.46	4.03	3.96	4.00

nineteen, eight and seventeen in E_1, E_2 and in pooled analysis, respectively.

The range of heterobeltiosis was -15.78 (Giant bajra X RHRB-259) to 25.99 (PMFT-905 X RHRB-278) in E_1, –26.96 (Giant bajra X RHRB-259) to 17.64 (RHRB-259 X RHRB-260) in E_2 environments and -21.26 (Giant bajra X RHRB-259) to 17.60 (PMFT-905 X RHRB-278) in pooled analysis. The number of crosses that registered significant positive heterobeltiosis were ten, six and seven in E_1, E_2 and in pooled analysis, respectively.

Number of tillers per plant(Table 4.4.2)

The positive heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -17.92 (PMFT-904 X RHRB-278) to 47.83 (PMFT-904 X PMFT-905) in E_1, –18.32 (Giant bajra X PMFT-904) to 12.35 (PMFT-904 x RHRB-260) in E_2 environments and –18.88 (PMFT-905 x RHRB-278) to 20.61 (PMFT-904 x PMFT-905) in pooled analysis. The number of crosses that registered significant positive relative heterosis were three, six and one in E_1, E_2 and in pooled analysis, respectively.

The range of heterobeltiosis was -26.13 (PMFT-905 x RHRB-260) to 37.84 (PMFT-904 x PMFT-905) in E_1, –22.77 (Giant bajra x PMFT-904) to 7.69 (RHRB-259 x RHRB-260) in E_2 environments and -23.43 (PMFT-905 x RHRB-260) to 13.71 (PMFT-904 x RHRB-905) in pooled analysis.

Number of leaves per plant (Table 4.4.2)

In E_1, the crosses *i.e.* Giant bajra x RHRB-260 and RHRB-259 x RHRB-278 exhibited the minimum and maximum relative heterosis, respectively; it varied from –16.54 to 22.51. In E_2, the two crosses *viz.*, Giant bajra x RHRB-278 and RHRB-259 x RHRB-278 recorded the minimum and maximum relative

Table 4.4.2: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for number of tillers/plant and number of leaves/plant in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Number of tillers/plant						Number of leaves/plant					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	-7.45	-18.32**	-12.97	-9.37	-22.77**	-14.60	-10.02**	-9.23**	-9.67**	-17.11**	-20.46**	-18.86**
2	Giant bajra X PMFT-905	9.36	-1.00	4.17	0.00	-1.98	0.00	15.26**	-9.68**	3.15	7.72*	-21.45**	-6.99*
3	Giant bajra X PMFT-907	-3.49	-15.34**	-9.63	-9.78	-20.79**	-15.53	13.43**	-13.23**	0.34	2.01	-26.40**	-12.38**
4	Giant bajra X RHRB-259	22.47*	10.61**	16.64	18.48	-1.98	7.76	-4.98	-10.53**	-7.67*	-16.78**	-27.06**	-21.96**
5	Giant bajra X RHRB-260	19.77	7.51	13.74	11.96	-7.92	1.55	-16.54**	-13.52**	-15.04**	-23.83**	-25.08**	-24.45**
6	Giant bajra X RHRB-282	3.16	-5.15	-0.94	0.00	-8.91*	-1.55	-0.17	-13.30**	-6.63*	-4.03	-21.45**	-12.87**
7	Giant bajra X RHRB-278	15.38	2.94	9.17	3.45	1.94	2.74	-5.97	-15.14**	-10.59**	-15.44**	-25.08**	-20.36**
8	PMFT-904 X PMFT-905	47.83**	-8.99**	20.61*	37.84**	-13.13**	13.71	-8.24*	-7.96*	-8.05*	-9.65	-8.77	-8.45*
9	PMFT-904 X PMFT-907	20.45	4.49	12.54	10.42	3.33	7.10	14.52**	4.78	9.96*	11.55**	0.88	6.52
10	PMFT-904 X RHRB-259	15.38	4.76	10.46	9.37	-2.22	3.87	11.58**	7.40	9.66*	5.58	-1.32	2.38
11	PMFT-904 X RHRB-260	7.95	12.35**	10.12	-1.04	1.11	0.00	4.63	-4.44	0.38	3.59	-5.70	-0.75
12	PMFT-904 X RHRB-282	4.12	2.73	3.50	3.06	1.08	2.20	-5.70	-4.64	-5.16	-9.82	-8.13	-8.99*
13	PMFT-904 X RHRB-278	-17.92	-8.81*	-13.48	-25.00	-14.56**	-20.00*	8.79	-6.09	1.58	5.98	-6.90	0.63
14	PMFT-905 X PMFT-907	2.62	-8.02*	-2.54	-11.71	-13.13**	-12.29	-0.60	3.91	1.48	-4.63	0.89	-2.11
15	PMFT-905 X RHRB-259	-10.66	-11.86**	-11.08	-20.72	-21.21**	-20.86*	8.49	-1.69	3.81	1.16	-8.93	-3.48
16	PMFT-905 X RHRB-260	-14.14	-7.60	-11.11	-26.13	-20.20**	-23.43*	7.33	-9.87*	-0.69	4.63	-10.27	-2.24
17	PMFT-905 X RHRB-282	12.92	3.13	8.38	6.31	0.00	3.43	6.37	-9.79*	-1.14	3.27	-13.82**	-4.72
18	PMFT-905 X RHRB-278	-21.59	-15.84**	-18.88*	-23.28	-17.48**	-20.55	-1.41	-3.51	-2.39	-5.41	-5.17	-3.73
19	PMFT-907 X RHRB-259	8.43	-1.20	3.80	4.65	-6.82	2.50	11.26**	-1.49	5.28	7.98	-6.16	1.34
20	PMFT-907 X RHRB-260	7.50	1.25	4.32	7.50	-7.95	-0.71	5.37	1.62	3.66	3.66	-0.90	1.54
21	PMFT-907 X RHRB-282	25.84*	9.39*	17.73	14.29	6.45	10.69	0.58	-11.60**	-5.07	-6.18	-17.89**	-11.64*
22	PMFT-907 X RHRB-278	19.39	6.81	13.18	0.86	-0.97	0.00	22.27**	-4.74	9.34*	22.27**	-9.05*	6.90
23	RHRB-259 X RHRB-260	4.82	12.00*	8.37	1.16	7.69*	4.40	8.51*	0.73	4.89	3.66	-6.31	-1.03
24	RHRB-259 X RHRB-282	6.52	8.77*	7.61	0.00	0.00	0.00	8.22*	-2.52	3.21	-1.82	-13.41**	-7.26
25	RHRB-259 X RHRB-278	7.92	8.29*	8.15	-6.03	-4.85	-5.48	22.51**	8.75*	15.93**	18.91**	-0.86	9.20*
26	RHRB-260 X RHRB-282	7.87	10.30*	9.28	-2.04	-2.15	-1.89	-2.88	-10.68**	-6.55	-8.00*	-15.04**	-11.29**
27	RHRB-260 X RHRB-278	-1.02	4.00	1.29	-16.38	-11.65**	-14.25	11.98**	-5.29	3.65	10.16*	-7.33	3.45
28	RHRB-282 X RHRB-278	-12.15	-8.16*	-10.10	-18.97	-12.62**	-15.89	-2.92	-11.30**	-6.97	-9.45*	-13.82**	-11.52*
	SED	0.42	0.12	0.31	0.49	0.14	0.36	0.30	0.29	0.30	0.35	0.33	0.34

respectively, ranging from –15.14 to 8.75, while in pooled analysis the range for relative heterosis was -15.04 (Giant bajra x RHRB-260) to 15.93 (RHRB-259 x RHRB-278). The number of crosses that registered significant positive relative heterosis were ten, one and four in E_1, E_2 and in pooled analysis, respectively.

The heterobeltiosis ranged from –23.83 (Giant bajra x RHRB-260) to 22.27 (PMFT-907 x RHRB-278) in E_1, -27.06 (Giant bajra x RHRB-259) to 0.89 (PMFT-905 x PMFT-907) in E_2 environments and -24.45 (Giant bajra x RHRB-260) to 9.2 (RHRB-259 x RHRB-278) in pooled analysis. The number of crosses that registered significant positive in heterobeltiosis were five and one in E_1 and pooled analysis, respectively.

Leaf length (cm) (Table 4.4.3)

The relative heterosis ranged from –15.93 (Giant bajra x PMFT-904) to 23.51 (RHRB-260 x RHRB-282) in E_1, -21.66 (Giant bajra x PMFT-907) to 11.17 (PMFT-904 x RHRB-259) in E_2 and -15.31 (Giant bajra x RHRB-259) to 6.33 (PMFT-907 x RHRB-260) in pooled analysis. The significant and positive relative heterosis were recorded in E_1 and E_2 by eight and one crosses, respectively.

The heterosis expressed over the better parent varied from –24.68 (Giant bajra x RHRB-260) to 15.34 (RHRB-260 xRHRB-282) in E_1, -37.06 (Giant bajra x RHRB-259) to -0.32 (PMFT-904 x RHRB-259) in E_2 environments and -30.18 (Giant bajra x RHRB-259) to 4.30 (RHRB-259 x RHRB-260) in pooled analysis. In E_1, three crosses expressed positive significant heterobeltiosis. However, the heterobeltiosis for this trait was very less in summer, 2009 (E_2) environment.

Table 4.4.3: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for leaf length (cm) and leaf width (cm) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Leaf length (cm)						Leaf width (cm)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	-15.93**	-13.09**	-14.64**	-20.13**	-28.57**	-24.27**	-3.70	-15.49**	-9.65*	-10.34**	-26.23**	-18.64**
2	Giant bajra X PMFT-905	5.01*	-10.28**	-2.06	-2.38	-25.35**	-13.64**	10.71**	3.38	7.09	6.90	-12.30**	-3.02
3	Giant bajra X PMFT-907	4.01	-21.66**	-8.35**	-10.14**	-34.62**	-22.15**	12.62**	-17.24**	-2.35	0.00	-31.15**	-16.12**
4	Giant bajra X RHRB-259	-14.21**	-16.67**	-15.31**	-23.57**	-37.06**	-30.18**	-4.31	-24.76**	-14.74**	-13.79**	-35.25**	-24.94**
5	Giant bajra X RHRB-260	-8.21	-9.98**	-9.07**	-24.68**	-27.66**	-26.15**	-18.56**	-21.03**	-19.88**	-31.90**	-36.89**	-34.51**
6	Giant bajra X RHRB-282	4.40	-17.10**	-6.22*	-9.23**	-26.75**	-17.82**	11.00**	-5.00	2.85	-4.31	-22.13**	-13.60**
7	Giant bajra X RHRB-278	0.60	-18.22**	-8.19**	-3.33	-28.32**	-15.58**	-2.63	2.86	0.00	-4.31	-11.48**	-8.06*
8	PMFT-904 X PMFT-905	-11.60**	-6.90	-9.65**	-13.60**	-8.32	-10.28**	4.81	-17.05**	-5.31	0.93	-19.78**	-5.90
9	PMFT-904 X PMFT-907	1.53	-7.19	-2.28	-8.19**	-8.93	-7.04	27.37**	1.16	15.09**	21.00**	-4.40	9.12
10	PMFT-904 X RHRB-259	-9.78**	11.17*	-1.44	-15.71**	-0.32	-9.44*	15.03**	-2.79	6.45	11.00**	-4.40	3.77
11	PMFT-904 X RHRB-260	5.19	2.54	4.02	-9.95**	-0.38	-6.06	4.49	2.44	3.51	-7.00	-7.69	-7.23
12	PMFT-904 X RHRB-282	0.89	-5.58	-2.03	-8.14**	-13.16**	-3.41	21.74**	0.59	11.56*	12.00**	-6.59	3.14
13	PMFT-904 X RHRB-278	-13.02**	-7.47	-10.66**	-14.05**	-14.18**	-14.10**	-21.70**	-8.38	-15.51**	-25.89**	-9.89	-17.42**
14	PMFT-905 X PMFT-907	4.34	-6.43	-0.47	-3.64	-6.78	-4.68	32.32**	-7.23	14.33**	21.30**	-9.41	7.76
15	PMFT-905 X RHRB-259	-3.81	-9.82*	-6.26	-8.16*	-20.24**	-13.30**	3.48	-19.08**	-7.05	-3.70	-20.45**	-9.94*
16	PMFT-905 X RHRB-260	12.44**	-12.78**	1.12	-1.84	-16.51**	-8.10*	15.05**	-3.80	6.27	-0.93	-10.59	-5.28
17	PMFT-905 X RHRB-282	2.88	-15.26**	-5.52	-4.33	-20.96**	-6.19	4.17	-4.29	0.34	-7.41*	-8.24	-7.76
18	PMFT-905 X RHRB-278	-7.87**	-5.58	-6.87*	-11.00**	-11.17**	-11.06**	-11.82**	4.05	-4.73	-13.39**	2.27	-6.31
19	PMFT-907 X RHRB-259	-1.00	-0.49	-0.77	-4.41	-12.26**	-4.34	4.92	-1.78	1.53	3.23	-5.68	-1.32
20	PMFT-907 X RHRB-260	12.65**	-0.71	6.33	5.93	-5.30	0.66	21.43**	3.90	12.85**	13.33**	-1.23	6.32
21	PMFT-907 X RHRB-282	15.78**	-9.76*	3.40	14.91**	-15.53**	-0.29	20.69**	5.66	13.51**	16.67**	3.70	10.53*
22	PMFT-907 X RHRB-278	5.96*	-6.55	0.28	-5.20	-11.77**	-8.09*	14.85**	-1.78	7.44	3.57	-5.68	-0.30
23	RHRB-259 X RHRB-260	6.71*	5.75	6.29	-2.89	-2.65	4.30	0.58	6.83	3.61	-7.53	-2.27	-4.97
24	RHRB-259 X RHRB-282	12.30**	-6.52	3.90	9.22**	-22.14**	-3.27	16.38**	2.41	9.44*	10.75**	-3.41	3.64
25	RHRB-259 X RHRB-278	-1.26	8.22	2.69	-8.77**	-9.20	-8.96*	-4.39	-11.36*	-7.72	-12.50**	-11.36	-12.01**
26	RHRB-260 X RHRB-282	23.51**	-14.70**	4.82	15.34**	-23.59**	-4.11	35.80**	1.99	19.54**	30.95**	-1.28	15.56**
27	RHRB-260 X RHRB-278	-3.22	-0.97	-2.19	-17.96**	-10.56*	-14.70**	-3.16	-5.59	-4.27	-17.86**	-13.64*	-15.92**
28	RHRB-282 X RHRB-278	1.24	-6.02	-2.15	-8.81**	-6.88	-7.19*	1.02	0.00	0.50	-11.61**	-5.68	-9.01
	SED	1.95	2.16	2.06	2.26	2.50	2.38	0.10	0.15	0.13	0.12	0.17	0.15

Leaf width (cm) (Table 4.4.3)

The positive heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -21.70 (PMFT-904 x RHRB-278) to 35.80 (RHRB-260 x RHRB-282) in E_1, –24.76 (Giant bajra x RHRB-259) to 6.83 (RHRB-259 x RHRB-260) in E_2 environments and –19.88 (Giant bajra x RHRB-260) to 19.54 (RHRB-260 x RHRB-282) in pooled analysis. The number of crosses that registered significant positive relative heterosis were thirteen and seven in E_1 and in pooled analysis, respectively.

The range of heterobeltiosis was -31.90 (Giant bajra x RHRB-260) to 30.95 (RHRB-260 x RHRB-282) in E_1, –36.89 (Giant bajra x RHRB-260) to 3.70 (PMFT-907 x RHRB-282) in E_2 environments and -34.51 (Giant bajra x RHRB-260) to 15.56 (RHRB-260 x RHRB-282) in pooled analysis. The number of crosses that registered significant positive heterobeltiosis were eight and two in E_1 and in pooled analysis, respectively.

Leaf area (cm^2) (Table 4.4.4)

In E_1, the crosses *i.e.* PMFT-904 x RHRB-278 and RHRB-260 x RHRB-282 exhibited the minimum (-31.50) and maximum (65.69) relative heterosis, respectively; in E_2, the minimum (-39.71) and maximum (12.90 relative heterosis was observed in the crosses Giant bajra x RHRB-259 and RHRB-259 x RHRB-260, respectively, while in pooled analysis the range for relative heterosis was -30.32 (Giant bajra x RHRB-260) to 28.33 (RHRB-260 x RHRB-282). The number of crosses that registered significant positive relative heterosis were eleven and six in E_1 and in pooled analysis, respectively.

The heterosis expressed over the better parent varied from –48.62 (Giant bajra x RHRB-260) to 49.14 (RHRB-260 x RHRB-282) in E_1, -58.76 (Giant bajra x RHRB-259) to 12.42

(RHRB-259 x RHRB-260) in E_2 environments and -51.19 (Giant bajra x RHRB-260) to 19.17 (PMFt-907 x RHRB-282) in pooled analysis. In E_1 and pooled analysis three and one crosses, respectively expressed positive significant heterobeltiosis.

Leaf weight (g) (Table 4.4.4)

The positive heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -43.63 (Giant bajra x RHRB-260) to 70.56 (PMFT-905 x RHRB-260) in E_1, –30.59 (PMFT-904 x PMFT-905) to 24.54 (RHRB-259 x RHRB-282) in E_2 environments and –30.72 (Giant bajra x RHRB-260) to 35.55 (RHRB-260 x RHRB-282) in pooled analysis. The number of crosses that registered significant positive relative heterosis were ten, five and seven in E_1, E_2 and in pooled analysis, respectively.

The range of heterobeltiosis was -59.51 (Giant bajra x RHRB-260) to 67.02 (PMFT-905 x RHRB-260) in E_1, –40.98 (Giant bajra x RHRB-259) to 14.05 (RHRB-282 x RHRB-278) in E_2 environments and -48.36 (Giant bajra x RHRB-260) to 32.86 (RHRB-260 x RHRB-282) in pooled analysis. The number of crosses that registered significant positive heterobeltiosis were seven, three and four in E_1, E_2 and in pooled analysis, respectively.

Stem weight (g) (Table 4.4.5)

The positive heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -52.64 (Giant bajra x RHRB-260) to 85.67(PMFT-905 x PMFT-907) in E_1, –28.47 (PMFT-905 x RHRB-260) to 31.91 (PMFT-905 x RHRB-259) in E_2 environments and –24.80 (Giant bajra x RHRB-260) to 50.36 (PMFT-905 x PMFT-907) in pooled analysis. The number of crosses that registered significant positive relative heterosis were fifteen, six and seven in E_1, E_2 and in pooled analysis.

The range of heterobeltiosis was -67.04 (Giant bajra x RHRB-260) to 70.76 (PMFT-905 x PMFT-907) in E_1, –42.02 (PMFT-904 x RHRB-282) to 21.70 (PMFT-905 x RHRB-278) in E_2 environments and -45.08 (Giant bajra x RHRB-260) to 41.86 (PMFT-905 x PMFT-907) in pooled analysis. The number of crosses that registered significant positive heterobeltiosis were eight and three in E_1 and in pooled analysis, respectively.

Leaf : stem ratio (Table 4.4.5)

In E_1, the crosses *i.e.* PMFT-905 x RHRB-278 and RHRB-260 x RHRB-282 exhibited the minimum and maximum relative heterosis, respectively; it varied from –36.36 to 24.24. In E_2, the minimum and maximum relative heterosis of -23.08 and 7.04 was recorded by Giant bajra x RHRB-260 and Giant bajra x RHRB-278, respectively, while in pooled analysis the range for relative heterosis was -26.53 (PMFT-905 x RHRB-278) to 10.64 (PMFT-907 x RHRB-282). Only three crosses registered significant positive relative heterosis in E_1.

The heterobeltiosis ranged from –39.51 (PMFT-905 x RHRB-278) to 13.89 (RHRB-260 x RHRB-282) in E_1, -23.61 (Giant bajra x RHRB-260) to 7.04 (Giant bajra x RHRB-278) in E_2 environments and -28.00 (PMFT-905 x RHRB-278) to 8.33 (PMFT-907 x RHRB-282) in pooled analysis. None of the cross exhibited significant positive heterobeltiosis in both the environments and in pooled analysis.

Green forage yield (q/ha) (Table 4.4.6)

Green forage yield is an attribute of economic importance, which the breeders attempt to improve by involving high yielding varieties.

The minimum and maximum relative heterosis was recorded by the crosses Giant bajra x RHRB-259 (-17.63) and

Table 4.4.4: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for leaf area (cm^2) and leaf width (cm) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Leaf area (cm^2)						Leaf weight (g)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	-19.2**	-28.50**	-23.45**	-28.42**	-46.92**	-37.70**	-31.35**	-22.60**	-26.97*	-51.25**	-34.98**	-43.78**
2	Giant bajra X PMFT-905	16.16**	-10.54*	4.15	4.26	-34.77**	-15.32**	-3.5	-7.50	-5.45	-31.57**	-26.23**	-29.12**
3	Giant bajra X PMFT-907	14.85**	-37.44**	-10.33*	-10.14**	-54.86*	-32.58**	17.64	-16.76*	0.96	-19.5*	-36.89*	-27.49**
4	Giant bajra X RHRB-259	-18.54**	-39.71**	-28.25**	-33.77**	-58.76**	-46.31**	-16.77	-18.64**	-17.63*	-39.64**	-40.98**	-40.25**
5	Giant bajra X RHRB-260	-28.21**	-32.52**	-30.32**	-48.62**	-53.73**	-51.19**	-43.63**	-16.70*	-30.72**	-59.51**	-35.25**	-48.36**
6	Giant bajra X RHRB-282	13.11**	-22.75**	-4.58	-12.96**	-42.52**	-27.79**	-8.61	-2.63	-5.80*	-32.45**	-24.58**	-28.84**
7	Giant bajra X RHRB-278	-1.96	-18.00**	-9.20*	-7.2	-36.61**	-21.96**	-18.94	-8.08	-13.83	-36.91**	-25.41**	-31.62**
8	PMFT-904 X PMFT-905	-6.94	-22.90**	-12.96*	-8.31	-24.99**	-13.06*	-8.76	-30.59**	-21.04	-8.97	-34.94**	-23.98
9	PMFT-904 X PMFT-907	28.92**	-6.48	14.36*	11.64**	-10.48	3.07	56.21*	-8.22	19.93	46.62*	-19.28*	8.46
10	PMFT-904 X RHRB-259	3.41	7.75	5.06	-6.35	-5.21	-5.91	18.18	20.29*	19.30	14.23	0.00	9.46
11	PMFT-904 X RHRB-260	9.26	4.76	7.39	-14.84**	-7.50	-11.99*	17.6	-8.41	3.31	15.41	-16.87	-1.38
12	PMFT-904 X RHRB-282	21.89**	-4.24	10.71	3.52	-4.59	0.65	59.68**	-14.68**	19.70**	49.99*	-22.91**	16.45**
13	PMFT-904 X RHRB-278	-31.5**	-15.46*	-25.34**	-36.16**	-20.23**	-29.88**	-3.33	-8.43	-6.05	-15.18	-12.29	-9.85
14	PMFT-905 X PMFT-907	36.81**	-12.46	17.09**	17.00**	-13.91	5.65	54.11**	4.72	27.20*	44.95*	-2.20	19.18
15	PMFT-905 X RHRB-259	-0.64	-25.53**	-9.83	-11.21*	-32.86**	-19.16**	40.34*	9.72	24.87*	35.35*	-3.58	18.77
16	PMFT-905 X RHRB-260	27.14**	-15.57	9.85	-1.95	-23.59**	-9.89	70.56**	-31.56**	16.13	67.02**	-33.88**	15.11
17	PMFT-905 X RHRB-282	6.18	-18.66**	-4.17	-10.92*	-21.15**	-12.79*	14.96	-8.85*	2.55	7.76	-12.40**	1.41
18	PMFT-905 X RHRB-278	-19.46**	-1.60	-12.77*	-23.87**	-9.52	-18.40**	-31.04*	-3.10	-16.63	-39.61**	-5.26	-22.85
19	PMFT-907 X RHRB-259	3.88	-1.55	1.68	-1.19	-9.89	0.95	23.57	6.78	15.15	12.36	0.00	13.33
20	PMFT-907 X RHRB-260	36.13**	3.05	21.20**	20.04**	-5.32	8.86	47.06**	11.73	28.31*	35.63	7.88	21.22
21	PMFT-907 X RHRB-282	39.54**	-2.31	20.31**	36.35**	-6.83	19.17**	34.87*	16.43**	25.32**	19.41	12.94**	16.23**
22	PMFT-907 X RHRB-278	20.87	-8.53	8.93	-1.35	-17.16*	-7.38	38.69*	-17.99*	9.73	15.26	-25.00**	-4.35
23	RHRB-259 X RHRB-260	5.73	12.90	8.70	-10.71	12.42	-1.75	1.66	12.50	6.98	0.09	1.97	2.62
24	RHRB-259 X RHRB-282	29.91**	-2.20	16.26*	20.89**	-14.24	14.34	46.69**	24.54**	36.18**	42.42*	13.43**	28.17**
25	RHRB-259 X RHRB-278	-5.72	-4.61	-5.30	-19.82**	-20.17**	-19.95**	20.51	19.08*	19.81	9.01	2.63	5.89
26	RHRB-260 X RHRB-282	65.69**	-13.56	28.33**	49.14**	-23.92**	14.29	67.93**	3.96	35.55**	60.72**	3.41	32.86**
27	RHRB-260 X RHRB-278	-9.63*	-9.32	-9.50	-32.99**	-23.85**	-29.51**	26.23	-9.51	8.28	12.6	-14.47	-0.62
28	RHRB-282 X RHRB-278	0.57	-6.01	-2.20	-19.36**	-11.00	-16.18**	-8.92	24.23**	5.84	-15.34	14.05**	-1.04*
	SED	7.37	7.89	7.63	8.50	9.11	8.82	3.27	2.03	2.72	3.77	2.35	3.14

Table 4.4.5: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for stem weight (g) and leaf : stem ratio in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Stem weight (g)						Leaf : stem ratio					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	-34.49**	-13.65*	-24.37**	-53.08**	-25.34**	-40.91**	6.98	-10.14	-2.22	6.15	-12.68	-4.35
2	Giant bajra X PMFT-905	21.98**	14.74*	18.53**	-16.13**	-8.47	-12.77*	-21.74**	-19.72**	-19.15**	-26.03**	-19.72**	-20.83*
3	Giant bajra X PMFT-907	19.72**	3.29	11.83	-21.28**	-19.91**	-20.69**	-5.63	-18.25**	-10.64	-12.99	-21.13**	-12.50
4	Giant bajra X RHRB-259	-14.2*	-10.61	-12.61	-40.79**	-37.37**	-39.29**	-7.04	-11.84*	-10.20	-14.29	-17.28**	-15.38*
5	Giant bajra X RHRB-260	-52.64**	7.17	-24.80**	-67.04**	-17.01*	-45.08**	16.79*	-23.08**	-2.13	11.11	-23.61**	-4.17
6	Giant bajra X RHRB-282	-15.05*	-15.70**	-15.37**	-34.98**	-18.95**	-27.95**	8.80	-12.58*	-4.35	4.62	-17.50**	-4.35
7	Giant bajra X RHRB-278	-9.5	-13.16	-11.20	-34.28**	-29.80**	-32.31**	-13.70	7.04	-4.17	-22.22**	7.04	-8.00
8	PMFT-904 X PMFT-905	10.85	-13.91	-3.07	3.53	-21.81*	-10.88	-18.25*	-18.84**	-17.39*	-23.29**	-21.13**	-20.83**
9	PMFT-904 X PMFT-907	64.63**	-8.48	22.76*	42.29**	-19.68*	7.03	-7.80	0.75	-4.35	-15.58	0.00	-8.33
10	PMFT-904 X RHRB-259	22.22*	27.27**	24.85*	14.86	-1.33	5.65	-4.96	-9.46	-8.33	-12.99	-17.28**	-15.38*
11	PMFT-904 X RHRB-260	14.39	-4.10	4.26	9.06	-15.96	-5.17	2.94	-6.47	0.00	-2.78	-9.72	-4.17
12	PMFT-904 X RHRB-282	34.39**	-35.21**	-5.49	21.93*	-42.02**	-14.92	17.74	-6.12	6.67	14.06	-13.75*	4.35
13	PMFT-904 X RHRB-278	13.77	-2.31	5.04	11.24	-9.84	1.48	-14.48	-7.25	-10.64	-23.46**	-9.86	-16.00*
14	PMFT-905 X PMFT-907	85.67**	23.18*	50.36**	70.76**	18.57	41.86**	-17.33*	-13.87*	-16.67*	-19.48*	-16.90*	-16.67*
15	PMFT-905 X RHRB-259	50.66**	31.91**	41.13**	49.68**	10.42	28.82*	-5.33	-17.11**	-12.00	-7.79	-22.22**	-15.38*
16	PMFT-905 X RHRB-260	71.48**	-28.47**	17.67	67.83**	-31.27**	16.29	0.69	-4.90	0.00	0.00	-5.56	0.00
17	PMFT-905 X RHRB-282	27.36**	-25.67**	-2.72	8.71	-38.87**	-18.71**	-12.78	-12.58**	-10.64	-20.55*	-17.50**	-12.50
18	PMFT-905 X RHRB-278	7.56	23.84*	16.25	-1.61	21.70	10.42	-36.36**	-21.13	-26.53**	-39.51**	-21.13**	-28.00**
19	PMFT-907 X RHRB-259	24.62	15.68	19.99	13.93	0.00	15.84	-1.30	-10.20	-4.00	-1.30	-18.52**	-7.69
20	PMFT-907 X RHRB-260	66.70**	7.58	34.25**	50.33**	7.39	28.09*	-14.09	4.35	-4.17	-16.88*	0.00	-4.17
21	PMFT-907 X RHRB-282	7.38	-18.95*	-7.81	-14.44	-35.29**	-26.46**	18.25*	1.37	10.64	5.19	-7.50	8.33
22	PMFT-907 X RHRB-278	53.43**	-20.27*	13.39	30.13*	-24.53*	1.93	-10.13	3.65	-2.04	-12.35	0.00	-4.00
23	RHRB-259 X RHRB-260	-3.22	9.39	2.96	-4.67	-5.30	-5.00	4.70	1.96	4.00	1.30	-3.70	0.00
24	RHRB-259 X RHRB-282	25.69*	-8.35	7.58	7.87	-34.24**	-16.40*	13.87	-9.32	2.04	1.30	-9.88	-3.85
25	RHRB-259 X RHRB-278	40.58**	31.81**	36.30**	29.37*	8.81	18.76	-13.92	-10.53	-9.80	-16.05*	-16.05*	-11.54
26	RHRB-260 X RHRB-282	28.59**	-16.47*	3.58	11.78	-33.40**	-14.26	24.24**	-13.16*	6.38	13.89	-17.50**	4.17
27	RHRB-260 X RHRB-278	28.62**	-0.83	13.33	20.03	-6.29	6.45	-3.27	-7.69	-6.12	-8.64	-8.33	-8.00
28	RHRB-282 X RHRB-278	-21.35*	-6.55	-13.20	-27.15*	-22.06**	-24.22**	12.06	-5.96	4.17	-2.47	-11.25	0.00
	SED	9.90	9.64	9.77	11.42	11.14	11.28	0.018	0.014	0.017	0.021	0.016	0.019

PMFT-907 x RHRB-278 (47.70) in E_1; it varied from –29.52 (Giant bajra x PMFT-907) to 56.15 (RHRB-259 x RHRB-260) in E_2 , while in pooled analysis the range for relative heterosis was -21.99 (Giant bajra x RHRB-259) to 45.37 (RHRB-259 x RHRB-260). The number of crosses that registered significant positive relative heterosis were fifteen, thirteen and fourteen in E_1, E_2 and in pooled analysis, respectively.

The heterobeltiosis ranged from –31.06 (Giant bajra x RHRB-259) to 44.08 (PMFT-907 x RHRB-278) in E_1, -48.12 (Giant bajra x RHRB-259) to 51.80 (RHRB-259 x RHRB-260) in E_2 environments and -39.38 (Giant bajra x RHRB-259) to 43.86 (RHRB-259 x RHRB-260) in pooled analysis. The number of crosses that registered significant positive in heterobeltiosis were ten, five and seven in E_1 , E_2 and pooled analysis, respectively.

Dry matter yield (q/ha) (Table 4.4.6)

In E_1, the crosses *i.e.* Giant bajra x RHRB-259 and RHRB-259 x RHRB-260 exhibited the minimum and maximum relative heterosis, respectively; it varied from –23.97 to 65.68. In E_2, the two crosses *viz.*, Giant bajra x PMFT-907 and RHRB-259 x RHRB-260 recorded the minimum and maximum relative heterosis, respectively, ranging from –32.07 to 104.00, while in pooled analysis the range for relative heterosis was -27.20 (Giant bajra x RHRB-259) to 81.03 (RHRB-259 x RHRB-260). The number of crosses that registered significant positive relative heterosis were twelve in E_1 and eleven in E_2 and ten in pooled analysis.

The heterobeltiosis ranged from –39.43 (Giant bajra x RHRB-259) to 64.89 (PMFT-907 x RHRB-278) in E_1, -51.96 (Giant bajra x RHRB-259) to 94.20 (RHRB-259 x RHRB-260) in E_2 environments and -45.42 (Giant bajra x RHRB-259) to 80.65

Table 4.4.6: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for green forage yield (q/ha) and dry matter yield (q/ha) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Green forage yield q/ha)						Dry matter yield (q/ha)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	3.62	-11.75	-3.86	-11.18	-24.63**	-17.74**	-6.05	-13.86*	-9.79	-20.65**	-26.72**	-23.56**
2	Giant bajra X PMFT-905	20.33**	4.73	13.67*	13.98*	-22.35**	-3.74	14.39*	-3.50	6.70	6.55	-25.90**	-8.95
3	Giant bajra X PMFT-907	0.90	-29.52**	-13.68*	-13.04*	-41.27**	-26.81**	-3.55	-32.07**	-16.93*	-17.51**	-43.84**	-30.08
4	Giant bajra X RHRB-259	-17.63*	-27.36**	-21.99**	-31.06**	-48.12**	-39.38**	-23.97**	-31.23**	-27.20**	-39.43**	-51.96**	-45.42**
5	Giant bajra X RHRB-260	-8.93	19.42**	4.09	-25.90**	-13.21*	-19.71**	-7.49	30.18**	9.80	-28.27**	-6.32	-17.79**
6	Giant bajra X RHRB-282	35.93**	15.95**	26.64**	28.88**	0.34	14.96*	22.65**	-11.89	7.50	22.06**	-25.03**	-0.43**
7	Giant bajra X RHRB-278	10.76	10.11	10.46	-2.48	-10.99	-6.63	15.00*	-9.76	3.56	-1.91	-27.63**	-14.19
8	PMFT-904 X PMFT-905	6.76	1.37	4.53	-3.99	-14.75	3.24	14.45	-3.74	6.78	2.93	-15.10	5.88*
9	PMFT-904 X PMFT-907	8.64	16.31*	12.29	7.94	12.90	11.07	-0.84	11.69	5.04	-2.34	7.89	4.16
10	PMFT-904 X RHRB-259	29.75**	18.30*	24.74**	26.09**	-5.07	10.96	30.10**	23.18*	27.07**	21.07**	-3.53	9.21
11	PMFT-904 X RHRB-260	27.59**	15.73	22.23*	19.83*	-5.07	7.74	32.79**	18.15	26.11**	19.46*	-3.91	8.20
12	PMFT-904 X RHRB-282	30.74**	10.20	21.30**	17.46*	8.48	13.54*	9.15	23.64*	15.43*	-7.45	23.59*	4.76
13	PMFT-904 X RHRB-278	-2.23	8.87	2.88	-5.22	1.84	1.39	-0.73	8.82	3.68	-1.91	1.27	0.86
14	PMFT-905 X PMFT-907	27.06**	25.18**	26.30**	14.93*	7.93	26.12**	24.96**	21.58*	23.57**	13.93	10.63	21.53*
15	PMFT-905 X RHRB-259	12.08	16.38	13.61	-1.74	9.80	2.18	13.61	4.18	10.13	-4.13	-9.30	-6.01
16	PMFT-905 X RHRB-260	0.00	10.10	3.73	-14.93*	6.76	-7.57	-0.52	6.88	2.34	-18.52*	-2.74	-12.81
17	PMFT-905 X RHRB-282	24.87**	-12.90	10.06	24.74**	-27.68**	1.83	35.11**	-7.35	19.01**	26.41**	-18.31	8.83
18	PMFT-905 X RHRB-278	0.56	-1.48	-0.23	-6.94	-12.17	-0.46	20.19**	6.78	14.84	9.25	0.75	10.81
19	PMFT-907 X RHRB-259	23.16**	2.87	14.49	18.93*	-15.52	2.84	10.02	12.89	11.24	0.95	-9.25	-3.71
20	PMFT-907 X RHRB-260	14.16	36.32**	23.94**	6.57	14.54	10.29	6.71	23.18*	13.99	-5.30	3.00	-1.51
21	PMFT-907 X RHRB-282	19.44**	27.20**	22.94**	7.94	21.61**	13.91*	-2.15	5.35	1.01	-15.97*	1.73	-9.01
22	PMFT-907 X RHRB-278	47.70**	39.54**	44.02**	44.08**	34.31**	43.47**	65.44**	32.49**	50.68**	64.89**	27.47**	47.80**
23	RHRB-259 X RHRB-260	38.42**	56.15*	45.37**	33.64**	51.80**	43.86**	65.68**	104.00**	81.03**	59.72**	94.20**	80.65**
24	RHRB-259 X RHRB-282	14.36*	17.66	15.72*	0.17	-6.70	-2.83	4.61	11.48	7.28	-16.36*	-12.72	-14.92
25	RHRB-259 X RHRB-278	22.29**	31.77**	26.17**	15.31	11.64	13.71	34.79**	45.92**	39.39**	24.06*	20.93	22.69*
26	RHRB-260 X RHRB-282	-3.30	33.33**	12.28	-17.81*	8.04	-6.52	-3.08	31.14**	10.74	-24.59**	6.62	-12.32
27	RHRB-260 X RHRB-278	23.71**	41.46*	31.23**	12.86	22.75*	17.17*	48.30**	67.42**	56.56**	32.01**	44.60**	37.54**
28	RHRB-282 X RHRB-278	15.89*	31.09**	22.52**	7.14	20.85*	13.13	8.25	28.83**	16.75*	-7.30	19.85*	3.38
	SED	37.34	32.54	35.03	43.12	37.58	40.45	7.68	7.07	7.38	8.87	8.17	8.53

(RHRB-259 x RHRB-260) in pooled analysis. The number of crosses that registered significant positive in heterobeltiosis were eight, five and six in E_1 , E_2 and pooled analysis, respectively.

Crude protein content [%] (Table 4.4.7)

For crude protein content relative heterosis varied from –8.43 RHRB-260 x RHRB-278) to 26.26 (PMFT-907 x RHRB-259) in E1, –8.07 (PMFT-904 x RHRB-278) to 37.98 (PMFT-907 x RHRB-259) in E_2 and –6.60 (RHRB-260 x RHRB-278) to 32.03 (PMFT-907 x RHRB-259) in pooled analysis. The number of crosses that registered significant positive relative heterosis were twelve, eight and ten in E_1, E_2 and in pooled analysis, respectively.

The heterobeltiosis ranged from –13.30 (PMFT-905 x RHRB-278) to 15.57 (PMFT-907 x RHRB-278) in E_1, -12.02 (PMFT-904 x RHRB-278) to 32.70 (PMFT-907 x RHRB-259) in E_2 environments and -9.10 (RHRB-260 x RHRB-278) to 26.39 (PMFT-907 x RHRB-259) in pooled analysis. The number of crosses that registered significant positive in heterobeltiosis were three each E_1 and E_2 and two in pooled analysis.

Crude fibre (%) (Table 4.4.7)

The negative heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -7.85 (PMFT-907 x RHRB-278) to 5.57 (Giant bajra x PMFT-907) in E_1, –5.14 (PMFT-904 x RHRB-282) to 1.91 (Giant bajra x RHRB-278) in E_2 environments and –5.19 (PMFT-907 x RHRB-278) to 3.13 (Giant bajra x PMFT-907) in pooled analysis. The number of crosses that registered significant negative relative heterosis were three, seven and two in E_1, E_2 and in pooled analysis, respectively.

The range of heterobeltiosis was -5.24 (PMFT-907 x RHRB-278) to 6.87 (Giant bajra x PMFT-907) in E_1, –4.46 (PMFT-904 x RHRB-282) to 2.64 (RHRB-260 x RHRB-278) in E_2

Table 4.4.7: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for crude protein (%) and crude fibre (%) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Crude protein (%)						Crude fibre (%)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	3.30	6.00	4.65	1.62	5.07	5.44	-2.38	-3.08*	-2.76	-0.50	-2.32	-1.45
2	Giant bajra X PMFT-905	8.21*	9.54	8.83*	6.45	4.49	6.35	-4.03*	-4.68**	-4.37**	-3.02	-4.44**	-3.76
3	Giant bajra X PMFT-907	-4.99	2.80	-1.33	-8.07	-6.78	-7.47	5.57**	0.80	3.13	6.87**	1.50	4.11*
4	Giant bajra X RHRB-259	19.68**	0.93	10.06*	3.24	-5.07	-0.91	-1.37	1.65	0.15	2.10	2.52	2.31
5	Giant bajra X RHRB-260	10.19**	0.87	5.64	4.87	-3.41	0.79	-1.83	-0.92	-1.37	-0.10	-0.26	-0.19
6	Giant bajra X RHRB-282	10.00**	6.20	8.10	6.45	5.63	6.57	3.32	-1.78	0.71	3.62	-1.71	0.88
7	Giant bajra X RHRB-278	-4.43	1.78	-1.34	-12.90**	-3.41	-8.27	1.34	1.91	1.61	5.53*	2.10	3.57
8	PMFT-904 X PMFT-905	-1.64	9.36	3.67	-1.64	5.20	1.74	1.66	-2.44	-0.42	2.54	-1.93	0.28
9	PMFT-904 X PMFT-907	-8.45	7.55	-0.80	-9.98	-1.69	-5.81	3.15	-3.49*	-0.23	3.86	-3.41*	0.16
10	PMFT-904 X RHRB-259	21.97**	14.59**	18.19**	6.70	8.67	7.67	-4.99**	-1.02	-3.01	-3.53	-0.95	-2.25
11	PMFT-904 X RHRB-260	3.43	5.35	4.45	0.00	1.73	0.93	-1.45	-0.50	-0.97	-1.29	-0.40	-0.83
12	PMFT-904 X RHRB-282	8.50*	7.13	7.80	6.70	5.63	7.67	0.75	-5.14**	-2.24	2.40	-4.46**	-1.10
13	PMFT-904 X RHRB-278	8.09	-8.07	0.06	0.00	-12.02*	-5.81	1.02	-0.56	0.23	3.16	0.40	0.80
14	PMFT-905 X PMFT-907	5.11	12.22*	8.43	3.35	6.40	4.83	-0.08	-0.78	-0.44	0.11	-0.35	-0.12
15	PMFT-905 X RHRB-259	20.05**	13.66*	16.87**	5.03	11.99	8.33	-2.01	0.83	-0.58	0.37	1.43	0.91
16	PMFT-905 X RHRB-260	1.73	7.84	4.66	-1.64	7.41	3.02	3.70	1.08	2.39	4.43*	1.50	2.97
17	PMFT-905 X RHRB-282	6.80	9.53	8.19	5.03	3.95	6.29	1.38	-2.88*	-0.77	2.14	-2.69	-0.31
18	PMFT-905 X RHRB-278	-6.28	8.86	1.07	-13.30**	8.28	-3.14	-1.35	1.94	0.28	1.63	2.39	1.56
19	PMFT-907 X RHRB-259	26.26**	37.98**	32.03**	12.10**	32.70**	26.39**	-2.54	-1.40	-1.96	-0.37	-1.24	-0.81
20	PMFT-907 X RHRB-260	-5.25	19.58**	6.54	-6.86	12.95*	4.61	2.57	-3.16*	-0.34	3.10	-3.14	-0.09
21	PMFT-907 X RHRB-282	8.65	14.67**	11.59*	8.63	3.49	6.06	-1.47	-2.87*	-2.17	-0.55	-2.27	-1.42
22	PMFT-907 X RHRB-278	22.96**	20.77**	21.93**	15.57**	15.09*	20.83**	-7.85**	-2.52	-5.19**	-5.24*	-1.66	-4.28*
23	RHRB-259 X RHRB-260	22.79**	11.34*	17.03**	10.69*	9.27	10.10	-2-99	-1.84	-2.42	-1.34	-1.66	-1.51
24	RHRB-259 X RHRB-282	16.51**	5.71	10.93*	3.43	-1.07	1.17	-2..23	-1.26	-1.75	0.91	-0.48	0.19
25	RHRB-259 X RHRB-278	4.19	8.58	6.41	-1.97	7.55	2.77	0.60	1.21	0.91	1.18	2.27	1.13
26	RHRB-260 X RHRB-282	5.23	9.11	7.23	3.43	3.95	3.73	2.63	1.52	2.07	4.13	2.13	3.12
27	RHRB-260 X RHRB-278	-8.43*	-4.66	-6.60	-12.53**	-5.54	-9.10	2.92	1.77	2.33	5.27*	2.64	3.06
28	RHRB-282 X RHRB-278	16.81**	10.08	13.42**	9.77	3.95	6.88	-0.59	-1.99	-1.28	3.21	-1.74	0.44
	SED	0.33	0.41	0.38	0.38	0.48	0.43	0.59	0.46	0.53	0.68	0.53	0.61

environments and -4.28 (PMFT-907 x RHRB-278) to 4.11 (Giant bajra x PMFT-907) in pooled analysis. The number of crosses that registered significant negative heterobeltiosis were one, three and one in E_1, E_2 and in pooled analysis, respectively.

Acid detergent fibre (%) (Table 4.4.8)

The negative heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -6.46 (Giant bajra x PMFT-907) to 8.81 (PMFT-905 x RHRB-260) in E_1, –3.64 (Giant bajra x RHRB-259) to 7.07 (PMFT-905 x RHRB-278) in E_2 environments and –2.66 (Giant bajra x PMFT-905) to 6.18 (PMFT-905 x RHRB-260) in pooled analysis. The two crosses registered significant negative relative heterosis in E_1 and E_2 environments.

The range of heterobeltiosis was -5.98 (Giant bajra x PMFT-907) to 9.69 (PMFT-905 x RHRB-260) in E_1, –2.98 (PMFT-904 x PMFT-907) to 6.61 (RHRB-259 x RHRB-278) in E_2 environments and -2.17 (Giant bajra x RHRB-282) to 6.93 (PMFT-905 x RHRB-260) in pooled analysis. The two crosses registered significant negative heterobeltiosis in E_1 only.

Neutral detergent fibre (%) (Table 4.4.8)

The negative heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -3.86 (RHRB-259 x RHRB-260) to 8.15 (PMFT-905 x RHRB-260) in E_1, –3.33 (PMFT-904 x RHRB-278) to 2.69 (RHRB-259 x RHRB-282) in E_2 environments and –3.19 (RHRB-259 x RHRB-260) to 5.14 (PMFT-905 x RHRB-260) in pooled analysis. The number of crosses that registered significant negative relative heterosis were six in E_1 and three each in E_2 and in pooled analysis, respectively.

The range of heterobeltiosis was -2.52 (PMFT-907 x RHRB-259) to 8.77 (PMFT-905 x RHRB-260) in E_1, –2.96 (PMFT-904 x RHRB-278) to 4.82 (Giant bajra x RHRB-259) in E_2

Table 4.4.8: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for ADF (%) and NDF (%) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	ADF (%)						NDF (%)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	-1.82	1.52	-0.14	0.29	2.15	0.59	2.31*	-1.96	0.15	4.22**	0.84	2.51
2	Giant bajra X PMFT-905	-3.54	-1.80	-2.66	-1.50	-1.40	-1.85	0.63	-0.69	-0.03	1.44	0.53	0.99
3	Giant bajra X PMFT-907	-6.46**	3.13*	-1.71	-5.98**	3.40*	-1.33	4.06*	1.92	2.99*	8.00**	4.51*	6.24**
4	Giant bajra X RHRB-259	-1.36	-3.64*	-2.49	-1.20	-1.26	-1.21	0.41	2.51	1.46	4.35**	4.82**	4.58**
5	Giant bajra X RHRB-260	-1.62	-0.69	-1.14	1.29	-0.5	0.39	3.69**	-0.32	1.66	5.13**	1.34	3.21*
6	Giant bajra X RHRB-282	-5.62**	0.62	-2.51	-4.88*	0.69	-2.17	0.34	2.25	1.30	3.39**	3.18	3.29*
7	Giant bajra X RHRB-278	-2.28	0.06	-1.13	-1.63	1.36	-0.84	2.78*	-0.45	1.14	5.92**	2.79	4.34**
8	PMFT-904 X PMFT-905	1.73	0.03	0.86	1.75	0.25	0.96	-0.40	-3.01*	-1.72	0.63	-1.48	-0.43
9	PMFT-904 X PMFT-907	0.44	-3.33*	-1.45	3.14	-2.98	-0.34	-2.68**	-2.84*	-2.76*	-0.87	-2.55	-2.02
10	PMFT-904 X RHRB-259	-1.74	-1.43	-1.60	0.53	0.37	0.43	-2.23*	-2.07	-2.15	0.29	-1.50	-1.48
11	PMFT-904 X RHRB-260	2.90	0.56	1.70	3.71	1.38	2.52	2.07*	-0.07	0.99	2.54*	1.07	1.80
12	PMFT-904 X RHRB-282	0.02	1.90	0.97	1.36	2.46	1.34	-2.63**	-2.44	-2.54*	-1.52	-0.59	-2.17
13	PMFT-904 X RHRB-278	-3.00	2.19	-0.41	-0.26	4.18*	0.02	-1.10	-3.33*	-2.23	0.04	-2.96	-1.48
14	PMFT-905 X PMFT-907	-2.16	-0.96	-1.56	0.44	-0.82	-0.34	-2.92**	-1.93	-2.42*	-0.07	-0.68	-0.37
15	PMFT-905 X RHRB-259	0.83	-1.33	-0.27	3.14	0.70	1.90	-1.28	-0.72	-0.99	1.75	0.26	1.00
16	PMFT-905 X RHRB-260	8.81**	3.61*	6.18**	9.69**	4.23*	6.93**	8.15**	2.21	5.14**	8.77**	2.64	5.67**
17	PMFT-905 X RHRB-282	-1.21	-0.02	-0.61	0.09	0.31	-0.14	-1.53	-0.46	-0.99	0.63	-0.15	-0.07
18	PMFT-905 X RHRB-278	3.49	7.07**	5.26**	6.39**	8.90**	5.82**	-0.02	0.94	0.47	2.20*	2.93	2.58
19	PMFT-907 X RHRB-259	-1.78	-1.60	-1.70	-1.44	0.56	-0.80	-2.64**	-0.35	-1.50	-2.52*	-0.08	-1.42
20	PMFT-907 X RHRB-260	-0.21	4.61**	2.22	3.29	5.09*	4.22*	1.45	1.28	1.37	3.82**	2.13	2.97*
21	PMFT-907 X RHRB-282	-.04	1.60	0.79	1.27	1.79	1.54	0.84	0.10	0.47	1.56	1.70	1.63
22	PMFT-907 X RHRB-278	-3.18	3.59*	0.15	-3.04	5.22**	0.84	0.29	-2.14	-0.93	0.98	-1.47	-0.93
23	RHRB-259 X RHRB-260	1.00	0.45	0.73	4.17	3.14	3.66	-3.86**	-2.55	-3.19**	-1.49	-2.00	-1.74
24	RHRB-259 X RHRB-282	2.55	1.76	2.16	3.53	4.20	3.87*	0.41	2.69	1.54	1.24	4.03*	2.62
25	RHRB-259 X RHRB-278	0.20	2.67	1.43	0.70	6.61**	3.07	0.37	-1.79	-0.71	1.18	-0.85	-0.63
26	RHRB-260 X RHRB-282	4.94**	2.04	3.49*	7.19**	2.31	4.73*	0.86	2.08	1.48	2.48*	2.84	1.91
27	RHRB-260 X RHRB-278	4.51*	-1.38	1.58	8.34**	-0.29	2.85	1.16	2.21	1.69	2.80**	3.78*	3.29*
28	RHRB-282 X RHRB-278	0.17	0.34	0.26	1.63	1.72	0.32	-0.66	-2.12	-1.38	-0.64	0.13	-0.25
	SED	0.79	0.64	0.72	0.91	0.74	0.83	0.58	0.99	0.82	0.68	1.15	0.94

environments and -2.17 (PMFT-904 x RHRB-282) to 6.24 (Giant bajra x PMFT-907) in pooled analysis. Only the cross combination PMFT-907x RHRB-259 registered significant negative heterobeltiosis in E_1.

Oxalic acid (%) (Table 4.4.9)

The negative heterosis for this trait is indicated as desirable direction. The range of relative heterosis was -25.45 (PMFT-907 x RHRB-278) to 9.27 (PMFT-905 x RHRB-278) in E_1, –24.88 (PMFT-907 x RHRB-259) to 8.20 (Giant bajra x RHRB-259) in E_2 environments and –20.30 (PMFT-907 x RHRB-278) to 3.21 (RHRB-260 x RHRB-278) in pooled analysis. The number of crosses that registered significant negative relative heterosis were seven, ten and six in E_1, E_2 and in pooled analysis, respectively.

The range of heterobeltiosis was -24.41 (PMFT-907 x RHRB-278) to 10.80 (PMFT-905 x RHRB-278) in E_1, –21.01 (PMFT-907 x RHRB-259) to 14.55 (Giant bajra x RHRB-259) in E_2 environments and -20.42 (PMFT-907 x RHRB-278) to 5.74 (PMFT-904 x PMFT-907, PMFT-904 x RHRB-278) in pooled analysis. The number of crosses that registered significant negative heterobeltiosis were four in E_1 and three in E_2 and two in pooled analysis.

***In vitro* dry matter digestibility [%]** (Table 4.4.9)

The positive heterosis for this trait is indicated as desirable direction. In E_1, the crosses *i.e.* Giant bajra x PMFT-907 and Giant bajra x PMFT-905 exhibited the minimum and maximum relative heterosis, respectively; it varied from –7.16 to 8.13. In E_2, it ranged from –3.78 (PMFT-904 x RHRB-278) to 7.24 (PMFT-905 x RHRB-259), while in pooled analysis the range for relative heterosis was -3.99 (PMFT-904 x RHRB-278) to 7.03 (Giant

Table 4.4.9: Estimates of relative heterosis [MP] and heterobeltiosis (BP) for oxalic acid (%) and IVDMD (%) in Kharif, 2008 (E_1), Summer, 2009 (E_2) environments and Pooled analysis (Pooled)

S. N.	Cross	Oxalic acid (%)						IVDMD (%)					
		Relative heterosis (MP)			Heterobeltiosis (BP)			Relative heterosis (MP)			Heterobeltiosis (BP)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
1	Giant bajra X PMFT-904	2.66	-4.40	-0.82	2.66	-3.05	0.00	-1.05	-2.62	-1.84	-2.86	-2.74	-2.69
2	Giant bajra X PMFT-905	-23.19**	-1.31	-10.08	-22.17**	5.87	-6.16	8.13**	.95**	7.03**	3.66*	2.99	3.32
3	Giant bajra X PMFT-907	6.78	-7.89	-0.74	8.20	2.82	5.68	-7.16**	-0.96	-4.11*	-8.74**	-3.64	-6.22**
4	Giant bajra X RHRB-259	-15.76**	8.20	-4.08	-11.09	14.55	1.51	2.69	1.63	2.16	0.32	-1.86	-0.77
5	Giant bajra X RHRB-260	-17.36**	-1.31	-9.49	-13.97*	5.87	-4.25	-1.69	-2.93	-2.30	-2.86	-4.77*	-3.82*
6	Giant bajra X RHRB-282	-7.09	-7.51	-7.29	-5.71	-6.05	-5.99	-1.50	0.12	-0.70	-3.18*	-1.21	-2.21
7	Giant bajra X RHRB-278	2.70	-6.50	-1.93	5.54	3.05	4.45	-4.54*	-2.68	-3.61*	-8.11**	-4.45*	-6.30*
8	PMFT-904 X PMFT-905	-4.16	-13.39*	-8.84	-2.88	-8.45	-5.54	2.79	-3.82*	-0.54	0.33	-6.61**	-3.18
9	PMFT-904 X PMFT-907	4.16	-3.84	0.03	5.54	5.71	5.74	-3.75**	-0.41	-2.09	-3.87*	-3.23	-3.43
10	PMFT-904 X RHRB-259	-18.28**	-17.72*	-18.01**	-13.75	-14.16	-13.85	-4.48**	0.84	-1.83	-4.95**	-2.74	-3.83*
11	PMFT-904 X RHRB-260	-1.17	-5.40	-3.31	2.88	0.00	1.55	0.49	2.55	1.52	-0.16	0.48	0.82
12	PMFT-904 X RHRB-282	-9.79	-8.81	-9.31	-8.45	-6.05	-7.39	4.00**	2.70	3.35*	3.87*	1.21	2.66**
13	PMFT-904 X RHRB-278	-2.70	2.63	0.00	0.00	11.42	5.74	-4.21**	-3.78*	-3.99*	-6.11**	-5.65**	-5.87
14	PMFT-905 X PMFT-907	-13.39*	-13.52*	-13.49*	-13.39	-10.25	-12.08	3.33*	4.70*	4.01*	0.74	4.62*	2.63
15	PMFT-905 X RHRB-259	-3.94	-16.80*	-10.36	0.00	-15.76*	-9.43	4.84**	7.24**	6.03**	2.83	6.51**	5.36*
16	PMFT-905 X RHRB-260	2.63	-10.25	-3.92	5.40	-10.25	-2.96	-4.95**	1.95	-1.52	-7.82**	1.01	-3.47
17	PMFT-905 X RHRB-282	-8.10	-13.87*	-10.96	-5.48	-6.05	-5.85	2.49	4.30*	3.40*	-0.08	2.74	1.32
18	PMFT-905 X RHRB-278	9.27	-9.89	-0.59	10.80	-7.58	1.07	5.78**	6.27**	6.03**	5.33**	5.20*	5.26
19	PMFT-907 X RHRB-259	-9.13	-24.88**	-17.13**	-5.40	-21.01**	-16.75*	-2.94*	3.62	0.28	-3.54*	2.82	-0.42
20	PMFT-907 X RHRB-260	2.63	-13.52*	-5.74	5.40	-10.25	-5.34	-2.42	-0.34	-1.40	-2.93	-1.18	-2.07
21	PMFT-907 X RHRB-282	-19.20**	-14.50*	-16.80**	-16.89*	-2.91	-10.21	-4.86**	0.93	-2.01	-4.86**	-0.50	-2.70
22	PMFT-907 X RHRB-278	-25.45**	-15.61*	-20.30**	-24.41**	-14.62*	-20.42**	2.90*	4.83*	3.86*	0.74	3.86	3.22
23	RHRB-259 X RHRB-260	-8.80	-14.32*	-11.52	-7.58	-13.24	-11.66	-3.05*	-0.94	-2.00	-4.15*	-2.52	-3.34
24	RHRB-259 X RHRB-282	-9.48	1.46	-4.14	-2.97	9.20	2.82	-0.29	2.04	0.86	-0.91	-0.17	-0.55
25	RHRB-259 X RHRB-278	5.02	-13.85*	-4.46	7.77	-10.50	-3.99	2.54	-0.34	1.10	1.00	-2.01	1.02
26	RHRB-260 X RHRB-282	-5.40	-8.32	-6.86	0.00	0.00	-0.14	1.19	-0.58	0.31	0.65	-1.16	0.28
27	RHRB-260 X RHRB-278	6.43	0.10	3.21	7.77	2.66	3.68	3.93**	1.93	2.94	1.22	1.85	1.62
28	RHRB-282 X RHRB-278	-17.72	-10.80	-14.22*	-14.16	0.00	-7.39	2.98*	1.34	2.16	0.82	0.83	0.83
	SED	0.09	0.10	0.09	0.10	0.12	0.11	0.81	1.07	0.95	0.94	1.23	1.10

bajra x PMFT-905). The number of crosses that registered significant positive relative heterosis were eight in E_1 and six each in E_2 and in pooled analysis.

The heterobeltiosis ranged from –8.74 (Giant bajra x PMFT-907) to 5.33 (PMFT-905 x RHRB-278) in E_1, -6.61 (PMFT-904 x PMFT-905) to 6.51 (PMFT-905 x RHRB-259) in E_2 environments and -6.30 (Giant bajra x RHRB-278) to 5.36 (PMFT-905 x RHRB-259) in pooled analysis. The number of crosses that registered significant positive in heterobeltiosis were two, three and two in E_1, E_2 and pooled analysis, respectively.

4.5 Genetic diversity studies among parental lines in pearl millet through D^2 analysis

To assess the amount of diversity existing in the eight parents for eleven quantitative characters viz., days to 50 % flowering, plant height (cm), number of tillers/plant, number of leaves/plant, leaf length (cm), leaf width (cm), leaf area (cm^2), leaf weight (g), stem weight (g), green fodder yield(kg/ka) and dry matter yield (kg/ha) of the pearl millet in both E_1 and E_2 the environments Mahalanobis multivariate D^2 statistic analysis was attempted and the results are presented below:

4.5.1 Grouping of genotypes through D^2 analysis

In all, six clusters were formed each in Kharif, 2008 (E_1) and summer, 2009 (E_2) environment and their composition is given in Table 4.5.1.

Cluster I and II contained two genotypes each in E_1 and E_2 environments, while other clusters Viz., III, IV, V and VI comprised of only single genotype. In Kharif, 2008 (E1), Cluster I comprised the genotypes PMFT-907 and RHRB-259 and in cluster II PMFT-904 and PMFT-905, while in summer, 2009 (E_2), Cluster I

Table 4. 5.1 : Grouping of eight pearl millet genotypes based on Mahalanobis D^2 distance in Kharif, 2008 (E_1) and Summer, 2009 (E_2) environments

Kharif, 2008 (E_1)			Summer, 2009 (E_2)		
Cluster	**No. of genotypes**	**Genotypes**	**Cluster**	**No. of genotypes**	**Genotypes**
I	2	PMFT-907, RHRB-259	I	2	PMFT-905, RHRB-278
II	2	PMFT-904, PMFT-905	II	2	PMFT-904, PMFT-907
III	1	RHRB-260	III	1	RHRB-282
IV	1	RHRB-282	IV	1	RHRB-259
V	1	RHRB-278	V	1	RHRB-260
VI	1	Giant bajra	VI	1	Giant bajra

comprised the genotypes PMFT-905 and RHRB-278 whereas cluster II contained PMFT-904 and PMFT-907. The genotypes RHRB-260, RHRB-282 and Giant bajra showed same clustering pattern in both the environments.

4.5.2 Intra and inter cluster distance

Intra and inter cluster distance (D) between possible pair of clusters in E_1 and E_2 are presented in Tables 4.5.2 and 4.5.3, respectively.

In Kharif, 2008 (E_1), the intra cluster distance (D) ranged from 00.00 (cluster III, IV, V, VI) to 6.444 (cluster II), while, it ranged from 00.00 (cluster IV, V,VI) to 5.408 (cluster II) in summer, 2009 (E_2).

In E_1, the maximum inter cluster distance (D = 32.523) was observed between cluster III (RHRB-260) and VI (Giant bajra) while in E_2, it was (D=39.966) between cluster IV (RHRB-259) and VI (Giant bajra) which indicated the presence of wider genetic diversity among the genotype included in these clusters.

Inter cluster distance was minimum (D=10.686) between cluster I ((PMFT-907, RHRB-259)) and cluster III (RHRB-260) in E_1 and it was (D=9.505) between cluster I (PMFT-907, RHRB-259) and cluster III (RHRB-260) in E_2 , which indicated close relationship between the genotypes of these clusters.

D^2 matrix denotes the distance between individual parents rather than clusters. Study revealed that maximum distance was observed between Giant bajra and RHRB-260 (1057.77) in E_1 and between Giant bajra and RHRB-259 (1597.30) in E_2. The minimum distance was observed between RHRB-259 and PMFT-907 (38.80) in E_1 and between PMFT-904 and PMFT-907 (29.25) in E_2 (Table 4.5.4).

Table 4.5.2 : Average intra and inter cluster distances (D) among six clusters in Kharif, 2008 (E_1)

Cluster	I	II	III	IV	V	VI
I	6.229	15.746	10.686	14.211	18.338	25.493
II		6.444	22.132	14.516	19.225	21.606
III			0.000	15.655	26.111	32.523
IV				0.00	26.126	26.044
V					0.000	16.749

Table 4.5.3 : Average intra and inter cluster distances (D) among six clusters in Summer, 2009 (E_2)

Cluster	I	II	III	IV	V	VI
I	4.445	17.351	9.505	18.577	10.997	23.325
II		5.408	17.473	9.884	16.308	37.042
III			0.000	21.093	15.516	24.008
IV				0.000	13.349	39.966
V					0.000	29.870

Table 4.5.4 : D^2 matrix distance between individual parent in E_1 (above diagonal) and E_2 (below diagonal) environments.

Parents	Giant bajra	PMFT-904	PMFT-905	PMFT-907	RHRB-259	RHRB-260	RHRB-282	RHRB-278
Giant bajra	**0.00**	537.68	395.99	691.21	608.56	1057.77	678.29	280.54
PMFT-904	1261.47	**0.00**	41.52	314.41	196.39	474.02	196.29	448.78
PMFT-905	545.52	257.24	**0.00**	293.26	187.68	505.65	225.14	290.41
PMFT-907	1482.69	29.25	347.91	**0.00**	38.80	87.09	183.28	395.13
RHRB-259	1597.30	90.27	344.55	105.11	**0.00**	141.27	220.59	277.41
RHRB-260	892.21	219.55	120.66	312.38	178.19	**0.00**	245.09	681.78
RHRB-282	576.39	272.28	95.26	338.31	444.91	240.73	**0.00**	682.56
RHRB-278	542.63	252.86	19.76	346.27	345.68	121.22	85.42	**0.00**

Table 4.5.5 : Cluster means for the eleven characters in Kharif, 2008 (E_1) and Summer, (2009 (E_2) environments.

Kharif, 2008 (E_1)

Cl.	Days to 50 % flowering	Plant height (cm)	No. of tillers/ plant	No. of leaves/ plant	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Leaf weight (g)	Stem weight (g)	Green fodder yield (q/ha)	Dry matter yield (q/ha)
I	47.66	165.80	2.77	7.71	65.51	3.05	140.15	19.60	76.39	462.96	88.87
II	51.66	160.32	3.46	8.50	74.01	3.45	184.41	20.07	88.73	532.92	105.765
III	48.33	147.56	2.65	8.20	53.91	2.61	101.53	20.89	86.13	415.63	75.06
IV	51.33	180.82	3.27	9.16	62.18	2.82	126.88	22.89	116.62	593.82	134.98
V	52.33	164.33	3.85	7.93	77.60	3.75	210.22	26.64	99.42	504.11	96.20
VI	56.33	196.82	3.09	9.93	84.13	3.87	235.42	47.87	219.78	662.55	136.27

Summer, (2009 (E_2)

Cl.	Days to 50 % flowering	Plant height (cm)	No. of tillers/ plant	No. of leaves/ plant	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Leaf weight (g)	Stem weight (g)	Green fodder yield (q/ha)	Dry matter yield (q/ha)
I	58.33	141.74	3.78	7.60	57.30	2.87	119.05	24.77	104.17	346.71	71.01
II	51.00	127.63	2.97	7.31	53.08	2.87	109.95	24.33	110.00	433.43	84.40
III	58.67	153.84	3.09	8.18	62.04	2.58	115.72	22.33	158.67	460.90	87.44
IV	50.33	116.60	2.60	6.36	41.29	2.91	87.24	18.33	69.00	270.08	49.48
V	56.67	121.13	2.40	7.40	49.09	2.47	87.98	22.56	94.33	286.01	54.74
VI	60.00	189.29	3.38	10.09	80.87	4.04	237.04	40.67	171.90	630.65	124.60

4.5.3 Cluster mean

Cluster mean for the eleven characters are computed and presented in the Table: 4.5.5.

Cluster mean revealed that the genotype Giant bajra which is included in cluster VI in E1 and E2 showed highest mean value for almost all the characters in both the environments except the genotype in cluster V (RHRB-278) in E1 and in cluster I (PMFT-905 and RHRB-278) in E_2 in which it had highest mean value for number of tillers per plant.

4.6 Molecular studies (RAPD analysis)

Total 43 arbitrary oligonucleotide primers of three primer series *viz.* OPA, OPC and OPE were used for RAPD analysis of eight parental lines. Out of them, 20 primers which generated polymorphism were selected for molecular analysis and diversity analysis. The data on maximum scorable bands, polymorphic loci, total loci, percentage polymorphism , size of DNA fragment and PIC values revealed by RAPD analysis is presented in Table 4.6.1.

4.6.1 Pooled RAPD Analysis

Pooled RAPD analysis of all 20 arbitrary oligonucleotide primers of three primer series *viz.* OPA , OPC and OPE generated total 806 scorable bands with 171 loci, among them 136 loci were found polymorphic, showing 79.53 % polymorphism. The minimum (115.19 bp) sized fragment was amplified by primer OPA-14, whereas maximum (2929.49 bp) sized fragment was amplified by primer OPC-6. A highest (100%) polymorphism was exhibited by primers OPE-5 and OPE-9 while the lowest polymorphism (50 %) was observed with OPE-3. The maximum scorable bands (69) and maximum loci (15) with all of them to be polymorphic were generated by primer OPA-4, whereas primer OPE-1 generated only

Table: 4.6.1 Maximum scorable bands, polymorphic loci, total loci, percentage Polymorphism and PIC values revealed by RAPD analysis

Sr. No.	Name of primer	Maximum scorable bands	Poly morphic loci	Total loci	% Polymo rphism	Molecular weight (bp)		PIC value
						Minimum	Maximum	
	OPA Series							
1	OPA-2	43	4	6	66.67	124.98	2401.55	0.029
2	OPA-3	39	7	8	87.50	346.06	1982.79	0.121
3	OPA-4	69	12	15	80.00	336.02	2303.70	0.237
4	OPA-5	53	8	11	72.73	427.97	2706.87	0.234
5	OPA-14	44	4	7	57.14	115.19	2372.74	0.165
	OPC Series							
6	OPC-6	34	9	12	75.00	366.28	2929.49	0.494
7	OPC-10	40	4	7	57.14	167.13	1766.29	0.3194
8	OPC-12	35	5	6	83.33	280.97	2338.15	0.098
9	OPC-13	40	6	8	75.00	367.01	2702.98	0.110
	OPE Series							
10	OPE-1	21	4	5	80.00	198.12	1834.17	0.342
11	OPE-3	40	5	10	50.00	342.85	2072.78	0.418
12	OPE-4	55	9	10	90.00	497.66	2714.35	0.120
13	OPE-5	47	12	12	100.00	257.42	2300.45	0.222
14	OPE-6	28	6	7	85.71	309.80	2324.45	0.258
15	OPE-7	34	6	7	85.71	436.54	1962.78	0.206
16	OPE-9	30	7	7	100.00	329.84	2081.12	0.215
17	OPE-15	39	8	10	80.00	378.50	2738.63	0.343
18	OPE-16	40	6	7	85.71	357.82	2104.80	0.122
19	OPE-18	30	5	6	83.33	374.97	1622.41	0.069
20	OPE-20	45	9	10	90.00	335.22	2102.26	0.243
	Pooled	**806**	**136**	**171**	**79.53**			

21 scorable bands. Primer OPE-1 amplified minimum 5 loci out of which, 4 were found polymorphic. The PIC value ranged from 0.029 (OPA-2) to 0.494 (OPC-06). On an average, per primer 6.8 polymorphic loci were generated.

4.6.2 Genetic diversity studies among parental lines in pearl millet through molecular marker system

Dendrogram (Figure: 4.21) based on unbiased measures of genetic distance (Table: 4.6.2) by UPGMA method using NTSYS-pc version 2.02 formed two major clusters which grouped all the genotypes. Among these two minor clusters, first one was again divided into two sub clusters, first sub cluster contained PMFT-904, PMFT-905, PMFT-907 and RHRB-259, while the second, third and fourth minor cluster belonged individual genotype i.e. RHRB-260,RHRB-278 and RHRB-282. The genotype Giant bajra alone included in separate cluster.

The genetic similarity and genetic dissimilarity matrix (Table: 4.6.2) revealed, genetic distance values ranging from 0.1429 to 0.4462. Maximum genetic distance (0.4462) was found between PMFT-905 and Giant bajra, whereas minimum genetic distance (0.1429) was observed between PMFT-904 and PMFT-905.

Table 4.6.2 Dice similarity and genetic distance for RAPD analysis

	Giant Bajra	PMFT-904	PMFT-905	PMFT-907	RHRB-259	RHRB-260	RHRB-282	RHRB-278
Giant bajra	****	0.6476	0.5538	0.6467	0.6193	0.5648	0.5573	0.6185
PMFT-904	0.3534	****	0.8571	0.7713	0.7305	0.6894	0.6732	0.7129
PMFT-905	0.4462	0.1429	****	0.7307	0.6961	0.7010	0.6737	0.6766
PMFT-907	0.3533	0.2287	0.2693	****	0.7714	0.7000	0.7041	0.7246
RHRB-259	0.3807	0.2695	0.3039	0.2286	****	0.7245	0.7396	0.7192
RHRB-260	0.4352	0.3102	0.2990	0.3000	0.2755	****	0.6593	0.6632
RHRB-282	0.4427	0.3268	0.3263	0.2959	0.2604	0.3407	****	0.6984
RHRB-278	0.3815	0.2871	0.3234	0.2754	0.2808	0.3368	0.3016	****

Genetic similarity (above diagonal) and genetic distance (below diagonal)

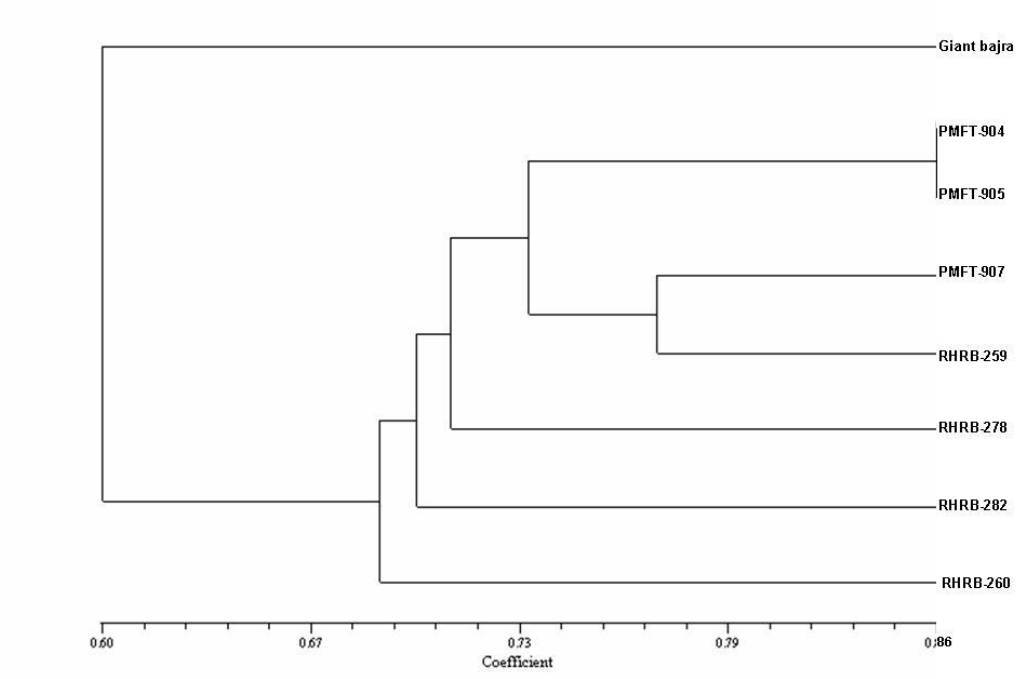


Fig: 4.21: The dendogram of eight parental lines of pearl millet based on UPGMA and similarity coefficient using RAPD data.

4.7 Comparison of the results of RAPD and D^2 analysis

In order to compare the results of the RAPD and D^2 analysis their results of the diversity analysis mean, genetic distance and dendrogram results were taken into consideration.

Overall results of the RAPD showed Dice Unbiased Measures of genetic simillarity and genetic distance matrix (Table: 4.6.2) revealed, genetic distance value ranged from 0.1429 to 0.4462, in terms of most closest and most divergent pair. Based on RAPD diversity data, PMFT-905 and Giant bajra were most divergent pair, where as PMFT-904 and PMFT-905 were closest one.

D^2 analysis revealed maximum inter cluster distance (D= 32.523) between cluster III (RHRB-260) and cluster VI (Giant bajra) in E_1 and (D= 39.966) between cluster IV (RHRB-259) and cluster VI (Giant bajra) in E_2. Inter cluster distance was minimum (D= 10.686) between cluster I (PMFT-907, RHRB-259) and cluster III (RHRB-260) in E_1 and (D= 9.525) between cluster I (PMFT-905, RHRB-278) and cluster III (RHRB-282) in E_2. However, D^2 matrix exhibited multivariate distance between individual parental genotypes RHRB-260 and Giant bajra with maximum distance (1057.77) in E_1 and between RHRB-259 and Giant bajra (1597.30) in E_2. Whereas minimum distance 38.80 and 29.25 was observed between PMFT-907 and RHRB-259 and between PMFT-907 and PMFT-907 in E_1 and E_2, respectively.

When comparing cluster results obtained from the RAPD and D^2 cluster analysis; Giant bajra, RHRB-260 and RHRB-282 formed major distinct clusters in both analysis, proving that it was the most diverse line among all parental genotypes. Pooled RAPD analysis grouped parental lines into 2 distinct clusters. In D^2

cluster analysis in kharif, 2008 (E1), four genotype *viz.* RHRB-260,RHRB-282,RHRB-278 and Giant bajra and in summer, 2009 (E_2) four genotype *viz.* RHRB-282,RHRB-259,RHRB-260 and Giant bajra formed individually separate clusters, whereas rest of the genotypes falls in cluster I and II.

4.8 Correlation studies for molecular divergence and hybrid performance (heterosis) for green forage yield and quality characters

Eight parental lines of pearl millet were evaluated to investigate the association between genetic distance of RAPD (GD_R) analysis and their correlation with hybrid performance (F_1 mean), mid parent (MP), specific combining ability (SCA), Mid parent heterosis (MPH) and Better parent heterosis (BPH) by using Pearson's simple correlation procedure. The results are presented in Table 4.8.1, 4.8.2 and 4.8.3 for E1, E2 and pooled analysis, respectively and described below:

In kharif,2008 (E_1) environment, the genetic distance of RAPD anaysis (GD_R) was positively and significantly correlated with F1 mean for the characters days to 50 % flowering (0.599), plant height (0.447) and leaf length (0.413) while, the correlation between GDR and MP was positive and significant for days to 50 % flowering (0.668) plant height (0.559), number of leaves (0.683), leaf weight (0.785), stem weight (0.795), green forage yield (0.522), dry matter yield (0.510) and IVDMD (0.512) and significant negative association with crude fibre (-0.407) and NDF (-0.521).

In summer, 2009 (E_2) environment, the association of genetic distance with F_1 mean was significant and positive for days to 50 % flowering (0.439), plant height (0.375), number of leaves (0.0.548), stem weight (0.795), leaf length (0.604) leaf width (0.466), leaf area (0.606), leaf weight (0.587) and stem weight

(0.586) Further, the correlation between GD_R and MP was positive and significant for days to 50 % flowering (0.689), plant height (0.747), number of leaves (0.791), leaf length (0.743), leaf width (0.567), leaf area (0.732), leaf weight (0.784), stem weight (0.627), green forage yield (0.570), dry matter yield (0.567) and IVDMD (0.411) and significant negative association with crude fibre content (-0.482) and NDF (-0.673).

On the basis of pooled mean, it is observed that the GD_R was positively and significantly correlated with F_1 mean for days to 50 % flowering (0.570) plant height (0.485), number of leaves (0.417), leaf length (0.595), leaf area (0.377), leaf weight (0.528), stem weight (0.552) and IVDMD (0.379) while, the correlation between GD_R and MP was positive and significant for most of the characters except number of tillers, leaf : stem ratio, CP (%), ADF (%) and oxalic acid. Further, significant negative association was found GD_R and MP for crude fibre (-0.502).

In present study, GD_R showed non significant association with SCA, MPH and BPH for almost all the characters in E_1, E_2 environments and over pooled means.

Table 4.8.1 : Correlation matrix for RAPD distance (GD) with F_1 mean, mid-parental value (MP), SCA, MPH and BPH in Kharif, 2008 (E_1) environment.

Sr. No.	Characters	Correlation coefficient for RAPD distance (GD) with				
		F1 mean	Mid parent	SCA	MPH	BPH
1	Days to 50 % flowering	0.599**	0.668**	0.176	0.237	0.313
2	Plant height (cm)	0.447*	0.559**	0.185	0.060	-0.153
3	Number of tillers/plant	-0.217	-0.007	-0.214	-0.222	-0.164
4	Number of leaves/plant	0.238	0.683**	-0.001	-0.244	0.341
5	Leaf length (cm)	0.413*	0.314	0.034	0.003	-0.184
6	Leaf width (cm)	-0.093	0.267	-0.143	-0.260	-0.333
7	Leaf area(cm2)	0.148	0.341	-0.080	-0.170	-0.286
8	Leaf weight /plant (g)	0.261	0.785**	-0.144	-0.208	-0.321
9	Stem weight /plant (g)	0.302	0.795**	-0.195	-0.294	-0.365
10	Leaf: Stem ratio	0.014	-0.333	0.128	0.181	0.182
11	Green forage yield (q/ha)	0.235	0.522**	0.013	-0.187	-0.232
12	Dry matter yield (q/ha)	0.190	0.510**	-0.041	-0.205	-0.220
13	Crude protein (%)	0.183	0.241	0.032	-0.059	-0.038
14	Crude fibre (%)	-0.187	-0.407**	-0.043	0.109	0.107
15	Acid detergent fibre (%)	-0.322	0.096	-0.243	-0.196	-0.236
16	Neutral detergent fibre (%)	0.033	-0.521**	0.167	0.212	0.304
17	Oxalic acid (%)	-0.146	-0.172	-0.082	-0.096	-0.098
18	IVDMD (%)	0.353	0.512**	0.111	0.092	0.008

*, ** significant at 5 % and 1 % level of significance , respectively.

Table 4.8.2 : Correlation matrix for RAPD distance (GD) with F_1 mean, mid-parental value (MP), SCA, MPH and BPH in Summer, 2009 (E_2) environment

Sr. No.	Characters	Correlation coefficient of RAPD distance (GD) with				
		F1 mean	Mid parent	SCA	MPH	BPH
1	Days to 50 % flowering	0.439*	0.689**	-0.087	-0.008	0.071
2	Plant height (cm)	0.375*	0.747**	-0.309	-0.246	-0.355
3	Number of tillers/plant	0.281	0.294	0.054	0.035	-0.013
4	Number of leaves/plant	0.548**	0.791**	-0.348	-0.285	-0.313
5	Leaf length (cm)	0.604**	0.743**	-0.305	-0.272	-0.355
6	Leaf width (cm)	0.466*	0.567**	-0.007	-0.108	-0.241
7	Leaf area(cm2)	0.606**	0.732**	-0.248	-0.206	-0.301
8	Leaf weight /plant (g)	0.587**	0.684**	-0.127	-0.173	-0.362
9	Stem weight /plant (g)	0.586**	0.627**	0.020	-0.099	-0.199
10	Leaf: Stem ratio	-0.167	0.176	-0.142	-0.217	-0.150
11	Green forage yield (q/ha)	0.329	0.570**	-0.072	-0.208	-0.318
12	Dry matter yield (q/ha)	0.206	0.567**	-0.133	-0.242	-0.322
13	Crude protein (%)	-0.101	0.302	-0.190	-0.293	-0.332
14	Crude fibre (%)	-0.026	-0.482**	0.009	-0.102	0.099
15	Acid detergent fibre (%)	-0.216	-0.326	-0.008	-0.027	-0.106
16	Neutral detergent fibre (%)	-0.024	-0.673**	0.253	0.241	0.352
17	Oxalic acid (%)	0.185	-0.300	0.110	0.275	0.321
18	IVDMD (%)	0.319	0.411*	0.200	0.024	0.013

*, ** significant at 5 % and 1 % level of significance , respectively.

Table 4.8.3 : Correlation matrix for RAPD distance (GD) with F_1 mean, mid-parental value (MP), SCA, MPH and BPH in pooled over environments

Sr. No.	Characters	Correlation coefficient for RAPD distance (GD) with				
		F1 mean	Mid parent	SCA	MPH	BPH
1	Days to 50 % flowering	0.570**	0.713**	0.032	0.110	0.104
2	Plant height (cm)	0.485*	0.692**	-0.72	-0.267	-0.368
3	Number of tillers/plant	-0.053	0.133	-0.140	-0.150	-0.135
4	Number of leaves/plant	0.417*	0.765**	-0.142	-0.235	-0.370
5	Leaf length (cm)	0.595**	0.608**	-0.152	-0.293	-0.364
6	Leaf width (cm)	0.175	0.450*	-0.101	-0.256	-0.357
7	Leaf area(cm2)	0.377*	0.580**	-0.165	-0.225	-0.335
8	Leaf weight /plant (g)	0.528**	0.761**	-0.189	-0.300	-0.334
9	Stem weight /plant (g)	0.552**	0.762**	-0.159	-0.238	-0.348
10	Leaf: Stem ratio	-0.048	-0.071	-0.040	0.028	0.086
11	Green forage yield (q/ha)	0.332	0.607**	-0.028	-0.230	-0.316
12	Dry matter yield (q/ha)	0.247	0.576**	-0.090	-0.247	-0.364
13	Crude protein (%)	0.069	0.302	-0.074	-0.240	-0.241
14	Crude fibre (%)	-0.140	-0.502**	-0.028	0.090	0.133
15	Acid detergent fibre (%)	-0.346	-0.124	-0.168	-0.231	-0.249
16	Neutral detergent fibre (%)	0.009	0.649**	0.236	0.282	0.342
17	Oxalic acid (%)	-0.013	-0.278	0.045	0.225	0.255
18	IVDMD (%)	0.379*	0.536**	0.167	0.071	0.001

*, ** significant at 5 % and 1 % level of significance, respectively.

5. DISCUSSION

Economical exploitation of hybrid vigour on commercial scale and systematic varietal improvement through hybridization in pearl millet for grain yield were considerably achieved during recent years. However, very little systematic breeding efforts and substantial improvement are being made to improve forage yield and quality in pearl millet.

In breeding cross pollinated crops identification of superior lines, from the variability created through hybridization, is the primary objective. Combining ability studies are very important as it helps in the selection of parents and crosses which give highest improvement for the character under consideration and also furnish the information on additive and non-additive portion of genetic variance present in the material under study. As environment plays an important role in the expression of a character and greatly influence the combining ability estimates, the study in a single environment may not provide reliable information.

A systematic selection of high yielding and stable genotypes may be possible through the study of genotype x environment interaction by using parents and their crosses over different environments. Random amplified polymorphic DNA analysis provides additional tool for detecting inbred lines differences at molecular level and in reliable, rapid and cost effective method.

Keeping this in view, the efforts were made in present investigation to study the extent of heterosis, to identify the best combining parental lines and to study the gene action for improvement in forage yield and yield attributing characters of crosses developed by using eight parents in diallel excluding reciprocals in two environments (Kharif, 2008 and Summer, 2009).

A study on molecular diversity among parents by RAPD markers and its relation with hybrid performance for forage yield was also undertaken. The results obtained in present investigation are discussed below, under suitable headings.

5.1 Mean performance of parents and hybrids

5.1.1 Mean performance of parents

From the data presented in Table 4.1.1 to 4.1.6, it can be seen that the parents included in the present investigations possessed wide variability in respect of characters studied. Most of the characters were found to be influenced greatly by the seasons and therefore, there was not much consistency in performance.

The parent Giant bajra showed higher mean performance for green forage yield and 13 forage yield and quality characters *viz.,* plant height, number of leaves/plant, leaf length, leaf width, leaf area, leaf weight, stem weight, dry matter yield, crude protein, crude fibre, NAF, oxalic acid and IVDMD per cent in E_1 and for all the characters except days to 50 % flowering and L:S ratio in E_2 and for 16 characters excluding L:S ratio and ADF percent in pooled analysis.

Parent RHRB-282 showed higher *per se* performance for 10 characters *Viz.,* plant height, number of tillers, number of leaves/plant, stem weight, green forage yield, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD per cent in E1, for 13 characters *viz.,* plant height, number of tillers, number of leaves/plant, leaf length, stem weight, L:S ratio, green forage yield, dry matter yield, crude protein, crude fibre, ADF, NDF, oxalic acid and IVDMD percent in E_2 and for 11 characters *viz.,* plant height, number of tillers, number of leaves/plant, leaf weight, stem weight,

green forage yield, dry matter yield, crude protein, ADF, oxalic acid and IVDMD per cent in pooled analysis.

Parent PMFT-904 had higher *per se* performance for 7, 9 and 11 characters in E_1, E_2 and in pooled analysis, respectively. v*iz.,* leaf length, leaf width, leaf area, crude protein, ADF and oxalic acid per cent in E_1; days to 50 % flowering, leaf width, leaf weight, stem weight, green forage yield, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD percent in E_2 and days to 50 % flowering, leaf length, leaf width, leaf weight, leaf weight, stem weight, green forage yield, crude protein, crude fibre, ADF, oxalic acid and IVDMD per cent in pooled analysis.

Parent PMFT-905 had higher *per se* performance for 11 characters v*iz.,* number of tillers, number of leaves, leaf length, leaf width, leaf area, green fodder yield, dry matter yield, crude protein, crude fibre, ADF and NDF per cent in E_1; for 4 characters viz., plant height, number of tillers, crude protein and crude fibre percent in E_2 and for 9 characters *viz.,* number of tillers, leaf length, leaf width, leaf area, dry matter yield, crude protein, crude fibre, ADF and NDF per cent in pooled analysis.

Parent PMFT-907 and RHRB-259 recorded lower mean values for days to 50 % flowering in E_1, E_2 and across seasons which is desirable, whereas, higher mean for L:S ratio was recorded by RBRB-259 and RHRB-278 in both the seasons and across the seasons. The parent RHRB- 260 had lower ADF and NDF per cent which is desirable in both the season as well as across the seasons.

High mean value of above parents for forage traits indicated, the parents Giant bajra, RHRB-282, PMFT-904 and

RHRB-278 should profitably be used in breeding programme for development of hybrids/varieties of pearl millet for forage purpose.

5.1.2 Mean performance of hybrids

From the mean data of crosses for different characters (Table 4.1.1.1 to 4.1.1.6) revealed that the crosses Giant bajra x RHRB-282, Giant bajra x PMFT-905, PMFT-905 x RHRB-282 in E_1, Giant bajra x RHRB-282, PMFT-907 x RHRB-278, Giant bajra RHRB-278 in E_2 had high mean for green forage yield as well as they exhibited good performance for most of the yield and quality traits. While, crosses Giant bajra x RHRB-282, PMFT-907 x RHRB-278 and Giant bajra x PMFT-905 were found promising for green forage yield, yield contributing and quality traits across the environments. Similarly, the crosses Giant bajra x RHRB-259 and PMFT-907 x RHRB-259 in E_1, PMFT-905 x PMFT-907 in both environments and across the environments were found to be the earliest for days to 50 % flowering.

5.2 Analysis of variance

A analysis of variance (Table 4.2.1.2 and 4.2.1.3) of diallel set in E_1 (Kharif, 2008) and E_2 (Summer, 2009) environments revealed significant mean sum of squares due to treatments and its sub division (Parents, hybrids and parents v/s hybrids) for all characters studied except mean squares due to parents for number of tillers/plant and oxalic acid in E_1 and for crude fibre content in E_2 and except mean squares due to parent v/s hybrids for number of tillers/plant, leaf length, L:S ratio, crude fibre (%), ADF (%), NDF (%), oxalic acid (%) and IVDMD in E_1 and except plant height, number of tillers, stem weight, ADF and NDF (%) in E_2 indicating sufficient variability among parents and hybrids. In previous studies such observations were also noted for

yield and yield contributing characters in pearl millet by Hapse (1989), Patil, (1990) and Rasal (1992).

The pooled analysis of variance (Table 4.2.2) revealed that the environments differed significantly for all the characters except L:S ratio, oxalic acid and IVDMD (%) suggesting sufficient diversity among the test environments. The significant differences among treatments, parents and hybrids were also observed for most of the characters suggesting substantial diversity among them. The significant mean squares due to parents vs. hybrids for most of the characters except number of tillers/plant, number of leaves/plant, leaf width, leaf weight, ADF, NDF and IVDMD (%) showed presence of heterosis in hybrids for the traits.

A pooled analysis of variances by the interactions of treatments x environments, parents x environments, hybrids x environments and parents vs. hybrids x environments were found significant for majority of the characters, except for number of tillers in case of treatments x environment and hybrids x environment; number of tillers, leaves per plant and oxalic acid (%) in case of parents x environment and except number of tillers, L:S ratio, crude protein, crude fibre, ADF, NDF, oxalic acid and IVDMD (%) in case of parents vs. hybrids x environments. Quendeba *et al.* (1996) also reported significant difference among crosses and parents and year x treatments for forage yield but non significant for IVDMD due to year x treatments. Shanmuganathan *et al.* (2005) and Kumar and Sinahania (2007) also found significant mean square of parent vs. hybrids for forage yield and most of the yield contributing characters.

These results suggested that the differences in the performance of the parents and hybrids were real for majority of

the characters in both the environments indicating the presence of heterosis for these characters.

5.3 Combining ability Analysis

5.3.1 Combining ability ANOVA

Combining ability analysis in individual environment (Table 4.3.1.1) and over pooled environments (Table 4.3.1.2) indicated highly significant mean squares due to gca and sca for all the characters in both the environments and over pooled except mean squares of gca for number of tillers per plant in E_1 and IVDMD in E_2 and mean squares due to sca for oxalic acid content in E_2 revealing importance of both additive and non additive type of gene effects for expression of these traits. Singh *et al.* (1979), Sreenivasulu and Sreeramulu (1980), Prakash kumar *et al.* (1982), Dass *et al.* (1985), Aher and Ugale (1995), Rathore *et al.* (2004), Shanmuganathan et al. (2005), Rohitashwa *et al.* (2006) and Kumar and Sanghani (2007) also reported similar results for yield and yield contributing characters in pearl millet.

Significant gca x environment for all the characters except number of tillers per plant, L:S ratio, crude protein, NDF, oxalic acid and IVDMD percent, while significant sca x environment interaction for all the characters except number of tillers per plant indicated importance of experimentation over environment to assess the genetic worth of genotypes. The magnitude of gca mean squares was higher than sca for all the characters in both the environments except for number of leaves/plant and IVDMD percent in E_1, ADF and IVDMD percent in E_2 and except for IVDMD percent in pooled over environments.

5.3.2 General combing ability effects

The genetic worth of the parents is evaluated on the basis of it combining ability. General combining ability (gca) of parent is a factor that predicts the performance of a parent over series of cross combination. High gca value parent for forage yield and quality character indicate that parent had favourable genes for yield and quality characters. Therefore, parent showing high gca effect may be extensively used in pearl millet improvement programme either to produce a synthetic variety or superior hybrid. The former goal can be achieved by following selection in successive generation with or without inbreeding.

The parent showing high performance is expected to produce desirable combination but this do not happen always hence combining ability had greater importance to exhibit the genetic potential of genotypes.

The data on gca estimates (Tables 4.3.2.1 and 5.1) for forage characters in pearl millet indicated that none of the parent showed significant and desirable gca effects for all the characters in both the environment and across the environments. However, Giant bajra, RHRB-282, and PMFT-904 were good general combiners for majority of the characters. Among the parents Giant bajra showed GCA effects in desirable direction for 13 out of 18 characters *viz.,* plant height, number of leaves, leaf length, leaf width, leaf area, leaf weight, stem weight, green forage yield, dry matter yield, crude protein, crude fibre, ADF and NDF percent in (E_1), for 12 characters *viz.,* plant height, number of tillers, number of leaves, leaf length, leaf width, leaf area, leaf weight, stem weight, green forage yield, dry matter yield, ADF and NDF percent (E_2), and for 15 characters *viz.,* plant height, number of leaves, leaf length, leaf width, leaf area, leaf weight, stem weight,

L:S ratio green forage yield, dry matter yield, crude protein, crude fibre, ADF, NDF and IVDMD percent across the environments.

The parent RHRB-282 showed high significant desirable gca effects for 10 important forage characters *viz.,* plant height, number of leaves, leaf weight, stem weight, green forage yield, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD percent in (E_1), for 11 characters *viz.,* plant height, number of tillers, leaf length, leaf weight, stem weight, L:S ratio, green forage yield, , crude protein, crude fibre, NDF and oxalic acid percent (E_2), and for 11 characters *viz.,* plant height, number of tillers, leaf weight, stem weight, L:S ratio green forage yield, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD percent across the environments.

Similarly parent PMFT-905 had significant desirable gca effect for plant height, number of tillers, leaf length, leaf width, leaf area, green forage yield, dry matter yield and in (E_1); only for days to 50 % flowering and plant height in (E_2) and for days to 50 % flowering, plant height, number of tillers, leaf width, leaf area and NDF per cent across the environments. The parents, PMFT-904, RHRB-259 and RHRB-260 showed significant and negative gca for days to 50 % flowering in both the environments. Similarly parent RHRB-278 showed significant and positive heterosis for plant height, leaf length, leaf area and dry matter yield in both the environments and across the environments.Chawala and Gupta (1982) in their combining ability studies pointed out that good combiner parents on the basis of gca effects also showed better performance.

Table 5.1 : Parents with significant and desirable GCA effects for forage characters in 8 x 8 diallel in pearl millet

Parents	Env.	Days to 50% flow.	Plant height (cm)	No. of tillers/ plant	No. of leaves/ plant	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Leaf weight (g)	Stem weight (g)
Giant bajra	E_1	++	**	+	**	**	**	**	**	**
	E_2	++	**	**	**	**	**	**	**	**
	Pooled	++	**	+	**	**	**	**	**	**
PMFT-904	E_1	**	++	+	++	+	+	+	++	++
	E_2	**	++	+	+	+	+	+	+	+
	Pooled	**	++	+	+	+	+	+	++	++
PMFT-905	E_1	+	**	**	+	**	**	**	++	+
	E_2	**	**	+	+	++	+	++	++	+
	Pooled	**	**	**	+	+	**	**	++	+
PMFT-907	E_1	**	+	+	+	++	**	+	+	+
	E_2	**	++	+	++	++	++	++	++	++
	Pooled	**	++	+	+	++	+	+	++	++
RHRB-259	E_1	**	++	+	++	++	++	++	+	++
	E_2	**	++	++	++	++	+	++	++	++
	Pooled	**	++	++	++	++	++	++	++	++
RHRB-260	E_1	**	++	++	++	++	++	++	+	++
	E_2	+	++	++	++	++	++	++	++	**
	Pooled	+	++	++	++	+	++	++	+	++
RHRB_282	E_1	+	**	+	**	**	+	++	**	+
	E_2	++	**	**	+	+	+	+	**	**
	Pooled	++	**	+	+	+	+	+	**	**
RHRB-278	E_1	++	**	+	+	**	+	**	+	++
	E_2	++	+	**	+	**	+	**	+	+
	Pooled	++	**	**	+	**	+	**	+	++

Table 5.1 contd.: Parents with significant and desirable GCA effects for forage characters in 8 x 8 diallel in pearl millet

Parents	Env.	L:S ratio	Green forage yield (q/ha)	Dry matter yield (q/ha)	Crude protein (%)	Crude Fibre(%)	ADF (%)	NDF (%)	Oxalic acid (%)	IVDMD (%)
Giant bajra	E_1	+	**	**	**	**	**	**	+	**
	E_2	++	**	**	+	+	**	**	**	+
	Pooled	++	**	**	**	**	**	**	**	**
PMFT-904	E_1	++	++	++	+	+	++	**	+	+
	E_2	+	+	**	+	+	+	+	+	+
	Pooled	++	+	++	**	+	*	**	*	+
PMFT-905	E_1	++	**	**	+	+	+	**	+	+
	E_2	++	++	++	+	+	+	+	+	+
	Pooled	++	++	+	+	+	+	**	+	+
PMFT-907	E_1	+	+	++	+	+	+	++	+	++
	E_2	+	**	+	+	+	+	+	+	+
	Pooled	+	+	++	+	+	+	++	++	+
RHRB-259	E_1	**	++	++	++	+	++	++	+	+
	E_2	**	++	++	+	++	++	+	+	++
	Pooled	**	++	++	+	++	++	++	++	++
RHRB-260	E_1	**	++	++	++	+	+	+	++	+
	E_2	+	++	+	+	++	+	+	++	+
	Pooled	**	+*	++	++	++	+	++	++	+
RHRB_282	E_1	+	**	**	**	**	+	+	**	**
	E_2	**	**	**	**	**	+	+	**	+
	Pooled	**	**	**	**	**	+	+	**	**
RHRB-278	E_1	+	**	**	++	++	++	++	++	++
	E_2	+	+	**	++	++	+	++	++	+
	Pooled	+	**	**	++	++	+	++	++	+

****** **Good combiner** **++** **Poor combiner** **+** **Average combiner**

High gca values of parents for forage yields and its contributing traits indicated that these parents had favourable gene, therefore may be used in forage pearl millet improvement programme through hybrid breeding.

When the gca effect and *per se* performance of the parents were considered, the close trend was noticed in the case of the most forage characters studied. The parent Giant bajra showing high mean performance also showed high gca effect for plant height, number of leaves, leaf length, leaf width, leaf area, leaf weight, green forage yield, dry matter yiled, crude protein, crude fibre and NDF per cent. Similarly the parent RHRB-282 showed high gca effect with high per se performonace for characters, plant height, number of tillers, leaf weight, stem weight, green fodder yield, dry matter yield, crude protein, crude fibre, NDF and oxalic acid percent in both the environments and across the environments. Similarly the parent RHRB-278 aslo exhibited significant gca effect with high mean performance for leaf length, leaf area and dry matter yield. Similar parallelism in pearl millet has been observed by Gill *et al.* (1974), Pokhriyal *et al.* (1976), Navale *et al.* (1991) and Rasal (1992).

The *per se* performance of parents along with gca effects could be a better criteria for choice of superior parents in hybridization programme (Rao, 1972). In present investigation, the results revealed that the parents Giant bajra, RHRB-282, RHRB-278 and PMFT-904 had relatively high degree of correspondence between *per se* performance and their gca effects for almost all the characters, which could be ascribed to predominant role of additive and additive x additive gene action for inheritance of these traits. Therefore, in selection of parents for hybridization due weightage should be given to *per se* performance along with their gca effects.

5.3.3 Specific combining ability effects

Selection of hybrid on basis of *per se* performance is not desirable/possible because hybrids exhibiting high *per se* performance may not always exhibit high magnitude of heterosis. Hence sca is an important criterion for selection of hybrids. The high estimates of sca might be due to the combination of favourable genes from genetically diverse lines. The role of both additive x additive and additive x dominance type of gene interactions for bringing out the high sca which reflect in term of high sca effects. Therefore, sca effects of cross combination along with gene action and appropriate breeding methods for improvement of forage yield and its contributing characters are discussed here. The best performing cross combinations based on sca effects for forage yield, yield contributing and quality traits are listed in Table 5.2 (kharif,2008 and summer, 2009) and Table 5.3 (Pooled analysis).

5.3.3.1 Days to 50 % flowering

For days to 50 per cent flowering, eight combinations Giant bajra x RHRB-259, PMFT-904 x PMFT-905 PMFT-904 x RHRB-260, PMFT-905 x PMFT-907, PMFT-905 x RHRB-259, PMFT-905 x RHRB-260, PMFT-905 x RHRB-282 and RHRB-282 x RHRB-278 showed significant negative sca effects under both the environments (Table 4.3.3.1). One or both the parents involved in the crosses are good general combiners for days to 50 % flowering.

5.3.3.2 Plant height (cm)

Of the ten, nine and twelve crosses showing significant positive sca effects for plant height in E_1, E_2 and pooled analysis, respectively (Table 4.3.3.1). The crosses PMFT-905 x RHRB-278, RHRB-259 x RHRB-260 and RHRB-259 x RHRB-278 displayed the

positive significant sca effects uniformly in both the seasons and also in pooled analysis. These combinations were derived from either good x good ,poor x poor and poor x good general combiners.

5.3.3.3 Number of tillers per plant

None of the same cross displayed the positive significant sca effects under both the environments (Table 4.3.3.1). The highest magnitude of positive sca effects was observed by PMFT-904 x PMFT-905 in E_1 and in pooled analysis and PMFT-904 x RHRB-260 in E_2. These combinations were derived from the parents having average x good, average x poor general combining ability.

5.3.3.4 Number of leaves per plant

For number of leaves, ten crosses in E_1, two in E_2, and five in pooled analysis showed significant positive sca effects. The highest and significant positive sca effect was noticed in the cross Giant bajra x PMFT-905 in E_1 and RHRB-259 x RHRB- 278 in E_2 (0.65) and in pooled analysis. The cross RHRB-259 x RHRB- 278 displayed the positive significant sca effects in both the seasons (Table 4.3.3.2) and was derived from the parents having poor x average general combining ability.

5.3.3.5 Leaf length (cm)

Eight, two and four crosses in E_1, E_2 and pooled analysis were recorded significant and high positive sca effects for leaf length. The highest being by the cross combination RHRB-260 x RHRB-282 in E_1, PMFT-904 x RHRB-259 in E_2 and Giant bajra x PMFT-905 in pooled analysis (Table 4.3.3.2). These cross combinations were derived from the parents having poor x good, average x poor and good x average general combining ability.

However, none of the same cross displayed the positive significant sca effects under both the environments.

5.3.3.6 Leaf width (cm)

It is revealed from the data presented in Table 4.3.3.2 that the cross combinations, RHRB-260 x RHRB-282 (0.63) expressed highest significant positive sca effect in E_1 and Giant bajra x PMFT-905 in E2 and in pooled analysis. The number of crosses, which recorded significant positive sca effects for this trait, were nine, two and eleven in E_1, E_2 and pooled analysis, respectively. The cross combination Giant bajra x PMFT-905 having parents of good x good general combining ability displayed the positive significant sca effects under both the environments.

5.3.3.7 Leaf area (cm^2)

For leaf area the cross combination RHRB-260 x RHRB-282 expressed highest significant positive sca effect in E_1, RHRB-259 x RHRB-260 in E_2 and Giant bajra x PMFT-905 (25.55) in pooled analysis (Table 4.3.3.3). The cross combinations Giant bajra x PMFT-905 and PMFT-904 x RHRB-259 displayed the positive significant sca effects for this trait under both the environments. These combinations were derived from good x average and average x poor general combiners.

5.3.3.8 Leaf weight (g)

The significant positive values of the sca effects for leaf weight were observed for six, two and six crosses in E_1, E_2 and pooled analysis, respectively (Table 4.3.3.3). The cross combination RHRB-260 x RHRB-282 recorded the highest significant positive sca effect in E_1, PMFT-904 x RHRB-259 in E_2 and RHRB-260 x RHRB-282 in pooled analysis. These cross combinations were derived from the parents having average x good, average x poor and

average x average general combining ability. None of the same cross displayed the positive significant sca effects under both the environments.

5.3.3.9 Stem weight (g)

Twelve, seven and eight crosses in E_1, E_2 and pooled analysis, respectively showed significant and high positive sca effects displayed for stem weight (Table 4.3.3.3). The four cross combinations viz., Giant bajra x PMFT-907, PMFT-905 x PMFT-907, PMFT-905 x RHRB-259 and RHRB-259 x RHRB-278 exhibited significant positive sca effects under both the environments. These cross combinations were derived from the parents having good x poor, poor x average average x poor and poor x poor general combining ability.

5.3.3.10 Leaf : stem ratio

Significant and positive sca effects for leaf : stem ratio were displayed by three, one and four crosses in E_1, E_2 and pooled analysis, respectively (Table 4.3.3.4). The highest significant positive sca effect was recorded by cross combinations Giant bajra x RHRB-260 in E_1, Giant bajra x RHRB-278 in E_2 and PMFT-907 x RHRB-282 in pooled analysis and derived from the parents having average x good, avrage x average and poor x average general combining ability.

5.3.3.11 Green fodder yield (q/ha)

For green fodder yield the significant and positive sca effects were recorded in ten crosses in E_1 and pooled analysis while for eight in E_2 (Table 4.3.3.4). The highest magnitude of sca effect was exhibited by Giant bajra x RHRB-282 in E_1 and in pooled analysis where as PMFT-907 x RHRB-278 in E_2. The five cross combinations *viz.,* Giant bajra x PMFT-905, Giant bajra x RHRB-

282 PMFT-905 x PMFT-907, PMFT-907 x RHRB-278 and RHRB-259 x RHRB-260 expressed the positive significant sca effects under both the environments. These cross combinations were derived from the parents having good x good, good x poor, poor x average , average x good and poor x poor general combining ability, respectively.

5.3.3.12 Dry matter yield (q/ha)

For dry matter yield nine crosses in E_1 and pooled analysis and eight crosses in E_2 registered significant sca effects (Table 4.3.3.4). However, only four crosses *viz.,* PMFT905 x PMFT-907, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260 and RHRB-260 x RHRB-278 exhibited significant and positive sca effects under both the environments having parents of good x poor, poor x good, poor x poor, and poor x good general combining ability, respectively.

5.3.3.13 Crude protein content (%)

Ten, three and seven crosses in E_1, E_2 and pooled analysis, respectively had significant positive sca effects for crude protein per cent (Table 4.3.3.5). Among them, the cross combinations PMFT-907 x RHRB-278 in E_1; PMFT-907 x RHRB-259 E_2 and pooled analysis exibibited the highest significant sca. The crosses PMFT-907 x RHRB-259 and PMFT-907 x RHRB-278 expressed the significant positive sca effects, in both the seasons possessing average x average and average x poor general combining ability parents.

5.3.3.14 Crude fibre (%)

Twelve crosses in E_1 and five each in E_2 and pooled analysis showed significant negative sca effects for crude fibre percent. The highest significant negative sca effects was observed in cross combination PMF-907 x RHRB-278 in E_1 and pooled

analysis and Giant bajra x PMFT-905 in E_2. The two crosses PMFT-907 x RHRB-278 (average x poor) and RHRB-259 x RHRB-278 (poor x poor) expressed the significant negative sca effects, in both seasons (Table 4.3.3.5).

5.3.3.15 Acid detergent fibre (%)

The highest negative and significant sca effects for acid detergent fibre per cent were exhibited by three crosses in E_1 and four crosses each in E_2 and pooled analysis (Table 4.3.3.5). The cross combination Giant bajra x RHRB-282 expressed highest significant negative sca effect in E_1, PMFT-904 x PMFT-907 in E_2 and Giant bajra x PMFT-905 (-0.89) in pooled analysis and derived the parents having good x average, average x average and good x average general combining ability, respectively.

5.3.3.16 Neutral detergent fibre (%)

The significant negative sca effects for neutral detergent fibre percent were recorded by six, two and seven crosses in E_1, E_2 and pooled analysis, respectively. In both the seasons and pooled analysis the cross combination RHRB-259 x RHRB-260 recorded the highest significant negative sca effect for NDF per cent (Table 4.3.3.6) and is derived from the parents having poor x average general combining ability.

5.3.3.17 Oxalic acid (%)

For oxalic acid content, eight, three and seven crosses in E_1, E_2 and pooled analysis, respectively exhibited significant negative sca effects (Table 4.3.3.6). The highest significant negative sca effects was observed in PMFT-904 x RHRB-278 in E_1, PMFT-904 x RHRB-260 in E_2 and PMFT-904 x RHRB-259 in pooled analysis. The cross PMFT-904 x RHRB-259 (average x average) expressed significant negative sca effects, in both the environmental conditions.

Table 5.2: Best performing hybrids based on SCA effects for forage yield and yield contributing characters in kharif, 2008 (E_1) and summer,2009 (E_2) environments.

Sr. No.	Character	Kharif, 2008 (E_1)		Summer,2009 (E_2)	
		No. of hybrids having sig.SCA	Best performing hybrids	No. of hybrids having sig.SCA	Best performing hybrids
1	Days to 50 % flowering	8	Giant bajra x RHRB-259, PMFT-905 x PMFT-907, PMFT-904 x PMFT-905	19	Giant bajra x PMFT-905, PMFT-905 x PMFT-907, PMFT-905 x RHRB-278
2	Plant height (cm)	10	Giant bajra x PMFT-905, PMFT-905 x RHRB-278, PMFT-905 x RHRB-282	10	RHRB-259 x RHRB-260, PMFT-905 x PMFT-907, RHRB-282 x RHRB-278
3	Number of tillers/plant	1	PMFT-904 x PMFT-905	11	Giant bajra x RHRB-259, PMFT-904 x RHRB-260, PMFT-907 x RHRB-278
4	Number of leaves/plant	10	Giant bajra x PMFT-905, PMFT-907 x RHRB-278, RHRB-259 x RHRB-278	2	RHRB-259 x RHRB-278, PMFT-905 x PMFT-907
5	Leaf length (cm)	8	RHRB-260 x RHRB-282, Giant bajra x PMFT-905, PMFT-905x RHRB-260	2	PMFT-904 x RHRB-259, RHRB-260 x RHRB-278
6	Leaf width (cm)	9	RHRB-260 x RHRB-282, PMFT-905 x PMFT-907, PMFT-904 x PMFT-907	3	Giant bajra x PMFT-905, Giant bajra x RHRB-278, RHRB-259 x RHRB-260
7	Leaf area(cm^2)	15	RHRB-260 x RHRB-282, Giant bajra x PMFT-905, PMFT-905 x PMFT-907	3	RHRB-259 x RHRB-260, Giant bajra x PMFT-905, PMFT-904 x RHRB-259
8	Leaf weight /plant (g)	6	RHRB-260 x RHRB-282, PMFT-905 x RHRB-260, PMFT-904 x RHRB-282	2	PMFT-904 x RHRB-259, PMFT-907 x RHRB-260
9	Stem weight /plant (g)	12	PMFT-905 x RHRB-260, Giant bajra x PMFT-905, PMFT-904 x RHRB-282	7	PMFT-904 x RHRB-259, PMFT-905 x RHRB-278, Giant bajra x PMFT-905

Table 5.2 contd.: Best performing hybrids based on SCA effects for forage yield and yield contributing characters in kharif, 2008 (E_1) and summer,2009 (E_2) environments.

Sr. No.	Character	Kharif, 2008 (E_1)		Summer,2009 (E_2)	
		No. of hybrids having sig.SCA	Best performing hybrids	No. of hybrids having sig.SCA	Best performing hybrids
10	Leaf: Stem ratio	3	Giant bajra x RHRB-260, PMFT-907 x RHRB-282, RHRB-282 x RHRB-278	3	Giant bajra x RHRB-278, PMFT-907 x RHRB-260, PMFT-905 x RHRB-260, ,
11	Green forage yield (q/ha)	10	Giant bajra x RHRB-282, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260	8	PMFT-907 x RHRB-278, RHRB-259 x RHRB-260, Giant bajra x RHRB-282
12	Dry matter yield (q/ha)	9	RHRB-259 x RHRB-260, PMFT-905 x RHRB-282, Giant bajra x RHRB-282	8	RHRB-259 x RHRB-260, Giant bajra x RHRB-260, RHRB-260 x RHRB-278
13	Crude protein (%)	10	PMFT-907 x RHRB-278, RHRB-282 x RHRB-278, RHRB-259 x RHRB-260	3	PMFT-907 x RHRB-259, PMFT-907 x RHRB-278, PMFT-907 x RHRB-260
14	Crude fibre (%)	12	PMFT-907 x RHRB-278, Giant bajra x PMFT-905, PMFT-904 x RHRB-259	5	Giant bajra x PMFT-905, PMFT-904 x RHRB-282, PMFT-907 x RHRB-260
15	Acid detergent fibre (%)	3	Giant bajra x RHRB-282, Giant bajra x PMFT-907, PMFT-904 x RHRB-278	4	PMFT-904 x PMFT-907, RHRB-260 x RHRB-278, Giant bajra x PMFT-905
16	Neutral detergent fibre (%)	6	RHRB-259 x RHRB-260, PMFT-905 x PMFT-907, PMFT-904 x PMFT-907	2	RHRB-259 x RHRB-260, RHRB-282 x RHRB-278
17	Oxalic acid (%)	8	PMFT-907 x RHRB-278, Giant bajra x PMFT-905, Giant bajra x RHRB-260	3	PMFT-907 x RHRB-259, RHRB-259 x RHRB-282, PMFT-904 x RHRB-259
18	IVDMD (%)	9	Giant bajra x PMFT-905, PMFT-904 x RHRB-282, RHRB-260 x RHRB-278	6	Giant bajra x PMFT-905, PMFT-905 x RHRB-259, PMFT-904 x RHRB-260

Table 5.3: Best performing hybrids based SCA effects for forage yield and yield contributing characters in pooled over environments

Sr. No.	Character	Best performing hybrids	No. of crosses having Sig. SCA
1	Days to 50 % flowering	PMFT-905 x PMFT-907, Giant bajra x RHRB-259, PMFT-905 x RHRB-259	17
2	Plant height (cm)	Giant bajra x PMFT-905, PMFT-905 x RHRB-278, RHRB-259x RHRB-260	12
3	Number of tillers/plant	PMFT-904 x PMFT-905, PMFT-907 x RHRB-278, PMFT-907 x RHRB-282	5
4	Number of leaves/plant	RHRB-259 x RHRB-278, Giant bajra x PMFT-905, PMFT-904 x PMFT-907	5
5	Leaf length (cm)	Giant bajra x PMFT-905, RHRB-259 x RHRB-278, PMFT-904 x RHRB-260	4
6	Leaf width (cm)	Giant bajra x PMFT-905, RHRB-260 x RHRB-282, PMFT-904 x PMFT-907	11
7	Leaf area(cm^2)	Giant bajra x PMFT-905, RHRB_260 x RHRB-282, PMFT-904 x PMFT-907	12
8	Leaf weight /plant (g)	RHRB-260 x RHRB-282, PMFT-905 x RHRB-259, PMFT-905 x PMFT-907	6
9	Stem weight /plant (g)	Giant bajra x PMFT-905, RHRB-259 x RHRB-278, PMFT-905 x PMFT-907	8
10	Leaf: Stem ratio	PMFT-907 x RHRB-282, PMFT-905 x RHRB-260, RHRB-282 x RHRB-278	5
11	Green forage yield (q/ha)	Giant bajra x RHRB-282, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260	10
12	Dry matter yield (q/ha)	RHRB-259 x RHRB-260, PMFT-907 x RHRB-278, RHRB-260 x RHRB-278	9
13	Crude protein (%)	PMFT-907 x RHRB-259, PMFT-907 x RHRB-278, PMFT-904 x RHRB-259	7
14	Crude fibre (%)	PMFT-907 x RHRB-278, Giant bajra x PMFT-905, RHRB-259 x RHRB-260	5
15	Acid detergent fibre (%)	Giant bajra x PMFT-905, PMFT-907 x PMFT-907, Giant bajra x RHRB-282	5
16	Neutral detergent fibre (%)	RHRB-259 x RHRB-260, PMFT-905 x PMFT-907, PMFT-904 x RHRB-282	7
17	Oxalic acid (%)	PMFT-907 x RHRB-278, PMFT-904 x RHRB-259, PMFT-907 x RHRB-259	7
18	IVDMD (%)	Giant bajra x PMFT-905, PMFT-904 x RHRB-282, PMFT-907 x RHRB-278	

5.3.3.18 *In vitro* dry matter digestibility (%)

The frequency of crosses having significant positive sca effects were ten, six and nine in E_1, E_2 and pooled analysis, respectively (Table 4.3.3.6). Among the crosses, Giant bajra x PMFT- 905 exhibited the highest significant positive sca effect in both the season and in pooled analysis. However, the five crosses viz., Giant bajra x MFT-905, PMFT-904 x RHRB-282, PMFT-905 x RHRB-259, PMFT-905 x RHRB-278 and PMFT-907 x RHRB-278 expressed the significant positive sca effects, in both the environmental conditions.These crosses derived from the parents having good x average, average x good, poor x average and average x poor general combining ability.

The top ranking crosses based on significant sca effects for green forage yield in both the seasons and pooled over seasons are given in Table 5.4. Most of the crosses with high sca effects in both the seasons and in pooled were associated with high *per se* performance. The cross exhibited gigh significant sca effect coupled with high mean performance for green forage yield and other six yield contributing and quality charcters viz., days to 50 per cent flowering, plant height, leaf area, dry matter yield and ADF percent in kharif, 2008 and three important characters in pooled analysis. This cross combination was derived from the parents having good x good combining ability. Similarly the cross combinations viz., Giant bajra x PMFT-905, PMFT-907 x RHRB-278, PMFT-904 x RHRB-282 and PMFT-905 x PMFT-907 in kharif 2008 ; PMFT-907 x RHRB-278, Giant bajra x RHRB-260 and PMFT-905 x PMFT-907 in summer 2009 and Giant bajra x RHRB-282, PMFT-907 x RHRB-278, Giant bajra x PMFT-905 and PMFT-905 x PMFT-907 exhibited significant effect for green forage yield and most of the yield contributing and quality characters. One or both the parents involved in these combinations was average or good combiners.

Table 5.4 : Significant specific combiners for green forage yield and their performance for other traits in pearl millet during Kharif, 2008 (E_1) and summer, 2009 (E_2) and pooled over seasons.

Cross	Mean GFY	SCA effect	GCA effects		Significant SCA effect in desirable direction to related characters
Kharif- 2008			**P_1**	**P_2**	
Giant bajra x RHRB-282	853.90	165.88	G	G	Days to 50% flowering, plant height , leaf area, dry matter yield, ADF (%)
PMFT-907 x RHRB-278	726.33	153.74	A	A	No. of leaves, leaf length, leaf width, leaf area, leaf weight, stem weight, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)
RHRB-259 x RHRB-260	596.70	118.95	P	P	Plant height, dry matter yield, crude preotein, Crude fibre and NDF (%)
Giant bajra x PMFT-905	755.14	94.21	G	G	Plant height, No. of leaves, leaf length, leaf width, leaf area, stem weight, dry matter yield, crude fibre, oxalic acid and IVDMD (%)
PMFT-904 x RHRB-282	697.53	82.71	P	G	Days to 50 % flowering, leaf width, leaf area, leaf weight, stem weight, L:S ratio, NDF and IVDMD (%)
PMFT-904 x RHRB-260	567.08	80.45	P	P	Leaf length, leaf area, dry matter yield, crude fibre and IVDMD (%)
PMFT-904 x RHRB-259	596.70	78.70	P	P	Plant height, No. of leaves, leaf width, leaf area, dry matter yield, crude protein, crude fibre, and oxalic acid (%)
PMFT-905x PMFT-907	681.07	71.21	G	A	Days to 50% flowering, leaf width, leaf area, stem weight, dry matter yield, NDF, oxalic acid and IVDMD (%)
Summer, 2009					
PMFT-907 x RHRB-278	564.61	87.57	G	A	No. of tillers, L:S ratio, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)
RHRB-259 x RHRB-260	434.15	83.21	P	P	Days to 50% flowering, Plant height, leaf width, leaf area, dry matter yield, crude fibre, and NDF (%)
Giant bajra x RHRB-282	632.82	75.83	G	G	-
PMFT-905x PMFT-907	453.70	66.77	P	G	Days to 50% flowering, plant height, No. of leaves, stem weight and dry matter yield
Giant bajra x RHRB-260	547.32	57.75	G	A	Days to 50 % flowering, plant height and No. of tilers

Cross	Mean GFY	SCA effect	GCA effects		Significant SCA effect in desirable direction to related characters
Pooled over seasons			**P_1**	**P_2**	
Giant bajra x RHRB-282	743.36	120.85	G	G	Days to flowering, dry matter yield, ADF (%)
PMFT-907 x RHRB-278	645.47	120.66	A	A	No. of tillers, No. of leaves, leaf width, leaf area, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)
RHRB-259 x RHRB-260	515.43	101.08	P	P	Plant height, leaf area, dry matter yield, crude protein, crude fibre, NDF and oxalic acid (%)
Giant bajra x PMFT-905	622.42	71.76	G	A	Days to 50 % flowering, Plant height, No. of leaves, leaf length, leaf width, leaf area, stem weight, dry matter yield, crude protein, crude fibre, ADF, oxalic acid and IVDMD (%)
PMFT-905x PMFT-907	567.38	68.99	P	A	Days to 50% flowering, Plant height, leaf width, leaf area, leaf weight,stem weight, dry matter yield, ADF, NDF and IVDMD (%)
PMFT-907 x RHRB-259	510.29	60.99	A	P	Days to 50% flowering, No. of leaves, leaf width, leaf area, leaf weight, stem weight, dry matter yield, crude protein, crude fibre, and oxalic acid (%)

G: Good, A: Average, P: Poor

The cross combination viz., RHRB-259 x RHRB-259 of low x low performing parents also exhibited high positive and significant sca effect for green forage yield and other most of the yield contributing and quality traits in both the seasons and pooled over seasons.

The significant sca effects for forage yield and its component were also observed earlier by Gupta and Gupta (1971), Patil (1990), Navale *et al.* (1991), Rasal (1992), Rathore et al. (2004), Shanumuganathan *et al.* (2005), and Kumar and Singhania (2007) noted previously that the best specific combinations were from either average or high general combiners.

The crosses with high sca effects as well as *per se* performance having at least one or both parents as good general combiner for green forage yield, would yield desirable transgressive segregants in later generations, if additive genetic system present in good general combiner and the complementary epistatic effects in F_1 act in same direction to maximize the desirable plant attribute. Some crosses showed poor sca effect even though they involved good x good general combiners. Such results are feasible due to lack of genetic diversity between the two parents involved. The results indicate that high general combiners for various traits may be included in a multiple crossing programme and desirable segregants in early generation may be subjected to biparental mating for the accumulation of favourable genes for various forage yield and quality traits.

5.3.4 Nature of Gene action

The estimates of components of genetic variance (σ^2gca and σ^2sca) and their ratio gives an idea about the nature of gene action, whether additive or non-additive for controlling the different characters under study. In the present study (Table 4.3.1.1 and 4.3.1.2), the genetic variance due to σ^2sca was of higher magnitude than that of σ^2gca for all the characters in kharif 2008 (E_1), summer, 2009 (E_2) seasons and in pooled analysis except for leaf length in summer, 2009 (E_2) season and in pooled analysis indicating the predominance of non- additive gene action in controlling these characters. The σ^2gca was of greater magnitude than that of σ^2sca for leaf length in summer, 2009 (E_2) season and in pooled analysis suggesting additive gene action operating for this character.

Similar finding for days to flowering was previously reported by Upadhyaya and Murty (1971), Gill *et al.* (1974), Dass *et al.* (1984), Satija and Thukral (1989), Chavan and Nerkar (1994), Balkrishanan and Das (1996), Naik *et al.* (1996), Azhauguvel *et al.* (1998), Shushir *et al.* (2005). On the contrary, Tyagi *et al.* (1978), Sreenivasulu and Sreeramulu (1980), Kunjir *et al.* (1988), Navale et al. (1991), Rasal (1992), Quendeba *et al.* (1993), Devanand and Das (1996), Karale *et al.* (1998), Gandhi *et al.* (1999), Rasal and Patil (2003), Haussmann *et al.* (2006) found additive gene action for days to 50 per cent flowing in pearl millet.

For plant height non- additive gene action was observed by Upadhyay and Murty (1971), Gill *et al.* (1974), Chawala and Gupta (1983), Gopalan and Sreerangasamy (1989), (Dass *et al.* (1984), Satija and Thukral (1989), Ashwinikumar and Dahiya (1991), Chavan and Nerkar (1994), Aher and Ugale (1995), Devanand and Das (1996), Balkrishanan and Das (1996), Naik *et al.* (1996), Azhauguvel *et al.* (1998), Latha and Shanmugasundaram (1998). On contrary, Yadav (1977), Tyagi *et al.* (1978), Sreenivasulu and Sreeramulu (1980), Quendeba *et al.* (1993), Rasal and Patil (2003), Haussmann *et al.* (2006) and Pachade (2006) reported additive gene action for plant height.

The non -additive gene action for number of tillers per plant also previously reported by Upadhyaya and Murty (1971), Yadav, 1977, Chawala and Gupta (1983), Dass *et al.* (1984), Gopalan and Sreerangasamy (1989), Ashwinikumar and Dahiya (1991), Kumar *et al.* (1992), Chavan and Nerkar (1994), Aher and Ugale (1995), Balkrishanan and Das (1996), Devanand and Das (1996), Azhauguvel *et al.* (1998), Latha and Shanmugasundaram

(1998), Karale *et al.* (1998), Singh and Sagar (2001) and Yadav *et al.* (2001). While additive gene action was also reported by Tyagi *et al.* (1978), Rasal (1992), Gandhi *et al.* (1999), Mohan *et al.* (1999), Rasal and Patil (2003), Haussmann *et al.* (2006) and Pachade (2006).

The non -additive gene action for number of leaves plant was also previously reported by Chawala and Gupta (1983), Gopalan and Sreerangasamy (1989), Devanand and Das (1996), and Karale *et al.* (1998), while Rasal (1992) observed predominance of additive gene action for number of leaves.

The predominance of additive gene action for leaf length and leaf width previously also was reported by Gopalan and Sreerangasamy (1989). On contrary Hooda et al. (1978), Chawala and Gupta (1983) and Pachade (2006) observed predominance of non-additive gene action for leaf length and leaf width.

From the earlier findings of Balkrishanan and Das (1996) and Devanand and Das (1996) confirm the present finding for predominance of non additive gene action for leaf area. On contrary, Rasal (1992) found additive gene action for leaf area. Gopalan and Sreerangasamy (1989) also reported non additive gene action for leaf weight and stem weight.

For green forage yield predominance of non- additive gene action was previously reported by Yadav (1977), Hooda *et al.* (1978), Prakash Kumar *et al.* (1982), and Chawala and Gupta (1982), Gopalan and Sreerangasamy (1989) and Rasal (1992). On contrary, additive gene action for this trait was noted by Devanand and Das (1996) and Pachade (2006).

Similarly, for dry matter yield predominance of non-additive gene action was observed by Hooda *et al.* (1978), Gopalan and Sreerangasamy (1989), Ashwinikumar and Dahiya (1991) and Rasal (1992), Yadav *et al.* (2002), Rohitsawa *et al.* (2006) and Suthamati *et al.* (2007). On contrary, Pachade (2006) reported additive gene action for dry matter yield.

From the earlier findings of Hooda *et al.* (1978), Indu and Gupta (1981), Gopalan and Sreerangasamy (1989) and Rasal (1992) confirm the present finding for predominance of non additive gene action for crude protein per percent. On contrary, Pachade (2006) found predominance of additive gene action for crude protein per cent.

The other quality traits viz., crude fibre, ADF, NDF, oxalic acid and IVDMD percent was also under the control of non-additive gene action. Previously predominance of non additive gene action was also observed by Suthamathi *et al.* (2007) for crude fibre per cent; Chawala and Gupta (1982) and Suthamathi *et al.* (2007) for oxalic acid content and for IVDMD per cent by Hooda *et al.* (1978) and Quendeba *et al.* (1996).

From this study, it appears that non- additive genetic variance is of more importance in forage pearl millet suggesting exploitation of this component in breeding programme by means of reciprocal recurrent selection.

5.4 Heterosis

Heterosis is a measure of deviation of progeny means from parental mean. Heterosis may be either positive or negative, depending on the magnitude of exploiting hybrid vigour, high degree of heterosis for yield and its components is pre-requisite in

crop improvement proramme. The negative heterosis is important for charters like earliness and some quality characters like crude fibre, ADF, NDF, and oxalic acid per cent in forage pearl millet.

Parents vs. crosses (P vs. C) interaction mean squares provide a squares were significant for most of the characters except number of tillers, leaf length, L:S ratio, crude fibre, ADF, NDF, oxalic acid and IVDMD per cent in kharif, 2008 and except plant height, number of tillers, stem weight, ADF and NDF in summer, 2009 and except number of tillers, L:S ratio, crude fibre, ADF, NDF, oxalic acid and IVDMD per cent in pooled analysis. But such comparision will test the differences between parental and hybrid group means. The significant differences could arise due to few but highly heterotic crosses (Arunachalum, 1974). Hence analysis of heterosis based on single crosses or between two lines or two populations, which have no common origin has its importance. (Falconer, 1989).

The percentage of heterosis over mid and better parents are presented in Table 4.4.1 to 4.4.9.

It can been seen from the table that an appreciable amount of heterosis over mid parent and better parent was found for almost all the characters except number of tillers, number of leaves, leaf length, leaf width, leaf : stem ratio and quality traits like crude fibre, ADF, NDF and IVDMD percent. The range of percentage of heterosis for eighteen characters has been also presented in Table 5.5 (Kharif, 2008), Table 5.6 (summer, 2009) and in Table 5.7 (Pooled analysis).

5.4.1 Days to 50 per cent flowering

The negative heterosis is of interest to the breeders as it indicates earliness. Twenty three crosses in kharif, 2008 and summer, 2009 and twenty five in pooled analysis over mid parent while fifteen in kharif, 2008 and in pooled analysis and sixteen in summer, 2009 over better parent displayed negative significant heterosis for this trait. Higher magnitude of negative heterosis over mid parent was noticed in Giant bajra x RHRB-259 in kharif, 2008, PMFT-905 x PMFT-907 in summer, 2009and in pooled analysis. While, over better parent, the highest negative heterosis was exhibited by PMFT-904 x PMFT-905 in kharif, 2008 and PMFT-905 x RHRB-259 in summer, 2009 and in poled analysis.

The negative significant heterosis for days to 50 per cent flowering was also previously reported by Pokhriyal *et al.* (1967), Singh (1970), Yadav (1977), Satija and Thukral (1989), Kulkarni *et al.* (1993), Chavan and Nerkar (1994), Patil *et al.* (1994), Karale *et al.* (1997), Yadav (1999), Singh and Sagar (2001), Manga and Dubey (2004), Pachade (2006) and Vagadiya *et al.* (2010).

5.4.2 Plant height (cm)

For plant height nineteen crosses in kharif, 2008, eight in summer, 2009 and seventeen in pooled analysis exhibited positive significant heterosis over mid parent while over better parent, ten in kharif, 2008 and six in summer, 2009 and seven in pooled analysis shoed significant positive heterosis. The magnitude of heterosis over mid parent and better parent was substantially higher for PMFT-905 x RHRB-278 in kharif 2008 and in pooled analysis.

Table 5.5 : Top ranked hybrids based on the basis of heterosis for green forage yield and its attributes in pearl millet in Kharif, 2008 (E_1) environments.

Character	Relative heterosis			Heteriobeltiosis		
	Range	Best crosses	Crosses showing sig. heterosis over MP	Range	Best crosses	Crosses showing sig. heterosis over BP
Days to 50 % flowering	-17.88 to -1.96	Giant bajra x RHRB-259	23	-12.08 to 1.41	PMFT-904 x PMFT-905	15
Plant height (cm)	-6.71 to 26.19	PMFT-905 x RHRB-278	19	-15.78 to 25.99	PMFT-905 x RHRB-278	10
Number of tillers/plant	-21.59 to 47.83	PMFT-904 x PMFT-905	3	-26.13 to 37.84	PMFT-904 x PMFT-905	1
Number of leaves/plant	-16.54 to 22.51	RHRB-259 x RHRB-278	10	-22.83 to 22.27	PMFT-907 x RHRB-278	5
Leaf length (cm)	-15.94 to 23.51	RHRB-260 x RHRB-282	8	-24.68 to 15.34	RHRB-260 x RHRB-282	3
Leaf width (cm)	-21.70 to 35.80	RHRB-260 x RHRB-282	13	-31.90 to 30.95	RHRB-260 x RHRB-282	8
Leaf area(cm^2)	-31.50 to 65.69	RHRB-260 x RHRB-282	12	-48.62 to 49.14	RHRB-260 x RHRB-282	3
Leaf weight /plant (g)	-43.63 to 70.56	PMFT-905 x RHRB-260	10	-59.51 to 67.02	PMFT-905 x RHRB-260	7
Stem weight /plant (g)	-52.64 to 85.67	PMFT-905 x PMFT-907	15	-67.04 to 70.76	PMFT-905 x PMFT-907	3
Leaf: Stem ratio	-36.36 to 24.24	RHRB-260 xRHRB-282	3	-39.51 to 13.89	RHRB-260 xRHRB-282	-
Green forage yield (q/ha)	-17.63 to 47.70	PMFT-907 x RHRB-278	15	-31.06 to 44.08	PMFT-907 x RHRB-278	10
Dry matter yield (q/ha)	-23.97 to 65.68	RHRB-259 xRHRB-260	12	-39.43 to 64.89	RHRB-259 xRHRB-260	8
Crude protein (%)	-8.43 to 26.26	PMFT-907 x RHRB-259	12	-13.30 to 15.57	PMFT-907 x RHRB-278	3
Crude fibre (%)	-7.85 to 5.57	PMFT-907 x RHRB-278	3	-5.24 to 6.87	PMFT-907 x RHRB-278	1
Acid detergent fibre (%)	-6.46 to 8.41	Giant bajra x PMFT-907	2	-5.98 to 9.69	Giant bajra x PMFT-907	2
Neutral detergent fibre (%)	-3.86 to 8.15	RHRB-259 xRHRB-260	6	-2.52 to 8.77	PMFT-905 x RHRB-259	1
Oxalic acid (%)	-25.45 to 9.27	PMFT-907 xRHRB-278	8	-24.41 to 10.80	PMFT-907 xRHRB-278	4
IVDMD (%)	-7.16 to 8.13	Giant bajra x PMFT-905	8	-8.74 to 5.33	Giant bajra x PMFT-905	3

Table 5.6 : Top ranked hybrids based on heterosis for green forage yield and its attributes in pearl millet in Summer, 2009 (E_2) environments.

Character	Relative heterosis			Heteriobeltiosis		
	Range	Best crosses	Crosses showing sig. heterosis over MP	Range	Best crosses	Crosses showing sig. heterosis over BP
Days to 50 % flowering	-17.03 to 9.52	PMFT-905 x PMFT-907	23	-15.03 to 1.41	PMFT-905 x RHRB-282	16
Plant height (cm)	-13.05 to 19.88	RHRB-259 x RHRB-260	8	-26.96 to 17.64	RHRB-259 x RHRB-260	6
Number of tillers/plant	-18.32 to 12.35	PMFT-904 x RHRB-260	7	-22.77 to 7.69	RHRB-259 x RHRB-260	1
Number of leaves/plant	-15.14 to 8.75	RHRB-259 x RHRB-278	2	-27.06 to 0.89	-	-
Leaf length (cm)	-21.66 to 11.17	PMFT-904 x RHRB-259	1	-37.06 to -0.32		-
Leaf width (cm)	-24.76 to 6.83	-	-	-36.89 to 3.70	-	-
Leaf area(cm^2)	-39.71 to 12.90	-	-	-58.76 to -12.42	-	-
Leaf weight /plant (g)	-30.59 to 24.54	RHRB-259 x RHRB-282	6	-40.98 to 14.05	RHRB-282 x RHRB-278	3
Stem weight /plant (g)	-28.47 to 31.91	PMFT-905 x RHRB-259	6	-42.02 to 21.70	-	-
Leaf: Stem ratio	-23.08 to 7.04	-	-	-23.61 to 7.04	-	-
Green forage yield (q/ha)	-29.52 to 56.15	RHRB-259 xRHRB-260	13	-48.12 to 51.80	RHRB-259 xRHRB-260	5
Dry matter yield (q/ha)	-32.07 to 104.0	RHRB-259 x RHRB-260	10	-51.96 to 92.20	RHRB-259 xRHRB-260	5
Crude protein (%)	-8.07 to 37.48	PMFT-907 x RHRB-259	8	-12.02 to 32.70	PMFT-907 x RHRB-259	3
Crude fibre (%)	-5.14 to 1.91	PMFT-904 x RHRB-282	7	-4.46 to 2.64	PMFT-904 x RHRB-282	3
Acid detergent fibre (%)	-3.64 to 7.07	Giant bajra x RHRB-259	2	-2.98 to 6.61	-	-
Neutral detergent fibre (%)	-3.33 to 2.69	PMFT-904x RHRB-278	3	-2.96 to 4.82	-	-
Oxalic acid (%)	-24.88 to 8.20	PMFT-907 x RHRB-259	11	-21.01 to 14.55	PMFT-907 x RHRB-259	3
IVDMD (%)	-3.78 to 7.24	PMFT-905 x RHRB-259	5	-6.61 to 6.51	PMFT-905 x RHRB-259	3

Table 5.7 : Top ranked hybrids based on heterosis for green forage yield and its attributes in pearl millet over pooled environments

Character	Relative heterosis			Heteriobeltiosis		
	Range	Best crosses	Crosses showing sig. heterosis over MP	Range	Best crosses	Crosses showing sig. heterosis over BP
Days to 50 % flowering	-16.56 to 0.92	PMFT-905 x PMFT-907	25	-12.42 to 8.20	PMFT-905 x RHRB-282	16
Plant height (cm)	-7.76 to 18.11	PMFT-905 x RHRB-278	17	-21.26 to 17.60	PMFT-905 x RHRB-278	7
Number of tillers/plant	-18.88 to 20.61	PMFT-904 x PMFT-905	3	-23.43 to 13.71	PMFT-904 x PMFT-905	1
Number of leaves/plant	-15.04 to 15.93	RHRB-259 x RHRB-278	4	-24.45 to 9.80	RHRB-259 x RHRB-278	1
Leaf length (cm)	-15.31 to 6.33	-	-	-30.18 to 4.30	-	-
Leaf width (cm)	-19.88 to 19.54	RHRB-260 x RHRB-282	7	-34.51 to 15.56	RHRB-260 x RHRB-282	2
Leaf area(cm^2)	-30.32 to 28.33	RHRB-260 x RHRB-282	6	-51.19 to 19.17	PMFT-907x RHRB-282	1
Leaf weight /plant (g)	-30.72 to 36.18	RHRB-259 x RHRB-282	7	-48.36 to 32.86	RHRB-260 x RHRB-282	4
Stem weight /plant (g)	-24.80 to 50.36	PMFT-905 x PMFT-907	7	-45.08 to 41.86	PMFT-905 x PMFT-907	8
Leaf: Stem ratio	-26.53 to 10.64	-	-	-28.90 to 8.70	-	-
Green forage yield (q/ha)	-21.99 to 45.37	RHRB-259 xRHRB-260	14	-39.38 to 43.86	RHRB-259 xRHRB-260	7
Dry matter yield (q/ha)	-27.20 to 81.03	RHRB-259 x RHRB-260	10	-45.42 to 80.65	RHRB-259 x RHRB-260	5
Crude protein (%)	-6.60 to 32.03	PMFT-907 x RHRB-259	10	-9.10 to 26.39	PMFT-907 x RHRB-259	2
Crude fibre (%)	-5.19 to 3.13	PMFT-904 x RHRB-278	2	-4.28 to 4.11	PMFT-904 x RHRB-278	1
Acid detergent fibre (%)	-2.66 to 6.18	-	-	-2.17 to 6.93	-	-
Neutral detergent fibre (%)	-3.19 to 5.14	RHRB-259 x RHRB-260	4	-2.17 to 6.24	-	-
Oxalic acid (%)	-20.30 to 3.21	PMFT-907 x RHRB-278	6	-20.42 to 5.74	PMFT-907 x RHRB-278	3
IVDMD (%)	-3.99 to 7.03	Giant bajra x PMFT-905	5	-6.30 to 5.36	PMFT-905 x RHRB-259	2

While in summer, 2009, the cross combination RHRB-259 x RHRB-260 exhibited higher magnitude of mid and better parent heterosis.

The positive heterosis for this trait was previously reported by Pokhriyal *et al.* (1967), Singh (1970), Singh and Singh (1972), Yadav (1977), Subramaniam and Rathinam (1980), Raveendran and Appadurai (1984), Satija and Thukral (1989), Khushwah and Singh (1992), Kulkarni *et al.* (1993), Chavan and Nerkar (1994), Patil *et al.* (1994), Balkrishnan and Das (1996), Karale *et al.* (1997), Singh and Sagar (2001), Manga and Dube (2004) and Vetriventhan *et al.* (2008)

5.4.3 Number of tillers per plant

Of the 28 crosses, only three in kharif, 2008 and pooled analysis and seven in summer, 2009 displayed positive and significant heterosis over mid parent, while over better parent, only one cross showed positive significant heterosis in kharif, 2008, summer, 2009 and in pooled analysis. The crosses exhibited the highest positive heterosis over mid parent for number of tillers were PMFT-904 x PMFT-905 in kharif, 2008 and pooled analysis and PMFT-904 x RHRB-260 in summer, 2009. While over better parent, PMFT-904 x PMFT-905 in kharif, 2008 and pooled analysis and RHRB-259 x RHRB-260 in summer, 2009 exhibited highest magnitude of positive heterosis.

Singh and Singh (1972), Yadav (1977), Subramanianm and Rathinam (1980), Raveendran and Appadurai (1984), Khushwah and Singh (1992), Kulkarni *et al.* (1993), Chavan and Nerkar (1994), Patil *et al.* (1994), Balkrishnan and Das (1996), Karale *et al.* (1997), Singh and Sagar (2001), and Vetriventhan *et al.* (2008) reported positive heterosis for number of tillers/plant. On contrary, Gartan *et al.* (1988) and Sheoran *et al.* (2000) found negative and low heterosis for this trait.

5.4.4 Number of leaves per plant

For number of leaves, ten, two and four crosses exhibited significant positive heterosis over mid parent in kharif, 2008, summer, 2009 and in pooled analysis, respectively, while only five crosses in Kharif,2008 and one in pooled analysis had positive significant heterosis over better parent. Only the cross combination RHRB-259 x RHRB-278 consistently displayed the highest magnitude of positive heterosis over better and mid parent.

Similar positive heterosis for this trait was also noticed by Yadav (1977), Chavan and Nerkar (1994), Karale *et al.* (1997) and Pachade (2006).

5.4.5 Leaf length (cm)

The range of heterosis for leaf length in summer, 2009 and in pooled analysis was found to be low. Only eight crosses over mid parent and three over better parent exhibited significant positive heterosis in kharif, 2008 and one over mid parent in summer, 2009. The cross combination, RHRB-260 x RHRB-282 displayed the highest magnitude of positive heterosis over mid parent and better parent in kharif, 2008 while, PMFT-904 x RHRB-259 over only mid parent in summer, 2009.

Kushwah and Singh (1992) and Pachade (2006) also reported positive heterosis for this trait while, Hirachand *et al.* (1973) found negative heterosis for leaf length in pearl millet.

5.4.6 Leaf width (cm)

Thirteen crosses in kharif, 2008 and seven in pooled analysis over mid parent and eight crosses in kharif,2008 and two in pooled analysis over better parent exhibited significant positive heterosis for leaf width. The cross combination, RHRB- 260 x RHRB-282 displayed the highest magnitude of positive heterosis over mid parent and better parent in kharif, 2008 and in pooled analysis also.

Singh (1970) and Kushwah and Singh (1992) also found positive heterosis for this trait while, Hirachand *et al.* (1973) reported negative heterosis for leaf width in pearl millet.

5.4.7 Leaf area (cm^2)

The number of crosses that registered significant positive relative heterosis were twelve in kharif, 2008 and six in pooled analysis, while over better parent only three in kharif, 2008 and one in pooled analysis registered significant positive heterosis for leaf area. Among them, the cross RHRB-260 x RHRB-282 in kharif, 2008 and in pooled analysis exhibited the highest significant positive relative heterosis while, the cross RHRB-260 x RHRB-282 in kharif, 2008 and PMFT-907 x RHRB-282 in pooled analysis displayed highest heterobeltosis . The positive heterosis for leaf area was also reported by Pokhriyal *et al.* (1967), Kulkarni *et al.* (1993), Balkrishnan and Das (1996) and Deore *et al. (*1997).

5.4.8 Leaf weight (g)

For leaf weight, ten, six and seven crosses exhibited significant positive heterosis over mid parent in kharif, 2008, summer, 2009 and in pooled analysis, respectively, while only seven crosses in Kharif, 2008 , three in summer, 2009 and four in pooled analysis had positive significant heterosis over better parent. The cross combination PMFT-905 x RHRB-260 in kharif, 2008 displayed the highest positive relative heterosis and heterobeltiosis while in summer 2009, RHRB-259 x RHRB-282 and RHRB282 x RHRB-278 exhibited the highest relative heterosis and heterobeltiosis, respectively. However, the cross RHRB-259 x RHRB-282 displayed the highest magnitude of positive heterosis over mid and better parent across the seasons.

5.4.9 Stem weight (g)

Fifteen, six and seven crosses exhibited significant positive heterosis over mid parent for this trait in kharif, 2008, summer, 2009 and in pooled analysis, respectively, while only three crosses in Kharif, 2008 and four in pooled analysis displayed positive significant heterosis over better parent. The cross combination PMFT-905 x PMFT-907 exhibited the highest positive relative heterosis and heterobeltiosis in kharif, 2008 and in pooled analysis, while in summer 2009, PMFT-905 x RHRB-259 and PMFT-905 x RHRB-278 exhibited the highest relative heterosis and heterobeltiosis, respectively.

5.4.10 Leaf : stem ratio

Only three crosses in Kharif, 2008 exhibited the significant positive relative heterosis. Among them, the highest magnitude of relative heterosis was recorded by RHRB-260 x RHRB-282. Pachade (2006) also reported positive heterosis for leaf : stem ration in pearl millet.

5.4.11 Green forage yield (q/ha)

Fifteen, thirteen and fourteen crosses in kharif, 2008, summer, 2009 and in pooled analysis, respectively displayed significant positive heterosis over mid parent. While, only ten, five and seven crosses in kharif, 2008, summer, 2009 and in pooled analysis, respectively displayed significant positive heterosis over better parent for green forage yield. Among them, the highest magnitude of significant and positive heterosis over mid parent and better parent was exhibited by PMFT-907 x RHRB-278 in kharif, 2008 and RHRB-259 x RHRB-260 in summer, 2009 and in pooled analysis. On the bais of pooled over seasons, the cross combinations viz., RHRB-259 RHRB-260, PMFT-907 x RHRB-278 and PMFT-905 x PMFT-907 exhibited high magnitude of relative heterosis and heterobeltiosis for green forage yield.

The high positive heterosis for green forage yield was also reported by Yadav (1977), Shinde and Desale (1985), Quendeba *et al.* (1996), Devanand and Das (1997), Dutt and Bainiwal (2002), Pachade (2006), Patil *et al.* (2008) and Vagudiya *et al.* (2010).

5.4.12 Dry matter yield (q/ha)

For dry matter yield twelve crosses in kharif, 2008, ten each in summer, 2009 and in pooled analysis exhibited positive significant heterosis over mid parent while over better parent, eight in kharif, 2008 and five each in summer, 2009 and pooled analysis showed significant positive heterosis. The magnitude of heterosis over mid parent and better parent was substantially higher for PMFT-259 x RHRB-260 in kharif, 2008, summer, 2009 and pooled analysis. However, the cross combination PMFT-907 x RHRB-278 in kharif, 2008 exhibited the highest heterobeltiosis. Pachade (2006) also reported positive heterosis for this trait .

5.4.13 Crude protein content [%]

Twelve, eight and ten crosses exhibited significant positive heterosis over mid parent for this trait in kharif, 2008, summer, 2009 and in pooled analysis, respectively, while only three crosses each in Kharif, 2008 and summer, 2009 and two in pooled analysis displayed positive significant heterosis over better parent. The cross combination PMFT-907 x RHRB-259 exhibited the highest positive relative heterosis in both the seasons and in pooled analysis while in kharif, 2008 season PMFT-907 x RHRB-278 and in summer 2009 and in pooled analysis the cross PMFT-907 x RHRB-259 exhibited the highest heterobeltiosis. Earlier, the high positive heterosis for crude protein per cent was also reported by Vaidya et al. (1983) and Devanand and Das (1997).

5.4.14 Crude fibre (%)

Three crosses in kharif, 2008, seven in summer, 209 and two in pooled analysis over mid parent and one cross each in kharif,2008 and pooled analysisand three in summer, 2009 over better parent exhibited significant negative heterosis for crude fibre (%). The cross combination, PMFT-907 x RHRB-278 in kharif, 2008 and in pooled analysis while, PMFT-904 x RHRB-282 in summer,2009 displayed the highest magnitude of negative heterosis over mid parent and better parent.

5.4.15 Acid detergent fibre (%)

The frequency of crosses for negative heterosis for this trait was found low. The cross combination Giant bajra x PMFT-907 exhibited the highest significant negative relative heterosis and heterobeltiosis in kharif, 2008 while Giant bajra x RHRB-259 exhibited the highest negative relative heterosis in summer, 2009.

5.4.16 Neutral detergent fibre (%)

For NDF, six, three and four crosses displayed significant negative heterosis over mid parent in kharif, 2008, summer, 2009 and in pooled analysis, respectively . These combinations viz., RHRB-259 x RHRB-260 in kharif, 2008 and in pooled analysis and PMFT-904 x RHRB-278 in summer, 2009 exhibited the highest negative relative heterosis. However, only the cross combination PMFT-907 x RHRB-259 exhibited significant negative heterosis over better parent in kharif, 2008 season.

5.4.17 Oxalic acid (%)

The significant negative relative heterosis for this trait were observed in seven, ten and six in kharif, 2008, sumer, 2009 and in pooled analysis, respectively. While, four in karif, 2008 and three crosses each in summer, 2009 and in pooled analysis displayed significant negative heterobeltiosis. The cross PMFT-907 x RHRB-278 in kharif, 2008 and in pooled analysis and PMFT-907

x RHRB-259 in summer, 2009 exhibited the highest negative relative heterosis as well as heterobeltiosis. Pachade (2006) also reported negative heterosis for this trait .

***5.4.18 In vitro* dry matter digestibility [%]**

Eight crosses in kharif, 2008 and five crosses each in summer, 2009 and in pooled analysis exhibited significant positive heterosis over mid parent for this trait , while only three crosses each in Kharif, 2008 and summer, 2009 and two in pooled analysis displayed positive significant heterosis over better parent. The cross combination Giant bajra x PMFT-905 exhibited the highest positive relative heterosis in kharif, 2008 and in pooled analysis while in summer, 2009 season the cross PMFT-905 x RHRB-259 had the highest positive relative heterosis. However, the highest magnitude of positive heterobeltiosis was noticed in the cross combinations PMFT-905 x RHRB-278 in kharif, 2008 and PMFT-95 x RHRB-259 in summer, 2009 and in pooled analysis. The high positive heterosis for IVDMD per cent in forage pearl millet was also reported by Quendeba et al. (1996).

The top ranking crosses on the basis of their *per se* performance, sca effects, relative heterosis and heterobeltiosis, (Table 5.8 to 5.10) for green forage yield and yield contributing characters in both the seasons and across the seasons displayed difference in their ranking, which suggested that crosses exhibiting high sca effects would not necessarily give either highest mean value or high heterotic effect and *vice versa*. In the experimental material, no single cross combination had desirable significant sca effects for all the characters under study.

The crosses exhibited high sca effect did not always involve both parents possessing high gca effects, there by suggesting importance of intra as well as inter-allelic interactions.

The high sca effects of crosses in general correspond to their high heterotic response, but these might also be accompanied by poor and/or average gca effects of the parents. The crosses having high sca effect for green forage yield per plant had in general registered desirable sca effects for most of the yield component characters, but those might not necessarily have higher sca effects for those characters, which suggested cumulative effects of various yield contributing attributes as a high sca effect for green forage yield and thereby high heterotic effects as well.

The foregoing discussion and information given in Table 5.8 to 5.10 clearly indicated that, for green forage yield, the cross combinations viz., Giant bajra x RHRB-282, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260, Giant bajra x PMFT-905 and PMFT-905 x PMFT-907 displayed significant and positive sca effects and heterosis over mid and better parent in both the seasons as well as across the seasons. These crosses exhibited significant and positive sca effects for at least one or more yield contributing characters. This appeared appropriate as yield being complex character dependent on number of component characters and suitable recombination of genes governing these characters might have produced promising hybrids. The cross combinations RHRB-259 x RHRB-260 consisted of poor x poor gca parents for green forage yield and other traits. The poor combining parents are highly responsive to the heterozygosity due to non-additive gene effect. In most of the crosses registering high sca effects as well as *per se* performance having at least one or both parents as good general combiner for green forage yield, would yield desirable transgressive segregants in later generations. Hence, these crosses could be advanced for selection in segregating generations to identify superior segregants for the development of improved varieties.

Table 5.8: Best crosses having mean performance, significant specific combiners and heterosis for green forage yield and their performance for other traits in pearl millet during Kharif- 2008)

Cross combination	Mean GFY	SCA effect	Heterosis (%) over		Significant SCA effects in desirable direction to related characters	Heterosis in desirable direction to related characters
			MP	BP		
Giant bajra x RHRB-282	853.90	165.88	35.93	28.88	Days to 50% flowering, plant height, leaf area, dry matter yield, ADF (%)	Days to 50% flowering, plant height, leaf weight, leaf area, dry matter yield, crude protein and ADF (%)
PMFT-907 x RHRB-278	726.33	153.74	47.70	44.08	No. of leaves, leaf length, leaf width, leaf area, leaf weight, stem weight, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)	Plant height, No. of leaves, , leaf length, leaf width, stem weight, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)
RHRB-259 x RHRB-260	596.70	118.95	38.42	33.64	Plant height, dry matter yield, crude protein, Crude fibre and NDF (%)	Plant height, No. of leaves, leaf length, dry matter yield, crude protein, and NDF (%)
Giant bajra x PMFT-905	755.14	94.21	20.33	13.98	Plant height, No. of leaves, leaf length, leaf width, leaf area, stem weight, dry matter yield, crude fibre, oxalic acid and IVDMD (%)	Days to 50 % flowering, Plant height, No. of leaves, leaf length, leaf width, leaf area, stem weight, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)
PMFT-904 x RHRB-282	697.53	82.71	30.74	17.46	Days to 50 % flowering, leaf width, leaf area, leaf weight, stem weight, L:S ratio, NDF and IVDMD (%)	Days to 50 % flowering, plant height, leaf width, leaf area, leaf weight, stem weight, crude protein, NDF and IVDMD (%)
PMFT-904 x RHRB-260	567.08	80.45	27.59	19.83	Leaf length, leaf area, dry matter yield, crude fibre and IVDMD (%)	Days to 50% flowering, plant height, dry matter yield
PMFT-904 x RHRB-259	596.70	78.70	29.75	26.09	Plant height, No. of leaves, leaf width, leaf area, dry matter yield, crude protein, crude fibre, and oxalic acid (%)	Days to 50 % flowering, Plant height, No. of leaves, leaf width, stem weight, dry matter yield, crude protein, ADF (%)
PMFT-905x PMFT-907	681.07	71.21	27.06	14.93	Days to 50% flowering, leaf width, leaf area, stem weight, dry matter yield, NDF, oxalic acid and IVDMD (%)	Days to 50% flowering, plant height, leaf width, leaf area, leaf weight, stem weight, dry matter yield, NDF, oxalic acid and IVDMD (%)
PMFT-905 x RHRB-282	740.24	65.08	24.87	24.74	Plant height, No. of leaves, dry matter yield	Days to 50 % flowering, Plant height, stem weight, dry matter yield

Table 5.9: Best crosses having mean performance, significant specific combiners and heterosis for green forage yield and their performance for other traits in pearl millet during Summer, 2009 (E_2) season.

Cross combination	Mean GFY	SCA effect	Heterosis (%) over		Significant SCA effects in desirable direction to related characters	Heterosis in desirable direction to related characters
			MP	BP		
PMFT-907 x RHRB-278	564.61	87.57	39.54	34.31	No. of tillers, L:S ratio, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)	Days to 50 % flowering, dry matter yield, crude protein, oxalic acid and IVDMD(%)
RHRB-259 x RHRB-260	434.15	83.21	56.15	51.80	Days to 50% flowering, Plant height, leaf width, leaf area, dry matter yield, crude fibre, and NDF (%)	Days to 50% flowering, Plant height, No. of tillers, leaf area, dry matter yield, crude protein*(%)
Giant bajra x RHRB-282	632.82	75.83	15.95	0.34	-	Days to 50 % flowering
PMFT-905x PMFT-907	453.70	66.77	25.18	7.93	Days to 50% flowering, plant height, No. of leaves, stem weight and dry matter yield	Days to 50% flowering, plant height, stem weight, dry matter yield, crude protein*,oxalic acid and IVDMD* (%)
PMFT-907 x RHRB-282	560.49	56.97	27.20	13.91	No. of tillers	No. of tillers, leaf weight, crude protein*, crude fibre and oxalic acid (%)
RHRB-282 x RHRB-278	556.99	49.68	31.09	20.85	Days to 50 % flowering,, plant height, dry matter yield and NDF (%)	Days to 50 % , plant height, leaf weight and dry matter yield
PMFT-907 x RHRB-282	560.49	56.97	27.20	13.91	No. of tillers	No. of tillers, leaf weight, crude protein, crude fibre and oxalic acid (%)
RHRB-282 x RHRB-278	556.99	49.68	31.09	20.85	Days to 50 % flowering,, plant height, dry matter yield and NDF (%)	Days to 50 % , plant height, leaf weight and dry matter yield
Giant bajra x PMFT-905	489.71	49.31	4.73	-22.35	Plant height, No. of tillers, leaf width, leaf area, stem weight, crude fibre, ADFand IVDMD (%)	Days to 50 % flowering, stem weight, crude fibre and IVDMD (%)

Table 5.10 : Best hybrids having mean performance Significant specific combiners and heterosis for green forage yield and their performance for other traits in pearl millet (Pooled over seasons)

Cross combination	Mean GFY	SCA effect	Heterosis (%) over		Significant SCA effects in desirable direction to related characters	Heterosis in desirable direction to related characters
			MP	BP		
Giant bajra x RHRB-282	743.36	120.85	26.64	14.96	Days to 50 %flowering, dry matter yield, ADF (%)	Days to 50 %flowering,
PMFT-907 x RHRB-278	645.47	120.66	44.02	43.47	No. of tillers, No. of leaves, leaf width, leaf area, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)	Days to flowering, plant height, No. of leaves, dry matter yield, crude protein, crude fibre, oxalic acid and IVDMD (%)
RHRB-259 x RHRB-260	515.43	101.08	45.37	43.86	Plant height, leaf area, dry matter yield, crude protein, crude fibre, NDF and oxalic acid (%)	Days to 50% flowering, Plant height, dry matter yield, crude protein, NDF(%)
Giant bajra x PMFT-905	622.42	71.76	13.67	-3.74	Days to 50 % flowering, Plant height, No. of leaves, leaf length, leaf width, leaf area, stem weight, dry matter yield, crude protein, crude fibre, ADF, oxalic acid and IVDMD (%)	Days to 50% flowering, Plant height, stem weight, crude protein, crude fibre and IVDMD(%)
PMFT-905x PMFT-907	567.38	68.99	26.30	26.12	Days to 50% flowering, Plant height, leaf width, leaf area, leaf weight, stem weight, dry matter yield, ADF, NDF and IVDMD (%)	Days to 50% flowering, Plant height, leaf width, leaf area, leaf weight*,stem weight, dry matter yield, NDF, oxalic acid and IVDMD (%)
RHRB-260 x RHRB-278	523.15	48.10	21.23	17.17	Plant height, dry matter yield and IVDMD (%)	Days to 50% flowering, plant height, and dry matter yield
PMFT-904 x RHRB-282	598.76	43.35	21.30	13.54	Days to 50% flowering, leaf width, leaf area, dry matter yield NDF and IVDMD (%)	Days to 50% flowering, plant height, leaf width, leaf area, leaf weight, stem weight, dry matter yield, NDF and IVDMD (%)

5.5 Genetic diversity studies among parental lines in pearl millet through D^2 analysis

By using Mahalanobis multivariate D^2 statistic, diversity existing in the eight parents for eleven quantitative characters in both the seasons was assessed. From the results presented in Table 4.5.1, it is revealed that six clusters were formed each in Kharif, 2008 (E_1) and Summer, 2009 (E_2) environment. Among them, Cluster I and II contained two genotypes each in E_1 and E2 environments, while other clusters comprised of only single genotype. The genotypes RHRB-260, RHRB-282 and Giant bajra showed same clustering pattern in both the seasons.

Further, inter - cluster values (Tables 4.5.2 and 4.5.3) revealed that the maximum inter cluster distance in kharif, 2008 season was observed between cluster III (RHRB-260) and VI (Giant bajra) while in summer, 2009, it was between cluster IV (RHRB-259) and VI (Giant bajra) which indicated the presence of wider genetic diversity among the genotype included in these clusters. The minimum inter cluster distance was noiced between cluster I (PMFT-907, RHRB-259) and cluster III (RHRB-260) in E_1 and between cluster I (PMFT-907, RHRB-259) and cluster III (RHRB-260) in E_2 , which indicated close relationship between the genotypes of these clusters.

D^2 matrix denotes the distance between individual parents rather than clusters. Study revealed that maximum distance was observed between Giant bajra and RHRB-260 in E_1 and between Giant bajra and RHRB-259 in E_2 while the minimum distance was observed between RHRB-259 and PMFT-907 in E_1 and between PMFT-904 and PMFT-907 in E_2 (Table 4.5.4).

Cluster means for the eleven characters presented in the Table: 4.5.5 revealed that the genotype Giant bajra which is

included in cluster VI in E1 and E2 showed highest mean value for almost all the characters in both the environments except the genotype in cluster V (RHRB-278) in E_1 and in cluster I (PMFT-905 and RHRB-278) in E_2 in which it had highest mean value for number of tillers per plant.

The results obtained are in agreement with Murthy and Tiwari (1967), Singh and Gupta (1979), Mukherji *et al.* (1981), Singh et al. (1981), Thete and Bapat (1986), Joshi *et al.* (1988), Biwas and Sasmal (1990), Yadav (1994), Dave and Joshi (1995), Hepziba *et al.* (1995), Quendeba *et al.* (1995), Suthamathi and Doraraj (1995), Tomar et al (1995), Hendre (1998), Shanmuganathan *et al.* (2006) and Lakshamana *et al.* (2010) in pearl millet.

5.6.1 Molecular study through RAPD analysis:

Grouping of parental lines to their respective pedigree and their individual identification with diversity analysis using both morphological as well as molecular markers (RAPD) are one of the emphasis of the study. Among a large category of molecular markers, random amplified polymorphic DNA (RAPD) is useful for assessment of genetic diversity (William *et al.* 1990). Since molecular based characterization of genotypes is independent of G x E interaction, it may be an efficient and effective tool to understand and explain the genotype variability and to make use of it in crop improvement programme.

Eight parental lines of pearl millet were analysed by using 20 arbitrary oligonucleotide primers of three primer series *viz.* OPA , OPC and OPE. Each primer template yielded distinct, easily detectable bands of variable intensities. Considering all primers and eight parental lines a total scorable amplifications products were obtained of which 79.53% were poly morphic (Table 4.6.1, Fig.5.1). Maximum percent polymorphism was obtained using RAPD primers OPE-5 and OPE-9 (100%) while the lowest

Fig. 5.1: Polymorphism (%) of RAPD markers

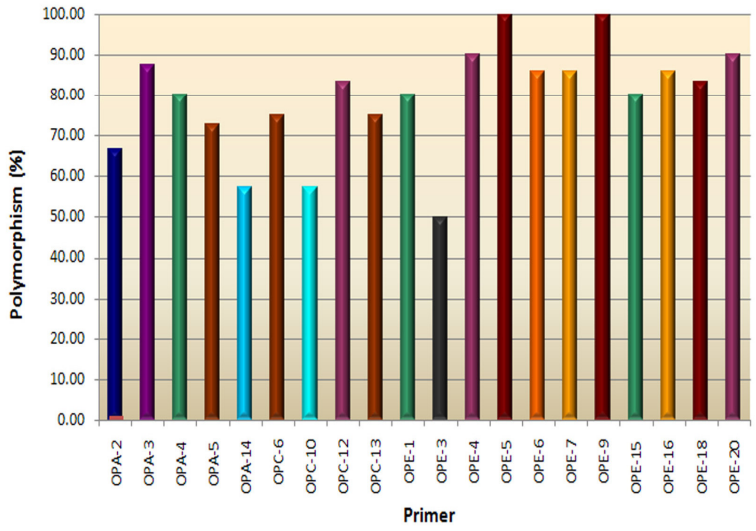
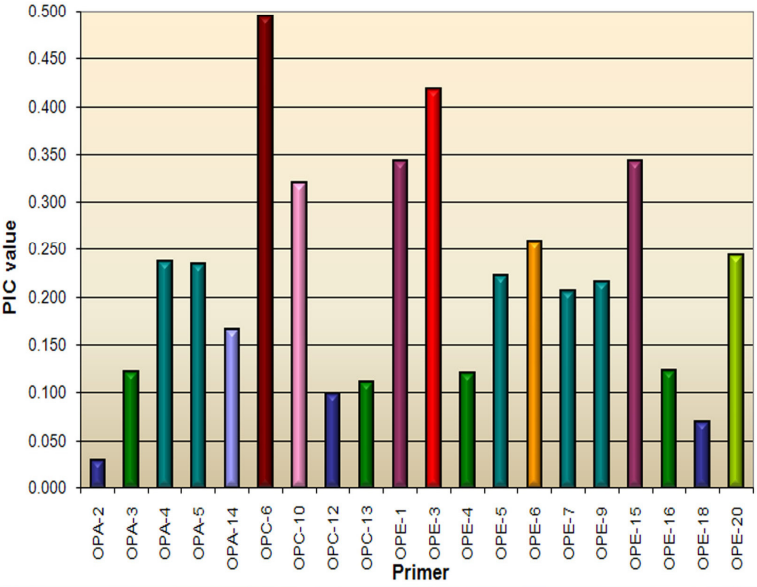


Fig. 5.2: PIC value of RAPD primers



polymorphism was observed with OPE-3 (50%). The maximum scorable bands (69) and maximum loci (15) with all of them to be polymorphic were generated by primer OPA-4, whereas primer OPE-1 generated only 21 scorable bands. Primer OPE-1 amplified minimum 5 loci out of which, 4 were found polymorphic. The size of scored bands ranged from 115.19 bp (OPA-14) to 2929.49 bp (OPC-6).The PIC provides the estimate of discriminating power of markers and it is a measure of allele diversity at a locus. The RAPD marker can have 0.500 PIC value. This was evident in the present study, as the highest PIC value of 0.494 was observed for the primer OPC-06. The PIC values ranged from 0.029 to 0.494, which was in accordance to the results obtained by Manimekalai and Nagarajan (2006) with 0.031 to 0.392 and Immanuel *et al.* (2010) with 0.137 to 0.434.

5.6.2 Genetic diversity studies among parental lines in pearl millet through RAPD markers

Dendrogram (Figure: 4.19) based on unbiased measures of genetic distance (Table: 4.6.2) by UPGMA method revealed that first sub cluster contained PMFT-904, PMFT-905, PMFT-907 and RHRB-259, while the second, third and fourth minor cluster belonged to single genotype i.e. RHRB-260, RHRB-278 and RHRB-282. The genotype Giant bajra alone included in separate cluster.

Further, Jaccards Unbiased Measures of genetic similarity and genetic dissimilarity matrix (Table: 4.6.2) revealed that maximum genetic distance was found between PMFT-905 and Giant bajra (0.4462), whereas minimum genetic distance was observed between PMFT-904 and PMFT-905 (0.1419).

The above investigation is in accordance with the study of Autunes *et al.* (1997), who clustered pearl millet genotypes into

three groups on the basis of their genetic distances. Chowdari *et al.* (1998a) determined the genetic diversity in five cytoplasmically male sterile and seven restorer lines of pearl millet by DNA fingerprinting using a (GATA)4 microsatellite and randomly amplified polymorphic DNAs and from cluster analysis and relationships among these lines revealed that they were not in agreement with the available pedigree data.

Agrama and Tuinstra (2003) used RAPD analysis for sorghum germplasm to compare suitability for quantifying genetic diversity. Chandra Shekara *et al.* (2005) analyzed the mitochondrial DNA (mt DNA) polymorphism by RAPD analysis among five pearl millet CMS lines and a male fertile maintainer (B) lines. They were able to distinguish all the male sterile and male fertile cytoplasms. Patil *et al.* (2006) revealed genetic diversity of commercial pearl millet hybrids based on RAPD markers; the consensus tree exhibited two distinct groups. Chandra Shekara *et al.* (2007) and Govindraj *et al.* (2009) also studied genetic diversity of elite pearl millet inbred lines, which revealed moderate genetic divergence in elite pearl millet germplasm.

5.7 Comparison of the results of RAPD and D^2 analysis

When comparing cluster results obtained from the RAPD and D^2 cluster analysis; Giant bajra, RHRB-260 and RHRB-282 formed major distinct clusters in both analysis, proving that diverse lines among all parental genotypes. Pooled RAPD analysis grouped parental lines into 2 distinct clusters. In D^2 cluster analysis in kharif, 2008, four genotypes *viz.* RHRB-260, RHRB-282, RHRB-278 and Giant bajra and in summer, 2009 (E_2) four genotypes *viz.* RHRB-282, RHRB-259, RHRB-260 and Giant bajra formed individually separate clusters, whereas rest of the genotypes falls in cluster I and II.

Based on RAPD diversity data, PMFT-905 and Giant bajra were most divergent pair, where as PMFT-904 and PMFT-905 were closest ones.

D^2 analysis revealed maximum inter cluster distance between RHRB-260 and Giant bajra in kharif, 2008 season and between RHRB-259 and Giant bajra in summer, 2009 while minimum inter cluster distance was observed between cluster I (PMFT-907, RHRB-259) and cluster III (RHRB-260) in kharif, 2008 and between cluster I (PMFT-905, RHRB-278) and cluster III (RHRB-282) in summer, 2009.

In this study after cluster analysis from the molecular and morphological methods observed that in both the studies, parental lines Giant bajra, RHRB-260 and RHRB-282 formed separate clusters. But for other parental lines, the classification was changed that shows the differences of these parental lines at molecular level. These two methods were not found comparable in distinguishing all the genotypes individually which was evident by the dendrogram pattern and D^2 analysis. Several other comparisons between morphological and molecular marker base study also indicated similar results such as by Ben-Har et al. (1995) in Maize, Roldan-Ruize *et al.* (2001) in rye grass, Kiani *et al.* (2002) in *Brassica napus*.

5.8 Correlation studies for molecular divergence and hybrid performance (heterosis) for green forage yield and quality characters

The efficiency of breeding program can be increased by choosing superior crosses to be made between divergent parents. For that, prediction of hybrid performance is of considerable importance and has much importance in breeding programme, Eight parental lines of pearl millet were evaluated to investigate the

association between genetic distance of RAPD (GD_R) analysis and their correlation with hybrid performance (F_1 mean), mid parent (MP), specific combining ability (SCA), mid parent heterosis (MPH) and better parent heterosis (BPH) by using Pearson's simple correlation procedure. The results are presented in Table 4.8.1, 4.8.2 and 4.8.3 for E_1, E_2 and pooled analysis, respectively and discussed below:

In kharif, 2008 (E_1) environment, the genetic distance through RAPD analysis (GD_R) was positively and significantly correlated with F_1 mean of the characters days to 50 % flowering , plant height while, in summer, 2009 (E_2) environment, the association of genetic distance with F1 mean was significant and positive for days to 50 % flowering , plant height, number of leaves, stem weight, leaf length, leaf width, leaf area, leaf weight and stem weight. On the basis of pooled means, GD_R was positively and significantly correlated with F_1 mean of days to 50 % flowering, plant height, number of leaves, leaf length, leaf area, leaf weight, stem weight, and IVDMD. However, the same was non significant for green fodder yield, dry matter yield and almost all quality traits.

Further, the GD_R was positively and significantly correlated with mid parent values of all the characters except number of tillers, leaf : stem ratio, CP (%), ADF (%) and oxalic acid and negative significant association was found between GD_R and MP for crude fibre and NDF per cent. However, GD_R showed non significant association with SCA, MPH and BPH for almost all the characters in E_1, E_2 environments and over pooled means.

Molecular markers (RFLP, APS, ALFP and SSR) have been used to directly ssess the genetic diversity and /or genetic distance between parental genotypes and its association with F_1 performance and heterosis has been tested by the earlier workers

in most of the crops viz., maize (Cerna *et al.* 1997, Betran *et al.* 2003); rice (Maroof *et al.* 1997, Immanuel Selvaraj *et al.* 2010), Chick pea (Sant *et al.* 1999); sunflower (Cheres *et al.* 2000); Cacao (Dias *et al.* 2003); *Medicago sativa* (Riday *et al.* 2003); winter triticale (Goral *et al.* 2005); barley ((Shahnejat-Bhghehari *et al.* 2005, Kadri Karim *et al.* 2010). Chowdari *et al.* (1998b) observed positive correlation between genetic distance and heterosis in pearl millet only for days to 50% flowering, ear head length and ear head width. While, Betran *et al.* (2003) found positive correlation between GD and F_1 performance, sca, midparent heterosis (MPH) and higher-parent heterosis (HPH) for grain yield in tropical Maize.

In most of the cases, correlation between RAPD based genetic distance and hybrid performance was very low to predict heterosis. Dias *et al.* (2004) studied 54 articles to evaluate divergence–heterosis association, out of them 28 detected diergence-heterosis association and 26 revealed negative or inconclusive results.

Such contrasting results showed that association between parental divergence and heterosis remain an unsolved question. Although genetic distance does not affect heterosis in a linear fashion, it is still important for realizing useful heterosis in crosses. In many circumstances the expression of heterosis is partly due to genetic diversity. Although it also depends on several other factors not completely elucidated, and for this reason it has been unpredictable.

Bernardo (1992) concluded that at least 30 to 50% of the QTLs affecting the trait (i.e. grain yield) should be linked to DNA markers to effectively predict hybrid performance with DNA marker heterozygosity.

The interpretation of the association between parental genetic distance and hybrid yield performance in genetic marker terms is not easy because marker should be located across the whole genome to accurately predict heterosis. However, convenient estimates of genetic distance from molecular data can be obtained by using a suitable DNA sampling technique. In turn, the RAPD markers represent random samples from the entire genome. Hence, it is possible to predict reliably heterosis for yield and its components by using randomly selected set of RAPD markers (Dias *et al.* 2003).

Riday *et al.* (2003) suggested that in many cases, progeny heterosis can be accounted for by the interaction of genes controlling morphologically divergent traits between the parents. In other cases, progeny heterosis could also be due to divergence between the parents at particular genetic loci that do not control field-level phenotypic differences. Genetic distance *per se* between parental genotypes, based on neutral molecular markers, however, does not reflect the potential of individual genotypes to produce heterosis in their progeny.

In this study, the hybrids obtained from very closely or distantly related parents showed low heterosis but crosses produced from parents from intermediate divergence classes tended to show higher heterosis for green forage yield, dry matter yield and most of the forage yield attributes. This suggest that intermediate divergence of parental lines could give higher heterosis for the traits. Moll *et al.* (1965) also reported that heterosis decreases beyond a certain level of genetic diversity because of incompatible gene combinations when two highly divergent parental populations are crossed.

6. SUMMARY AND CONCLUSION

The present investigation entitled "Genetic studies and molecular analysis for green forage yield in Pearl millet [*Pennisetum glaucum* (L.) R Br.]" was conducted at AICRP on Forage Crops, Mahatma Phule Krishi Vidyapeeth, Rahuri during Kharif 2008 and summer 2009. The experimental material was developed during summer, 2008 by crossing eight parental lines in a half diallel mating design. Under field level investigation, the resulting 28 hybrids along with 8 parents were grown in a randomized block design, with three replications in kharif 2008 and summer 2009 seasons. The experimental material was evaluated for eighteen characters, comprising of green forage yield, its components and fodder quality characters. Molecular studies were conducted to distinguish parental lines by using genomic DNA polymorphism revealed by RAPD molecular markers. Correlation studies were conducted to evaluate association of genetic distance revealed by molecular markers with mean hybrid performance, MP value, sca effects, mid parent and better parent heterosis for forage yield and yield components in kharif 2008 and summer 2009 seasons and in pooled over seasons. The objectives of the field level investigation were to study the combining ability and nature of gene action of various genotypes, magnitude of heterosis, under two seasons. The salient features of the results obtained are summarized as below:

5.1 Mean performance

The mean values for different characters under the two seasons revealed that the green forage yield and majority of the yield contributing characters were found to excel in the favourable environment kharif, 2008 (E_1). However, in summer,2009 (E_2), there was considerable reduction in the plant stature and forage

yield. Among the parents, the highest green forage and dry matter yield was recorded by Giant bajra and RHRB-282 in kharif, 2008 as well as summer, 2009 seasons. The same parents were found to be superior for majority of the yield contributing characters. Regarding the days to 50 per cent flowering, PMFT-907 and RHRB-259 were the early flowering parents under both the environmental conditions. For L:S ratio RHRB-259 was the superior parent, whereas RHRB-278 had lower ADF and NDF percent in both the seasons and across the seasons. The results revealed that a combination of various forage yield contributing factors and their expression/ modification under various environmental conditions had resulted in the enhancement of yield. Different parents exhibited their superiority for kharif as well as summer seasons, which indicated that the genetic expression of this character is modified by the environmental conditions.

Among the hybrids, the high green forage yield was recorded by Giant bajra x RHRB-282, PMFT-907 x RHRB-278 and Giant bajra x RHRB-278 in the both the seasons and across the seasons. These hybrids also, were found to bear one or more forage yield contributing traits. Similarly, the crosses Giant bajra x RHRB-259 and PMFT-907 x RHRB-259 in E_1, PMFT-905 x PMFT-907 in both environments and across the environments were found to be the earliest for days to 50 % flowering.

5.2 Analysis of variance

A analysis of variance of diallel set in E_1 (Kharif, 2008) and E_2 (Summer, 2009) environments revealed significant mean sum of squares due to treatments and its sub division (parents, hybrids and parents v/s hybrids) for all characters studied except mean squares due to parents for number of tillers/plant and oxalic acid in E_1 and for crude fibre content in E_2 and except mean

squares due to parent v/s hybrids for number of tillers/plant, leaf length, L:S ratio, crude fibre (%), ADF (%), NDF (%), oxalic acid (%) and IVDMD in E_1 and except plant height, number of tillers, stem weight, ADF and NDF (%) in E_2 indicating sufficient variability among parents and hybrids. The pooled analysis of variance revealed that the environments differed significantly for all the characters except L:S ratio, oxalic acid and IVDMD (%) suggesting sufficient diversity among the test environments. The significant differences among treatments, parents and hybrids were also observed for the characters suggesting substantial diversity among them. The significant mean squares due to parents vs. hybrids for most of the characters except number of tillers/plant, number of leaves/plant, leaf width, leaf weight, ADF, NDF and IVDMD (%) showed presence of heterosis in hybrids for the traits.

A pooled analysis of variances by the interactions of treatments x environments, parents x environments, hybrids x environments and parents vs. hybrids x environments were found significant for majority of the characters, except for number of tillers in case of treatments x environment and hybrids x environment; number of tillers, leaves per plant and oxalic acid (%) in case of parents x environment and except number of tillers, L:S ratio, crude protein, crude fibre, ADF, NDF, oxalic acid and IVDMD (%) in case of parents vs. hybrids x environments. These results suggested that the differences in the performance of the parents and hybrids were real for majority of the characters in both the environments indicating the presence of heterosis for these characters.

5.3 Combining ability analysis

Mean squares due gca and sca were highly significant for all the characters in both the seasons and across the seasons except mean squares of gca for number of tillers per plant in E_1

and IVDMD in E_2 and mean squares due to sca for oxalic acid content in E_2 revealing importance of both additive and non additive type of gene effects for expression of these traits. Significant gca x environment for all the characters except number of tillers per plant, L:S ratio, crude protein, NDF, oxalic acid and IVDMD percent, while significant sca x environment interaction for all the characters except number of tillers per plant indicated importance of experimentation over environment to assess the genetic worth of genotypes. The magnitude of gca mean sum of squares was higher than sca for all the characters in both the environments except for number of leaves/plant and IVDMD percent in E_1, ADF and IVDMD percent in E_2 and except for IVDMD percent in pooled over environments.

The general combining ability effects and *per se* performance for various characters under both the seasons revealed that, Giant bajra, RHRB-282, PMFT-904 were found to be a good and consistent general combiner for green forage yield and most of the forage traits. It was observed that the *per se* performance for different characters in general, agreement with the gca effects. However, there were many exceptions to this observation which can be attributed to the intra and/or inter allelic interaction of genes modified by environmental factors.

Estimates of sca effects did not reveal any specific trend among the crosses. Most of the crosses with high sca effects were associated with high *per se* performance. The hybrids *viz.,* Giant bajra x RHRB-282 in kharif, 2008 ; PMFT-907 x RHRB-278, in summer 2009 and Giant bajra x RHRB-282 in pooled analysis exhibited highest significant effect for green forage yield and most of the yield contributing and quality characters. However, the cross combination viz., RHRB-259 x RHRB-259 of low x low

performing parents also exhibited high positive and significant sca effect for green forage yield and other most of the yield contributing and quality traits in both the seasons and pooled over seasons.

The estimates of components of genetic variance (σ^2gca and σ^2sca) revealed that variance due to σ^2sca was of higher magnitude than that of σ^2gca for all the characters in kharif 2008, summer, 2009 seasons and in pooled analysis except for leaf length in summer, 2009 (E_2) season and in pooled analysis indicating the predominance of non- additive gene action in controlling these characters.

5.4 Magnitude of heterosis

The extent of relative heterosis (MP) and heterobeltiosis (BP) were estimated for all the characters, under the two seasons and over the seasons.

The expression of relative heterosis and heterobeltiosis in the positive direction was maximum for stem weight followed by leaf weight, leaf area and dry matter yield in both the seasons and in pooled analysis. The magnitude of relative heterosis and heterobeltiosis in the negative direction was maximum for stem weight. The magnitude of heterosis for majority of the traits was found to be higher in kharif, 2008 season, as compared to the summer, 2009. The hybrids that exhibited high heterobeltiosis for green forage yield were PMFT- 907 x RHRB-278 and RHRB-259 xRHRB-260 in both the seasons and in pooled analysis. These hybrids also exhibited superiority for one or more yield contributing characters. The most heterobeltiotic hybrids for crude protein percent were PMFT-907 x RHRB-259 and PMFT-907 x RHRB-278 in both the seasons and in pooled analysis for IVDMD

the heterotic combinations were Giant bajra x RHRB-259 in kharif, 2008 and PMFT-905 x RHRB-259 and PMFT-905 x RHRB-278 in summer, 2009 season and in pooled analysis. The superior heterobeltiotic hybrid for oxalic acid, was PMFT-907 x RHRB-278 in kharif, 2008 and PMFT-907 x RHRB-259 in summer.2009 season and in pooled analysis.

The hybrids Giant bajra x RHRB-282, PMFT-907 x RHRB-278, RHRB-259 x RHRB-260, Giant bajra x PMFT-905 and PMFT-905 x PMFT-907 showed significant and positive sca effects, heterobeltiosis and high *per se* performance in both the seasons as well as across the seasons. These crosses exhibited significant and positive sca effects and heterobeltiosis for at least one or more yield contributing characters.

5.5 D^2 clustering analysis

Genetic diversity studied by using Mahalanobis D^2 statistic indicated that material studied was genetically diverse. The genotypes were grouped in six clusters each in Kharif, 2008 (E_1) and summer, 2009 (E_2) environment. Among them, Cluster I and II contained two genotypes each in E_1 and E_2 environments, while other clusters comprised of only single genotype. The genotypes RHRB-260, RHRB-282 and Giant bajra showed same clustering pattern in both the seasons.

Maximum inter cluster distance was observed between cluster III (RHRB-260) and VI (Giant bajra) in kharif, 2008 season while, in summer, 2009, it was between cluster IV (RHRB-259) and VI (Giant bajra) which indicated the presence of wider genetic diversity among the genotype included in these clusters. The minimum inter cluster distance was between cluster I ((PMFT-907, RHRB-259)) and cluster III (RHRB-260) in E_1 and between

cluster I (PMFT-907, RHRB-259) and cluster III (RHRB-260) in E_2 , which indicated close relationship between the genotypes of these clusters.

5.6 Molecular studies

Pooled RAPD Analysis of all 20 arbitrary oligo-nucleotide primers of three primer series *viz.* OPA, OPB, and OPC generated total 806 scorable bands with 171 loci, among that 136 loci were found polymorphic, showed 79.53 % polymorphism.

Dendrogram based on unbiased measures of genetic distance by UPGMA method formed two major clusters which grouped all the 8 genotypes. The first major cluster contains parent Giant bajra only; where as second major cluster divides other parental lines into four minor clusters.

5.7 Comparison of the results of RAPD and D^2 analysis

When comparing cluster results obtained from the RAPD and D^2 cluster analysis; Giant bajra, RHRB-260 and RHRB-282 formed distinct cluster in both the analysis, proving that it was the most diverse line among all parental genotypes.

5.8 Corrlation between molecular divergence and hybrid performance

Over all results suggested that genetic distance through RAPD data showed significant positive correlation in desired direction with pooled F_1 mean for some yield contributing characters but non significant for green fodder yield, dry matter yield and almost all quality traits. Further, GD_R was positively and significantly correlated with mid parent values of all the characters except number of tillers, leaf : stem ratio, CP (%), ADF (%) and oxalic acid and negative significant association was found between

GD_R and MP for crude fibre and NDF per cent. Over all genetic distance showed non significant correlation with F_1 mean, sca effects, mid parent and better parent heterosis for green fodder yield, dry matter yield and majority of quality traits in both the seasons. However,some cross combinations had high mean performance, sca effects BPH and mid parent heterosis involving the parents of moderate to high genetic distance.

Based on the results obtained, the following conclusions can be drawn.

(1) The parents displayed differential response to the varying environments, with none of the parents exhibiting superiority for mean performance for all the traits. However, parents Giant bajra and RHRB-282 were the superior for green forage yield and majority characters under both the environments. The hybrids, which showed high green forage yield were Giant bajra x RHRB-282 and PMFT-907 x RHRB-278 in kharif, 2008 and summer, 2009 seasons and in pooled analysis. These hybrids also recorded high heterobeltiosis and were found promising for green forage yield and other forage yield contributing characters.

(2) Estimates of gca effects for various characters revealed that parents Giant bajra, PMFT-905 and RHRB-282 were the superior and consistent general combiners for green forage yield and majority of traits, indicates that these parents holds great potential and should be included in future breeding programmes for character enhancement in both the seasons.

(3) A comparison of the estimates of sca effects and *per se* performance revealed that the presence of good or average general combiners in the hybrids invariably resulted in better

performance of the crosses. The highest sca effect for green forage yield was recorded by the hybrids Giant bajra x RHRB-282 and PMFT-907 x RHRB-278 in kharif, 2008 and summer, 2009, respectively. These hybrids are also expected to yield transgressive segregants in segregating generations and could be utilized for isolation of high yielding superior genotypes through breeding approaches.

(4) It was observed that yield attributes differed under various environmental situations in their capacity to contribute towards high gca for yield. The sca effects of the crosses also varied under different environmental situations. This indicated that the character expression in pearl millet is highly influenced by the environmental conditions existing during the crop growth.

(5) The predominant role of non-additive gene action in the genetic expression of most of the characters. However, additive gene action was also observed for leaf length. Under these circumstances, the breeding strategy involving biparental mating with reciprocal recurrent selection should be employed so that both additive as well as non-additive gene action could be exploited simultaneously for further improvement of the traits in the population.

(6) D2 statistic indicated that parental lines studied was genetically diverse.

(7) The molecular studies concluded that, Polymorphism information content (PIC value) for RAPD analysis ranged from 0.029 (OPA-02) to 0.494 (OPC-06). The diversity at molecular level can be used for selecting parents for attempting better hybrid combinations. Such molecular investigation has

considerable importance in crop improvement programme and can help in identifying parents for the better hybrid combinations and cataloguing the genetic diversity in the breeding material if more markers and genotypes are included in study.

(8) Comparison of cluster analysis obtained from the RAPD and D^2 cluster analysis; Giant bajra, RHRB-260 and RHRB-282 formed distinct clusters in both the analysis, proving that these were the most diverse lines among parental genotypes.

(9) Over all genetic distance showed non significant correlation with F_1 mean, sca effects, Mid parent and better parent heterosis for green fodder yield, dry matter yield and majority of quality traits in both the seasons. Some cross combinations had high mean performance, sca effects BPH and mid parent heterosis involving the parents of moderate to high genetic distance.

(10) Hence, it is concluded that genetic distance estimates based on the RAPDs may be useful for the grouping of genetically diverse parents, which may result heterotic combinations, in forage pearl millet.

Future breeding methodology

To plan an efficient breeding strategy, breeder should have genetic information of concerned plant species. The knowledge of genetic structure that determines the expression of character in relation to adaptability and productivity greatly helps in the exploitation of available genetic resources. Therefore, based on the material used and the results obtained from the present study certain suggestions can be made for future pearl millet fodder improvement programme.

In the present study, improvement of the traits showing preponderance of non-additive gene action could be achieved through recurrent selection, by way of inter-mating the most desirable segregants followed by selection, or the use of multiple crosses or bi-parental mating, while the trait like leaf length showing preponderance of additive gene action could be improved through producing transgressive segregants followed by simple selection for the desired traits.

Giant bajra, RHRB-282, PMFT-904 and RHRB-278 possessed high concentration of favourable genes for the respective traits and may be utilized in crossing programme in order to generate wide genetic variability for effective selection in developing high yielding early maturing varieties/population of fodder pearl millet.

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*Original not seen

8. VITA

GORAKSHANATH CHANGDEO SHINDE

A candidate for the degree of

DOCTOR OF PHILOSOPHY

2011

Title of the Thesis : Genetic studies and molecular analysis for forage yield in Pearl millet [*Pennisetum glaucum* (L.) R Br.]

Major Field : Agricultural Botany (Cytogenetics and Plant Breeding)

Biographical information

Personal : Born on 1st June, 1963 at Kanoli, Tal. Sangamner, Dist. Ahmednagar, (M.S.), India. Son of Late Shri. Changdeo Shankar Shinde.

Educational :

1. Attended primary education at Kankapur, Tal. Sangamner, Dist. Ahmednagar and secondary and higher secondary education at Sahyadri High school and Junior College, Sangamner. Passed XIIth Std. in first class in 1981.
2. Completed B. Sc. (Agri.) course at College of Agriculture, Pune from 1981 to 1984 under Mahatma Phule Krishi Vidyapeeth, Rahuri and and obtained the degree in First class with distinction.
3. Obtained M.Sc. (Agri.) degree in Cytogentics and Plant Breeding from

Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri in First class with Distn., in 1995.

4. Thesis for Doctor in Philosophy in Cytogenetics and Plant Breeding is being submitted to Mahatma Phule Krishi Vidyapeeth, Rahuri

Professional :

1. Selected as Junior Research Assiatant and worked at Agricultural Research Station, Savalvihir Farm, Kopergaon from 20.2.1988 to 6.7.1993.
2. Promoted to the post of Senior Research Assistant and worked at Oilseeds Research Station, Jalgaon from 7.7.1993 to 31.10.1996; at Bajra Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri from 1.11.1996 to 31.3.2002 and at Cotton Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri from 1.4.2002 to 16.1.2008.
3. Working as Senior Research Assistant in Grass Breeding Scheme, Mahatma Phule Krishi Vidyapeeth, Rahuri w.e.f. 17.1.2008.
4. Associated in the development of Pearl millet hybrid Shanti (RHRBH-9808) and cotton varieties Viz., RHC-0688, RAC-024 and RHarb-02-1.

APPENDIX-I

Meteorological week wise weather data at Central Campus, Mahatma Phule Krishi Vidyapeeth, Rahuri.

Kharif, 2008 crop season.

M.W.	Period	Rainfall (mm)	RD	Humidity		Temp (°C)	
				Mor.	Even.	Max.	Min.
28	9 July-15 July	1.3	0	88.0	52.0	31.8	22.4
29	16 July-22 July	2.1	0	90.0	45.0	33.8	21.8
30	23 July-29 July	28.5	2	93.0	69.0	29.7	22.1
31	30 July-5 Aug.	26.6	2	94.0	65.0	29.8	22.0
32	6 Aug-12 Aug.	30.0	2	95.0	75.0	23.6	21.8
33	13 Aug-19 Aug.	0.0	0	92.0	55.0	30.2	21.8
34	20 Aug-26 Aug.	8.0	1	92.0	49.0	32.3	21.0
35	27Aug-2 Sept.	28.1	2	94.0	55.0	31.5	21.8
36	3 Sept-9 Sept.	158.2	6	95.0	70.0	30.0	21.9
37	10 Sept-16 Sept.	127.3	3	94.0	77.0	28.4	21.4
38	17 Sept-22 Sept.	15.9	1	92.0	65.0	29.1	21.2
39	22 Sept-30 Sept.	0.0	0	93.0	47.0	31.0	18.3
	Total	**426.0**	**19**				

Summer, 2009 crop season.

M.W.	Period	Rainfall (mm)	RD	Humidity		Temp (°C)	
				Mor.	Even.	Max.	Min.
6	5 Feb-11 Feb.	0.0	0	93	33	36.8	22.6
7	12 Feb-18 Feb.	0.0	0	95	46	35	22.4
8	19 Feb-25 Feb.	0.0	0	94	53	33.1	22.7
9	26 Feb-4 Mar.	0.0	0	93	63	31.5	22.4
10	5 Mar-11 Mar.	0.0	0	93	69	29.9	22.4
11	12 Mar-18 Mar.	2.7	1	94	75	29.6	22.4
12	19 Mar-25 Mar	0.0	0	94	73	29.2	22
13	26 Mar-1 Apr9.	0.0	0	94	65	30.9	21.1
14	2 Apr-8 Apr.	0.0	0	94	61	31.6	22
15	9 Apr-15 Apr.	0.0	0	94	59	32.2	21.9
16	16 Apr-22 Apr.	0.0	0	95	71	29.9	21.4
17	23 Apr-29 Apr.	0.0	0	93	72	29.7	21.6
18	30 Apr-6 May.	0.0	0	93	72	29.2	21.2
	Total	**2.7**	**1**				

Plate VII

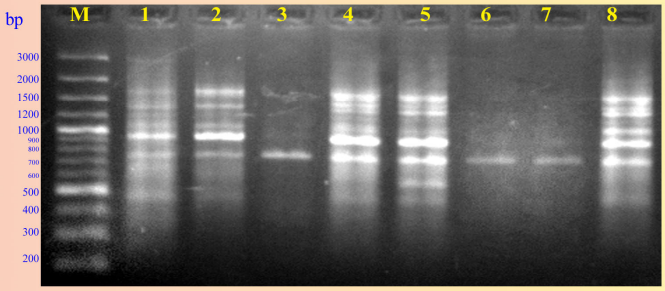

Fig. 4.17: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 15

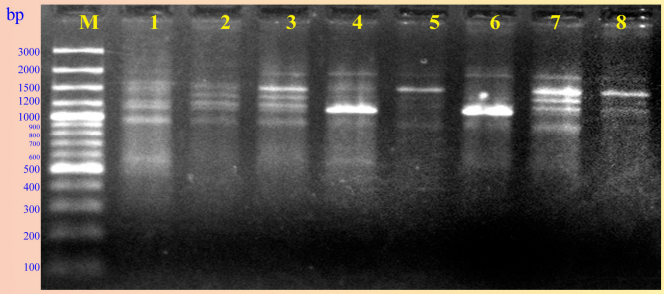

Fig. 4.18: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 16

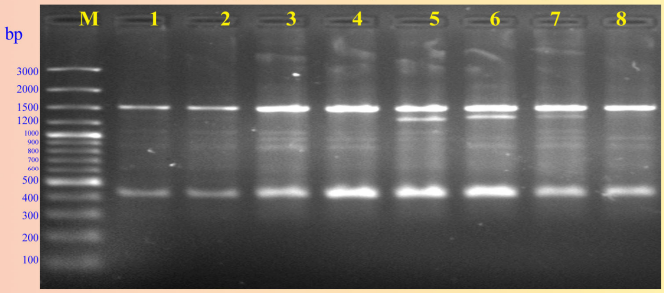

Fig. 4.19: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 18

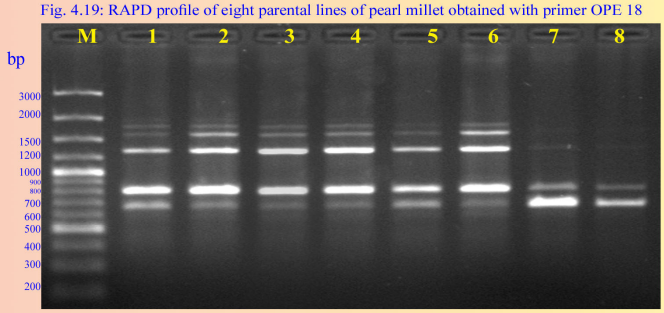

Fig. 4.20: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 20

Lane M = Marker

Lane	Genotypes	Lane	Genotypes
1	Giant bajra	5	RHRB-259
2	PMFT-904	6	RHRB-260
3	PMFT-905	7	RHRB-282
4	PMFT-907	8	RHRB-278

Plate VI

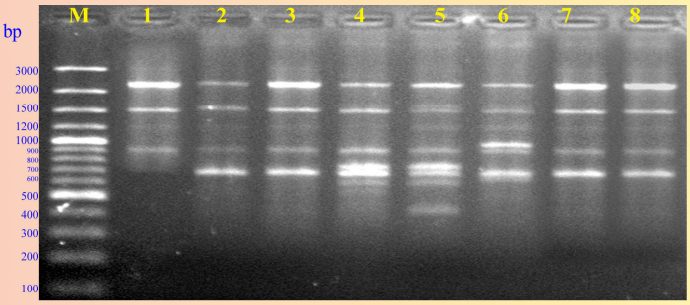

Fig. 4.13: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 05

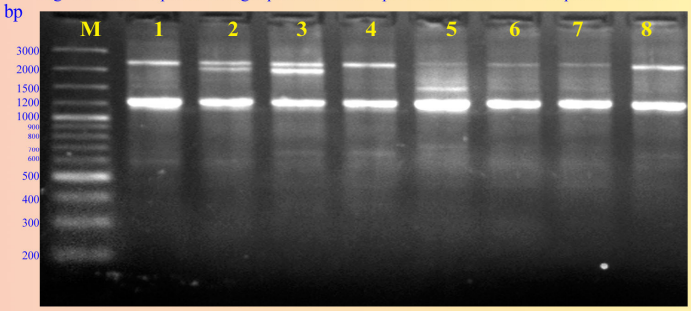

Fig. 4.14: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 06

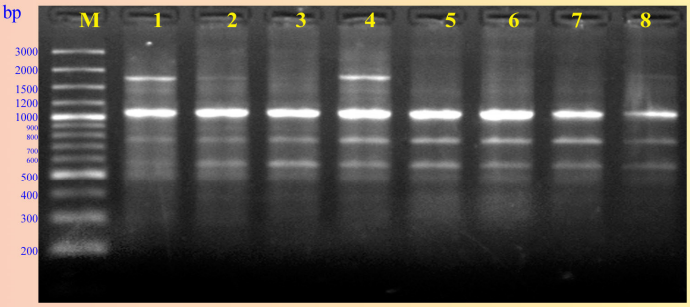

Fig. 4.15: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 07

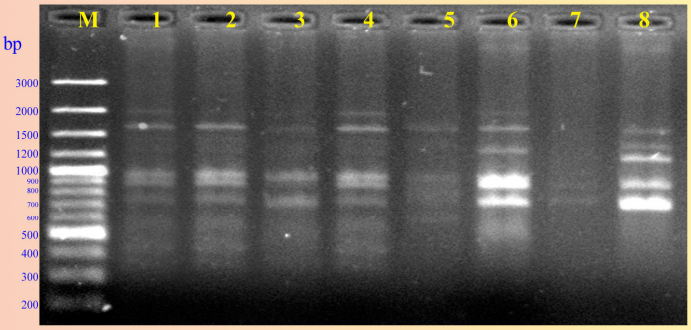

Fig. 4.16: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 09

Lane M = Marker

Lane	Genotypes	Lane	Genotypes
1	Giant bajra	5	RHRB-259
2	PMFT-904	6	RHRB-260
3	PMFT-905	7	RHRB-282
4	PMFT-907	8	RHRB-278

Plate V

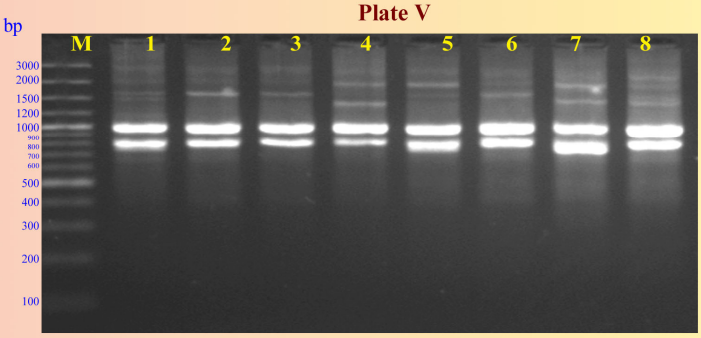

Fig. 4.9: RAPD profile of eight parental lines of pearl millet obtained with primer OPC 13

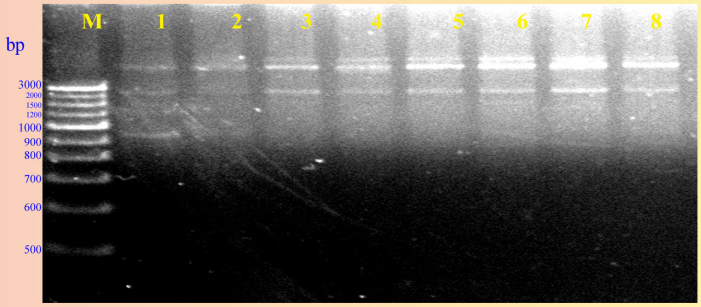

Fig. 4.10: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 01

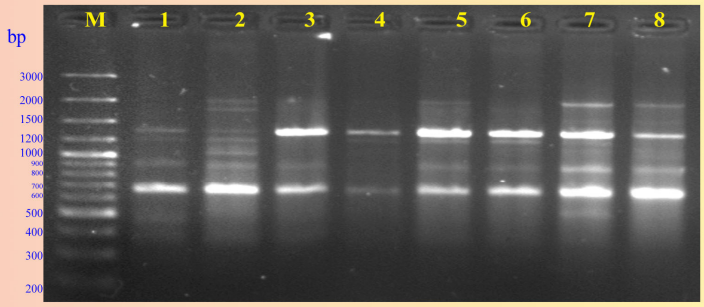

Fig. 4.11: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 03

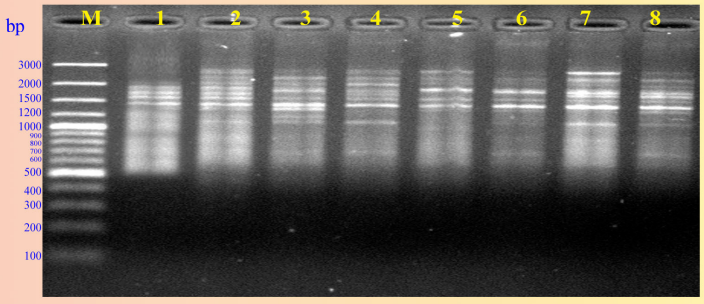

Fig. 4.12: RAPD profile of eight parental lines of pearl millet obtained with primer OPE 04

Lane M = Marker

Lane	Genotypes
1	Giant bajra
2	PMFT-904
3	PMFT-905
4	PMFT-907
5	RHRB-259
6	RHRB-260
7	RHRB-282
8	RHRB-278

Plate IV

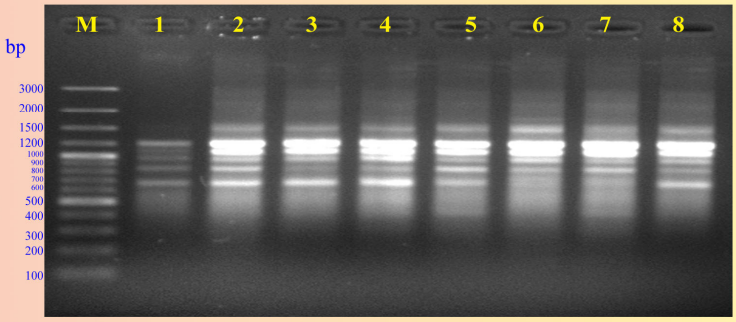

Fig. 4.5: RAPD profile of eight parental lines of pearl millet obtained with primer OPA 14

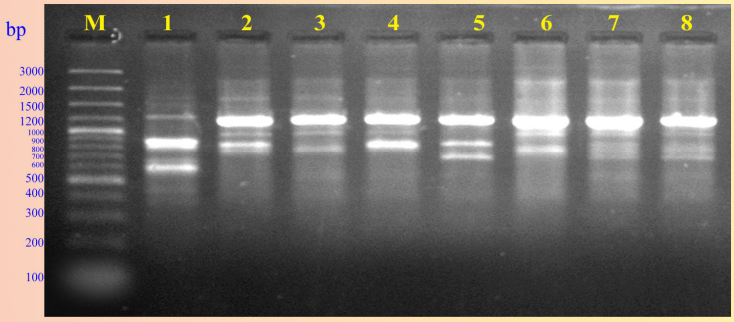

Fig. 4.6: RAPD profile of eight parental lines of pearl millet obtained with primer OPC 06

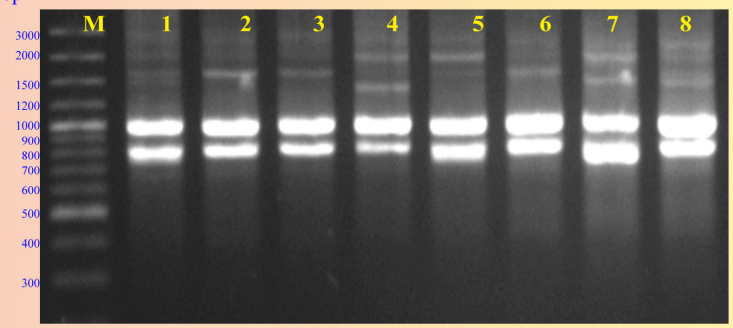

Fig. 4.7: RAPD profile of eight parental lines of pearl millet obtained with primer OPC 10

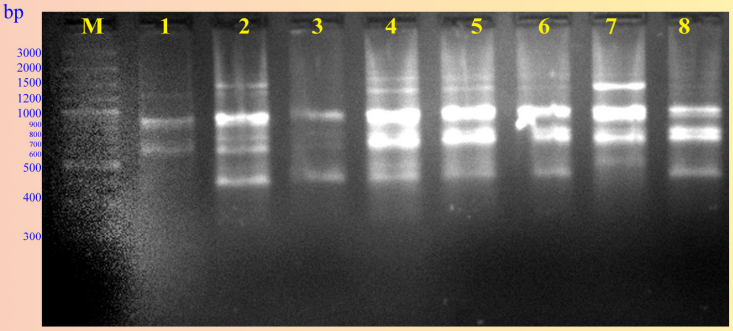

Fig. 4.8: RAPD profile of eight parental lines of pearl millet obtained with primer OPC 12

Lane M = Marker

Lane	Genotypes
1	Giant bajra
2	PMFT-904
3	PMFT-905
4	PMFT-907
5	RHRB-259
6	RHRB-260
7	RHRB-282
8	RHRB-278

Plate III

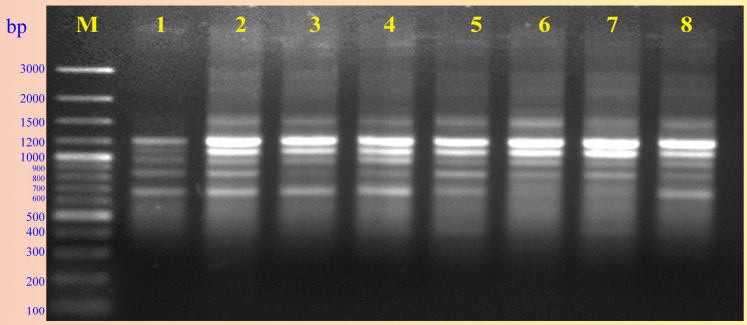

Fig. 4.1: RAPD profile of eight parental lines of pearl millet obtained with primer OPA 02

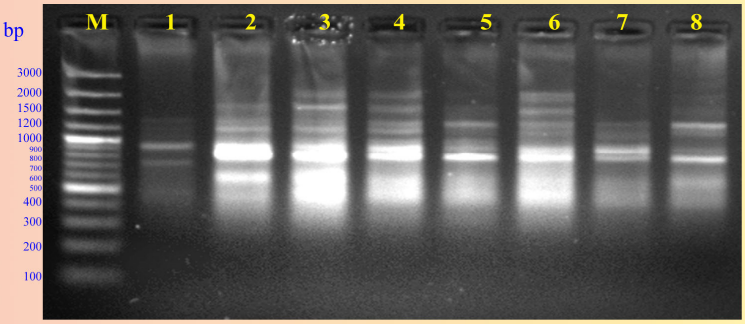

Fig. 4.2: RAPD profile of eight parental lines of pearl millet obtained with primer OPA 03

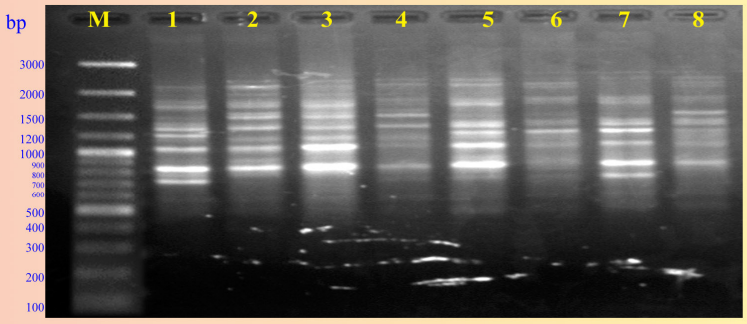

Fig. 4.3: RAPD profile of eight parental lines of pearl millet obtained with primer OPA 04

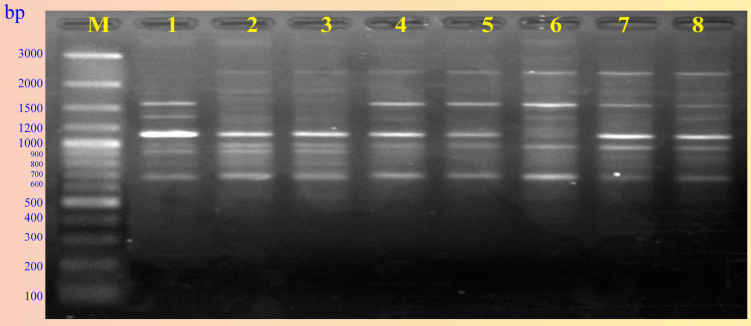

Fig. 4.4: RAPD profile of eight parental lines of pearl millet obtained with primer OPA 05

Lane M = Marker

Lane	Genotypes
1	Giant bajra
2	PMFT-904
3	PMFT-905
4	PMFT-907
5	RHRB-259
6	RHRB-260
7	RHRB-282
8	RHRB-278

Giant bajra

PMFT-904

PMFT-905

PMFT-907

Plate I : Parental lines of pearl millet used for crossing programme.

RHRB-259

RHRB-260

RHRB-282

RHRB-278

Plate II : Parental lines of pearl millet used for crossing programme.

PMFT-905 x RPMFT-907

Giant bajra x RHRB-282

PMFT-907 x RHRB-278

PMFT-907 x RHRB-282

Plate VIII : Photographs of promising pearl millet hybrids.

Giant bajra x PMFT-905

PMFT-904 x RHRB-259

PMFT-905 x RHRB-282

Plate IX : Photographs of promising pearl millet hybrids.