STUDIES ON HETEROSIS AND COMBINING ABILITY IN PEARL MILLET (Pennisetum americanum (L.) Leeke)

By

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B. Sc. (Agri.) First Class with Distn.

A Thesis submitted to the

MAHATMA PHULE AGRICULTURAL UNIVERSITY,

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in partial fulfilment of the requirements for the degree

of

Master of Science (Agriculture)

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Cytogenetics And Plant Breeding

DEPARTMENT OF AGRICULTURAL BOTANY

POST - GRADUATE INSTITUTE

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Approved :

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MAHATMA PHULE AGRICULTURAL UNIVERSITY
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CANDIDATE'S DECLARATION

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

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This is to certify that the thesis entitled "Studies on heterosis and combining ability in pearl millet (*Pennisetum americanum* (L.) Leeke)" submitted to the Faculty of Agricultural Science, Mahatma Phule Agricultural University, Rahuri, Dist. Ahmednagar (Maharashtra) for the award of Degree of MASTER OF SCIENCE (AGRICULTURE) in CYTOGENETICS AND PLANT BREEDING, embodies the results of a *bona-fide* research carried out by Shri Ulhas Madhukar Borle, under my guidance and supervision and that no part of thesis has been submitted for any Degree or Diploma. The assistance and help received during the course of this investigation have been acknowledged.

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CERTIFICATE

This is to certify that the thesis entitled "Studies on heterosis and combining ability in pearl millet (*Pennisetum americanum* (L.) Leeke)" submitted in partial fulfilment of the requirements of the Post-Graduate Agricultural Institute, Mahatma Phule Agricultural University, Rahuri for the award of Degree of MASTER OF SCIENCE (AGRICULTURE) in CYTO-GENETICS AND PLANT BREEDING, embodies the results of a *bona-fide* research carried out by Shri Ulhas Madhukar Borle under the guidance and supervision of Dr. S.D. Ugale, Professor (Bajra Breeding), Mahatma Phule Agricultural University, Rahuri and that no part of the thesis has been submitted for any Degree or Diploma.

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Dr. N. D. PATIL

Dated : 16.12.85

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(Ulhas M. Borle)

RAHURI

Dated : 12-12-1985

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LIST OF ABBREVIATIONS

Inb.	:	Inbred
SP	:	Superior parents.
MP	:	Mid parents.
g.c.a.	:	General combining ability.
s.c.a.	:	Specific combining ability.
δ^2g.c.a.	:	Variance for general combining ability.
δ^2s.c.a.	:	Variance for specific combining ability.
δ^2e.	:	Error variance.
L.S.D.	:	Least significant difference.
C.D.	:	Critical difference.
S.E. $\pm$	:	Standard error.
h^2	:	Heritability percentage.
s.s.	:	Sum of squares.

ABSTRACT

"STUDIES ON HETEROSIS AND COMBINING ABILITY IN PEARL MILLET (Pennisetum americanum (L.) Leeke).

by

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MASTER OF SCIENCE (AGRICULTURE)
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Major Professor	:	Dr. S. D. Ugale
Department	:	Cytogenetics and Plant Breeding.

The present investigations entitled "Studies on heterosis and combining ability in pearl millet(Pennisetum americanum (L.) Leeke)" was carried out in the Department of Botany, Mahatma Phule Agricultural University, Rahuri. Ninety-two treatments consisting of 2 male sterile lines and 30 newly developed inbreds with their 60 hybrids and check (BK-560-230) were grown in RBD with two replications to study the nature and magnitudes of heterosis for grain yield and other yield attributing characters, general and specific combining effects, gene action and heritability for ten characters viz; days to flowering, plant height, number of tillers, number of nodes, internode length, number of leaves, earhead length, earhead girth, 500-grain weight and grain yield per plant.

Considerable amount of genetic variability was observed among the parents and hybrids for all the characters studied. Between females, 5141 A was superior

for days to flowering, number of nodes, earhead length and 500-grain weight, while 5054 A for plant height; number of tillers and leaves and grain yield per plant. All the male parents had thicker earhead and bolder grains.

The considerable amount of heterosis was observed for all the characters. However, percentages of heterosis were high for grain yield per plant, 500-grain weight, plant height, number of leaves and internodal length. The positive heterosis for grain yield per plant was observed in twenty-seven and twenty-nine crosses based on 5141 A and 5054 A female parents, respectively. Among the crosses showing significant positive heterosis for grain yield, very high percentages were noted in 5141 A x RBS-23(277.32) and 5054 A x Inb.1022 (257.45) crosses. The hybrids of RBS-23, Restorer-3, Inb.1022, RBS-243-2, Inb.1002-1, Inb.1043 Inb.45, RBS-225 and RBS-359 with 5141 A and the hybrids of Inb.1022, RBS-23, Inb.1002-1, RBS-243-2, Restorer-3, Inb.337-1, Inb.45 and RBS-225 were found to be promising.

As regards the general combining ability effects among the male sterile lines, 5141 A had higher values of g.c.a. effects for days to flowering, number of nodes, earhead length and 500-grain weight and was the best general combiner for these attributes. 5054 A was the best general combiner for plant height, number of tillers, number of leaves and grain yield per plant. Both the female parents were average general combiner for internode length and earhead girth.

Among the male parents, RBS-23, RBS-225, Inb.1022, Restorer-3, Inb.142-2, Inb.1043, Inb.337-1, Inb.1002-1 and Inb.45 were the best general combiners for grain yield per plant. Best general combiners for grain yield were also the best general combiners for one or more yield contributing characters.

The best specific combinations for days to flowering were 5054 A x Restorer-3 and 5054 A x RBS-347,for plant height 5141 A x Inb.492 and 5141 A x Manmad Local,for number of tillers 5141 A x RBS-23, for number of nodes 5054 A x Inb.1002-1, for internode length 5054 A x RBS-359, for number of leaves 5054 A x Inb.1002-1, for earhead length 5141 A x Rahuri Long Earhead, for earhead girth 5054 A x Inb.1022, for 500-grain weight 5054 A x RBS-347 and for grain yield per plant 5141 A x RBS-359.

The significance of positive s.c.a. effects for grain yield was found to be influenced by significance of positive effects for one or more yield contributing trait. Significance of g.c.a. and s.c.a. effects indicated the importance of both additive and non-additive genetic effects with predominance of latter for all the traits except number of nodes on main shoot.

Considering the <u>per se</u> performance, heterosis percentages and s.c.a. effects, the crosses which out-yielded BK-560-230 the standard check and high yielding parents and could be considered for exploiting hybrid vigour are 5141 A x Restorer-3, 5141 A x RBS-23, 5141 A x Inb.1043, 5054 A x Inb.1002-1, 5054 A x Inb.1022, 5054 A x Inb.337-1, 5054 A x Inb.45, 5054 A x RBS.225 and 5054 A x RBS-243-2.

1. INTRODUCTION

1. INTRODUCTION

Pearl millet is an important cereal crop in Africa, India, Pakistan and some of the middle eastern countries. It is one of the important food crops in India and is grown in the states of Rajasthan, Maharashtra, Gujarat, Punjab, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, and some part of Jammu and Kashmir.

Bajra is adapted to a wide range of ecological conditions and suited particularly to the conditions of moisture stress. The specific features of this crop are high photosynthetic efficiency, efficient absorption and utilization of soil moisture and nutrients, high nutrient value, superior performance under low soil fertility, short growing season and response to subsequent importance in cultural practices which contribute to its popularity.

The area under this crop in the world is about 532.48 lakh hectares and production is 339.48 lakh tonnes. The average per hectare yield is 638 kg. In India, the total area under this crop is 118.10 lakh hectares with the production of 76.24 lakh tonnes during 1983-84. The average per hectare yield in the country is 645 kg(Anonymous,1984).

In Maharashtra, it is grown on an area of 18.12 lakh hectares with a production of 9.08 lakh tonnes of grain. Among the cereals, this crop ranks second and is next to sorghum in respect of area. However per hectare

grain production of this crop is only 500 kg.

The production of hybrid bajra has become practical since the finding of the cytoplasmic male sterility and fertility restoring genes. In U.S.A., Burton (1958) developed the first cytoplasmic male sterile line Tift 23 A at Tifton Georgia. By using this male sterile line with many other restorers a number of hybrids were evolved and released for cultivation on commercial basis. The first hybrid HB-1 (Tift-23-A x Bil 3 B) was released by Punjab Agricultural University, Ludhiana. The male sterile line Tift 23 A was then used in all the subsequent hybrids released for commercial cultivation. As a result, there was tremendous increase in the production of bajra in the country.

However, Tift 23 A was found to be susceptible to downy mildew. The hybrids based on this male sterile line were succumbed heavily to the downy mildew during 1974-75 and 1975-76. As a result there was sudden short fall in grain production, almost to the original level or less than 4 million tonnes. The hybrid production programme thus, faced a serious set-back. The situation prompted the pearl millet breeder to search for downy mildew resistant source of male sterility. The immediate testing of some of the available male sterile lines in the country revealed that none of these could match Tift 23 A in producing potential commercial hybrid (Pokhariyal et al. 1974).

A number of male sterile lines showing resistance to downy mildew were evolved at I.A.R.I., New Delhi, and among them 5141 A and 5054 A were produced through back-cross substitution. Because of their high combining ability for grain yield and high degree of disease resistance, these lines immediately became popular.

Some of the hybrids developed with these male sterile lines are BJ-104 (5141 A x J-104), BD-763 (5141 A x D-763), BK-560-230 (5141 A x K-560-230) and CJ-104 (5054 A x J-104). They have shown a high degree of disease resistance and high stability over a wide range of environment and have been recommended for a large scale cultivation in the country.

A number of inbreds having bold grains, with thicker earheads and good resistance to downy mildew were available in the Bajra Improvement Project. Considering the possibility of getting good hybrids of some of these promising inbreds with 5141 A and 5054 A male sterile lines having good agronomic base and to understand the nature of inheritance of grain yield and its important components, the present investigations were planned with the following objectives :

1. Assessment of hybrid vigour in F_1 combination for characters of economic importance.
2. Estimation of general and specific combining ability effects.

3. To estimate various type of gene effects controlling different characters under study.
4. To estimate heritability and,
5. To isolate promising inbred lines for exploiting hybrid vigour.

2. REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The literature pertaining to the present investigations, has been reviewed under the following sub-headings.

i. Heterosis
ii. Combining ability
iii. Gene action and,
iv. Heritability.

2.1 Heterosis :

The phenomenon of heterosis is of wide spread occurence in the field of biological sciences. The study of heterosis has a direct bearing on the breeding methodology to be employed for varietal improvement.

Shull, (1914) suggested the term 'heterosis' for hybrid vigour; heterozygosity; or heterotic stimulus. Stebbins (1957) has defined heterosis as 'greater adaptedness to human needs; which has been obtained in particular environment, through artificial selection, followed by hybridization. The brief review of the research work done on heterosis in pearl millet has been given below.

2.1.1 Days to flowering :

Burton (1951), Ahluwalia and Patnaik (1963), Murty et al. (1967), Lal and Singh (1968), Phul and Singh (1970), Phul et al. (1973) and Thete (1984) noticed

negative heterosis for days to flowering, in their studies, However, Tyagi et al. (1975) did not observe heterotic effect for this character.

2.1.2 Plant height :

The heterosis for plant height was observed to be significant and positive by Singh and Singh (1974), Burton (1951), Ahluwalia and Patnaik (1963), Murty et al.(1967), Lal and Singh (1968), Burton and Powell (1968), Singh and Lal (1969), Singh (1970), Phul and Singh (1970), Phul et al. (1973), Subramaniam and Rathinam (1980), Sreenivasulu and Sreeramulu (1980), Rao et al. (1983) and Kale (1985).

2.1.3 Number of tillers/plant :

The positive heterosis over mid and better parent for number of tillers was noticed by Singh and Lal (1969), Tiwari (1970), Gupta and Sindhu (1972), and Tyagi et al. (1975). However, Jain et al. (1961), Ahluwalia et al.(1962) and Thete (1984) reported negative heterosis over mid and better parents.

2.1.4 Number of internodes :

Lal and Singh (1968), Singh (1970), Deshpande (1980) and Thete (1984) recorded positive heterosis for number of internodes.

2.1.5 Internode length :

Thete (1984) observed significant positive heterosis for internode length.

2.1.6 Number of leaves :

The heterosis was found to be positive for number of leaves by Burton (1951) and Deshpande (1980). However, Sreenivasulu and Sreeramulu (1980) observed negative heterosis for this character.

2.1.7 Earhead length :

For earhead length, positive heterosis was recorded by Murty et al. (1967), Burton and Powell (1968), Singh (1970), Phul and Singh (1970), Sundarpandian (1973), Phul et al. (1973), Subramaniam and Rathinam (1980), Mukherji et al. (1981), Rao et al. (1983), Thete (1984), and Kale (1985). However, Ahluwalia and Patnaik (1963) reported negative heterosis for this character.

2.1.8 Earhead girth :

In most of the previous studies the heterosis was recorded to be positive for this character (Singh,1970; Sundarpandian, 1973; Phul et al. 1973; Tyagi et al. 1975; Subramaniam and Rathinam, 1980 and Thete 1984). However, there are also reports of negative heterosis (Jain et al. 1961; Ahluwalia et al. 1962 and Kale 1985).

2.1.9 500-grain weight :

The grain weight was found to be increased significantly in F_1 by Phul et al. (1973), Sodani et al. (1978), Subramaniam and Rathinam (1980), Rao et al. (1983)

and Kale (1985). However, Ahluwalia and Patnaik (1963) recorded significant decrease in grain weight.

2.1.10 Grain yield/plant :

Burton (1951), Ahluwalia and Patnaik (1963), Burton and Powell (1968), Singh (1970), Phul et al. (1973), Sundarpandian (1973), Sreenivasulu and Sreeramulu (1980), Subramanium and Rathinam (1980), Mukherji et al. (1981), Rao et al. (1983), Vaidya et al. (1983) and Kale (1985) reported positive heterosis for grain yield per plant. However, in the studies conducted by Jain et al. (1961) and Ahluwalia et al. (1962) heterotic effect was negative.

2.2 Combining ability :

The concept of combining ability is becoming increasingly important in the plant breeding as it provides the mean of understanding the nature of gene action involved in control of yield and other important attributes and thus also provides a basis for adopting a suitable breeding procedure (Sprague and Tatum, 1942). The Line x Tester analysis is a precise approach to estimate the general and specific combining ability effects of parents and at the same time it is useful in estimating various types of gene effects (Kempthorne, 1957).

Sprague and Tatum (1942) defined the term 'general combining ability' as "an average performance of a line in hybrid combination" and the term 'specific

combining ability' is used to designate those classes in which certain combinations do relatively better or worse than that would be expected on the basis of the average performance of the lines involved. Allard (1960) defined the general combining ability as "the average performance of a strain in the series of crosses" and the specific combining ability as "the deviation from the performance predicted on the basis of general combining ability". In general, the combining ability is defined as "the relative ability of a genotype to transmit its desirable performance to its crosses".

Griffing (1956) is of the opinion that g.c.a. involved both additive effects as well as additive interaction. Kempthorne (1957) precisely defined the g.c.a. and s.c.a. variance of half-sib and full-sib in a random mating population as under.

Where;

δ^2 g.c.a. = Cov. (H.S.) and

δ^2 s.c.a. = Cov. (F.S.)-2 Cov. (H.S.)

General combining ability (g.c.a.) is relatively more important in previously unselected material. But, specific combining ability (s.c.a.) seems to have greater importance for the material which is previously selected for general combining ability.

The literature pertaining to the studies on combining ability in pearl millet has been reviewed as given below.

2.2.1 Days to flowering :

The g.c.a. effects were found to be predominant for days to flowering in the studies conducted by Jain et al. (1961),Bains (1971) and Thete (1984). The significance of both g.c.a. and s.c.a. effects for this character was noticed by Gupta and Sindhu (1972), Gupta and Singh (1973), Phul et al. (1973), Tyagi et al. (1975 and 1978), Sreenivasulu and Sreeramulu (1980), Subramaniam and Rathinam (1980), Yadav et al. (1981) and Kale (1985).

2.2.2 Plant height :

Gill et al. (1969), Thete (1984) and Kale (1985) reported significant g.c.a. effects for this character. However, significance of both g.c.a. and s.c.a. effects were reported by Gupta and Sindhu (1972), Gupta and Singh (1973), Badwal (1973), Phul et al. (1973), Tyagi et al. (1978), Sreenivasulu and Sreeramulu (1980) and Subramaniam and Rathinam (1980).

2.2.3 Number of tillers/plant :

For tillers per plant the specific combining ability effects were found to be important in the studies conducted by Kale (1985). However, the importance of both g.c.a. and s.c.a. effect was noticed by Gupta and Sindhu (1972), Phul et al. (1973), Badwal et al. (1973),

Gupta and Singh (1973), Tyagi et al. (1975 and 1978), Sreenivasulu and Sreeramulu (1980), Yadav et al. (1981) and Kapoor et al. (1982).

2.2.4 Number of internodes :

Badwal (1970) noted importance of both g.c.a. and s.c.a. effects for number of internodes. However, Thete (1984) reported importance of s.c.a. effects.

2.2.5 Internode length :

The g.c.a. effects were found to be predominant for the length of internodes in the studies conducted by Sreenivasulu and Sreeramulu (1980) and Thete (1984).

2.2.6 Number of leaves :

For number of leaves, g.c.a. effects were found to be predominant in the studies conducted by Gupta et al. (1970), Chaudhari and Jana (1976) and Sreenivasulu and Sreeramulu (1980). Basavaraju et al. (1980) reported however the importance of s.c.a. effects for this character.

2.2.7 Earhead length :

The g.c.a. effects were found to be predominant for earhead length by Gill et al. (1969), Thete (1984) and Kale (1985). The influence of both g.c.a. and s.c.a. effects was observed by Gupta and Sindhu (1972), Gupta and Singh (1973), Phul et al. (1973), Badwal et al. (1973), Tyagi et al. (1975 and 1978), Sreenivasulu and Sreeramulu (1980), Subramaniam and Rathinam (1980), Mukherji et al.

(1980) and Yadav et al. (1981).

2.2.8 Earhead girth :

Gill et al. (1969), Thete (1984) and Kale (1985) noted preponderance of g.c.a. effects for earhead girth. predominance of both g.c.a. and s.c.a. effects for this character was reported by Gupta and Sindhu (1972), Gupta and Singh (1973), Phul et al. (1973), Tyagi et al.(1975 and 1978), Sreenivasulu and Sreeramulu (1980) and Yadav et al. (1981).

2.2.9 500-grain weight :

Phul et al. (1973), Badwal et al. (1973) and Kale (1985) reported significant g.c.a. effects for this character. However, Gill et al. (1969) and Thete (1984), showed significant s.c.a. effects. The g.c.a. and s.c.a. effects were significant in the studies conducted by Gupta and Singh (1973), Tyagi et al. (1975 and 1978), Sreenivasulu and Sreeramulu (1980) and Subramaniam and Rathinam (1980).

2.2.10 Grain yield/plant :

The predominance of g.c.a. effects for grain yield was recorded by Phul et al. (1973), Badwal et al. (1973), Gill et al. (1974) and Kale (1985). The importance of s.c.a. effects, however, was reported by Gill et al. (1969) and Thete (1984). Gupta et al. (1973), Pokhariyal et al (1974), Tyagi et al. (1975), Tyagi et al. (1978),

Singh et al. (1980), Sreenivasulu and Sreeramulu (1980), Subramaniam and Rathinam (1980) and Yadav et al. (1981) reported the importance of both g.c.a. and s.c.a. effects.

2.3 Gene action :

Estimation of different types of gene effects is very important in exploiting hybrid vigour commercially and development of new synthetic and composite varieties in a cross pollinated crops like pearl millet. The literature on gene action governing various character in pearl millet is reviewed in brief as follows.

2.3.1 Days to flowering :

Days to flowering is under monogenic control was observed by Lal and Singh (1968). The dominance genetic effects were noticed by Gupta et al. (1968) and Hari Har Ram and Singh (1975). Gupta and Nanda (1968) reported overdominance in their study. Singh and Lal (1969) observed duplicate type of epistasis, while Tiwari (1975) noted the complimentary type of gene action.

The additive genetic effects, for this character were reported by Mahadevappa and Ponnaiya (1966), Phul (1969), Bains (1971), Tiwari (1975), Yadav (1977), Sandhu et al. (1980), Sreenivasulu and Sreeramulu (1980) and Thete (1984).

The non-additive genetic effects for days to flowering were reported by Thakare and Murty (1972),

Tyagi et al. (1975), Basavaraju et al. (1980), Singh et al. (1982) and Tyagi et al. (1982).

2.3.2 Plant height :

The additive genetic effects were found to be controlling plant height by Singh and Singh (1941), Yadav (1977), Sreenivasulu and Sreeramulu (1980) and Yadav et al. (1981). However, importance of non-additive genetic effects was observed by Singh et al. (1982) and Thete (1984). The duplicate type of interaction was reported by Singh and Lal (1969), While multiplicative nature of gene action was recorded by Burton (1951). The over-dominance was however, reported by Burton (1969).

2.3.3 Number of tillers/plant :

The duplicate type of epistasis controlling this character was noted by Singh and Lal (1969). However, over dominance and dominance genetic effects were recorded by Singh et al. (1979) and Subramaniam and Rathinam (1980), respectively.

Murty et al. (1967), Badwal et al. (1973), Tiwari (1974), Tyagi et al. (1975), Shrinivasan et al. (1978) and Thete (1984) reported the greater influence of the additive genetic effects. Gill et al. (1974), Yadav (1977), Sodani et al.(1981), Singh et al. (1982) and Kapoor et al (1982) observed the influence of the non-additive genetic effects.

2.3.4 Number of internodes :

Thete (1984) reported predominance of non-additive genetic effects for number of internodes.

2.3.5 Internode length :

Deshpande (1980) and Sreenivasulu and Sreeramulu (1980) observed length of internodes to be mostly governed by non-additive genetic effects. However, Thete (1984) showed importance of additive genetic effects for internode length.

2.3.6 Number of leaves :

Chaudhary and Jana (1976) reported that additive genetic effects are more important for number of leaves. Predominance of non-additive genetic effects, however,were reported by Basavaraju et al. (1980).

2.3.7 Earhead length :

Burton (1951) reported that the earhead length was under the monogenic control. The importance of additive genetic effects for this character was reported by Phul and Singh (1970), Gupta and Singh (1971), Sandhu et al. (1980), Sodani et al. (1981) and Thete (1984). However, non-additive genetic effects were recorded by Phul and Singh (1970), Gill et al. (1974), Mukherji et al. (1981) and Gupta and Phul (1982).

2.3.8 Earhead girth :

Jain et al. (1961) observed the additive with partial dominance type of genetic effects influencing this character. However, Tyagi et al. (1978), Sandhu (1980), and Thete (1984) reported the predominance of the additive genetic effects.

The non-additive genetic effects were noted by Badwal (1973), Gupta et al. (1974), Tyagi et al. (1975), Mukherji et al. (1981) and Gupta and Phul (1982).

2.3.9 500-grain weight :

The influence of the additive genetic effects for this character was reported by Yadav (1977), Srinivasan et al. (1978) and Yadav et al (1981).

Tyagi et al. (1975), Basavaraju et al. (1980), Sodani et al. (1981) and Thete (1984) found that the grain weight was controlled by the non-additive genetic effects.

Mahadevappa and Ponnaiya (1966) reported the non-allelic interaction for this trait. While, Singh and Lal (1970) noticed the duplicate type of epistasis.

2.3.10 Grain yield/plant :

Singh and Singh (1941), Mahadevappa (1968), Yadav (1977), Sreenivasulu and Sreeramulu (1980), Sodani et al. (1981) and Singh et al. (1982) reported the importance of additive genetic effects for grain yield per plant.

However, Badwal et al. (1973), Mukherji et al. (1981) and Thete (1984) observed that the grain yield was under the influence of the non-additive genetic effects.

2.4 Heritability :

Heritability is an useful measure of considering the ratio of genetic variance to the total phenotypic variance. Lush (1945) has defined the heritability as "the portion of observed variance for which difference in heredity is responsible". According to Allard (1960), heritability specifies "the proportion of total variability that is due to genetic causes of the ratio of the genetic variance to the total variance".

Heritability in a narrow sense is the ratio of "additive genetic variance to the total phenotypic variance" and measures the portion of the total variation which can be utilized for the improvement of a given population with respect to that trait, by selection.

Heritability in a broad sense, is the ratio of the total genotypic variance to the total phenotypic variance and it provides a measure of the overall importance of heritability determination of a trait.

Robinson (1966) classified the heritability estimates in the cultivated plants in three categories as follows.

Category	Range
Low	5-10
Medium	10-30
High	30-60

To the plant breeder, heritability estimates are important because they indicate the expected performance of progeny based on the performance of parents. Therefore improvement of many agriculturally valuable traits depend upon accurate evaluation of the heritability of the traits.

The literature on the previous studies on heritability in pearl millet has been reviewed as given below.

2.4.1 Days to flowering :

Lal and Singh (1968), Phul (1969), Gupta and Sindhu (1972), Gupta and Dhillon (1974), Chaudhary et al. (1980), and Sodani et al. (1981) reported high values of heritability for days to flowering. The heritability values were moderate to high in the studies conducted by Sandhu et al. (1980), Phul et al. (1980) and Kale (1985). However, Burton (1951) observed lower values of the estimates of heritability for this trait.

2.4.2 Plant height :

This character was found to be highly heritable by Phul (1969), Tiwari (1971), Gupta and Sindhu (1972) and

Chaudhary et al. (1980). The heritability for this trait was found to be moderate by Gupta and Dhillon (1974), Sharma et al. (1978), Phul et al. (1980), while lower values were reported by Mukherji et al. (1980).

2.4.3 Number of tillers/plant :

The heritability values for tillers per plant were found to be high in the studies conducted by Tiwari (1971) and Singh et al. (1983), while Mukherji et al.(1980) reported lower such values.

2.4.4 Number of internodes :

Deshpande (1980) reported low heritability value for number of internodes. However, Thete (1984) reported moderate heritability estimates for this trait.

2.4.5 Internode length :

High heritability estimates were observed for this character by Thete (1984).

2.4.6 Number of leaves :

Number of leaves were reported to be highly heritable by Tiwari (1971) and Chaudhari and Jana (1976).

2.4.7 Earhead length :

This character was found to be highly heritable by Jain et al. (1961), Lal and Singh (1968), Nanda and Phul (1974), Sodani et al. (1981) and Singh et al. (1983).

Sharma et al. (1978) and Sandhu et al. (1980) reported moderate to high heritability, while Mukherji et al. (1980) observed lower values of the estimates of heritability.

2.4.8 Earhead girth :

Earhead girth was reported to be highly heritable by Jain et al. (1961), Gupta and Dhillon (1974), Nanda and Phul (1974) and Mukherji et al. (1982). Moderate to high value of heritability were recorded by Sharma et al. (1978), while Chaudhary et al. (1980) and Mukherji et al. (1980) reported the lower values.

2.4.9 500-grain weight :

Lal and Singh (1968), Singh and Lal (1970), Hirachand and Ahmad (1976) reported high heritability for grain weight, while, lower values of the estimates of heritability for this trait was reported by Shinde (1980).

2.4.10 Grain yield/plant :

The grain yield was reported to be highly heritable by Gupta and Dhillon (1974), Nanda and Phul (1974) Appadurai and Subramaniam (1975), Chaudhary et al. (1980) and Singh et al. (1983). This character however, was found to be moderately heritable by Shinde (1980) while Nanda and Phul (1974) and Mukherji et al. (1980) noted lower values of the heritability.

3. MATERIAL AND METHODS

3. MATERIAL AND METHODS

The investigations entitled "Studies on heterosis and combining ability in pearl millet(Pennisetum americanum (L.) Leeke)" were conducted at the Mahatma Phule Agricultural University, Rahuri during the period from 1983-85. The details of material used and the statistical procedures followed during the course are described below.

3.1 Material :

The present study was undertaken on Line x Tester set of 60 F_1 hybrids involving two male sterile lines and thirty newly developed inbreads. This material was selected from different inbred stocks available in the Bajra Improvement Project, Mahatma Phule Agricultural University, Rahuri. Genotypes possessing diversity for yield and other components were selected.

The parents included in the studies, with their pedigree and salient features are as given below.

3.1.1 Females :

1. 5141 A :

This male sterile line was developed at I.A.R.I., New Delhi by back-crossing 1587 (selection from Baroda Bajri No.4) as a doner parent to Tift 23 A. It is early, and grows 115 to 125 cm tall. The length of earhead

measures 19 to 22 cm. The number of tillers per plant are 3 to 4. The leaf sheath and nodes are covered with dense hair.

2. 5054 A :

This male sterile line was also developed at I.A.R.I., New Delhi, by back crossing Kano-2457, a Nigerian origin, with Tift 23 A. This line is earlier than the male sterile line 5141 A. The tiller number of this male sterile line ranges from 3 to 7 and earheads are tappering and measures 17 to 21 cm in length. The leaf sheath is covered with sparse hairs and hairs are also present on the nodes. In the late stage of growth, the leaf and stem are light purple in colour.

3.1.2 Males :

In all 30 inbred lines based on yield performance, uniformity and other desirable characters were selected for studying their combining abilities with two different promising male sterile lines. These inbred lines used as males in the present studies were developed at the Bajra Improvement Project, Rahuri.

1. Restorer-3 :

This is the early maturing inbred which grows 120 to 130 cm and it flowers within 44 days. It produces 2 to 3 tillers per plant and the earheads are 16 to 17 cm in length. The 500-grain weight is 4 g.

2. Inb.1002-1 :

This inbred grows 130 to 140 cm and flowers within 46 days. The tillers are 3 to 4 and earheads are 21 to 22 cm long. The 500-grain weight is 5 g.

3. Inb.1002-2 :

The plant height of this inbred is 138 cm and tillers are 2 to 3 per plant. It flowers within 46 days and the earheads are 25 to 26 cm long. The 500-grain weight is 5 g.

4. Inb.1008 :

This is the medium tall inbred having 3 to 4 tillers per plant. The earhead length is 28 to 29 cm and 500-grain weight is 5 g.

5. Inb.1019 :

This inbred grows 155 to 165 cm and produces 1 to 2 tillers and flowers within 48 days. The earhead length is 20 to 21 cm and 500-grain weight is 4 g.

6. Inb.1022 :

The inbred is medium tall (168 cm) and produces 2 to 3 tillers per plant. The earhead length is 19 to 20 cm and 500-grain weight is 3 g.

7. Inb.1026 :

The plant height of the inbred is 175 to 180 cm and produces 1 to 2 tillers per plant. It flowers within

49 days, has earhead length 19 to 20 cm and the weight of the 500-grain is 4 g.

8. Inb.142-2 :

This is the early maturing inbred which flowers within 44 days and produces 2 to 3 tillers per plant. The plant height is 167 cm and earheads are 25 to 26 cm long. The 500-grain weight is 5 g.

9. Inb.337-1 :

This inbred grows 150 to 155 cm tall and the tillers are 2 to 3 per plant. It flowers within 46 days and has 23 to 24 cm long earheads. The 500-grain weight is 6 g.

10. Inb.1036 :

The plant height of the inbred is 155 to 160 cm producing 1 to 2 tillers per plant and has 24 to 25 cm long earheads. The weight of the 500-grain is 5 g.

11. Inb.1037 :

The inbred is medium tall (160 cm) and flowers within 45 days. It produces 2 to 3 tillers per plant. The earhead length measures 24 to 25 cm and the 500-grain weight is 4 g.

12. Inb.1043 :

The plant height of the inbred is 150 to 155 cm and produces 3 to 4 tillers per plant. It flowers within

47 days and the earhead length is 23 to 24 cm and has very bold grains (5g/500-grain).

13. Rahuri long earhead :

This is very tall inbred (215 to 220 cm) and produces 1 to 2 tillers per plant. It flowers within 48 days and earheads are 50 cm long with bold grain (5g/500-grain).

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14. Sel. J-104 :

This inbred flowers within 47 days and grows 150 to 160 cm tall and the tillers per plant are 2 to 3. Earheads measures 21 to 22 cm long and the 500-grain weight is 4 g.

15. Inb.45 :

It is early inbred and grows 160 to 165 cm tall. It produces 2 to 3 tillers per plant and has earheads measuring 23 cm. The weight of 500-grain is 4 g.

16. Inb.483 :

The plant height of this inbred is 160 cm and it flowers within 48 days. The tillers produced by the inbred are 2 to 3 per plant. The earheads measures 25 cm and has very bold grain (5g/500-grain).

17. Inb.492 :

This inbred is very short (97 cm) and flowers within 47 days. It produces 2 to 3 tillers per plant

T. 1599

23. RBS-28 :

The plant height of the inbred is 148 cm and it flowers within 47 days. The tillers are 2 to 3 per plant and earhead length is 16 cm. The weight of the 500-grain is 4 g.

24. Inb.492-1 :

This inbred grows 140 to 145 cm tall and the tillers are 3 to 4 per plant. It flowers within 45 days and has 18 to 19 cm long earheads. The 500-grain weight is 4 g.

25. RBS-225 :

The plant height of this inbred is 145 cm and it flowers within 46 days. The tillers are 2 to 3 per plant and earhead length is 22 cm. The grains are very bold (6g/500-grains).

26. RBS-240 :

It is an early inbred and grows 157 cm tall. It produces 2 to 3 tillers per plant and has earheads measuring 21 cm. The grains are very bold (5g/500-grains).

27. RBS-243-2 :

This is the early maturing inbred which grows 148 cm tall. The tillers are 1 to 2 and the earheads are 18 to 19 cm long. The 500-grain weight is 3 g.

28. RBS-347 :

The height of the inbred is 150 to 160 cm and it flowers within 47 days. The per plant tillers are 2 to 3 and the earhead length measures 22 to 23 cm. The 500-grain weight is 6 g (very bold).

29. RBS-359 :

This is the early inbred which flowers within 40 days and grows 160 cm tall. The tillers are 2 to 3 and the earheads are 18 to 19 cm long. The 500-grain weight is 5 g.

30. RBS-431-6 :

This is the medium tall inbred and flowers within 46 days. It produces 4 to 5 tillers per plant and the earheads are 24 cm long. The 500-grain weight is 5 g.

3.2 Methods :

Total 60 crosses were effected. The crossed seed was obtained during the summer season of 1983-84. The females were maintained by crossing A and B lines of respective male sterile lines. The male parents were selfed by using the butter paper bags. The selfed seed was used to grow the male parents in the experiment during kharif (1984-85).

3.3 Experimental design :

3.3.1 Preparation of land :

A uniform piece of land was selected for laying out the trial. The land was prepared by ploughing and harrowing, so as to have fine tilth.

3.3.2 Layout :

The experiment was laid out in randomised block design with two replications. The total number of treatments were 92 comprising of 60 F_1s, 2 female parents and 30 male parents. One standard check BK-560-230 was also included. Each entry was represented by two rows of 5.00 meter length with total 30 plants. The distance between two rows was 45 cm and plant to plant in each row was 15 cm. A distance of one meter was kept in between replications to serve as a path.

3.3.3 Sowing :

The final experiment, comprising of 92 treatments and one standard check with two replications was sown on July 10, 1984 by placing two seeds per hill. On July 24, 1984 thinning was carried out with a view to keep only one healthy plant per hill and maintaining the required plant population of 30 per treatment. The fertilizer dose, irrigations, weeding etc. were done as per schedule and all the after cares were followed.

3.4 Recording the observations :

The observation on various characters were recorded on five randomly selected plants (excluding border plants) from each entry in each replication. The plants were labelled for this purpose at the time of flowering (40 to 50 days after sowing).

i. Days to flowering :

Number of days required for flowering were calculated as the days required from sowing to flowering.

ii. Plant height (cm) :

The plant height was recorded from the ground level to the tip of the main earhead (at the time of complete maturity of the crop).

iii. Number of tillers/plant :

Total number of ear-bearing tillers of the observation plants, from each replication, were recorded at maturity and averages were worked out.

iv. Number of internodes :

Number of internodes on main shoot were recorded at harvesting.

v. Internode length (cm) :

At the centre of the main shoot, the length of internode was measured at maturity.

vi. Number of leaves :

Number of leaves on main shoot were counted at maturity.

vii. Earhead length :

The length of earhead of main shoot was measured from the peduncle in centimeters.

viii. Earhead girth :

The diameter of the middle most portion of main ear was recorded and it was multiplied by 3.14 (22/7) to get the girth of earhead.

ix. 500-grain weight (g) :

Five hundred grain from each of the five plants were counted randomly and weighed.

x. Grain yield/plant (g) :

The grain yield for each of the five individual plants was recorded by harvesting and threshing the individual plant separately and the average calculated represents the yield per plant.

3.5 Statistical analysis :

The data collected for each character on individual plant basis for five observational plants were averaged and the mean values thus obtained were used for the statistical analysis.

3.5.1 Analysis of variance :

The first step in the line x tester analysis is to perform analysis of variance for Randomised Block Design (R.B.D.) to test the significance of difference among genotypes including crosses and parents.

The analysis of variance for all metric traits under study was carried out as follows.

Sr. No.	Source of	D.F.	S.S.	M.S.S.	F value Calculated	F value Tab.
1.	Replications	(r-1)	R.S.S.	$\frac{R.S.S.}{(r-1)}$	$\frac{R.M.S.S.}{E.M.S.S.}$	-
2.	Treatments	(n-1)	T.S.S.	$\frac{T.S.S.}{(n-1)}$	$\frac{T.M.S.S.}{E.M.S.S.}$	-
3.	Error	(r-1)(n-1)	E.S.S.	$\frac{E.S.S.}{(r-1)(n-1)}$	-	-
	Total	(rn-1)	S.S.			

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

2. Total S.S. = Total sum of square of all the observations - C.F.

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

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

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

Where,

r = Number of replications.

n = Number of treatments.

G.T. = Grand total.

S.S. = Sum of square.

C.F. = Correction factor.

R.S.S. = Replication sum of squares.

T.S.S. = Treatment sum of squares

E.S.S. = Error sum of squares.

M.S.S. = Mean sum of squares.

The metric traits which appeared to be significant were further subjected to line x tester analysis.

In order to test the significance of crosses and parents individually; further partitioning of treatment S.S. was done for males, females, males Vs females,hybrids and hybrids Vs parents.

Sr. No.	Source of	D.F.	Mean sum of square	F value Calculated	F value Tab.
1.	Replications	(r-1)			
2.	Treatments	(n-1)			
3.	Parents	(p-1)			
4.	Hybrids	(h-1)			
5.	Parents Vs hybrids	(1)			
6.	Males	(m-1)			
7.	Females	(f-1)			
8.	Males Vs females	(1)			
9.	Error	(r-1)(m-1)			
	Total				

Where,

r = Number of replications.

n = Number of treatments.

p = Number of parents.

h = Number of hybrids.

m = Number of males.

f = Number of females.

3.5.2 Estimation of values of heterosis over superior and mid parental values :

The values of the estimates of the heterosis were estimated as given below.

1. Per cent heterosis over SP = $\frac{\bar{F}_1 - \overline{SP}}{\overline{SP}} \times 100$

Where,

$\bar{F}_1$ = Mean of F_1 hybrid.

$\overline{SP}$ = Mean of the superior parent of that particular cross.

2. Per cent heterosis over MP = $\frac{\bar{F}_1 - \overline{MP}}{\overline{MP}} \times 100$

Where,

$\bar{F}_1$ = Mean of F_1 hybrid.

$\overline{MP}$ = Mean of the two parents of that particular F_1 cross

= $\frac{\bar{P}_1 + \bar{P}_2}{2}$

The heterosis was tested by the least significant difference as below.

$$\text{LSD for SP} = \sqrt{\frac{2\ me}{r}} \times t \text{ at 5\% and 1\% level of significance for error d.f.}$$

$$\text{LSD for MP} = \sqrt{\frac{3\ me}{2r}} \times t \text{ at 5\% and 1\% level of significance for error d.f.}$$

Where,

me = Error mean sum of squares

r = Number of replications.

3.5.3 Analysis of variance for combining ability :

Combining ability analysis for 60 hybrids was based on the procedure developed by Kempthorne (1957); related to Design-II Comstock and Robinson (1952). The sum of square due to different factors was partitioned as shown below.

Sr. No.	Source	D.F.	S.S.	M.S.S.	Expected M.S.
1.	Replications	(r-1)	$\sum \frac{X^2_{..k}}{mf} - \frac{X^2_{...}}{mfr}$	-	-
2.	Hybrids	(mf-1)	$\sum \frac{X^2(ij)..}{r} - \frac{X^2_{...}}{mfr}$		
3.	i)Males	(m-1)	$\sum \frac{X^2_{i..}}{fr} - \frac{X^2_{...}}{mfr}$	M_1	$\sigma^2 + r[\text{Cov.}(\text{F.S.}) - 2\ \text{Cov.}(\text{H.S.})] + [fr.\ \text{Cov.}(\text{H.S.})]$
	ii)Females	(f-1)	$\sum \frac{X^2_{.j.}}{mr} - \frac{X^2_{...}}{mfr}$	M_2	$\sigma^2 + r[\text{Cov.}(\text{F.S.}) - 2\ \text{Cov.}(\text{H.S.})] + [mr.\ \text{Cov.}(\text{H.S.})]$

Continued..

Sr. No.	Source	D.F.	S.S.	M.S.S.	Expected M.S.
iii)	Males x females	$(m-1)(f-1)$	$\sum \frac{X^2(ij)..}{r} - \frac{Xi^2..}{fr}$	M_3	$\delta^2 + r$ [Cov. (F.S.) -2 Cov. (H.S.)]
iv)	Error	$(r-1)(mf-1)$	By substraction	M_4	
	Total	$(mfr-1)$	$\sum X^2(ij)K - \frac{X^2...}{mfr}$		

Where,

m = Number of male parents.

f = Number of female parents.

r = Number of replications.

X... = Grand total.

X..k = Sum of the k^{th} replication.

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

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

Xi.. = Sum of the i^{th} male parents over all females and replications.

Xijk = $(ij)^{th}$ observation in k^{th} replication.

M_1 = Mean sum of squares of males.

M_2 = Mean sum of squares of females.

M_3 = Mean sum of squares of males x females interaction.

M_4 = Error mean sum of squares.

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

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

$$\text{Cov.(F.S.)} = \frac{(M_1 - M_4) + (M_2 - M_4) + (M_3 - M_4)}{3r} + \frac{6r\ \text{Cov.(H.S.)} - r(M+f)\ \text{Cov.(H.S.)}}{3r}$$

After estimating the Cov. (H.S.) and Cov.(F.S.) by above equations; variance due to general combining ability (δ^2g.c.a.) and variance due to specific combining ability (δ^2s.c.a.) were estimated as.

δ^2 g.c.a. = Cov. (H.S.)

here breeding coefficient = 1

δ^2 s.c.a. = [Cov.(F.S.)-2 Cov.(H.S.)]

3.5.4 Percentage contribution of males; females; males x females interaction to S.S. for hybrids :

The percentage contribution of males; females and males x females to the hybrid were calculated as.

1. Percentage contribution of males. = $\frac{\text{Male S.S.}}{\text{Hybrid S.S.}} \times 100$
2. Percentage contribution of females. = $\frac{\text{Female S.S.}}{\text{Hybrid S.S.}} \times 100$
3. Percentage contribution of males x females. = $\frac{\text{Male x female S.S.}}{\text{Hybrid S.S.}} \times 100$

3.5.5 Estimation of general and specific combining ability effects :

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

$$Xijk = U + gi + gj + Sij + eijk$$

Where;

U = Population mean.

gi = g.c.a. effect of the i^{th} male parent.

gj = g.c.a. effect of j^{th} female parent.

Sij = s.c.a. effect of the $(ij)^{th}$ combination.

eijk = Error associated with the observation Xijk.

i = Number of male parents 1,2,....m.

j = Number of female parents, 1,2,....f.

k = Number of replications, 1,2,3,....r.

The individual effects were estimated as follows.

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

Where,

X... = Grand total.

b) $gi = \frac{Xi..}{fr} - \frac{X...}{mfr}$

Where,

Xi.. = Total of i^{th} male parent over all female and replications.

c) $gj = \frac{X.j.}{mr} - \frac{X...}{mfr}$

Where;

Xij. = Total of j^{th} female parent over all male parents and replications.

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

Where,

Xij = $(ij)^{th}$ combination total over all replications.

m = Number of male parents.

f = Number of female parents.

r = Number of replications.

3.5.6 Calculation of S.E. of difference between general and specific combining ability effects of two parents :

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

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

ii) $\text{Var.}(gj_1-gj_2)\text{females} = \frac{2(\text{Error variance})}{rm}$

$\text{S.E.}(gj_1-gj_2)\text{females} = \sqrt{\text{Var.}(gj_1-gj_2)\text{females}}$

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

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

1. S.E. (g.c.a. for lines) $= \sqrt{me/rt}$

2. S.E. (g.c.a. for testers) $= \sqrt{me/rl}$

3. S.E. (g.c.a. effects) $= \sqrt{me/r}$

3.5.7 Gene action :

The following formula was used to know the gene action.

Gene action = $\hat{\sigma}^2$ g.c.a./$\hat{\sigma}^2$ s.c.a.

The ratio > 1 indicate the additive gene action and < 1 indicate non-additive gene action.

3.5.8 Heritability :

Heritability in narrow sense was computed from the variance components. The heritability was calculated by the following formula of Lush (1945) :

$$h^2 = \frac{\sigma^2_g}{\sigma^2_g + \sigma^2 s + \sigma^2_e} \text{ (in narrow sense)}$$

Where,

σ^2_g = Estimated variance due to g.c.a.

σ^2_s = Estimated variance due to s.c.a.

σ^2_e = Error mean sum of squares.

4. RESULTS

4. RESULTS

The results of the present investigations after analysis are presented under following headings.

i) Means and variance

ii) Heterosis

iii) Combining ability

iv) Gene action and,

v) Heritability

4.1 Means and analysis of variance :

The mean performance of parents and hybrids and analysis of variance for different characters are presented in Table 1 and 2, respectively and are described in brief as given below.

4.1.1 Days to flowering :

From the data presented in Table 1, it is observed that 'F' test for days to flowering was highly significant.

Between females, 5054 A was early and flowered in 42 days. 5141 A took 43.50 days to flower.

Among the male parents, RBS-359 was the earliest which flowered in 40 days. The male parents Inb.142-2 and RBS-243-2 flowered in 43.50 days, while Inb.1026 was late and took 49 days to flower. The remaining males, flowered between 44 to 48 days.

Table 1. Mean performance of different characters in parents and hybrids.

Parents/hybrids	Characters									
	Days to flowering	Plant height (cm)	Number of tillers/ plant	Number of inter nodes	Inter node length (cm)	Number of leaves	Earhead length (cm)	Earhead girth (cm)	500-grain weight (g)	Grain yield/ plant (g)
1	2	3	4	5	6	7	8	9	10	11
Females										
5141 A	43.50	116.50	4.00	5.70	14.40	5.60	18.10	6.30	3.25	31.00
5054 A	42.00	118.80	5.20	5.70	15.10	5.75	20.45	6.25	2.44	21.40
Males										
Restorer-3	44.00	125.90	3.00	6.90	15.30	6.50	16.20	7.15	3.90	23.50
Inb.1002-1	45.50	132.60	3.10	5.50	15.50	5.50	21.50	9.60	4.50	19.50
Inb.1002-2	45.50	137.40	2.20	5.00	15.50	5.10	25.80	8.60	4.75	18.00
Inb.1008	47.00	157.30	3.40	5.30	16.90	6.30	28.90	8.05	4.30	58.50
Inb.1019	48.00	158.70	1.20	6.40	17.10	6.40	20.50	9.93	3.40	40.50
Inb.1022	47.50	167.80	2.70	7.30	14.60	7.30	19.40	9.75	2.55	23.50
Inb.1026	49.00	178.00	1.80	7.40	14.80	7.90	19.80	9.25	4.00	36.50
Inb.142-2	43.50	166.90	2.40	6.40	16.80	5.30	25.70	9.15	4.60	50.50
Inb.337-1	46.00	151.30	2.20	6.50	15.20	5.70	23.40	7.70	5.10	44.50
Inb.1036	46.00	157.90	1.70	6.30	17.70	5.90	24.70	8.75	4.50	36.00

Continued.....

Table 1. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Inb.1037	45.50	159.60	2.80	6.10	18.60	5.40	24.00	7.55	3.10	30.00
Inb.1043	46.50	153.10	3.10	6.80	16.10	5.00	23.20	8.00	4.90	54.00
Rahuri Long Earhead	47.50	217.90	1.30	6.90	19.30	5.80	49.40	7.40	4.60	36.00
Sel.J-104	47.00	154.80	2.80	5.90	18.80	6.60	21.20	8.00	3.90	39.50
Inb.45	45.50	161.00	2.70	6.80	20.90	6.40	22.85	7.15	3.75	33.50
Inb.483	47.50	160.00	2.60	7.10	17.50	6.40	24.45	7.10	4.95	49.00
Inb.492	47.00	96.20	2.50	5.20	12.90	6.90	33.10	6.90	4.50	23.50
Inb.564	45.50	178.70	3.00	5.70	17.30	6.10	24.40	9.50	3.75	43.00
RHRB-28-2	46.00	195.50	2.20	7.10	20.30	6.40	21.50	8.80	3.25	66.00
RHRB-28-4	45.00	186.00	2.30	7.00	18.70	5.60	19.10	9.50	4.15	59.00
Manmad Local	45.50	169.30	2.10	6.40	19.40	6.20	19.10	7.05	5.10	19.50
RBS-23	44.50	84.50	2.30	5.50	11.70	7.90	21.30	7.28	2.95	17.50
RBS-28	46.50	148.40	2.80	7.40	15.90	8.50	15.60	6.38	3.40	40.00
Inb.492-1	44.50	140.70	3.30	6.20	16.40	5.10	18.40	7.03	3.75	39.50
RBS-225	46.00	145.00	2.30	6.80	15.70	5.20	21.50	7.93	5.80	36.00
RBS-240	45.00	156.20	2.30	6.60	18.40	4.60	20.60	7.15	4.45	36.00
RBS-243-2	43.50	147.70	2.00	6.50	16.90	5.10	18.50	6.78	3.00	20.50

Continued.....

Table 1. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
RBS-347	46.50	154.60	2.40	6.50	17.20	5.40	22.40	6.65	5.50	29.00
RBS-359	40.00	159.30	2.20	7.00	18.50	8.40	18.60	6.93	4.10	41.00
RBS-431-6	45.50	165.10	4.10	6.70	17.70	5.90	23.20	6.68	5.00	34.00
Hybrids										
5141 A x Restorer-3	48.00	163.80	4.40	6.40	18.50	7.20	26.00	7.25	4.00	81.10
x Inb.1002-1	41.50	142.70	4.30	5.60	19.80	5.80	25.20	7.30	3.75	55.50
x Inb.1002-2	41.50	134.40	2.90	5.80	15.30	6.00	23.80	8.30	4.25	39.50
x Inb.1008	41.00	156.00	3.30	5.90	19.30	6.10	25.10	7.40	5.00	50.50
x Inb.1019	46.00	161.80	3.20	6.40	18.70	6.90	25.20	8.20	3.90	55.50
x Inb.1022	46.00	167.60	3.00	6.90	19.40	7.80	21.90	7.50	3.25	66.50
x Inb.1026	43.00	127.00	3.25	5.60	18.75	5.70	21.80	6.75	3.50	34.00
x Inb.142-2	42.50	160.00	3.40	6.50	17.40	7.30	23.10	7.70	3.40	68.00
x Inb.337-1	46.00	152.30	3.90	6.30	17.60	7.40	22.90	7.15	3.35	53.50
x Inb.1036	41.50	136.80	4.10	6.20	19.00	6.80	22.50	6.60	4.00	48.00
x Inb.1037	41.00	142.50	3.80	6.60	18.90	6.30	23.10	6.65	3.60	33.00
x Inb.1043	45.00	163.50	3.70	7.20	20.10	6.80	24.30	7.80	3.70	75.00
x Rahuri Long Earhead	45.50	178.90	3.05	7.00	18.90	6.90	40.50	6.80	3.40	43.00
x Sel.J-104	42.50	138.00	3.50	6.40	18.60	6.00	23.10	6.80	3.50	43.50

Continued.....

Table 1. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5141A x Inb.45	46.00	162.00	3.00	6.80	19.60	6.40	27.60	7.40	3.90	55.00
x Inb.483	43.00	150.30	3.10	6.80	18.90	7.00	21.80	7.55	3.95	47.50
x Inb.492	49.50	172.00	2.60	7.10	18.80	7.50	26.00	7.20	3.45	41.00
x Inb.564	43.00	138.50	3.10	6.10	18.40	6.20	24.80	7.40	3.40	50.50
x RHRB-28-2	43.50	163.00	4.50	6.30	21.10	6.90	23.50	7.10	4.00	59.50
x RHRB-28-4	42.50	153.90	4.10	6.40	19.60	6.60	24.00	7.80	3.44	65.50
x Manmad Local	43.00	181.50	2.60	6.70	23.90	6.90	22.50	7.05	5.10	48.50
x RBS-23	48.00	175.60	4.30	7.50	19.60	7.70	25.40	7.15	3.50	91.50
x RBS-28	47.00	159.10	4.30	6.60	19.70	7.30	21.80	6.35	3.50	44.00
x Inb.492-1	43.50	160.60	2.40	6.50	16.80	7.10	26.90	7.15	3.60	57.00
x RBS-225	43.00	164.20	3.90	6.10	19.40	6.60	26.40	8.10	4.25	71.00
x RBS-240	43.50	160.40	2.90	6.00	18.50	6.50	22.50	7.25	3.65	52.00
x RBS-243-2	42.00	157.50	2.90	6.40	17.90	6.80	20.30	7.05	3.55	62.50
x RBS-347	47.50	152.10	3.60	6.30	18.50	6.90	25.00	6.60	3.50	52.00
x RBS-359	42.00	149.90	3.90	6.50	17.10	6.60	22.60	6.75	3.40	64.60
x RBS-431-6	41.50	139.20	3.50	5.40	19.80	6.00	22.00	6.85	4.25	37.00
5054A x Restorer-3	44.00	161.30	3.90	6.10	15.60	6.90	21.00	6.70	3.40	68.00

Continued.....

Table 1. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5054 A x Inb.1002-1	44.00	159.30	4.30	7.00	18.60	7.60	24.90	7.65	3.60	72.50
x Inb.1002-2	44.50	142.10	2.90	6.10	18.40	6.70	24.70	8.50	4.55	32.50
x Inb.1008	44.50	142.10	4.00	6.30	18.00	6.80	24.00	8.05	5.00	47.50
x Inb.1019	47.00	160.30	3.40	5.90	20.00	6.50	28.30	7.60	4.10	57.50
x Inb.1022	46.50	177.10	3.30	7.40	20.30	7.90	22.40	8.70	4.45	84.00
x Inb.1026	45.00	137.80	3.60	6.20	19.00	6.30	23.30	7.15	3.35	49.00
x Inb.142-2	43.50	168.40	3.80	6.30	18.80	6.50	23.00	6.70	3.40	74.50
x Inb.337-1	44.00	178.20	3.20	7.10	18.40	7.40	24.70	7.15	3.95	78.50
x Inb.1036	46.50	138.60	3.40	5.90	19.50	6.10	21.20	6.80	2.75	45.50
x Inb.1037	47.00	144.80	4.40	5.80	19.70	6.00	22.70	6.60	2.25	52.00
x Inb.1043	48.00	154.90	4.90	5.80	21.10	6.10	23.70	7.10	3.20	62.51
x Rahuri Long Earhead	48.00	171.90	2.90	6.60	18.50	6.90	34.00	6.90	3.35	55.00
x Sel.J-104	41.50	151.50	4.70	5.50	18.80	6.40	24.20	7.05	3.95	57.00
x Inb.45	47.50	161.90	3.50	6.00	19.10	6.60	24.60	6.95	3.25	66.50
x Inb.483	45.50	149.40	4.10	5.70	17.05	7.30	23.40	7.90	4.00	44.00
x Inb.492	47.00	145.10	3.70	5.80	17.40	7.80	23.40	7.20	3.50	51.85
x Inb.564	44.00	143.60	3.60	6.60	16.70	6.40	21.80	7.20	3.50	50.50

Continued.....

Table 1. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5054 A x RHRB-28-2	43.50	157.10	4.50	6.60	19.80	7.10	21.80	6.90	2.90	57.50
x RHRB-28-4	44.00	148.00	4.10	6.10	17.40	6.30	22.40	7.25	3.60	42.50
x Manmad Local	47.00	154.60	4.10	6.20	20.50	6.70	21.10	7.05	2.60	54.50
x RBS-23	48.00	168.00	3.00	6.30	21.20	6.60	26.90	7.40	3.90	69.50
x RBS-28	47.00	146.20	4.30	6.40	19.80	7.00	19.70	6.40	4.45	57.50
x Inb.492-1	45.50	166.40	2.80	6.20	17.60	7.50	25.40	6.90	3.45	51.00
x RBS-225	48.00	157.90	4.10	6.10	19.20	7.10	24.30	7.75	4.25	84.00
x RBS-240	48.00	163.90	4.70	6.40	20.30	7.30	23.80	7.05	3.50	65.00
x RBS-243-2	44.00	165.20	3.90	6.00	20.00	7.40	20.40	6.50	3.50	71.00
x RBS-347	43.50	158.60	4.30	6.40	20.60	7.00	21.20	6.70	5.00	42.50
x RBS-359	45.00	177.40	3.25	6.75	21.65	8.00	22.20	7.10	3.05	39.50
x RBS-431-6	41.50	152.50	3.25	6.00	18.90	6.00	19.80	6.50	3.95	44.50
Check BK-560	44.50	154.50	2.50	6.60	21.00	7.00	21.90	6.70	4.00	55.00
'F' test	----------Highly significant----------									
S.E. ±	0.79	3.94	0.41	0.44	0.89	0.35	0.84	0.29	0.12	2.82
L.S.D.at 5%	1.57	7.84	0.81	0.88	1.77	0.70	1.67	0.57	0.23	5.62
L.S.D. at 1%	2.07	10.36	1.07	1.17	2.34	0.93	2.20	0.75	0.31	7.42

Table 2. Partitioning of the variance for ten different characters in L x T mating design in pearl millet.

Sr. No.	Source of variation	D.F	Mean sum of square									
			Days to flowering	Plant height (cm)	Number of tillers /plant	Number of inter-nodes	Inter-node length (cm)	Number of leaves	Earhead length (cm)	Earhead girth (cm)	500-grain weight (g)	Grain yield/ plant (g)
1.	Replication	1	45.01**	261.10**	0.73*	0.41	0.65	1.14**	1.66	0.09	0.04	1.41
2.	Parent	31	6.48**	1392.55**	1.28**	0.89**	8.42**	1.97**	72.62**	2.02**	1.43**	328.95**
3.	Female	1	2.25	5.29	1.44**	0.00	0.49	0.02	5.52**	0.01	0.66**	92.16**
4.	Male	29	5.68**	1302.37**	0.74**	0.88**	8.38**	2.08**	75.70**	1.65**	1.27**	334.52**
5.	Female Vs male	1	33.75**	5394.90**	16.64**	2.05**	17.66**	0.88**	50.46**	14.62**	6.72**	404.30**
6.	Hybrids	59	10.38**	316.38**	0.73**	0.42**	4.09**	0.64**	20.32**	0.55**	0.62**	367.75**
7.	Parents Vs hybrids	1	30.45**	361.70**	43.01**	0.17	204.13**	18.94**	61.88**	35.32**	6.27**	17183.26**
8.	Error	91	0.62	15.52	0.16	0.20	0.79	0.12	0.70	0.08	0.01	7.96

* = Significant at 5% level.

** = Significant at 1% level.

Among the hybrids, developed by using 5141 A male sterile line; the hybrids 5141 A x Inb.1008;(41 days); 5141 A x Inb.1037 (41 days); 5141 A x Inb.1036 (41.50 days) and 5141 A x RBS-431-6 (41.50 days) were early to flower. The remaining hybrids flowered between 42 to 49.50 days. Hybrid 5141 A x Inb.492 was late (49.50 days).

Of the hybrids based on 5054 A male sterile line, the hybrids 5054 A x Sel.J-104 and 5054 A x RBS-431-6 were early which flowered in 41.50 days. The other comparatively early hybrids were 5054 A x Inb.142-2; 5054 A x RHRB-28-2 and 5054 A x RBS-347 which flowered in 43.50 days. Remaining hybrids flowered in 44 to 48 days.

Among 60 hybrids, 29 were earlier than the check BK-560.

4.1.2 Plant height :

The 'F' test for plant height was highly significant (Table 1).

Between female parents, 5054 A was tall(118.80 cm) Among the males; Rahuri Long earhead was the tallest (217.90 cm) and was followed by RHRB-28-2 (195.50 cm) and RHRB-28-4 (186.00 cm). The short males were, RBS-23 (84.50 cm) and Inb.492 (96.20 cm). The height of rest of the males ranged from 125.90 to 178.70 cm.

Among the hybrids of which 5141 A was the female parent, 5141 A x Manmad Local (181.50 cm) and

5141 A x Rahuri Long earhead (178.90 cm) were taller. Rest of the hybrids had plant height ranging from 127.00 to 175.60 cm.

The hybrids produced by utilizing 5054 A viz; 5054 A xInb.337-1(178.20 cm), 5054 A x RBS-359 (177.40 cm), 5054 A x Inb.1022 (177.10 cm) and 5054 A x Rahuri Long earhead (171.90 cm) were comparatively taller. The height of the remaining hybrids was in the range of 137.80 to 168.40 cm.

Out of 60 hybrids, 35 were taller and 25 hybrids were shorter than BK-560.

4.1.3 Number of tillers/plant :

Highly significant differences were observed for a number of tillers per plant.

The female 5054 A produced more effective tillers per plant (5.20) than 5141 A (4.00). Among the males, RBS-431-6 (4.10) had highest number of tillers. The number of tillers in other males were ranged from 1.20 to 3.40.

Out of 30 hybrids, developed by using 5141 A; 5141 A x RHRB-28-2 (4.50) and 5141 A x Restorer-3 (4.40) produced more number of tillers, while 5141 A x Inb.492-1 (2.40), 5141 A x Inb.492 (2.60) and 5141 A x Manmad Local (2.60) was shy in tillering. The other hybrids produced tillers ranging from 2.90 to 4.30.

The hybrids involving 5054 A produced tiller ranging from 2.80 to 4.90. The highest number of tillers (4.90) were recorded in 5054 A x Inb.1043 and was followed by 5054 A x Sel. J-104 and 5054 A x RBS-240 (4.70). The hybrid 5054 A x Inb.492-1 produced the least number of tillers per plant (2.80).

All the 60 hybrids, produced higher number of tillers than the check, BK-560.

4.1.4 Number of inter-nodes :

From the Table 1, it can be seen that 'F' value was highly significant for this character. Both of the females produced same number of nodes (5.70). Among the males, Inb.1026 and RBS-28 had highest number of nodes (7.40).

Of the hybrids in which 5141 A was the female parent, 5141 A x RBS-23 had highest number of nodes (7.50) and was followed by 5141 A x Inb.1043 (7.20). The nodes in other hybrids were ranging from 5.40 to 7.10.

The hybrid 5054 A x Inb.1022 had highest number of nodes (7.40) which involves 5054 A as a female parent. The rest of the hybrids based on this female had nodes between 5.50 and 7.10.

Out of 60 hybrids, 25 produced higher number of nodes than BK-560.

4.1.5 Internode length :

The 'F' test for length of internodes was highly significant (Table 1).

Between females, 5054 A (15.10 cm) and among males, Inb.45 had highest internodal length (20.90 cm)

Among the hybrids developed by utilizing 5141 A male sterile line, 5141 A x Manmad Local had highest internodal length, (23.90 cm). Rest of the hybrids had internodal length from 15.30 to 21.10 cm.

Regarding hybrids developed by utilizing 5054 A male sterile line, 5054 A x RBS-359 (21.65 cm) had produced highest internodal length followed by 5054 A x RBS-23 (21.20 cm) and 5054 A x Inb.1043 (21.10 cm). The other hybrids produced internodal length between 15.60 and 20.60 cm.

Out of 60 hybrids, 5 produced longer internodes than check BK-560.

4.1.6 Number of leaves :

The 'F' test for this character was highly significant (Table 1).

The female 5054 A produced more leaves (5.75) than 5141 A (5.60).

Among the males, RBS-28 had highest number of leaves (8.50) followed by RBS-359 (8.40), RBS-23 (7.90) and Inb.1022 (7.90).

Of the hybrids in which 5141 A was the female parent, 5141 A x Inb.1022 had the highest number of leaves (7.80) followed by 5141 A x RBS-23 (7.70); 5141 A x Inb.492 (7.50) and 5141 A x Inb.337-1 (7.40). The hybrid 5141 A x Inb.1026 had the lowest number of leaves (5.70). The rest of the hybrids had leaves ranging from 5.80 to 7.70.

The female parent 5054 A produced the hybrids measuring from 6.00 to 8.00 number of leaves; the lowest being in 5054 A x Inb.1037 (6.00) and highest in 5054 A x RBS-359 (8.00).

In all, 19 hybrids produced higher number of leaves than BK-560.

4.1.7 Earhead length :

The 'F' test for earhead length was highly significant (Table 1).

The female 5054 A had longer earheads (20.45 cm) than 5141 A (18.10 cm).

Rahuri long Earhead produced longest earheads (49.40 cm) followed by the male, Inb.492 (33.10 cm); Inb.1008 (28.90 cm) and Inb.142-2 (25.70 cm).

Among the hybrids, developed by using 5141 A female parent, 5141 A x Rahuri Long Earhead produced the longest earhead (40.50 cm). The other hybrids with appreciably longer earheads were, 5141 A x Inb.45 (27.60cm), 5141 A x Inb.492-1 (26.90 cm) and 5141 A x RBS-225(24.40cm). 5141 A x RBS-243-2, however, produced the shortest earheads (20.30 cm). Rest of the hybrids ranged from 21.80 to 26.00 cm.

The female parent 5054 A produced hybrids having earheads measuring from 19.70 to 34.00 cm of length. The highest length of earheads was recorded in case of 5054 A x Rahuri Long Earhead. The other crosses which produced longer earheads were 5054 A x Inb.1019 (28.30 cm), 5054 A x RBS-23 (26.90 cm) and 5054 A x Inb.492-1 (25.40 cm).

Out of 60 hybrids, 46 produced longer earheads than BK-560.

4.1.8 Earhead girth :

The 'F' test for earhead girth was highly significant. The female 5141 A had thicker earheads (6.30 cm) comparatively than 5054 A (6.25 cm).

The thickness of the earhead of the male parents was found to be ranging between 6.38 and 9.93 cm. The highest thickness was noted in case of Inb.1019 (9.93 cm), while lowest in RBS-28 (6.38 cm).

The thickness of the earheads in the crosses in which 5141 A was female parent was between 6.35 and 8.30 cm. The crosses in which thicker earheads were noted were: 5141 A x Inb.1002-2 (8.30 cm); 5141 A x Inb.1019 (8.20 cm); and 5141 A x RBS-225 (8.10 cm).

As regards the hybrids based on 5054 A male sterile line, 5054 A x Inb.1022 had highest earhead girth (8.70 cm) followed by 5054 A x Inb.1002-2 (8.50 cm) and 5054 A x Inb.1008 (8.05 cm). The rest of the hybrids had earhead measuring between 6.40 and 7.90 cm.

Of the 60 hybrids; 53 produced thicker earheads, than BK-560.

4.1.9 500-grain weight :

The differences for 500-grain weight were statistically significant.

The female parent 5141 A had greater size of grain (3.25 g) than 5054 A (2.44 g).

The male parents RBS-225 (5.80 g); RBS-347 (5.50 g); Manmad Local and Inb.337-1 (5.10 g) produced bolder grains. The other males produced grains weighing 2.55 to 5.00 g/500-seeds.

The weight of 500-grains in the hybrids involving 5141 A was 3.25 to 5.10 g. The heaviest grains

among these were noted in 5141 A x Manmad Local (5.10 g/500 grains);followed by 5141 A x Inb.1008(5.00 g); 5141 A x Inb.1002-2; 5141 A x RBS-225 and 5141 A x RBS-431-6 (4.25 g). The hybrids in which 5054 A female 5054 A x Inb.1008 (5.00 g) and 5054 A x RBS-347 (5.00 g) produced comparatively heavier grains. The grain weight in other hybrids was 2.25 to 4.55 g/500 grains.

In all, 12 hybrids produced bolder grains than BK-560.

4.1.10 Grain yield/plant :

The differences in grain weight among different parents and hybrids were statistically significant(Table 1).

Between females, 5141 A produced the higher grain yield (31.00 g). Among the males, RHRB-28-2(60.00 g); RHRB-28-4 (59.00 g) and Inb.1008 (58.50 g) had comparatively higher grain yields.

Of the 30 hybrids involving 5141 A female parent, 5141 A x RBS-23 (91.50 g) produced highest grain yield followed by 5141 A x Restorer-3 (81.10 g); 5141 A x Inb.1043 (75.00 g) and 5141 A x RBS-225 (71.00 g). The remaining hybrids produced grain yields between 33.00 to 68.00 g/plant. 5141 A x Inb.1037 (33.00 g) was the poorest yielder.

The yield of the hybrids derived from 5054 A female parent was ranged from 32.50 to 84.00 g/plant.

The higher grain yield was observed in case of hybrids 5054 A x Inb.1022; 5054 A x RBS-225 (84.00 g); 5054 A x Inb. 337-1 (78.50 g); 5054 A x Inb.142-2 (74.50 g) and 5054 A x Inb.1002-1 (72.50 g).

Out of 60 hybrids, 28 hybrids out-yielded BK-560.

4.2 Heterosis :

The percentage of the increase or decrease heterosis over superior (heterobeltiosis) and mid-parental value for ten important characters were calculated and have been presented in Table 3.

4.2.1 Days to flowering :

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

The significant and negative heterosis over mid-parent was recorded in fourteen and over superior parent in six of the thirty crosses based on 5141 A female parent (Table 3). The range of heterosis in the former set of crosses was between -3.37 and -9.39 per cent, while in latter, it was -4.60 to -5.75 per cent. The rest of the crosses showed either positive or non-significant heterosis. The higher percentages of heterosis were recorded in 5141 A x Inb.1008 and 5141 A x Inb.1037 crosses. The percentages of heterosis over mid and superior parent in the former cross were -9.39 and -5.75 and in latter -7.87 and -5.75, respectively.

Table 3. Heterosis in pearl millet for different characters in different crosses.

Hybrids	Days to flowering		Plant height (cm)		Number of tillers/plant		Number of inter nodes		Inter node length (cm)	
	Heterosis over		Heterosis over		Heterosis over		Heterosis over		Heterosis over	
	SP(%)	MP(%)	SP(%)	MP(%)	SP(%)	MP(%)	SP(%)	MP(%)	SP(%)	MP(%)
1	2	3	4	5	6	7	8	9	10	11
5141 A x Restorer-3	10.34**	9.71**	30.10**	35.15**	10.00	25.71*	- 7.25	1.59	20.92**	24.58**
x Inb.1002-1	- 4.60*	- 6.74**	7.61*	14.57**	7.50	21.13*	- 1.75	0.00	27.74**	32.44**
x Inb.1002-2	- 4.60	- 6.74*	- 2.18**	5.87*	-27.50**	- 6.45	1.75	8.41	- 1.29	2.34
x Inb.1008	- 5.75	- 9.39**	- 0.83**	13.95**	-17.50	-10.81	3.51	7.27	14.20**	23.32**
x Inb.1019	5.75**	0.55	1.95	17.59**	-20.00	23.08	0.00	5.79	9.36	18.73**
x Inb.1022	5.75**	1.09	- 0.12	17.90**	-25.00**	-10.45	- 5.48	6.15	32.88**	33.79**
x Inb.1026	- 1.15	- 7.03**	-28.65**	-13.75**	-18.75	12.07	-24.32**	-14.50*	26.69**	28.42**
x Inb.142-2	- 2.30	- 2.30	- 4.13	12.91**	-15.00	6.25	1.56	7.43	3.57	11.54*
x Inb.337-1	5.75**	2.79	0.66	13.74**	- 2.50	25.81*	- 3.08	3.28	15.79**	18.92**
x Inb.1036	- 4.60*	- 7.26**	-13.36**	- 0.29	2.50	43.85**	- 1.59	3.33	7.34	18.38**
x Inb.1037	- 5.75**	- 7.87**	-10.71**	3.22	- 5.00	11.76	8.20	11.86	1.61	14.55**
x Inb.1043	3.45	0.00	6.79**	21.29**	- 7.50	4.23	5.88	15.20*	24.84**	31.80**
x Rahuri Long Earhead	4.60*	0.00	-17.90**	6.99**	-23.75*	15.09	1.45	11.11	- 2.07	12.17**

Continued.....

Table 3. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5141 A x Sel.J-104	- 2.30	- 6.08**	-10.85**	1.73	-12.50	2.94	8.47	10.34	- 1.06	12.05*
x Inb.45	5.75**	3.37*	0.62	16.76**	-25.00*	-10.45	0.00	8.80	- 6.22	11.05*
x Inb.483	- 1.15	- 5.49**	- 6.06*	8.72**	-22.50*	- 6.06	- 4.23	6.25	8.00	18.50**
x Inb.492	13.79**	9.39**	47.64**	61.73**	-35.00**	-20.00	24.56**	30.28**	30.56**	37.73**
x Inb.564	- 1.15	- 3.37*	-22.50**	- 6.17**	-22.50*	-11.43	7.02	7.02	6.36	16.09**
x RHRB-28-2	0.00	- 2.79	-16.62**	4.49*	12.50	45.16**	-11.27	- 1.56	3.94	21.61**
x RHRB-28-4	- 2.30	- 3.95*	-17.26**	1.75	2.50	30.16**	- 8.57	0.79	4.81	18.43**
x Manmad Local	- 1.15	- 3.37*	7.21**	27.01**	-35.00**	-14.75	4.69	10.74	23.20**	41.42**
x RBS-23	10.34**	9.09**	50.73**	74.73**	7.50	36.51**	31.58**	33.93**	36.11**	50.19**
x RBS-28	8.05**	4.44**	7.21**	20.12**	7.50	26.47*	-10.81	0.76	23.90**	30.03**
x Inb.492-1	0.00	- 1.14	14.14**	24.88**	-40.00**	-34.25**	4.84	9.24	2.44	9.09
x RBS-225	- 1.15	- 3.91*	13.24**	25.58**	- 2.50	23.81*	-10.29	- 2.40	23.57**	28.90**
x RBS-240	0.00	- 1.70	2.69	17.64**	-27.50**	- 7.94	- 9.09	- 2.44	0.54	12.80**
x RBS-243-2	- 3.45	- 3.45*	6.64*	19.23**	-27.50**	- 3.34	- 1.54	4.92	5.92	14.38**
x RBS-347	9.20**	5.56**	- 1.62	12.21**	-10.00	12.50	- 3.08	3.28	7.56	17.09**
x RBS-359	5.00*	0.60	- 5.90*	8.70**	- 2.50	25.81*	- 7.14	2.36	- 7.57	3.95
x RBS-431-6	- 4.60*	- 6.74**	-15.69**	- 1.14	-14.63	-13.58	-19.40**	-12.90*	11.86*	23.36**

Continued.....

Table 3. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5054 A x Restorer-3	4.76*	2.33	28.12**	31.83**	-25.00**	- 4.88	-11.59	- 3.17	1.96	2.63
x Inb.1002-1	4.76*	0.57	20.14**	26.73**	-17.31*	3.61	22.81**	25.00**	20.00**	21.57**
x Inb.1002-2	5.95**	1.71	3.42	10.92**	-44.23**	-21.62*	7.02	14.02	18.71**	20.26**
x Inb.1008	5.95**	0.00	- 9.66**	2.93	-23.08**	- 6.98	10.53	14.55*	6.51	12.50*
x Inb.1019	11.90**	4.44**	1.01	15.53**	-34.62**	6.25	- 7.81	- 2.48	16.96**	24.22**
x Inb.1022	10.71**	3.91*	5.54*	23.59**	-36.54**	-16.46	1.37	13.85*	34.44**	36.70**
x Inb.1026	7.14**	- 1.10	-22.58**	- 7.14**	-30.77**	2.86	-16.22**	- 5.34	25.83**	27.09**
x Inb.142-2	3.57	1.75	0.90	17.89**	-26.92**	0.00	- 1.56	4.13	11.90*	17.87**
x Inb.337-1	4.76*	0.00	17.78**	31.95**	-38.46**	-13.51**	9.23	16.39*	21.05**	21.45**
x Inb.1036	10.71**	5.68**	-12.22**	0.18	-34.61**	- 1.45	- 6.35	- 1.67	10.17*	18.90**
x Inb.1037	11.90**	7.43**	- 9.27**	4.02	-15.38	10.00	- 4.92	- 1.69	5.91	16.91**
x Inb.1043	14.29**	8.47**	1.18	13.94**	- 5.77	18.07*	-14.71*	- 7.20	31.06**	35.26**
x Rahuri Long Earhead	14.29**	7.26**	-21.11**	2.11	-44.23**	-10.77	- 4.35	4.76	- 4.15	7.56*
x Sel.J-104	- 1.19	- 6.74**	- 2.13	10.75**	- 9.62	17.50*	- 6.78	- 5.17	0.00	10.91*
x Inb.45	13.10**	8.57**	0.56	15.73**	-32.69**	-11.39	-11.76	- 4.00	- 8.61*	6.11
x Inb.483	8.33**	1.68	- 6.63**	7.17**	-21.15**	5.13	-19.72**	-10.94	- 2.57	4.60
x Inb.492	11.90**	5.62**	22.14**	34.98**	-28.85**	- 3.90	1.75	6.42	15.23*	24.29**

Continued.....

Table 3. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5054 A x Inb.564	4.76*	0.57	-19.64**	- 3.46	-30.77**	-12.20	15.79*	15.79*	- 3.47	3.09
x RHRB-28-2	3.57	- 1.14	-19.64**	- 0.03	-13.46	21.62*	- 7.04	3.13	- 2.46	11.86**
x RHRB-28-4	4.76*	1.15	-20.43**	- 2.89	-21.15**	9.33	-12.86*	- 3.94	- 6.95	2.96
X Manmad Local	11.90**	7.43**	- 8.68**	7.32**	-21.15**	12.33	- 3.13	2.48	5.67	18.84**
X RBS-23	14.29**	10.98**	41.41**	65.27**	-42.31**	-20.00*	10.63	12.50	40.40**	58.21**
x RBS-28	11.90**	6.21**	- 1.48	9.43**	-17.31*	7.50	-13.51*	- 2.29	24.52**	27.74**
x Inb,492-1	8.33**	5.20**	18.27**	28.25**	-46.15**	-34.12**	0.00	4.20	7.32	11.75*
x RBS-225	14.29**	9.09**	8.90**	19.71**	-21.15**	9.33	-10.29	- 2.40	22.29**	24.68**
x RBS-240	14.29**	10.34**	4.93	19.20**	- 9.62	25.33**	- 3.03	4.06	10.33*	21.19**
x RBS-243-2	4.76*	2.92	11.85**	23.98**	-25.00**	8.33	- 7.69	- 1.64	18.34**	25.00**
x RBS-347	3.57	- 1.69	2.59	16.02**	-17.31*	13.16	- 1.54	4.92	19.77**	27.55**
x RBS-359	12.50**	9.76**	11.36**	27.58**	-37.50**	-12.16	- 3.57	6.30	17.03**	28.87**
x RBS-431-6	- 1.19	- 5.14**	- 7.63**	7.43**	-37.50**	-30.11**	-10.45	- 3.23	6.78	15.24**
S.E. ±	0.79	0.68	3.94	3.41	0.41	0.35	0.44	0.38	0.89	0.77
L.S.D.at 5%	1.57	1.36	7.84	6.79	0.81	0.70	0.88	0.77	1.77	1.53
L.S.D.at 1%	2.07	1.79	10.36	8.97	1.07	0.92	1.17	1.01	2.34	2.02

Table 3. Heterotis in pearl millet for different characters in different crosses.

Hybrids	Number of leaves		Earhead length (cm)		Earhead girth (cm)		500-grain weight (g)		Grain yield/ plant (g)	
	Heterosis over		Heterosis over		Heterosis over		Heterosis over		Heterosis over	
	SP(%)	MP(%)	SP(%)	MP(%)	SP(%)	MP(%)	SP(%)	MP(%)	SP(%)	MP(%)
	12	13	14	15	16	17	18	19	20	21
5141 A x Restorer-3	10.77	19.00**	43.65**	51.60**	1.40	7.81*	2.56	11.89**	161.61**	197.61**
x Inb.1002-1	3.57	4.50	17.21**	27.27**	-23.96**	- 8.18**	-16.67**	- 3.23	79.03**	119.80**
x Inb.1002-2	7.14	12.15*	- 7.75*	8.43*	- 3.48	11.41**	-10.53**	6.25*	27.42**	61.22**
x Inb.1008	- 3.17	2.52	-13.15**	6.81*	- 8.07*	3.14	16.28**	32.45**	-13.67**	12.85*
x Inb.1019	7.81	15.00**	22.93**	30.57**	-17.38**	1.08	14.71**	17.29**	37.04**	55.24**
x Inb.1022	6.85	20.93**	12.89**	16.80**	-23.08**	- 6.54**	0.00	12.07**	114.52**	144.04**
x Inb.1026	-27.85**	-15.56**	10.10*	15.04**	-27.03**	-13.18**	-12.50**	- 3.45	- 6.85	0.74
x Inb.142-2	30.36**	33.95**	-10.12**	5.48	-15.85**	- 0.32	-26.09**	-13.38**	34.65**	66.87**
x Inb.337-1	29.82**	30.97**	- 2.14	10.36**	- 7.14	2.14	-34.31**	-19.76**	20.22**	41.72**
x Inb.1036	15.25*	18.26**	- 8.91**	5.14	-24.57**	-12.29**	-11.11**	3.23	33.33**	43.28**
x Inb.1037	12.50	14.54*	- 3.75	9.74**	-11.92**	- 3.97	10.77**	13.39**	6.45	8.20
x Inb.1043	21.43**	28.30**	4.74	17.68**	- 2.50	9.09**	-24.49**	- 9.20**	38.89**	76.47**
x Rahuri Long Earhead	18.97**	21.05**	-18.02**	20.00**	- 8.10*	- 0.73	-26.08**	-13.38**	19.44*	28.36**

Continued.....

Table 3. (Contd...)

	12	13	14	15	16	17	18	19	20	21
5141 A x Sel.J-104	- 9.09	- 1.64	8.96*	17.56**	-15.00**	- 4.90	-10.26**	- 2.09	10.13	23.40**
x Inb.45	0.00	6.67	20.79**	34.80**	3.50	10.04**	4.00	11.43**	64.18**	70.54**
x Inb.483	9.37	16.67**	-10.84**	2.47	6.34	12.69**	-20.20**	- 3.66	- 3.06	18.75**
x Inb.492	8.70	20.00**	-21.45**	1.56	4.34	9.09*	-23.33**	-10.97**	32.26**	50.46**
x Inb.564	1.64	5.98	1.63	16.70**	-22.11**	- 6.33*	- 9.33**	- 2.86	17.44**	36.49**
x RHRB-28-2	7.81	15.00**	9.30*	18.69**	-19.32**	- 5.96	23.08**	23.08**	- 9.85*	22.68**
x RHRB-28-4	17.86**	17.86**	25.65**	29.03**	-17.89**	- 1.27	-17.23**	- 7.16**	11.02*	45.56**
x Manmad Local	11.29	16.95**	17.80**	20.97**	-11.88**	- 1.40	0.00	22.16**	56.45**	92.08**
x RBS-23	- 2.53	14.07**	19.25**	28.93**	- 4.03	4.00	7.69*	12.90**	195.16**	277.32**
x RBS-28	-14.12**	3.55	20.44**	29.38**	-19.62**	-10.56**	2.94	5.26	10.00	23.94**
x Inb.492-1	26.79**	32.71**	46.20**	47.40**	- 8.33*	1.42	- 4.00	2.86	44.30**	61.70**
x RBS-225	17.86**	22.22**	22.79**	33.33**	- 8.99**	6.58*	-26.72**	- 6.08**	97.22**	111.94**
x RBS-240	16.07*	27.45**	9.22**	16.28**	2.84	8.61*	-17.98**	- 5.19*	44.44**	55.22**
x RBS-243-2	21.43**	27.10**	9.73*	10.93**	-19.89**	- 6.62*	9.23*	13.60**	101.61**	142.72**
x RBS-347	23.21**	25.45**	11.61**	23.46**	-18.52**	- 8.33*	-36.36**	-20.00**	67.74**	73.33**
x RBS-359	-21.43**	- 5.71	21.51**	23.16**	-19.64**	- 8.16*	-17.07**	- 7.48**	57.32**	79.17**
x RBS-431-6	1.69	4.35	- 5.17	6.54	- 5.52	1.11	-15.00**	3.03	8.82	13.85

Continued.....

Table 3. (Contd...)

	12	13	14	15	16	17	18	19	20	21
5054 A x Restorer-3	6.15	12.65*	2.69	14.60**	- 6.29	0.00	-12.82**	7.26*	189.36**	202.90**
x Inb.1002-1	32.17**	35.11**	15.81**	18.71**	- 20.31**	- 3.47	-20.00**	3.74	238.79**	254.52**
x Inb.1002-2	16.52**	23.50**	- 4.26	6.81*	- 1.16	14.48**	- 4.21	26.56**	51.87**	64.97**
x Inb.1008	7.94	12.86*	-16.96**	- 2.74	0.00	12.59**	16.28**	48.37**	- 18.80**	18.90**
x Inb.1019	1.56	7.00	38.05**	38.22**	- 23.43**	- 6.03	20.59**	40.41**	41.98**	85.78**
x Inb.1022	8.22	21.07**	9.54*	12.42**	- 10.77**	8.75**	74.51**	78.36**	257.45**	274.16**
x Inb.1026	-20.25**	- 7.69	13.94**	15.78**	- 22.70**	- 7.74*	-16.25**	4.04	34.25**	69.26**
x Inb.142-2	13.04*	17.65**	-10.51**	- 0.33	- 26.78**	-12.99**	-26.09**	- 3.41	47.53**	107.23**
x Inb.337-1	28.70**	29.26**	5.56	12.66**	- 7.14	2.51	-22.55**	4.77	76.40**	138.24**
x Inb.1036	3.39	4.72	-14.17**	- 6.09	- 22.29**	- 9.33**	-38.89**	-20.75**	26.39**	58.54**
x Inb.1037	4.35	7.62	- 5.42	2.14	- 12.58**	- 4.35	-27.42**	-18.77**	73.33**	102.33**
x Inb.1043	6.09	13.49*	2.16	8.59*	- 11.25**	- 0.35	-34.69**	-12.81**	16.76**	65.81**
x Rahuri Long Earhead	18.97**	19.48**	-31.17**	- 2.65	- 6.76	1.10	-27.17**	- 4.83	52.78**	91.64**
x Sel.J-104	- 3.03	3.64	14.15**	16.21**	- 11.88**	- 1.05	1.28	24.61**	44.30**	87.19**
x Inb.45	3.13	8.64	7.66*	13.63**	- 2.80	3.73	-13.33**	5.00	98.51**	142.26**
x Inb.483	14.06*	20.16**	- 4.29	4.23	11.27**	18.35**	-19.19**	8.25**	-10.20	25.00**
x Inb.492	13.04*	23.32**	-29.31**	-12.61**	4.35	9.51*	-22.22**	0.86	120.64**	130.96**

Continued.....

Table 3. (Contd...)

	12	13	14	15	16	17	18	19	20	21
5054 A x Inb.564	4.91	8.02	-10.66**	- 2.79	-24.21**	- 8.57**	- 6.67*	13.09**	17.44**	56.83**
x RHRB-28-2	10.94	16.87**	1.40	3.93	-21.59**	- 8.31*	-10.77**	1.93	-12.88**	31.58**
x RHRB-28-4	9.57	11.01*	9.54*	13.27**	-23.68**	- 7.94*	-13.25**	9.26**	-27.97**	5.72
x Manmad Local	8.06	12.13*	3.18	6.70	-11.88**	- 1.05	-49.02**	-31.03**	154.67**	166.50**
x RBS-23	-16.46**	- 3.30	26.29**	28.86**	- 0.67	8.03*	32.20**	44.71**	224.77**	257.33**
x RBS-28	-17.65**	- 1.75	- 3.67	9.29*	-18.99**	- 9.54**	30.88**	52.40**	43.75**	87.30**
x Inb.492-1	30.43**	38.25**	24.21**	30.76**	-11.54**	- 1.78	- 8.00*	11.47**	29.11**	67.49**
x RBS-225	23.48**	29.68**	13.02**	15.85**	-12.92**	2.31	-26.72**	3.16	133.33**	192.68**
x RBS-240	26.96**	41.06**	15.53**	15.96**	0.00	6.02	-21.35**	1.60	80.56**	126.48**
x RBS-243-2	28.70**	36.41**	- 0.24	4.75	-26.14**	-13.62**	16.67**	28.68**	231.78**	238.90**
x RBS-347	21.74**	25.56**	- 5.36	- 1.05	-17.28**	- 6.62	- 9.09**	25.94**	46.55**	68.65**
x RBS-359	- 4.76	13.07**	8.56*	13.70**	-15.48**	- 3.07	-25.61**	- 6.73*	- 3.66	26.60**
x RBS-431-6	1.69	3.00	-14.66**	- 9.28**	-10.34**	- 3.70	-21.00**	6.18*	30.88**	60.65**
S.E. ±	0.35	0.31	0.84	0.73	0.29	0.25	0.12	0.10	2.82	2.44
L.S.D. at 5%	0.70	0.61	1.67	1.44	0.57	0.49	0.23	0.20	5.62	4.86
L.S.D. at 1%	0.93	0.80	2.20	1.91	0.75	0.65	0.31	0.27	7.42	6.43

None of the crosses involving 5054 A female parent showed significant negative heterosis over superior parent. However, over mid parent two crosses viz, 5054 A x Sel.J-104 (-6.74%) and 5054 A x RBS-431-6 (-5.14%) did show desirable heterosis. The remaining crosses showed either positive or non-significant heterosis.

4.2.2 Plant height :

For plant height, among the crosses having 5141 A as a female parent, ten showed significant and positive heterosis (6.63 to 50.73%) over superior parent and higher percentages were recorded in 5141 A x RBS-23 (50.73), 5141 A x Inb.492 (47.64) and 5141 A x Restorer-3 (30.10) crosses. Over mid parent 23 hybrids expressed significant and positive heterosis ranging from 4.49 to 74.73 per cent and the crosses 5141 A x RBS-23 (74.73%); 5141 A x Inb.492 (61.73%) and 5141 A x Restorer-3 (35.15%) were more heterotic.

The crosses involving 5054 A as a female parent exhibited significant and positive heterosis ranging from 5.54 to 41.41%, over superior parent in ten crosses. The heterotic effect was more pronounced in 5054 A x RBS-23 (41.41%); 5054 A x Restorer-3 (28.12%; and 5054 A x Inb.492 (22.14%) crosses. As regards the heterosis over mid parent, 32 crosses showed significant positive heterosis ranging from 7.17 to 65.27%. The higher such percentages

were noted in 5054 A x RBS-23 (65.27),5054 A x Inb.492 (34.98), 5054 A x Inb.337-1 (31.95) and 5054 A x Restorer-3 (31.84) crosses.

In remaining crosses based on both 5141 A and 5054 A female parents either negative or non-significant heterosis was recorded.

4.2.3 Number of tillers/plant :

Of 30 hybrids developed by using 5141 A female parent only ten crosses exhibited heterosis ranging from 21.13 to 45.16% over mid-parent. The higher magnitude of heterosis was noted in 5141 A x RHRB-28-2 (45.16%); 5141 A x Inb.1036 (43.86%), 5141 A x RBS-23 (36.51%) and 5141 A x RHRB-28-4 (30.16%).

Only four crosses viz; 5054 A x Inb.1043 (18.07%), 5054 A x Sel.J-104 (17.50%), 5054 A x RHRB-28-2 (21.62%) and 5054 A x RBS-240 (25.33%), based on 5054 A showed significant positive heterosis over mid-parent. None of the crosses based on either 5141 A or 5054 A female parent expressed significant positive heterosis over superior parent.

4.2.4 Number of internodes :

Out of 30 hybrids derived from 5141 A female parent two viz; 5141 x RBS-23 (31.58%) and 5141 A x Inb.492 (24.56%) expressed significant positive heterosis over-superior parent and three viz; 5141 A x RBS-23 (33.93%); 5141 A x Inb.492 (30.28%) and 5141 A x Inb.1043(15.20%) over mid parents

Two crosses viz; 5054 A x Inb.1002-1 (22.81%) and 5054 A x Inb.564 (15.79%) involving 5054 A as a female parent showed significant positive heterosis over superior parent. Over mid parent positive heterosis ranging from 13.85 to 25 per cent was noticed in five such crosses. The higher percentages of heterosis were noted in 5054 A x Inb.1002-1 (25%) and 5054 A x Inb.1022 (13.85) crosses.

The remaining crosses had either non-significant or negative estimates of heterosis.

4.2.5 Internode length :

Thirteen crosses involving 5141 A female parent exhibited significant positive heterosis over superior parent for internodal length. The percentages of such heterosis were ranging from 11.86 (5141 A x RBS-431-6) to 36.11 (5141 A x RBS-23). The significant positive heterosis over mid parent was observed in most of the crosses. The higher values of heterosis, however, were noted in 5141 A x RBS-23 (50.19%), 5141 A x Manmad Local (41.42%) and 5141 A Inb.492 (37.73%) crosses.

The significant and positive heterosis ranging from 10.17 to 40.39% over superior parent was observed in 17 crosses having 5054 A as female parent. The higher percentages of such heterosis were recorded in 5054 A x RBS-23 (40.40); 5054 A x Inb.1043 (31.06); and 5054 A x Inb.1022 (34.44). In all 24 crosses expressed significant positive heterosis (11.74 to 58.21%) over mid-parent.

4.2.6 Number of leaves :

For number of leaves, in 11 crosses involving 5141 A female parent the positive and significant heterosis (15.25 to 30.36%) over superior parent was noticed. The highest heterotic expression was noticed in 5141 A x Inb.142-2 (30.36%) and was followed by that in 5141 A x Inb.337-1 (29.82%), 5141 A x Inb.492-1 (26.79%). As regards the heterosis over mid-parent significant positive heterosis was recorded in 21 crosses and the range was from 12.15 (5141 A x Inb.1002-2) to 33.95% (5141 A x Inb.142-2).

In all the 12 crosses derived from 5054 A female parent exhibited significant positive heterosis over superior parent. The range of percentages of heterosis was between 13.04 (5054 A x Inb.142-2 and 5054 A x Inb.492) to 32.17% (5054 A x Inb.1002-1). The significant positive heterosis over mid-parent was observed in 20 hybrids. The higher percentages were noted in 5054 A x RBS-240 (41.06), 5054 A x Inb.492-1 (38.25) and 5054 A x RBS-243-2 (36.41).

4.2.7 Earhead length :

Among the crosses having 5141 A as female parent; 18 showed significant and positive heterosis (8.96 to 46.20%) over superior parent and higher percentages were recorded in 5141 A x Inb.492-1 (46.20),

5141 A x Restorer-3 (43.65), and 5141 A x RHRB-28-4 (25.65). Of the 25 heterotic crosses, the magnitude of positive heterosis over mid parent was higher in 5141 A x Restorer-3 (51.60%); 5141 A x Inb.492-1(47.40%) and 5141 A x Inb.45 (34.80%).

Eleven and twenty four crosses based on 5054 A showed significant positive heterosis over superior and mid-parent, respectively. The range of the positive heterosis in the former set of crosses was 7.66 to 38.04%; while it was 6.81 to 38.21% in the latter set of crosses. The hybrids 5054 A x Inb.1019, 5054 A x Inb.492-1 and 5054 A x RBS-23 were more heterotic.

4.2.8 Earhead girth :

None of the crosses having 5141 A as female parent showed significant positive heterosis over superior parent for earhead girth. However, the eight crosses exhibited significant positive heterosis over mid parent for this character. The hybrids 5141 A x Inb.483(12.69%) and 5141 A x Inb.1002-2 (11.41%) expressed higher magnitude of heterosis.

Only one hybrid viz; 5054 A x Inb.483 (11.27%) based on 5054 A exhibited significant positive heterosis over superior parent. Over mid parent, however, significant positive heterosis (8.03 to 18.35%) was noted in six crosses. Such heterosis percentages were higher in

5054 A x Inb.483 (18.35%) and 5054 A x Inb.1002-2 (14.48%). The remaining crosses showed either negative or non significant heterosis for this character.

4.2.9 500-grain weight :

The positive and significant heterosis over superior parent ranging from 7.69 to 23.08% for 500-grain weight was recorded in six crosses, having 5141 A as female parent. The higher magnitude of the heterotic effects were noticed in 5141 A x RHRB-28-2 (23.08%); 5141 A x Inb.1008 (16.28%) and 5141 AxInb.1019 (14.70%), crosses. Eleven crosses showed significant positive heterosis over mid parent and the percentages were ranging between 6.25 to 32.45. The higher percentages of such heterosis were noted in 5141 A x Inb.1008 (32.45%), 5141 A x RHRB-28-2 (23.08%), 5141 A x Manmad Local(22.16%) and 5141 A x Inb.1019 (17.29%), crosses.

The six crosses viz; 5054 A x Inb.1022(74.51%), 5054 A x RBS-23 (32.20%), 5054 A x RBS-28 (30.88%); 5054 A x Inb.1019 (20.59%); 5054 A x RBS-243-2 (16.67%) and 5054 A x Inb.1008 (16.27%) derived from 5054 A female parent showed significant positive heterosis over superior parent. The heterosis over mid parent ranging from 6.18 to 78.36%, however, was recorded in 15 crosses. The combinations 5054 A x Inb.1022 (78.36%), 5054 A x RBS-28(52.40%),

5054 A x Inb.1008 (48.37%); 5054 A x RBS-23 (44.71%) and 5054 A x Inb.1019 (40.41%) were more in heterotic effect.

4.2.10 Grain yield/plant :

For grain yield per plant percentages of the positive heterosis over both, superior (11.02 to 195.16%) and mid parent (12.85 to 277.32%) were very high. Of the 22 crosses showing positive heterosis over superior parent, magnitude were higher in 5141 A x RBS-23 (195.16%), 5141 A x Restorer-3 (161.61%), 5141 A x Inb.1022 (114.52%), 5141 A x RBS-243-2 (101.61%) and 5141 A x RBS-225(97.22%). Only two crosses viz; 5141 A x Inb.1008 (-13.67%) and 5141 A x RHRB-28 (-9.85%) showed significant negative heterosis.

When the heterosis based on mid parent was considered, it was observed that 27 crosses exhibited significant positive heterosis ranging from 12.85 to 277.32%. The heterotic effects in 5141 A x RBS-23 (277.32%), 5141 A x Restorer-3 (197.61%), 5141 A x Inb.1022 (144.04%), 5141 A x RBS-243-2 (142.72%) and 5141 A x Inb.1002-1 (119.80%) were of greater magnitude.

In the crosses in which 5054 A was the female parent, positive and significant heterosis over superior parent was noticed in 25 of the 30 crosses and the percentages were ranging between 15.75 and 257.45.

The heterotic effects were more pronounced in 5054 A x Inb.1022 (257.45%), 5054 A x Inb.1002-1 (238.79%), 5054 A x RBS-243-2 (231.78%), 5054 A x RBS-23 (224.77%), 5054 A x Restorer-3 (189.36%) and 5054 A x Manmad Local (154.67%) crosses. Only three crosses showed significant negative heterotsis. As regards the heterosis over mid parent 29 of the 30 crosses exhibited significant positive heterosis (18.90 to 274.16%). The higher percentages of heterosis were observed in 5054 A x Inb.1022 (274.16), 5054 A x RBS-23 (257.33); 5054 A x Inb.1002-1 (254.52), 5054 A x RBS-243-2 (238.90) and 5054 A x Restorer-3 (202.90). None of the crosses showed significant negative heterosis over mid parent.

4.3 Analysis of variance for combining ability :

The details of analysis of variance for combining ability for ten different characters have been presented in Table 4 and described in brief as given below.

4.3.1 Variance due to females :

The variance due to females were significant for the days to flowering, number of effective tillers; earhead length; grain yield per plant; and 500-grain weight. The variance due to females for rest of the characters were non-significant.

Table 4. Analysis of variance for combining ability.

Source of variation	D.F	Mean sum of square									
		Days to flowering	Plant height (cm)	Number of tillers/ plant	Number of internodes	Internode length (cm)	Number of leaves	Earhead length (cm)	Earhead girth (cm)	500-grain weight (g)	Gr yi pl (
Female	1	63.08**	50.60	2.94**	0.75	0.55	0.59*	24.84**	0.08	0.37**	22
Male	29	12.73**	482.06**	0.88**	0.37	5.16**	0.88**	35.92**	0.91**	0.66**	56
Female x Male	29	6.21**	159.86**	0.50**	0.43*	3.15**	0.39**	4.57**	0.20**	0.60**	17
Error	59	0.35	17.65	0.17	0.24	0.86	0.13	0.80	0.09	0.01	1
$\hat{\sigma}^2$g.c.a. for lines		1.63	80.55	0.10	-0.02	0.50	0.12	7.84	0.18	0.02	9
$\hat{\sigma}^2$g.c.a. for testers		0.95	- 1.82	0.04	0.01	-0.04	0.01	0.34	-0.01	-0.01	(
$\hat{\sigma}^2$s.c.a. for L x T		2.93	71.10	0.16	0.11	1.14	0.13	1.88	0.06	0.29	8

* = Significant at 5% level.

** = Significant at 1% level.

4.3.2 Variance due to males :

The variances for combining ability due to males were found to be significant for all the characters except for number of nodes on main shoot.

4.3.3 Variances due to females x males interaction :

The variance due to females x males interaction was observed to be significant for all the characters studied.

The magnitudes of variances due to females were greater than those due to males and females x males interaction for the days to 50 per cent flowering; number of effective tillers and number of nodes on main shoot. For the number of leaves, earhead length and grain yield per plant, the magnitudes were higher than females x males interactions. Due to males, the values of the variances were higher than those due to females x males interaction for all the characters except number of nodes on main shoot.

4.4 g.c.a. and s.c.a. effect for parents and their crosses :

The estimates of general combining ability effects of females and males; and specific combining ability effects for the hybrids are presented in Table 5 and 6 respectively and have explained brief as given below.

Table 5. The estimates of the general combining ability effects for ten characters in pearl millet.

Sr. No.	Parents	Characters									
		Days to flowering	Plant height (cm)	Number of tillers/ plant	Number of internodes	Internode length (cm)	Number of leaves	Earhead length (cm)	Earhead girth (cm)	500-grain weight (g)	Grain yield/ plant (g)
1	2	3	4	5	6	7	8	9	10	11	12
	Females										
1.	5141 A	-0.73**	-0.65*	-0.16**	0.08*	-0.07	-0.07**	0.46**	0.03	-0.06**	- 1.37**
2.	5054 A	0.73**	0.65*	0.16**	-0.08*	0.07	0.07**	-0.46**	-0.03	-0.06**	1.37**
	S.E. ±	0.04	0.31	0.03	0.04	0.07	0.03	0.07	0.02	0.01	0.25
	C.D. at 5%	0.09	0.62	0.06	0.07	0.14	0.05	0.13	0.04	0.02	0.51
	C.D. at 1%	0.12	0.82	0.08	0.09	0.18	0.07	0.18	0.06	0.02	0.67
	Males										
3.	Restorer-3	1.29**	6.40**	0.51**	-0.08	-1.95**	0.25	-0.43	-0.23	-0.01	18.33**
4.	Inb.1002-1	-1.96**	-5.15**	0.66**	-0.03	0.20	-0.10	1.12**	0.27*	-0.04	7.78**
5.	Inb.1002-2	-1.71**	-17.90**	-0.74**	-0.38	-2.15**	-0.45**	0.32	1.19**	0.69**	-20.22**
6.	Inb.1008	-1.96**	- 7.10**	0.01	-0.23	-0.35	-0.35*	0.62	0.52**	1.29**	- 7.22**
7.	Inb.1019	1.97**	4.90**	-0.34*	-0.18	0.35	-0.10	2.82**	0.69**	0.29**	0.28
8.	Inb.1022	1.54**	16.20**	-0.49**	0.82**	0.85*	1.05**	-1.78**	0.89**	0.14**	19.03**
9.	Inb.1026	-0.71**	-23.75**	-0.22	-0.43	-0.12	-0.80**	-1.38**	-0.26*	-0.29**	-14.72**

Continued.....

Table 5. (Contd...)

1	2	3	4	5	6	7	8	9	10	11	12
10	Inb.142-2	-1.71**	8.05**	-0.04	0.07	-0.90*	0.10	-0.88*	-0.01	-0.31**	15.03**
11.	Inb.337-1	0.29	9.10**	-0.09	0.37	-0.99**	0.60**	-0.13	-0.06	-0.06	9.78**
12.	Inb.1036	-0.71**	-18.45**	0.11	-0.28	0.25	-0.35*	-2.08**	-0.51**	-0.34**	- 9.47**
13.	Ibn.1037	-0.71**	-12.50**	0.46**	-0.13	0.30	-0.65**	-1.03**	-0.58**	-0.79**	-13.72**
14.	Inb.1043	1.79**	3.05	0.66**	0.17	1.60**	-0.35*	-0.07	0.24*	-0.26**	12.53**
15	Rahuri Long Earhead	2.04**	19.25**	-0.67**	0.47	-0.30	0.10	13.32**	-0.36**	-0.34**	- 7.22**
16.	Sel.J-104	-2.71**	-11.40**	0.46**	-0.38	-0.30	-0.60**	-0.28	-0.28*	0.01	- 5.97**
17.	Inb.45	2.04**	5.80**	-0.39*	0.07	0.35	-0.30*	2.17**	-0.03	-0.14**	4.53**
18.	Inb.483	-0.46	- 6.30**	-0.04	-0.08	-1.02**	0.35*	-1.33**	0.52**	0.26**	-10.47**
19.	Inb.492	3.54**	2.40	-0.49**	0.12	-0.90	0.85**	0.77*	-0.01	-0.24**	- 9.80**
20.	Inb.564	-1.21**	-15.10**	-0.29	0.02	-1.45**	-0.50**	-0.63	0.09	-0.26**	- 5.72**
21.	RHRB-28-2	-1.21**	3.90*	0.86**	0.12	1.45**	0.20	-1.28**	-0.21	-0.26**	2.28
22.	RHRB-28-4	-1.46**	- 5.20**	0.46**	-0.08	-0.50	-0.35*	-0.73*	0.32**	-0.19**	- 2.22
23.	Manmad Local	0.29	11.90**	-0.29	0.12	3.20**	-0.01	-2.13**	-0.16	0.14**	- 4.72**
24.	RBS-23	3.29**	15.65**	0.01	0.57**	1.40**	0.35*	2.22**	0.07	-0.01	24.28**

Continued.....

Table 5. (Contd...)

1	2	3	4	5	6	7	8	9	10	11	12
25.	RBS-28	2.29**	- 3.50*	0.66**	0.17	0.75	0.35*	-3.18**	-0.83**	0.26**	- 5.47**
26.	Inb.492-1	-0.21	7.35**	-1.04**	0.02	-1.80**	0.50**	2.22**	-0.18	-0.19**	- 2.22
27.	RBS-225	0.79**	4.90**	0.36*	-0.23	0.30	0.05	1.42**	0.72**	0.54**	21.28**
28.	RBS-240	1.04**	5.99**	0.16	-0.13	0.40	0.10	-0.78*	-0.06	-0.14**	2.28
29.	RBS-243-2	-1.71**	5.20**	-0.24	-0.13	0.05	0.30*	-3.58**	-0.43**	-0.19**	10.53**
30.	RBS-347	0.79**	- 0.80	0.31	0.02	0.55	0.15	-0.83*	-0.56**	0.54**	- 8.97**
31.	RBS-359	-1.21**	7.50**	-0.07	0.29	0.38	0.50**	-1.53**	-0.28*	-0.49**	- 4.22**
32.	RBS-431-6	-3.21**	-10.30**	-0.27	-0.63**	0.35	-0.80**	-3.03**	-0.53**	0.39**	-15.47**
	S.E. ±	0.24	1.67	0.17	0.19	0.37	0.14	0.36	0.12	0.05	1.36
	C.D. at 5%	0.47	3.34	0.33	0.39	0.74	0.28	0.71	0.24	0.10	2.72
	C.D. at 1%	0.63	4.44	0.44	0.52	0.98	0.37	0.95	0.32	0.13	3.62

Table 6. Estimates of specific combining ability effects for crosses in pearl millet.

Crosses	Characters									
	Days to flowering	Plant height (cm)	Number of tillers/ plant	Number of internodes	Internode length (cm)	Number of leaves	Earhead length (cm)	Earhead girth (cm)	500-grain weight (g)	Grain yield/ plant (g)
1	2	3	4	5	6	7	8	9	10	11
5141 A x Restorer-3	2.73**	1.90	0.41*	0.07	1.52**	0.22	2.05**	0.25*	0.24**	7.92**
x Inb.1002-1	-0.53*	- 7.65**	0.16	-0.78**	0.67	-0.83**	-0.31	-0.20	0.02	-7.13**
x Inb.1002-2	-0.78**	- 3.20	0.16	-0.23	-1.48**	-0.28	-0.91*	-0.13	-0.21**	4.87**
x Inb.1008	-1.03**	7.60**	-0.19	-0.28	0.72	-0.28	0.10*	-0.35**	-0.06	2.87*
x Inb.1019	0.23	1.40	0.06	0.17	-0.58	0.27	-2.00**	0.27*	-0.16**	0.37
x Inb.1022	0.48*	-4.10*	0.01	-0.33	-0.38	0.02	-0.71	-0.63**	-0.66**	-7.38**
x Inb,1026	-0.28	-4.75**	-0.02	-0.38	-0.06	-0.23	-1.21**	-0.23	0.02	-6.13**
x Inb.142-2	0.23	-3.55*	-0.04	0.02	-0.63	0.47**	-0.41	0.47**	-0.06	-1.88
x Inb.337-1	1.73**	-12.30**	0.51**	-0.48*	-0.33	0.07	-1.36**	-0.03	-0.36**	-11.13**
x Inb.1036	-1.78**	- 0.25	0.51**	0.07	-0.18	0.42**	0.20	-0.13	0.57**	2.62
x Inb.1037	-2.28**	- 0.50	-0.14	0.32	-0.33	0.22	-0.26	-0.00	0.62**	- 8.13**
x Inb.1043	-0.78**	4.95**	-0.44**	0.62**	-0.43	0.42**	-0.16	0.32**	0.19**	7.62**
x Rahuri Long Earhead	-0.53*	4.15*	0.23	0.12	0.27	0.07	2.80**	-0.08	-0.03	- 4.63**

Continued.....

Table 6. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5141 A x Sel.J-104	1.23**	- 6.10**	-0.44**	0.37	-0.03	-0.13	-1.01	-0.15	-0.28**	-5.38**
x Inb.45	-0.03	0.70	-0.09	0.32	0.32	-0.03	1.05**	0.20	0.27**	-4.38**
x Inb.483	-0.53*	1.10	-0.34*	0.47*	0.99**	-0.08	-1.26**	-0.20	-0.08	3.12*
x Inb.492	1.98**	14.10**	-0.39*	0.57**	0.77*	-0.08	0.85*	-0.03	-0.08	-4.05**
x Inb.564	0.23	- 1.90	-0.09	-0.33	0.92	-0.03	1.05**	0.07	-0.11*	1.37
x RHRB-28-2	0.73**	3.60*	0.16	-0.23	0.72	-0.03	0.40	0.07	0.49**	2.37
x RHRB-28-4	-0.03	3.60*	0.16	0.07	1.17**	0.22	0.35	0.25*	-0.14**	12.87**
x Manmad Local	-1.28**	14.10**	-0.59**	0.17	1.77**	0.17	0.25	-0.03	1.19**	- 1.63
x RBS-23	0.73**	4.45**	0.80**	0.52**	-0.73	0.62**	-1.21**	-0.15	-0.26**	12.37**
x RBS-28	0.73**	7.10**	0.16	0.02	0.02	0.22	0.60	-0.05	-0.53**	- 5.38**
x Inb.492-1	-0.28	- 2.25	-0.04	0.07	-0.33	-0.13	0.30	0.10	0.02	4.37**
x RBS-225	-1.78**	3.80*	0.06	-0.08	0.17	-0.18	0.60	0.15	-0.06	- 5.13**
x RBS-240	-1.53**	-1.10	-0.74**	-0.28	-0.83*	-0.33*	-1.11**	0.07	0.02	- 5.13**
x RBS-243-2	-0.28	-3.20	-0.34*	0.12	-0.98**	-0.23	-0.51	0.25*	-0.03	- 2.88*
x RBS-347	2.73**	-2.60	-0.19	-0.13	-0.98**	0.02	1.45**	-0.08	-0.80**	6.12**
x RBS-359	-0.78**	-13.10**	0.48**	-0.20	-2.21**	-0.63**	-0.26	-0.20	0.12**	13.87**
x RBS-431-6	0.73**	- 6.00**	0.28	-0.38	0.52	0.07	0.65	0.15	0.09	- 2.38

Continued.....

Table 6. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
5054 A x Inb.564	-0.23	1.90	0.09	0.33	-0.92*	0.03	-1.05**	-0.07	0.11*	-1.37
x RHRB-28-2	-0.73**	-3.60*	-0.16	0.23	-0.72	0.03	-0.40	-0.07	-0.49**	-2.37
x RHRB-28-4	0.03	-3.60*	-0.16	-0.07	-1.17**	-0.22	-0.35	-0.25*	0.14**	-12.87**
x Manmad Local	1.28**	-14.10**	0.59**	-0.17	-1.77**	-0.17	-0.25	-0.03	-1.19**	1.63
x RBS-23	-0.73**	- 4.45**	-0.81**	-0.52**	0.73	-0.62**	1.21**	0.15	0.26**	-12.37**
x RBS-28	-0.73**	- 7.10**	-0.16	-0.02	-0.02	-0.22	-0.60	0.05	0.53**	5.38**
x Inb.492-1	0.28	2.25	0.04	-0.07	0.33	0.13	-0.30	-0.10	-0.02	- 4.37**
x RBS-225	1.78**	- 3.80*	-0.06	0.08	-0.17	0.18	-0.60	-0.15	0.06	5.13**
x RBS-240	1.53**	1.10	0.74**	0.28	0.83*	0.33*	1.11**	-0.07	-0.02	5.13**
x RBS-243-2	0.28	3.20	0.34*	-0.12	0.98**	0.23	0.51	-0.25*	0.03	2.88*
x RBS-347	-2.73**	2.60	0.19	0.13	0.98**	-0.02	-1.45**	0.08	0.80**	-6.12**
x RBS-359	0.78**	13.10**	-0.48**	0.20	2.21**	0.63**	0.26	0.20	-0.12*	-13.87**
x RBS-431-6	-0.73**	6.00**	-0.28	0.38	-0.52	-0.07	-0.65	-0.15	-0.09	2.38
S.E. ±	0.24	1.67	0.17	0.19	0.37	0.14	0.36	0.12	0.05	1.36
C.D. at 5%	0.47	3.34	0.33	0.39	0.74	0.28	0.71	0.24	0.10	2.72
C.D. at 1%	0.63	4.44	0.44	0.52	0.98	0.37	0.95	0.32	0.13	3.62

4.4.1 Days to flowering :

From the Table 5, it can be seen that the female 5141 A had significant negative while 5054 A had significant positive g.c.a. effects for this character. Among the males RBS-431-6 had highest negative value of g.c.a. effects and was followed by that of Sel.J-104; Inb.1002-1 and Inb.1008. Out of 30 males, 14 showed significant negative, while 12 positive g.c.a. effects. The Inb.492 showed the highest value of positive g.c.a. effects, followed by RBS-23, RBS-28, Rahuri Long Earhead and Inb.45.

As regards s.c.a. effect, thirteen and nine crosses based on 5141 A female parent showed significant negative and positive effects, respectively. The higher values of the negative s.c.a. effect were found in 5141 A x Inb.1037, 5141 A x Inb.1036 and 5141 A x RBS-225 crosses, while such values of positive s.c.a. effect were recorded in 5141 A x RBS-347; 5141 A x Restorer-3 and 5141 A x Sel. J-104.

Of the crosses involving 5054 A female parent, seven and twelve crosses had significant negative and positive s.c.a. effect, respectively. The magnitude of the negative s.c.a. effects were higher in 5054 A x Restorer-3; 5054 A x Inb.492-1 and 5054 A x Inb.337-1, crosses while that of positive s.c.a. effects in 5054 A x Inb.1037, 5054 A x Inb.1036 and 5054 A x RBS-225, crosses.

4.4.2 Plant height :

The data on g.c.a. effects, presented in Table 5, indicated that the female 5054 A showed significant positive while 5141 A significant negative g.c.a. effects. Out of 30 male parents, 14 and 12 showed significant positive and negative g.c.a. effects, respectively. Rahuri Long Earhead, Inb.1022 and RBS-23 had higher values of the positive g.c.a. effects, while Inbreds.1026; 1036 and 1002-2 had higher values of the negative g.c.a. effects.

Among the crosses derived from 5141 A female parent nine had significant positive while thirteen had significant negative s.c.a. effects. The crosses involving male parent, Inb.492; Manmad Local and Inb.1008 had higher magnitude of positive s.c.a. effects; while, combinations having RBS-359; Inb.337-1 and Inb.1002-1 male parents showed higher values of the negative s.c.a. effects.

Of the crosses having 5054 A as a female parent eight showed significant positive effect while eleven showed negative effects. The higher values among the former crosses were noted in 5054 A x Inb.337-1,5054 A x RBS-359 and 5054 A x Inb.1002-1 crosses; while among the latter such values were observed in 5054 A x Inb.492, 5054 A x Manmad Local and 5054 A x Inb.1008, crosses.

4.4.3 Number of tillers/plant

The female parent 5141 A had significant negative, while 5054 A had significant positive g.c.a. effects.

Among the males, five and seven showed significant positive and negative values of the g.c.a. effects, respectively. The higher values of the positive g.c.a. effects were noted in Inb.1002-1; Inb.1043 and RBS-28 while such values of negative g.c.a. effects were found in Inb.492-1; Inb.1002-2 and Rahuri Long Earhead.

The crosses of 5141 A with Restorer-3, Inb.337-1, Inb.1036, RBS-23 and RBS-431-6 showed significant positive s.c.a. effects while those with Inb.1043, Inb.483, Inb.492, Manmad Local, RBS-240 and RBS-243-2 showed significant negative s.c.a. effects.

Of the crosses based on 5054 A, seven and four showed significant positive and negative s.c.a. effects, respectively. The crosses 5054 A x RBS-28 and 5054 A x Inb.337-1 showed higher values of the negative effects, while 5054 A x RBS-240 and 5054 A x Manmad Local showed such values of the positive s.c.a. effects.

4.4.4 Number of internodes :

For node number on main shoot, 5141 A and 5054 A showed significant positive and negative g.c.a. effects, respectively.

Among the male parents Inb.1022 and Manmad Local had significant positive, while RBS-431-6, had significant negative g.c.a. effects.

Four crosses viz., 5141 A x Inb.1037; 5141 A x Inb.483, 5141 A x Inb.492 and 5141 A x RBS-23 exhibited significant positive s.c.a. effects while, 5141 A x Inb.1002-1 and 5141 A x Inb.337-1 had significant negative s.c.a. effects.

Two crosses viz; 5054 A x Inb.1002-1 and 5054 A x Inb.337-1 and four crosses viz; 5054 A x Inb.1043, 5054 A x Inb.483; 5054 A x Inb.492 and 5054 A x RBS-23, based on 5054 A female parent, showed significant positive and negative s.c.a. effects, respectively.

4.4.5 Internode length :

None of the female parents had significant g.c.a. effects.

Out of thirty male parents, five viz; Inb.1022; Inb.1043; RHRB-28-4; Manmad Local and RBS-23 and seven viz; Restorer-3, Inb.1002-1, Inb.142-2; Inb.337-1, Inb.483; Inb.564 and Inb.492-1 showed significant positive and negative g.c.a. effects, respectively.

Five crosses based on 5141 A female parent and involving Restorer-3; Inb.483; Inb.492, RHRB-28-4; and Manmad Local as male parent; expressed significant

positive s.c.a. effects and same number of crosses of this female with Inb.1002-2; RBS-240, RBS-243-2, RBS-347 and RBS-359 male parent had significant negative s.c.a. effects.

As regards the significant combining ability of the crosses derived from 5054 A female parent, five involving Inb.1002-2; RBS-240, RBS-243-2, RBS-347 and RBS-359 male parents and six involving Restorer-3,Inb.483, Inb.492, Inb.564, RHRB-28-4 and Manmad Local male parents showed significant positive and negative s.c.a. effects, respectively.

4.4.6 Number of leaves :

The female parents 5141 A and 5054 A showed significant negative and positive g.c.a. effects, respectively.

Of the male parents, nine showed positive g.c.a. effects, while eleven had negative g.c.a. effects.

Four crosses viz; 5141 A x Inb.1026, 5141 A x Inb.1036, 5141 A x Inb.1043, and 5141 A x RBS-23 and three crosses viz; 5141 A x Inb.1002-1, 5141 A x RBS-240, 5141 A x RBS-359 involving 5141 A showed significant positive and negative s.c.a. effects, respectively.

Out of 30 crosses having 5054 A as a female parent, three viz; 5054 A x Inb.1002-1; 5054 A x RBS-240

and 5054 A x RBS-359 and four viz; 5054 A x Inb.142-2; 5054 A x Inb.1036; 5054 A x Inb.1043 and 5054 A x RBS-23 exhibited significant positive and negative effects, respectively.

4.4.7 Earhead length :

For earhead length, 5141 A showed positive while 5054 A negative g.c.a. effects.

Eight male parents had positive, while fifteen had negative g.c.a. effects.

Among the crosses involving 5141 A as a female parent, 5141 A x Restorer-3; 5141 A x Rahuri Long Earhead, 5141 A x Inb.564 and 5141 A x RBS-359 exhibited significant positive s.c.a. effects; while 5141 A x Inb.1002-2, 5141 A x Inb.1019, 5141 A x Inb.1026, 5141 A x Inb.337-1, 5141 A x Inb.483, 5141 A x RBS-23 and 5141 A x RBS-240 showed significant negative s.c.a. effects.

Of the crosses in which 5054 A was the female parent,5054 A x Inb.1002-2, 5054 A x Inb.1019, 5054 A x Inb.1026, 5054 A x Inb.337-1 and 5054 A x Sel.J-104 showed positive while 5054 A x Restorer-3, 5054 A x Rahuri Long Earhead, 5054 A x Inb.45, 5054 A x Inb.492, 5054 A x Inb.564 and 5054 A x RBS-359 negative s.c.a. effects.

Eight crosses based on 5141 A female parent and involving Manmad Local, Inb.1037, Inb.1036,RHRB-28-2, Inb.45, Restorer-3, Inb.1043 and RBS-359 as male parents, exhibited significant positive s.c.a. effects and ten crosses of this female with RBS-359, Inb.1022, RBS-28, Inb.337-1, Sel.J-104, RBS-23, Inb.1002-2, Inb.1019, RHRB-28-4 and Inb.564 male parents had significant negative s.c.a. effects.

Out of 30 crosses having 5054 A as a female parent, ten and eight crosses showed significant positive and negative s.c.a. effects. The higher magnitudes in former were observed in 5054 A x RBS-347, 5054 A x Inb.1022, 5054 A x RBS-28 and 5054 A x Inb.337-1 and that of latter in 5054 A x Manmad Local, 5054 A x Inb.1037, 5054 A x Inb.1036 and 5054 A x RHRB-28-2.

4.4.10 Grain yield/plant :

For grain yield per plant g.c.a. effects of the 5141 A female parent was negative while that of 5054 A, positive.

Of the nine male parents showing significant positive g.c.a. effects, magnitude was higher in RBS-23, RBS-225, Inb.1022, Restorer-3, Inb.142-2, while of the fifteen showing significant negative g.c.a. effects, values were higher in Inb.1002-2, RBS-431-6 and Inb.1037.

Nine crosses based on 5141 A female parent had significant positive s.c.a. effects with higher values in 5141 A x RBS-359, 5141 A x RHRB-28-4 and 5141 A x RBS-23. Twelve crosses showed significant negative s.c.a. effects and the magnitude was higher in 5141 A x Inb.337-1, 5141 A x Inb.1037, 5141 A x Inb.1022 and 5141 A x Inb.1002-1 crosses.

As regards the specific combining ability effects of the crosses involving 5054 A as a female parent, twelve showed significant positive, while nine negative s.c.a. effects. Among the crosses showing positive s.c.a. effects, higher values were recorded in 5054 A x Inb.337-1, 5054 A x Inb.1037, 5054 A x Inb.1002-1 and 5054 A x Inb.1022. Of the crosses having significant negative s.c.a. effects, magnitude was higher in 5054 A x RBS-359, 5054 A x RHRB-28-4 and 5054 A x RBS-23.

4.5 Gene action and heritability :

The values of the estimates of g.c.a. and s.c.a. variances, their ratios and percentages of the heritability are presented in Table 7.

It can be seen from this table that values of the variances due to g.c.a. effects were higher for grain yield per plant and plant height among the characters studied.

Table 7. Estimates of general and specific combining ability and heritability for ten different characters in pearl millet.

Sr. No.	Character	$\hat{\sigma}^2$g.c.a.	$\hat{\sigma}^2$s.c.a.	$\hat{\sigma}^2$g.c.a./$\hat{\sigma}^2$s.c.a.	h^2(%)
1.	Days to flowering	0.99	2.93	0.34	23.17
2.	Plant height(cm)	3.33	71.10	0.05	3.61
3.	Number of tillers/ plant	0.04	0.16	0.27	11.57
4.	Number of internodes	0.01	0.11	0.03	0.94
5.	Internode length(cm)	-0.01	1.14	-0.01	- 0.46
6.	Number of leaves	0.01	0.13	0.08	4.08
7.	Earhead length(cm)	0.81	1.88	0.43	23.10
8.	Earhead girth(cm)	0.01	0.06	0.16	5.76
9.	500-grain weight(g)	-0.01	0.29	-0.01	- 0.83
10.	Grain yield per plant(g)	6.91	81.37	0.09	6.91

The values of the s.c.a. effects were higher for plant height and grain yield per plant among the ten characters. The values of the s.c.a. variances for all the ten characters studied were higher than those of g.c.a. variances. The ratios of variances due to g.c.a. and s.c.a. effects were less than unity for the characters.

Of the ten characters studied, the values of the heritability estimates were medium for days to flowering (23.17%), earhead length (23.10%) and effective tillers per plant (11.57%). The values of the rest of the characters ranged between -0.46 and 6.91 per cent which were low.

4.6 Percentage contribution of females,males and females x males to the hybrid s.s. :

Percentage contribution of males, females and females x males to the sum of squares of hybrids are presented in Table 8.

The contribution of female parents was ranged between 10.30 (days to flowering) to 0.23 (internode length) per cent.

The contribution of male parents was ranged from 43.58 (number of nodes) to 86.88 per cent (earhead length).

Table 8. Percentage contribution of females, males and females x males interaction to S.S. of hybrids.

Sr. No.	Characters	Source of variation		
		Females (%)	Males (%)	Females x Males (%)
1.	Days to flowering	10.30	60.27	29.43
2.	Plant height (cm)	0.27	74.89	24.83
3.	Number of tillers/ plant	6.85	59.38	33.76
4.	Number of internodes	3.02	43.58	53.39
5.	Internode length(cm)	0.23	61.97	37.81
6.	Number of leaves	1.57	68.47	29.96
7.	Earhead length (cm)	2.07	86.88	11.05
8.	Earhead girth (cm)	0.25	81.41	18.33
9.	500-grain weight(g)	1.01	52.06	46.93
10.	Grain yield/plant(g)	1.04	75.64	23.32

The percentages of contribution by male parents to the hybrids were higher for all the characters than those by female parents. The contribution due to females x males was ranged between 11.05(earhead length) to 53.39 (number of nodes on main stem) per cent.

5. DISCUSSION

5. DISCUSSION

In allogamous crop like pearl millet the breeder is interested to develop heterozygous populations in the form of hybrids or synthetics by combining promising inbred lines. Though the performance of parents themselves gives some indications regarding their usefulness, their long term potentialities are the least known at the begining of the programme. The combining ability analysis assesses the utility value of the crosses and the parents. The utility of the line x tester design (Kempthorne, 1957) in deciding about the relative capabality of a number of female and male parents to produce desirable hybrids is well known.

The general combining ability is defined as "the average performance of a line in a series of crosses" and the specific combining ability is used to refer those cases in which certain combinations perform relatively better or worse than would be expected on the basis of the average performance of the lines involved (Sprague and Tatum, 1942). Burton (1958) developed a cytoplasmic genetic male sterile line for the first time in pearl millet and utilization of this type of sterility led to the development of number of commercial hybrids which marked a major step in increasing yield levels of this crop. The increase in the production per unit area and per unit time is the basic aim in breeding field crops The yield is the complex

character dependent on several other component characters. The knowledge of variation and nature of combining ability of inbreds for grain yield and its attributes is of imense importance to the breeder in planing heterosis or recombination breeding programme.

The existing two male sterile lines viz; 5141 A and 5054 A have good agronomic base. The number of newly developed bold-seeded and disease resistant inbreds, were also available with the Bajra Improvement Project. Considering the usefulness of line x tester design in assessing the performance of large number of genotypes, the present investigations were aimed at studying the heterosis and combining ability for grain yield and yield contributing attributes of the newly developed inbreds. The results of the present investigations are presented in chapter IV and the same have been discussed in brief as under.

5.1 Mean performance and analysis of variance :

The data on mean performance of the parents are presented in Table 1. From this table, it can be seen that each of the female lines used in the present investigations had some desirable attributes. The line 5141 A was found to be superior in earhead girth (6.30 cm), grain yield per plant (31.00 g) and 500-grain weight (3.25 g/500-seed), while 5054 A was early flowering(42 days),tall (118.80 cm), with good tiller number per plant (5.20), internodal length (15.10 cm), number of leaves (5.75) and had long ears (20.45 cm).

All the newly developed inbreds involved as male parents in the present investigation had thicker earheads (6.38 to 9.93 cm) and bolder grains (2.25 to 5.80 g/500-grains) than both the females. The male parents, RBS-225 (5.80 g), RBS-347 (5.50 g), Manmad Local (5.10 g), Inb.337-1 (5.10 g), RBS-431-6 (5.00 g), Inb.483 (4.95 g) and Inb.1043 (4.90 g) produced bold grains and Inb.1019 (9.93 cm), Inb.1022 (9.75 cm), Inb.1002-1 (9.60 cm), Inb.564 (9.50 cm) had more girth of the ear compared to rest of the female and male parents included in this study. The inbreds RBS-359 (40 days), Inb.142-2 and RBS-243-2 (43.50) were early in flowering. Both the female lines viz; 5141 A (4.00) and 5054 A (5.20) had produced higher number of tillers than all the males except RBS-431-6 (4.10). Out of 30 male lines, 20 had higher grain yield per plant compared to female lines like 5141 A and 5054 A. The male parent RHRB-28-2 produced the highest grain yield (66.00 g) per plant amongst the parental lines and was followed by RHRB-28-4 (59.00 g) and Inb.1008 (58.50 g).

5.2 ANOVA :

The data presented in Table 2 shows that the variances due to parents Vs hybrids which may be taken as a measure of heterosis, were highly significant for all the characters except number of nodes on main stem. The variances due to females for days to flowering, plant height, number of nodes, internodal length, number of leaves, earhead girth were non-significant. This might be

due to their close relation for these traits. The mean sum of squares due to males were highly significant for all the characters.

As regards the crosses, the differences were highly significant for all the characters under study. Upadhyay and Murty (1971), Thakare and Murty (1972), Kunjir (1982) and Kale (1985) also observed significant differences amongst hybrids for all the characters in their studies. Jain and Majumdar (1975) observed significant differences among hybrids for plant height, ear length and grain yield per plant. Thete (1984), recorded significant differences for all the characters except tillers per plant.

5.3 Heterosis :

The utilization of heterosis in breeding hybrid varieties has opened the new vistas to boost up the crop yield in major cross pollinated species. The heterosis breeding in pearl millet has made tremendous impact and a number of high yielding hybrids have been released for general cultivation. So as to upgrade the yield levels further, it is essential to develop restorers having potentialities to produce high yielding hybrids with other desirable attributes like earliness, disease resistance etc. The heterosis for grain yield and its attributes, studied in the crosses of two male sterile lines with thirty newly developed inbreds (Table 3) has been discussed in brief and presented below.

From Table 3, it can be seen that an appreciable amount of heterosis over mid and superior parent was found for almost all the characters. The range of the percentages of heterosis recorded for different characters has been presented in Table 9.

Fourteen and two crosses based on 5141 A and 5054 A female parents; respectively showed negative heterosis for days to flowering. The negative heterosis is of interest to the breeders as it indicate earliness. Among all the hybrids, 5141 A x Inb.1002-1, 5141 A x Inb.1002-2, 5141 A x Inb.1008, 5141 A x Inb.1037, 5054 A x Sel.J-104 and 5054 A x RBS-431-6 were early(over SP, -1.19 to -5.75 and over MP, -5.14 to -9.39).The character earliness was found to be dominant in most of the crosses. The negative heterosis for days to flowering was also previously reported by Burton (1951), Ahluwalia et al. (1963), Murty et al. (1967), Lal and Singh (1968), Phul and Singh (1970), Phul et al. (1973), Thete (1984) and Kale (1985).

Twenty three hybrids based on 5141 A and twenty two involving 5054 A female were heterotic for plant height indicating role of dominance gene action for this trait. The magnitude of heterosis for plant height was between 4.48 to 74.73% in the former set of crosses, while it was between 7.17 to 65 27% in the latter. The positive heterosis for plant height was also observed by Singh and Singh (1941), Burton (1951), Ahluwalia et al. (1963), Murty et al. (1967), Lal (1969), Singh (1970), Phul et al. (1973),

Table 9. The range of heterosis for ten characters in pearl millet.

Sr. No.	Characters	Range of the percentages of heterosis	
		Over SP	Over MP
1.	Days to flowering	- 5.75 to 14.28	- 9.39 to 10.98
2.	Plant height (cm)	-28.65 to 50.73	-13.75 to 74.73
3.	Number of tillers/ plant	-46.15 to 12.50	-34.25 to 45.16
4.	Number of inter-nodes	-24.32 to 31.58	-14.50 to 33.93
5.	Internode length (cm)	- 8.61 to 40.40	2.34 to 58.21
6.	Number of leaves	-27.85 to 32.17	-15.56 to 38.25
7.	Earhead length(cm)	-31.17 to 46.20	-12.61 to 51.60
8.	Earhead girth (cm)	-27.02 to 11.27	-13.62 to 18.35
9.	500-grain weight(g)	-49.02 to 74.51	-31.03 to 78.36
10.	Grain yield/plant (g)	-27.96 to 257.45	0.74 to 277.32

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Subramaniam and Rathinam (1980), Sreenivasulu and Sreeramulu (1980) and Kale (1985).

In respect of tillers per plant, ten crosses with 5141 A as female and four combinations with 5054 A as female showed positive heterosis ranging from 21.13 to 45.16% and 17.50 to 25.33%, respectively. The crosses 5141 A x RHRB-28-2, 5141 A x Restorer-3, 5141 A x RBS-23, 5141 A x RBS-28, 5054 A x Inb.1002-1, 5054 A x Inb.1043, 5054 A x RHRB-28-2 and 5054 A x RBS-240 had higher number of tillers per plant and were also heterotic. Lal and Singh (1969), Tewari (1970), Gupta and Sindhu (1972), Tyagi et al. (1975) and Singh et al. (1980) also noted positive heterosis for tillers per plant in their studies. The negative heterosis exhibited by number of crosses for this character in the present investigations was in conformity with the results reported by Jain et al. (1961), Ahluwalia et al. (1962) and Thete (1984).

For the number of nodes on main stem, only three crosses involving 5141 A as a female parent showed heterosis over mid and two over superior parent respectively with the range of 15.20 to 33.93% in the former while 24.66 to 31.58% in latter. Among the crosses involving 5054 A female line, 5054 A x Inb.564 (15.79%) and 5054 A x Inb.1002-1 (22.81%) showed significant positive heterosis over superior parent while five crosses showed heterosis over mid parent and the

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range was from 13.85 to 25.00%. The positive and significant heterosis for nodes on main stem was previously observed by Lal and Singh (1968), Tewari (1970), Badwal (1970), Deshpande (1980) and Thete (1984).

The number of hybrids showed significant increase in internodal length over their mid as well as superior parent. Thirteen and Twenty seven crosses involving 5141 A as a female parent showed significant positive heterosis over superior and mid parents respectively, for this character. The range of heterosis over superior parent was from 11.86 to 36.11% and that for mid parent it was from 11.54 to 50.19%. Seventeen and twenty four crosses in which 5054 A was involved showed significant positive heterosis over superior and mid parent, respectively. The positive heterosis for internodal length was also reported previously by Thete (1984).

In respect of number of leaves on main stem, positive heterosis over superior and mid parent was observed in 11 and 21 crosses respectively, in which 5141 A was a female parent. The range in the former was between 15.25 and 30.36%, while in latter case it was between 12.15 and 33.95%. Twelve and twenty crosses based on 5054 A showed significant positive heterosis ranging from 13.04 to 32.17% and 11.01 to 41.06%, over SP and MP respectively. This was in confirmity with the previous studies of Tewari (1970), Singh (1970), Patil (1979), Deshpande (1980) and Thete (1984).

Of the 30 crosses based on 5141 A, 18 produced significant and positive heterosis (8.96 to 46.20%) over superior parents and 25 over mid parents (6.80 to 51.60%) for earhead length. Among the crosses involving 5054 A, 17 excelled the performance of mid parent by 6.81 to 38.22% and twelve that of superior parents by 7.66 to 38.04%. The expression of positive heterosis in most of the crosses revealed dominance of longer earhead in general. The crosses involving inbreds like 491-1, Restorer-3, 1019, 1022, 45, RBS-23, RBS-225 and RBS-359 produced longer earheads. There are possibilities of developing high yielding hybrids by utilizing inbreds showing heterotic effects for this attribute as a number of previous studies have indicated that the earhead length plays a major role in producing higher grain yield per plant. (Murty et al. 1967, Burton and Powell, 1968; Singh, 1970; Phul and Singh, 1970; Sundarpandian,1973; Phul et al. 1973; Subramaniam and Rathinam, 1980; Mukherji et al. 1981; Thete 1984 and Kale, 1985).

In most of the crosses except a few involving 5141 A and 5054 A as female parents, the negative heterosis was observed for girth of earhead. These results are in agreement with those reported by Jain et al. (1961), Ahluwalia et al. (1962) and Kale (1985). However, Meenakshi et al. (1977) in their study indicated that the girth of earhead is an important yield contributing character.

For grain weight, 11 and 15 crosses involving 5141 A and 5054 A as female parents showed significant positive heterosis ranging from 6.25 to 32.54% and 6.18 to 78.36% respectively, over mid-parent. Six crosses each involving 5141 A (7.69 to 23.08%) and 5054 A (16.28 to 74.51%) showed significant positive heterosis over superior parent. In the previous studies conducted by Phul et al. (1973), Sodani et al. (1978), Subramaniam and Rathinam (1980), Rao et al. (1983) and Kale (1985) such type of heterosis for grain weight was also observed. These data indicate the need of giving due weightage to the parents showing substantial heterosis for grain weight in different cross combinations for exploiting hybrid vigour for grain yield per plant.

The positive heterosis over mid parent (12.85 to 277.32%) and superior parent (11.02 to 195.16%) for grain yield was noticed in 27 and 22 crosses based on 5141 A female parent. Twenty nine crosses involving 5054 A as a female parent exhibited heterotic effect (18.90 to 274.16%) over mid parent and twenty five (15.76 to 257.45%) over superior parent. The data revealed that in most of the crosses higher grain yield per plant was found to be dominant trait. In general the crosses of inbreds RBS-23, Restorer-3, Inb.1022, RBS-225 and Inb.142-2 with both the female parents produced very high heterotic effects in respect of this trait (Table 10). In addition, the heterotic effects for grain yield in the crosses of inbreds 1043

and Inb.337-1 with 5141 A and 5054 A were also appreceable in magnitude. Incidently, all these crosses had also higher mean values than the high yielding parents and the standard check BK-560. These crosses may be useful for replasing some of the present pearl millet hybrids.

It is interesting to note that not all the crosses showing very high heterosis were also higher yielding. For example, the crosses of 5141 A with Manmad Local, Inb.1002-2, RBS-359 and crosses of 5054 A with Inb.1002-2, Inb.1037, Inb.492, Manmad Local were highly heterotic but mean values for grain yield were lesser than the high yielding parents and also the standard check BK-560. Kale (1985) also recorded that not all the crosses, heterotic for grain yield were also higher yielding.

These crosses having high heterotic effect, also higher grain yield could be tested at different locations for testing their yield performance under different environmental conditions. While selecting a particular hybrid, it is, therefore, necessary to consider the per se performance in addition to its heterotic effect for grain yield.

The heterotic effects for grain yield in the crosses involving 5141 A and 5054 A was found to be mostly influenced by heterosis for either one or more of the yield contributing attribute like plant height, tillers per plant, internodal length, number of nodes, number of leaves, ear length, girth and 500-grain weight.

Table 10. The crosses having high mean grain yield per plant and showing high heterotic effects.

Name of the crosses	Mean grain yield (g/plant)	Heterosis over SP (%)	Heterosis over MP (%)
5141 A x RBS-23	91.50	195.16	277.32
5141 A x Restorer-3	81.10	161.61	197.61
5141 A x Inb.1043	75.00	38.89	76.47
5141 A x RBS-225	71.00	97.22	111.94
5141 A x Inb.142-2	68.00	34.65	66.87
5141 A x Inb.1022	66.50	114.52	144.04
5054 A x Inb.1022	84.00	257.45	274.16
5054 A x RBS-225	84.00	133.33	192.68
5054 A x Inb.337-1	78.50	76.40	138.24
5054 A x Inb.142-2	74.50	47.52	107.23
5054 A x Inb.1002-1	72.00	238.79	254.52
5054 A x RBS-243-2	71.00	231.78	238.90
5054 A x Restorer-3	68.00	189.36	202.90
5054 A x Inb.45	66.50	98.51	142.26
BK-560	55.00	-	-

5.4 ANOVA for combining ability :

The analysis of variance for combining ability as presented in Table 4 indicated the existance of significant differences for combining ability effects among the females for all the characters except plant height, number of internodes, internodal length and earhead girth. The magnitude

of g.c.a. variances due to females were much higher than those due to males and s.c.a. variances due to female x male interactions for days to flowering, number of tillers per plant and number of nodes on main shoot. Badwal (1970), Tyagi et al. (1975), Kunjir (1982), Thete (1984) and Kale (1985) in their studies also noted such higher magnitude of g.c.a. effects of females for days to flowering, number of tillers per plant and number of nodes on main shoot.

The differences among males were significant for all the characters except number of nodes on main shoot and the magnitude of the variances due to general combining ability of males were comparatively higher than those of specific combining ability for all the characters except number of nodes for which variance due to specific combining was higher. These observations reveal the importance of general combining ability effects for grain yield per plant and its most of the componental characters.

5.5 General combining ability effects :

The g.c.a. effects of the female parent 5141 A were higher for days to flowering, number of nodes, earhead length, earhead girth and 500-grain weight. This female parent was found to be the best general combiner for the above characters, and average combiner for internodal length and earhead girth. The poor combining ability of this male sterile line was observed for plant height, number of tillers, number of leaves and grain yield per plant.

The female 5054 A was found to be the best general combiner for plant height, number of tillers, number of leaves and grain yield per plant. This male sterile line, however, exhibited negative g.c.a. effects for number of nodes, earhead length, girth and 500-grain weight and positive for days to flowering, indicating its poor general combining ability for these characters. Both the female parents were found to be average general combiners for internodal length and earhead girth. Kale (1985) in his study observed 5141 A to be the good combiner for 500-grain weight while 5054 A was the best general combiner for tillers and grain yield per plant, in the studies conducted by Kunjir (1982), Thete (1984) and Kale (1985).

Among the males, RBS-23, RBS-225, Inb.1022, Restorer-3, Inb.142-2, Inb.1043, Inb.337-1, Inb.1002-1 and Inb.45 were found to be the best general combiners for grain yield per plant. The inbreds 1019, RHRB-28-2, RHRB-28-4, Inb.492-1 and RBS-240 were the average combiners for this trait, while rest of the inbreds had significant negative g.c.a. effects, suggesting their poor general combining ability.

The male parents showing very high general combining ability effects for grain yield per plant were also the best general combiners for one or more yield contributing characters. Inb.1022 was found to be the best

general combiner for eight characters, RBS-23 and RBS-225 for six characters, Inb.1002-1 for five characters. Inbred 1043 and RBS-243-2 for four characters, Restorer-3, Inb.142-2 and Inb.337-1 for three characters and Inbred-45 for two characters (Table 11).

Similar was the case with the male parents showing average general combining ability for grain yield per plant. They were either best or average general combiners for one or more yield contributing characters.

None of the parents, however, showed consistently high general combining ability effects for all the characters. Therefore it is difficult to select a parent which is best general combiner for all the characters. The male parents which exhibited high general combining ability effects for more than one character in addition to grain yield are given in Table 11.

Incidently, it can be seen that the male parents which exhibited high general combining ability for grain yield were the same which expressed very high heterotic effects in combination with 5141 A and 5054 A for grain yield and had mean grain yield per plant higher than the high yielding parents and also the standard check BK-560-230.

From these findings, it is apparent that high general combining ability effects for grain yield could be attributed to the high general combining ability effects for

Table 11. Best general combiners (male parents) for different characters in combination with grain yield.

Parents	Best general combining ability for	
	Number of characters	Name of the characters
Inb.1022	8	Grain yield, days to flowering, plant height, number of internodes, Internode length, number of leaves, earhead girth and 500-grain weight.
RBS-23	6	Grain yield, plant height, number of internodes, internode length, number of leaves and earhead length.
RBS-225	6	Grain yield, plant height, number of tillers, earhead length, earhead girth and 500-grain weight.
Inb.1002-1	5	Grain yield, days to flowering, number of tillers, earhead length and girth.
Inb.1043	4	Grain yield, days to flowering, plant height and earhead girth.
RBS-243-2	4	Grain yield, days to flowering, plant height and earhead length.
Restorer-3	3	Grain yield, plant height and number of tillers.
Inb.142-2	3	Grain yield, days to flowering and plant height.
Inb.337-1	3	Grain yield, plant height and number of leaves.
Inb.45	2	Grain yield and earhead length.

one or more yield contributing traits. The male parents RBS-23, RBS-225, Inb.1043, Inb.142-2, Inb.1022, Inb.337-1, Inb.243-2, Inb.45 are therefore worth considering as they are better combinations for one or other yield attributing character and hence could be used to exploit hybrid vigour or involved in crossing programme so as to combine desirable yield contributing traits. The recombinants could form a base material for development of new restorers or synthetic populations.

5.6 The specific combining ability effects of hybrids :

Out of thirty crosses based on 5141 A female parent, twelve exhibited significant negative s.c.a. effects for days to flowering. The higher magnitudes of s.c.a. effects were recorded in 5141 A x Inb.1037, 5141 A x Inb.1036, 5141 A x RBS-225 and 5141 A x RBS-240. Out of these, former two were derived from high x high, while latter from high x poor general combiners. Of the ten crosses based on 5054 A and showing significant negative s.c.a. effects, five viz; 5054 A x Restorer-3, 5054 A x RBS-347, 5054 A x Inb.492, 5054 A x Inb.337-1 and 5054 A x Sel.J-104 had produced higher magnitude of significant negative s.c.a. effects. The first three crosses were derived from poor x poor; the fourth one from poor x average and the last from the combination of poor x high general combiners; for days to flowering.

For plant height, ten of the thirty crosses derived from 5141 A (poor general combiner) female parent produced significant positive s.c.a. effects and the higher magnitudes were noted in crosses involving male parents, Inb.492 (average general combiner), Manmad Local and RBS-28 (high general combiner) and Inb.1008 (poor general combiner). The combinations of 5054 A with RBS-359, Inb.337-1, Inb.1002-1, Sel.J-104, RBS-28, RBS-431-6, Inb.1026 and Inb.142-2 produced significant s.c.a. effects and these combinations were either between high x high or high x poor general combiners.

Five and seven crosses involving 5141 A (poor general combiner) and 5054 A (high general combiner) female parents, respectively showed significant positive s.c.a. effects for number of tillers per plant. The inbreds involved in these crosses with 5141 A were high (Restorer-2) and average (Inb.337-1, Inb.1036, RBS-23 and RBS-359) general combiners, while with 5054 A, high (Inb.1043 and Sel.J-104), average (Inb.483, Manmad Local, RBS-240 and RBS-243-2) and poor (Inb.492) general combiners.

The combinations involving inbreds like 1043, 483, 492 and RBS-23 with 5141 A showed significant s.c.a. effects for number of nodes on main stem and were either between parents having high and average or high and high general combining ability (Table 6). Specific combining ability

estimates suggest that the crosses 5054 A x Inb.1002-1 and 5054 A x Inb.337-1 are the best combinations and may be used for exploiting the high s.c.a. effects through further breeding programme for producing superior types for more number of nodes. These crosses were derived from poor x average general combiners.

Of the thirty crosses based on 5141 A female parent, five exhibited significant positive s.c.a. effects for internode length and the male parents involved were Restorer-3, Inb.483, Inb.492, RHRB-28-4 and Manmad Local. Of these five crosses, two were derived from average x poor, two from average x average and one from average x high general combiners. The crosses in which 5054 A was the female parent (average general combiner) produced significant positive s.c.a. effect for the internode length in five crosses involving male parents like Inb.1002-2 (poor general combiner), RBS-240, RBS-243-2, RBS-347 and RBS-359 (average general combiners).

For the number of leaves on main shoot, four crosses of 5141 A female parent with Inb.142-2, Inb.1036, Inb.1043 and RBS-23 male parents produced significant positive s.c.a. effects. These crosses were derived from either poor x average, poor x poor or poor x high general combiners. Three crosses viz; 5054 A x Inb.1002-1, 5054 A x RBS-359 and 5054 A x RBS-240 showing positive s.c.a. effects were the combinations between high x poor, high x high and high x average general combiners, respectively.

Seven and eight crosses involving 5141 A (high general combiner) and 5054 A (poor general combiner) female lines respectively showed significant positive s.c.a. effects for earhead length. The pollinators in the crosses based on 5141 A were with high (Rahuri Long Earhead, Inb.45 and Inb.492), average (Restorer-3, Inb.1008 and Inb.564) and poor (RBS-347) general combining ability. In the crosses derived from 5054 A, the parents with high general combining ability were Inb.1019 and RBS-23, with average: Sel.J-104, Inb.337-1 and Inb.1002-2 and with poor: Inb.1026, Inb.483 and RBS-240.

For earhead girth, six crosses based on 5141 A female parent produced significant positive s.c.a. effects and the male parents involved were Restorer-3, Inb.1008, Inb.142-2, Inb.1043, RHRB-28-4 and RBS-243-2. These combinations were between average x poor, average x average and average x high general combiners. Two crosses based on 5054 A viz; 5054 A x Inb.1008 and 5054 A x Inb.1022 exhibited significant s.c.a. effects for this trait and were between average x high general combiners.

The crosses of Restorer-3, Inb.1036, Inb.1037, Inb.1043, Inb.45, RHRB-28-2, Manmad Local and RBS-359 with female parent 5141 A showed significant s.c.a. effects for 500-grain weight. These crosses were between high x average, high x poor and high x high general combiners (Table 6).

The restorers involved in the combinations of 5054 A and which showed significant s.c.a. effects were Inb.1002-2, Inb.1019, Inb.1022, Inb.337-1, Sel.J-104, Inb.564, RHRB-28-4, RBS-23, RBS-28, and RBS-347. These hybrids were between either poor x high, poor x average or poor x poor general combiners.

Ten crosses involving 5141 A (Poor general combiner) and thirteen, 5054 A (high general combiner) showed significant s.c.a. effects for grain yield per plant. The inbreds involved in the crosses with 5141 A were high (Restorer-3, Inb.1043 and RBS-23), average (RHRB-28-4 and Inb.492-1) and poor (RBS-359) general combiners. In the crosses involving 5054 A, pollinators with high general combining ability were Inb.1002-1, Inb.1022, Inb.337-1, Inb.45, RBS-225 and RBS-243-2, with average RBS-240 and with poor Inb.1026, Inb.1037, Rahuri Long Earhead, Sel. J-104, Inb.492, and RBS-28.

The crosses based on 5141 A and showing significant positive s.c.a. effects for grain yield were also showing significant positive s.c.a. effects for days to flowering, number of tillers, length and girth of earhead and 500-grain weight. The crosses derived from 5054 A female parent showing significant positive s.c.a. effects for grain yield were also showing such values for days to flowering, plant height, earhead length and 500-grain weight. The influence of s.c.a. effects of yield

of heterosis. For example, the combination of 5141 A and RHRB-28-4 had very high value (12.87) of the s.c.a. effect but the heterosis percentages were 11.02 and 45.56 over superior and mid parent, respectively. Contrary to this, among the crosses based on 5054 A and showing significant s.c.a. effect of grain yield per plant the hybrid between 5054 A and RBS-243-2 had the highest value (2.88) of the s.c.a. effect but it ranked third in respect of percentage of heterosis over mid and better parent. These data indicate that either significanceof s.c.a. effects or its magnitude can not always be related with significance or magnitude of heterosis. Further, either female and male or both of the parents of the crosses showing heterosis for grain yield were good general combiners for either grain yield or one or more yield components. This reveal the fact that both g.c.a. and s.c.a. effects played an important role in the expression of heterosis for grain yield and other traits under study. The data on gene action has also indicated the importance of both additive and non-additive gene action for grain yield and most of the yield components studied. Reddy and Arunachalam (1981), Thete (1984) and Kale (1985) also noted high heterosis with low or non-significant specific combining ability effects for grain yield.

If we consider mean grain yield, s.c.a. and heterotic effects, it can clearly be seen that the crosses having highly significant s.c.a. and heterotic effects were

not always high yielders. The crosses 5141 A x Inb.1002-2 and 5054 A x Inb.1026 had 4.87 and 6.13 s.c.a. effects, respectively and their respective magnitudes of heterotic effects over superior parent were 27.42 and 34.25% However, the mean grain yield per plant of the former cross was 39.50g and that of latter was 49.00 g per plant and these values were lower than the values of standard check BK-560 (55.00 g) and also high yielding male parents. These facts suggests that while selecting a specific combination for exploiting hybrid vigour for grain yield, due consideration, also needs to be given to the per se performance of that cross.

Considering the per se performance, heterotic effects and s.c.a. effects, the combinations which could be selected for exploiting hybrid vigour are; 5141 A x Restorer-3, 5141 A x RBS-23, 5141 A x Inb.1043, 5054 A x Inb.1002-1, 5054 A x Inb.1022, 5054 A x Inb.337-1, 5054 A x Inb.45, 5054 A x RBS-225 and 5054 A x RBS-243-2. These crosses can be tested at different locations for their stability in grain yield.

5.7 Gene action and heritability :

The information on nature and relative magnitude of gene action controlling a particular character is of immense importance in the development of efficient breeding programme in crop species which are amenable to commercial production of F_1 hybrid seed and also to develop synthetics,

composites or varieties having desirable attributes. In the present investigations, gene action and heritability was studied for the ten different characters and has been discussed in brief.

Significance of g.c.a. and s.c.a. effects for all the characters except number of nodes on main stem indicated the influence of both additive and non-additive gene action in the expression of these characters. The highest magnitude of g.c.a. variance was recorded for grain yield per plant followed by plant height, days to flowering and earhead length. For the same characters s.c.a. variance were also high. Considering the ratio of variances due to g.c.a. and s.ca. the values of the ratio were less than one for all the characters indicating the predominance of non-additive gene action, as s.c.a. is attributed primarily to deviation from additive scheme caused by dominance and epistasis, while g.c.a. is associated with genes which are additive in nature (Kambal and Webster, 1965). The predominance of non-additive genetic effects for days to flowering was also reported previously by Thakare and Murty (1972), Tyagi et al. (1975), Basavaraju et al. (1980), Singh et al. (1982) and Tyagi et al. (1982).

For plant height non-additive gene action was reported by Singh and Lal (1969), Burton (1969), Singh et al. (1982) and Thete (1984), while for number of tillers, influence of non-additive genetic effects were noted by Gill et al. (1974), Yadav (1977), Sodani et al. (1981), Singh et al. (1982) and Kapoor et al. (1982). Importance of

additive in nature (Kambal and Webster, 1965). The predominance of non-additive genetic effects for days to flowering was also reported previously by Thakare and Murty (1972), Tyagi et al. (1975), Basavaraju et al. (1980), Singh et al. (1982) and Tyagi et al. (1982).

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non-additive gene action for the number of nodes on main stem was noted by Thete (1984), while for length of the internode by Sreenivasulu and Sreeramulu (1980). For the attribute, number of leaves on main stem role of non-additive gene action was recorded by Basavaraju et al.(1980), while for earhead length Phul and Singh (1970), Gill et al. (1974), Mukherji et al. (1981) and Gupta and Phul (1982). For earhead girth such genetic effects were recorded by Gupta et al. (1974), Tyagi et al. (1975), Mukherji et al. (1981) and Gupta and Phul (1982). The influence of non-additive gene action in the expression of 500-grain weight and grain yield per plant were previously reported by Tyagi et al. (1975), Basavaraju et al. (1980), Sodani et al. (1981), Thete (1984), and Mukherji et al. (1981), . Thete (1984), respectively.

Since both non-additive and additive components of genetic variance are important for most of the agronomic characters, and as the former being higher in magnitude, the emphasis on exploiting hybrid vigour would be appropriate. The crosses among the parents having high mean and high g.c.a. for grain yield and other characters could also be planned. This will provide an opportunity to develop inbreds possessing different desirable yield components through selection in segregating generation. Basavaraju et al. (1980) also indicated the possibility of simultaneous improvement for different traits through selection in segregating generation of the crosses involving parents with high g.c.a. for more than one trait.

Heritability :

The heritability in narrow sense was medium for days to flowering, earhead length and number of effective tillers per plant, while low for the rest of the characters. Among the characters studied, selection would comparatively be effective for the traits showing medium heritability. The heritability values were moderate, for days to flowering in the studies conducted by Sandhu et al. (1980), Phul et al. (1980) and Kale (1985); for earhead length by Sharma et al. (1978) and Sandhu et al. (1980). While lower values of heritability were recorded by Mukherji (1980) for plant height, earhead girth and grain yield per plant.

5.8 Percentage contribution to the s.s. of hybrids :

It was observed that females had contributed less to the s.s. of hybrids for all the characters as compared to the males and females x males interaction.

The contribution of males was the highest for all characters as compared to the females and females x males interaction except for number of nodes on main shoot.

The contribution of interaction (females x males) was greater than the parents for number of nodes on main shoot.

Patil (1979) also reported higher contribution of males to the s.s. of hybrids for earhead length as compared

to the females and females x males interaction. Thete(1984) observed higher contribution of males for days to flowering, number of nodes, length of internodes, earhead length and grain yield per plant, while Kale (1985) noted higher contribution of males for 500-grain weight as compared to that of females.

From the studies on heterosis and combining ability in general it can be concluded that the considerable amount of heterosis in desirable direction was observed for all the characters. The percentages of heterosis were higher for grain yield per plant, 500-grain weight, plant height, number of leaves and internodal length. Considering the per se performance, heterotic effects, and s.c.a. effects, the combinations 5141 A x Restorer-3, 5141 A x RBS-23, 5141 A x Inb.1043, 5054 A x Inb.1002-1, 5054 A x Inb.1022, 5054 A x Inb.337-1, 5054 A x Inb.45, 5054 A x RBS-225 and 5054 A x RBS-243-2 are worth considering and could be tested at different locations. The parents Inb.1022, RBS-23, RBS-225, Inb.1002-1, Inb.1043,RBS-243-2, Restorer-3, Inb.142-2, Inb.337-1 and Inb.45 have high g.c.a. for two or more characters. The crosses among these parents could be planned so as to develop new inbreds possessing different desirable yield components.

6. SUMMARY AND CONCLUSIONS

The analysis of variance revealed highly significant differences for all the characters. Between the female parents 5141 A was superior for days to flowering, number of nodes, earhead length and 500-grain weight, while 5054 A was better for plant height, number of tillers, number of leaves and grain yield per plant.

All the newly developed inbreds had thicker earheads and bolder grains than the female parents. Inbreds, RBS-359, RBS-243-2, Inb.142-2, and Restorer-3 were early, while inbreds RBS-431-6, Inb.492-1, and Inb.1008 produced more number of tillers. Inbreads 1019, 1022, 1002-1, 564 and RHRB-28-4 had thicker earheads. The inbred RHRB-28-2 had the highest grain yield per plant among all the parents and was followed by RHRB-28-4 and Inb.1008.

Twelve crosses based on 5141 A and ten involving 5054 A as the female parent showed negative heterosis for days to flowering.

Of the thirty crosses based on each of the two male sterile lines, significant and positive heterosis for tillers per plant was recorded in ten crosses based on 5141 A and four on 5054 A female parent.

For plant height twenty three and twenty two crosses involving 5141 A and 5054 A female parents, respectively showed significant positive heterosis.

The heterosis for grain yield in hybrids based on 5141 A was found to be mainly influenced by heterosis for plant height, internodal length, number of leaves and earhead length. The most of the promising hybrids based on this female were those in which inbreds, RBS-23, Restorer-3, Inb.1022, RBS-243-2, Inb.1002-1, Inb.1043, Inb.45, RBS-225 and RBS-359 were the male parents.

In the crosses derived from 5054 A male sterile line, the heterosis for grain yield was found to be influenced by heterosis for plant height, internodal length, number of leaves, earhead length and 500-grain weight. The oustanding crosses were in which Inb.1022, RBS-23, Inb.1002-1, RBS-243-2, Restorer-3, Inb.337-1, Inb.45, and RBS-225 were involved as male parents.

In general both the female lines viz, 5141 A and 5054 A and Inbreds 1022, 1002-1, 1002-2, 45, RBS-23, RBS-243-2, RBS-225 and Restorer-3 were found to be promising and are worth considering in future heterosis breeding programme in pearl millet.

As regards the general combining ability effects between the female parents 5141 A was the best general combiner for days to flowering, number of nodes, earhead length and 500-grain weight and average for internode length and earhead girth, while 5054 A was the best general combiner for plant height, number of tillers per plant, number of leaves and grain yield per plant.

Among the male parents, RBS-23, RBS-225, Inb.1022, Restorer-3, Inb.142-2, Inb.1043, Inb.337-1, Inb.1002-1 and Inb.45 were the best general combiners, while Inb.1019, RHRB-28-2, RHRB-28-4, Inb.492 and RBS-240 were the average general combiners; for grain yield per plant.

Best general combiners for grain yield per plant were also the best general combiners for one or more yield contributing characters. Inb.1022 was found to be the best general combiners for eight characters, RBS-23 and RBS-225 for six characters, Inb.1002-1 for five characters, Inb.1043 and RBS-243-2 for four characters, Restorer-3 and Inb.142-2 for three characters and Inb.45 for two characters.

The male parents, which exhibited very high general combining ability for grain yield were the same which expressed very high heterotic effects in combination with 5141 A and 5054 A for grain yield per plant and had mean grain yield higher than high yielding parents and the standard check BK-560-230.

The best specific combinations for days to flowering were 5054 A x Restorer-3 and 5054 A x RBS-347, for plant height 5141 A x Inb.492 and 5141 A x Manmad Local, for number of tillers 5141 A x RBS-23, for number of nodes 5054 A x Inb.1002-1, for internode length 5054 A x RBS-359, for number of leaves 5054 A x Inb.1002-1,

for earhead length 5141 A x Rahuri Long Earhead, for earhead girth 5054 A x Inb.1022, for 500-grain weight 5054 A x RBS-347 and for grain yield per plant 5141 A x RBS-359.

From the studies on specific combining ability of different crosses in general; it appears that significant positive s.c.a. effects for grain yield could be attributed to the significant positive s.c.a. effects for one or more of the yield components like days to flowering, number of tillers/plant, earhead length, 500-grain weight and plant height.

The data on heterosis and combining ability indicated that significance of s.c.a. effects or its magnitude can not always related with significance or magnitude of heterosis. Both g.c.a. and s.c.a. effects were found to play an important role in the expression of heterosis for grain yield and other traits. The data on gene action has also indicated the importance of both additive and non-additive gene action with predominance of latter for all the traits except number of nodes on main shoot.

The contribution of males to the s.s. of hybrids was more than females and females x males interaction for all the characters, except number of nodes on main shoot.

Considering the per se performance, heterosis percentages and s.c.a. effects, the crosses which out-yielded BK-560, the standard check and high yielding parents and could be considered for exploiting hybrid vigour are; 5141 A x Restorer-3, 5141 A x RBS-23, 5141 A x Inb.1043, 5054 A x Inb.1002-1, 5054 A x Inb.1022, 5054 A x Inb.337-1, 5054 A x Inb.45, 5054 A x RBS.225 and 5054 A x RBS-243-2.

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* Original not seen.

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