GENETIC STUDIES FOR QUANTITATIVE TRAITS AND INHERITANCE OF RUST RESISTANCE IN PEARL MILLET [*Pennisetum glaucum* (L.) R. Br.]

By

Mr. Ingle Narayan Prabhakar
(Reg. No. Ph.D./2018/11)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413 722, DIST. AHMEDNAGAR
MAHARASHTRA, INDIA

in partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)

DEPARTMENT OF AGRICULTURAL BOTANY

POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
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CANDIDATE’S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institution
for a Degree or
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The assistance and help received during the course of this investigation have been duly acknowledged.

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Place : MPKV, Rahuri

Date : / /2023 **(S.A. Ranpise)**

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"Agriculture is backbone of Indian economy and being the member of agricultural family we all are bound together to have progress in Indian agriculture scenario and these are my little steps towards this path"

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LIST OF ABBREVIATIONS AND SYMBOLS USED

ANOVA	:	Analysis of variance
B_1	:	Back cross with female parent
B_2	:	Back cross with male parent
BP	:	Better parent
C.D.	:	Critical difference
cm	:	Centimeter
d.f.	:	Degrees of freedom
DHLBI	:	Dhule Bajra Inbred
et al.	:	et alli (co-worker)
e.g.	:	For example
etc.	:	Etcetera
Fe	:	Iron
Fig.	:	Figure
F_1	:	First filial generation
F_2	:	Second filial generation
g	:	Gramme (s)
GCA	:	General combining ability
ha	:	Hectare (s)
i.e.	:	That is
ICRISAT	:	International Crops Research Institute for the Semi-Arid Tropics
Max.	:	Maximum
mg/kg	:	milligram per kilogram
Min.	:	Minimum
MPKV	:	Mahatma Phule Krishi Vidyapeeth
MP	:	Mid parent
No.	:	Numbers
P_1	:	Female parent
P_2	:	Male parent
Res.	:	Research
R	:	Resistance
S	:	Susceptible
SD	:	Standard deviation
S.H.	:	Standard heterosis
Sci.	:	Science
SCA	:	Specific combining ability
T.S.	:	Transgressive segregants
Univ.	:	University
wt.	:	Weight
viz.,	:	Vide lacet (Namely)
Zn	:	Zinc
°C	:	Degree Celsius
(+)	:	Increasing parent
(-)	:	Decreasing parent
χ^2	:	Chi-square
/	:	Per
σ^2	:	Variance

ABSTRACT

"GENETIC STUDIES FOR QUANTITATIVE TRAITS AND INHERITANCE OF RUST RESISTANCE IN PEARL MILLET [*Pennisetum glaucum* (L.) R. Br.]"

By

Mr. INGLE NARAYAN PRABHAKAR

A Candidate for the Degree
of
DOCTOR OF PHILOSOPHY (AGRICULTURE)
in
AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)
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Research Guide	:	Dr. S.V. Pawar
Department	:	Agricultural Botany
Major Field	:	Genetics and Plant Breeding

The present investigation entitled "Genetic studies for quantitative traits and inheritance of rust resistance in pearl millet [*Pennisetum glaucum* (L.) R. Br.]" aimed to study the heterosis and combining ability, gene action, identification of transgressive segregants and inheritance of rust resistance. Nine diverse inbreds were selected and crossed in a 9 x 9 half diallel fashion during *summer*-2019. The effected 36 crosses along with their inbreds and check Phule Adishakti were grown during *Kharif*-2019 for heterosis and combining ability study. For generation mean study six generations (P_1 P_2, F_1, F_2, B_1 and B_2) of the two crosses *viz.,* DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138 were selected and evaluated during *Kharif*-2021. The transgressive segregation was shown in two crosses *viz.,* DHLBI-1708 x DHLBI-181138 and DHLBI-1708 x DHLBI-18963 during *Kharif*-2021.

For inheritance of rust resistance study in pearl millet, two rust susceptible and two resistant inbreds were selected. Total of three F_1 (susceptible x resistant, resistant x susceptible and resistant x resistant), their F_2, B_1 and B_2 generations were evaluated and scored for their reaction to rust under greenhouse and field conditions during *Kharif*-2021. All the research trials were conducted at Post Graduate Farm, Department of Agricultural Botany, M.P.K.V., Rahuri.

The analysis of variance for treatments revealed that significant mean sum of squares for all the characters, which suggested that there was significant genetic variation among them. The cross combination DHLBI-1708 x DHLBI-181138 exhibited highest *per se* performance and highly significant standard heterosis for grain yield per plant, plant height, number of effective tillers per plant, earhead girth, grain Fe and grain Zn content. The other cross combinations DHLBI-1708 x DHLBI-18963, DHLBI-181181 x DHLBI-181138 and DHLBI-18963 x DHLBI-181138 exhibited high *per se* performance with highly significant better parent and standard heterosis for grain yield and yield contributing characters with quality characters. These crosses could be exploited to isolate desirable transgressive segregants in subsequent generations.

Analysis of variance for combining ability revealed that the mean sum of squares due to GCA and SCA were highly significant for all the characters. However, σ^2gca/ σ^2sca ratio was less than unity for all the characters except grain Fe and Zn, suggesting predominance of non-additive gene effects in control of the studied characters. Among all nine inbreds, the estimates of GCA effects showed that the inbreds DHLBI-181138 was good general combiner for eight characters, i.e. plant height, number of effective tillers per plant, earhead length, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn content and also had high *per se* performance for grain yield per plant. Inbreds, DHLBI-1708 and DHLBI-18963 were also found good general combiner along with good *per se* performance for most of the yield contributing characters and identified as superior inbred for grain yield and its components, indicating holds great potential and should be included in further breeding programme for pearl millet improvement.

With respect to estimates of specific combining ability for grain yield, it was observed that the hybrid DHLBI-1708 x DHLBI-18963 evinced highly significant SCA effects for grain yield as well as for plant height, number of effective tillers per plant, 1000-grain weight and grain Fe content. The other cross combinations *viz.*, DHLBI-1708 x DHLBI-181138, DHLBI-181181 x DHLBI-181138, DHLBI-18963 x DHLBI-181138 and DHLBI-1708 x DHLBI-181181 showed high SCA effects along with high mean performance for grain yield. The desirable transgressive segregants may be obtained from these crosses.

From the data of mean values of both the crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138 indicated that, the F_1 means were higher than mid parental means values and comparable to better parent mean values in respects of all the traits which indicated both partial and over dominance. The F_2 means were estimated lower than the F_1 mean values in both the crosses. The means of backcross populations tended towards their respective parents. These result indicated the predominance of non-additive gene action. The scaling tests and joint scaling test were highly significant in both the crosses for all the characters indicating the inadequacy of simple additive-dominance model, justifying the use of six parameter model for detection of epistatic gene interactions. The six generation mean analysis in both the crosses indicated significance of both additive and dominance gene effects. While, most of the traits showed significance of one or more interaction types (additive x additive [i], additive x dominance [j] and dominance x dominance [l]). Based on the sign of [h] and [l] components, both duplicate and complementary types of epistasis were detected in both the crosses with few exceptions.

For grain yield, the dominant component (h) and dominance x dominance (l) gene interaction was found significant for characters *viz.,* days to 50% flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, 1000-grain weight, grain yield per plant and grain Fe, these characters can be improved by recurrent selection for SCA. Additive gene action along with additive x additive (i) followed by dominance (h) was found significant for the characters *viz*., days to 50% flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, earhead girth, 1000-grain weight, grain Fe and grain Zn. For improvement of these characters, one should follow the simple selection in early segregating generations.

Transgressive segregants in desirable directions were observed for all the characters in F_2 generation of both the crosses *viz*., DHLBI-1708 x DHLBI-181138 and DHLBI-1708 x DHLBI-18963 In general, highest proportion of individuals transgressed beyond the increasing parent recorded for grain yield per plant followed by 1000-grain weight, earhead girth, earhead length, number of effective tillers per plant, plant height, days to maturity and days to flowering. Better parent was found to be transgressed simultaneously with transgression of one or more other characters. The most promising transgressive segregants in DHLBI-1708 x DHLBI-181138 was plant number 124 and plant number 160 of cross DHLBI-1708 x DHLBI-18963 could be evaluated for further improvement and development of new inbred lines in pearl millet.

From the inheritance of rust resistance study in pearl millet, both the crosses DHLBI-967 x DHLBI-1035 (S x R) and DHLBI-1035 x DHLBI-1103 (R x S) showed the goodness of fit to 3R: 1S segregation ratio in F_2 population and 1R : 1S ratio was observed in their backcross populations under greenhouse and field condition which indicated that rust resistance in pearl millet is controlled by single dominant gene. However, no segregation was observed in F_2 and backcross population of cross DHLBI-1013 x DHLBI-1035 (R x R) for rust resistance, which indicated that both inbreds might have the same resistant gene.

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1. INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is an annual tillering diploid (2n=2x=14) crop, belongs to family *Poaceae*, subfamily *Panicoidae*, commonly known as bajra, cat-tail millet, or bulrush millet in different continents and it is believed to be originated in Africa from where it was imported to India (Krishnaswamy, 1962). Pearl millet is a highly cross-pollinated crop because of protogynous flowering condition and wind borne pollination mechanism, which satisfy one of the essential biological demand for hybrid development.

In arid and semi-arid continents of the world pearl millet is generally grown and accounts for about 50 per cent of the total global production of millets. India is the largest single producer of the crop, both in terms of area and production. The West and Central Africa region has large area under millets, of which more than 90 per cent is pearl millet. In India pearl millet is mainly cultivated in the states of Rajasthan, Uttar Pradesh, Maharashtra, Haryana, Gujarat, Karnataka, Madhya Pradesh, Tamil Nadu and Andhra Pradesh with 7.54 million hectare total area, production of 10.36 million tons with national average productivity of 1374 kg/ha. In Maharashtra, pearl millet is grown on an area of 6.72 lakh hectares and annual production of 5.11 lakh tons with state average productivity is of 761 kg/ha (Anonymous, 2021).

Pearl millet is generally grown in areas where environmental conditions, especially rainfall, temperature and soil fertility, are too harsh to grow other cereal crops. It is the most drought tolerant and warm season cereal crop predominantly grown as a staple food for millions of people and also form an important fodder crop for livestock population. It is nutritionally superior and staple food for millions of people living in unbearable environmental conditions which are characterized by erratic rainfall. In fact, it is the only appropriate and efficient crop for arid and semi-arid circumstances because of its capacity to utilization soil moisture and higher level of heat tolerance than sorghum and maize (Harinarayana *et al.*, 1999). Most of the farmers priorate this crop as low cost, low risk option not only by choice but also by necessity (Harinarayana, 1987).

World Health Organisation has recognised that micronutrient malnutrition resulting from dietary deficiency of one or more micronutrients as a serious human health problem worldwide. It is estimated that over 3 billion people in the world suffer from micronutrient malnutrition and that about 2 billion peoples of these have an iron deficiency (Govindaraj *et al.*, 2011). In Asia about 35 per cent of children between 0-5 years of age suffer from iron and zinc deficiency. It also affects larger segment of population mostly women, infants and children from poor families in the country (Singh *et al.*, 2009). Ascendancy of anaemia in pregnant women is highest (87.5 per cent) in India. Pearl millet is a highly nutritious cereal with high levels of metabolizable energy, protein and more balanced amino acid profile (Andrews and Kumar, 1992). The levels of iron and zinc content in pearl millet cultivars are far higher than those reported in improved wheat and maize varieties (Rai *et al.*, 2008). A large number of genetic variations has been detected for iron and zinc and other minerals in pearl millet (Jambunathan and Subramanian, 1988). It is considered that increasing iron and zinc proportion in these crops could increase the dietary intake of iron and zinc. By understanding these problems, the development of genotypes with high micronutrient is vital to address human health problems.

For the enhancement of effective heterosis breeding programme in pearl millet, one need to have cognition about genetic architecture and prepotency of parents in their hybrid combinations. Selection based on phenotypic appearance alone does not lead to expected success in hybrid breeding programme. Therefore, a study on combining ability is very important for any crop breeders which helps in the selection of parents and crosses as it also provides highest improvement for the characters under consideration and satisfy the information on additive and non-additive portion of genetic variance available in the material under study. Information on the nature and magnitude of gene action is important in understanding the genetic potential of a population and deciding the breeding procedure to be adopted in a given population. The information on combining ability and heterotic pattern of the current breeding material can be used to create new source of populations for hybrid and population breeding with increased genetic variability. It also provides a guideline to determine the value of source populations and appropriate procedures to use in crop improvement programme. This knowledge in fact helps in exploiting heterosis for commercial purpose.

Many plant breeders have reported transgressive segregations in hybrid progenies and suggested that transgressive segregation may be used as a positive tool in plant breeding. The conventional idea of hybridization is to recombine in a new derivative, the desirable characteristics already observed in two parents. Perhaps a more imaginative approach to plant breeding is to consider the possibilities of transgressive segregation. A character which is absent in the original parents may appear in the segregating generations (Gardner, 1968). In certain cases, transgressive segregants are produced in F_2 population by accumulation of favourable genes by means of segregation and recombination from the parents involved in hybridization. Genetically diverse parents having better combining ability are more likely to give rise to transgressive segregants. As a result, the intensity of the character in the new derivative is greater than that in either parent. Here, each parent is expected to contribute different desirable genes which when brought together by recombination give rise to transgressive segregants.

In general, growth and productivity of pearl millet crop has been hampered by the incidence of diseases and pest. Among pest and diseases, pearl millet is attacked by a large number of diseases caused by fungal, bacterial, viral and nematode pathogens. However, diseases that are considered economically important which includes downy mildew, blast, rust, ergot and smut. Among these several diseases, rust has become a disease of considerable importance in recent years because it severely affects both forage and fodder value and thereby limiting the exploitation of heterosis. Pearl millet leaf rust is known to occur in all the areas where the crop is grown. Due to intensive seed production in the summer season and crop overlapping in some Indian regions, the disease has spread widely. For hybrid seed production, the crop is grown in the post-rainy season during January-April that coincides with cool nights (15-20°C) and warm days (25-34°C). During this period the abundant dew formation occurring on the foliage in the mornings helps urediniospores to germinate and cause infection.

Pearl millet rust disease caused by *Puccinia substriata* var. *indica* Ramachar & Cumm. Occasional out breaks may lead to severe losses in grain yield and forage quality. In the rainy season in India, rust generally occurs after anthesis resulting in little or no reduction in grain yield, though there may be substantial reduction in fodder quality. However, rust is a major grain yield reducer in the post rainy season crop

(Andrews *et al*., 1985). Breeding for rust resistance is the only cheapest, eco-friendly and surest measure to overcome this disease. Resistance to rust, in most cases, has been reported to be controlled by single dominant genes (Andrews *et al*., 1985). The field and greenhouse rust screening techniques have been developed and resistance sources have been identified (Singh *et al*., 1997). The information on inheritance of resistance will have a direct bearing on the breeding efficiency for genetic management of this disease. Therefore, improvement of a variety/hybrid for rust resistance is of great importance to increase production and productivity. Hence, there is a need to study the inheritance of rust resistance in pearl millet. Considering the importance of above information for crop improvement, the present study on "Genetic studies for quantitative traits and inheritance of rust resistance in pearl millet [*Pennisetum glaucum* (L.) R. Br.]" was attempted with the following objectives:

1. To estimate the extent of heterosis, general and specific combining ability of parents and their crosses for quantitative traits.
2. To study gene action for grain yield and its components.
3. To identify transgressive segregants for quantitative traits.
4. To study the inheritance of rust resistance in pearl millet.

2. REVIEW OF LITERATURE

In order to focus on the further improvement of the crop, literature pertaining to the aspects under investigation are reviewed and presented under the following suitable heads.

2.1 Heterosis
2.2 Combining ability
2.3 Gene action for grain yield and its component traits
2.4 Transgressive segregation
2.5 Inheritance of rust resistance

2.1 Heterosis

The term heterosis is most broadly and widely applied by breeders in the field of crop improvement and is considered as major breakthrough in breeding technique. Koelreuter (1766) reported initially evidence for heterosis. He noted that vigour in crosses increased with the increase in dissimilarity of parents. Shull (1908) coin the term "heterosis". It refers as the phenomenon in which the F_1 hybrid derived by crossing two genetically dissimilar individuals shows the increased or decreased vigour over the better or mid-parent value. Later on, Fonseca and Patterson (1968) used the new term "heterobeltiosis" to describe improvement of heterozygotes in relation to better parent.

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

Heterosis is the measure of deviation of progeny means from parental means. The heterosis (%) was calculated in terms of mid parent heterosis (MP), heterobeltiosis (BP) and standard heterosis (SH). Kadambavanasundaram (1980) proposed that the heterotic expression over standard or best variety should alone be given due importance for commercial exploitation of hybrid vigour.

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

Singh and Sagar (2001) examined the genetic analysis of grain yield and its components in pearl millet in rainfed and irrigated condition and reported positive heterosis for number of productive tillers per plant, ear length, days to maturity, ear head weight per plant and grain yield per plant but negative heterosis for days to flowering.

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

The ten early maturing pearl millet populations were used to study genetic and heterotic relationship by Jindal and Sagar (2003) and examined that for days to 50 per cent flowering accounted for 55.57 per cent variances out of which 85 per cent was due to specific heterosis.

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

Manga and Dubey (2004) performed diallel analysis involving nine restorer lines of pearl millet in which presence of good amount of heterosis for grain yield, earliness, productive tillers per plant, ear head length, ear head weight, 1000 grain weight, harvest index and biomass.

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

Yadav (2006) evaluated 12 crosses between selected landraces and observed high heterosis for grain yield with mean heterosis of 17 per cent in pearl millet. Other traits *viz*., days to flowering, plant height and panicle length were less heterotic with mean heterosis ranging between 2-4 per cent.

Izge *et al.* (2007) examined heterosis for quantitative characters with diallel of 45 hybrids of pearl millet at two locations. Considerable higher percentage heterosis was exhibited among in almost all traits *viz.*, days to 50 per cent flowering (negative), tillers per plant, plant height, panicle length, 1000 grain weight and grain yield. However, higher parent heterosis of 85.13 and 114.05 for yield per plant and total grain yield per hectare, respectively were obtained in this study.

Kumar and Singhania (2007) evaluated 126 crosses in line x tester design (14L x 9T) in pearl millet for grain yield and component characters to study the magnitude of heterosis. Analysis of variance indicated significant differences among genotypes for all the characters on pooled as well as in individual environments. Mean sum of squares due to parents vs. hybrids were significant for all the characters indicating presence of heterosis.

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

Vetriventhan *et al.* (2008) performed line x tester analysis in pearl millet and reported highest and significant negative relative heterosis, heterobeltiosis and standard heterosis in the cross ICMA 94111A x PT 5259 and the same combination showed negative relative heterosis, heterobeltiosis and standard heterosis for the trait plant height. High heterosis reported for grain yield over better parent was ranged from -52.97 to 131.70 per cent; while low heterosis over better parent was observed in days to 50 per cent flowering which ranged from -21.77 to 2.82 per cent.

Chotaliya *et al.* (2009) examined heterosis using restorer with half diallel design in pearl millet. The high magnitude of heterobeltiosis was found for grain yield per plant, fodder yield per plant, number of effective tillers per plant and 1000 grain weight, while moderate heterosis over better parent was exhibited for ear head girth and earhead. Days to 50 per cent flowering and days to maturity displayed the least heterotic values. The maximum positive heterosis for grain yield per plant was observed to be 194.65 and 153.22 per cent over mid and better parent, respectively. The crosses *viz*., J-2480 x D-23, J-2467 x J-2474 and J-2467 x D-23 depicted high heterosis, *per se* performance, coupled with high SCA effects and involved both or at least one good combiner parents.

Lakshmana *et al.* (2010b) undertook investigation to quantify the magnitude of heterosis for alloplasmic isonuclear lines of pearl millet. The mean as well as range of heterosis for days to flowering, days to maturity, plant height, flag leaf area and 1000-grain weight was limited in all the three sources of cytoplasm. The magnitude of heterosis was high for ear weight, grain yield/ear and grain yield/plant and A4 based hybrids had maximum heterosis for grain yield per plant and other panicle components, followed by A1 and A5 indicating a distinct advantage of these cytoplasm.

Vagadiya *et al.* (2010a) used four cytoplasmic genic male sterile lines with 12 diverse pollinators of pearl millet which were crossed in line x tester design and reported high magnitude of heterosis for grain yield per plant, fodder yield per plant and earheads weight per plant; medium level of heterosis was exhibited for days to 50 per cent flowering, days to maturity, node number per plant and 1000-grain weight.

Bhadalia *et al.* (2011) studied the extent of heterosis to identify superior new inbred with good combining ability in pearl millet. The high magnitude of standard heterosis was observed for grain yield per plant, number of effective tillers per plant, ear head width and harvest index: while moderate to low heterosis over standard check hybrid (GHB-744) was found for rest of the traits under study. The highest positive heterosis for grain yield per plant over better parent and standard check was observed to be 77.82 and 42.91 per cent respectively. The cross *viz*., J-2454 x J-2467, J-2454 x J-2511 and J-2340 x J-2511 displayed high *per se* performance, high positive significant standard heterosis and heterobeltiosis.

Govindraj (2011) observed the heterosis for grain iron and zinc across rainy and summer season in pearl millet. The mid parent heterosis for grain iron varied from -57.71 to 24.52 per cent in rainy season, from -46.19 to 38.51 per cent in summer season and from -49.03 to 26.36 per cent across the season. The MP heterosis for grain zinc ranged from -40.84 to 12.23 per cent in rainy season, from -37.39 to 37.80 per cent in summer season and from -36.82 to 14.10 per cent across the season. In rainy season only one hybrid had positive and significant MP heterosis for iron, however none of hybrid exhibited significant and positive BP heterosis in individual as well as across season for iron and zinc.

Velu *et al.* (2011) determined varied level of heterosis among hybrids of pearl millet for both Fe (-12 to 19 %) and for Zn (-18 to 20 %). Among the hybrids, 22 hybrids showed mid-parent heterosis for Fe and 14 hybrids for Zn, of which 4 were in positive direction for both Fe (11.5-19.3 %) and Zn (11.8-19.6 %). Of the five hybrids having high grain Fe, four hybrids were derived from both high x high and one hybrid from high x low parent crosses.

Bachkar *et al.* (2014) evaluated hybrids of pearl millet along with two checks (RHRBE 9808 and AHB 1666) at three locations for identification of superior hybrids based on standard heterosis. The highest positive standard heterosis for grain yield per plant was 70.81 per cent. Heterosis for grain yield might have resulted from heterosis for its component traits, mainly, number of effective tillers per plant, ear head girth and number of grains per cm^2. The crosses *viz*., MS 99111 x AIB 214. MS 88004 A x R 451-1, MS 94111 x IC 1153, MS 88004 A x PPC 7 and MS 88004 x AIB 214 were promising on the basis of mean performance and standard heterosis.

Kanatti *et al.* (2014) analysed heterosis for grain iron and zinc densities in pearl millet. None of the hybrids showed significant better-parent heterosis for Fe density, however, 62 hybrids had significant mid-parent heterosis, of which 3 were positive and 59 were negative. Patterns for Zn density were similar to those for the Fe density. The Zn density among the hybrids varied from 25.8 to 48.2 mg/kg, but only two of these hybrids had significant better-parent heterosis. Forty-five hybrids (23 %) had significant mid-parent heterosis, of which 6 were positive and 39 were negative.

Mungra *et al.* (2014) performed heterosis of 66 F_1s for fourteen grain and yield characters in pearl millet. The crosses ICMA-05333 x J-2527, ICMA-04111 x J-2534, ICMA-05333 x J-2340, ICMA-04111 x J-2454 and ICMA-92777 x J-2340 were the best heterotic combinations for grain yield per plant, which recorded 35.77, 28.90, 21.85, 16.74 and 13.74 per cent standard heterosis, respectively. Whereas the crosses, ICMA- 05333 x J-2527, ICMA-05333 x J-2454, ICMA-92777 x J-2454, ICMA- 04111 x J-2539 and ICMA-92777 x STPT-115 were the best heterotic combinations for grain yield per plant, which recorded 227.18, 170.49, 124.24, 119.23 and 110.67 per cent heterobeltiosis, respectively. The heterosis for grain yield per plant was associated with the heterosis expressed by its component characters.

Pawar *et al.* (2015) conducted a heterosis study in pearl millet, in which heterosis ranged from -8.24 to 3.87 per cent and heterobeltiosis from -13.09 to 2.05 per cent in pooled analysis for days to 50 % flowering. While for days to maturity heterosis and heterobeltiosis ranged from -7.32 to 4.90 per cent and -11.0 to 1.06 per cent, respectively in pooled analysis. Among cross combinations, RHRBI 138 x S-12/30088 and S-12/30109 x S-12/30088 exhibited significant negative heterosis and heterobeltiosis in desirable direction for days to 50 % flowering and days to maturity in all four environments.

Patel *et al*. (2016) investigated that the highest significant positive heterobeltiosis and standard heterosis in pearl millet were observed for grain yield in the hybrid ICMA 98444 x J 2526 and ICMA 96222 x A1B-2 respectively. The majority of yield and yield contributing characters had a more numbers of hybrids found significant positive heterobeltiosis and standard heterosis under study.

Salagarkar and Wali (2016) reported the extent of heterosis in F_1s of pearl millet for grain yield and its components. The hybrid ICMA 94555 x ASRLT 106 showed highest significant mid parent, better parent and standard heterosis over check GHB-558 towards positive direction for panicle girth (cm). The hybrid ICMA 81A x ASRLT 167 showed highest significant mid parent, better parent and standard heterosis over check GHB-558 for grain yield per hectare (ka/ha). While ICMA 8IA x ART 107, showed highest significant positive heterosis over the three checks used in the experiment for 1000 seed weight (gm).

Acharya *et al.* (2017) studied heterosis in pearl millet, the cross JSMA 20102 x J-2496 depicted the significantly the highest and positive heterobeltiosis (112.68 %), standard heterosis (126.60 %) as well as the highest seed yield per plant. JMSA 20102 x J-2479 and JMSA 20102 x J-2500 were the next two best crosses exhibited significant and positive heterobeltiosis (97.10 and 68.84 %, respectively), standard heterosis (110.04 and 79.92 %, respectively) for grain yield per plant.

Karvar *et al*. (2017) analysed 48 hybrids of pearl millet which were produced by line (4) x tester (12) crossing programme and found maximum positive standard heterosis for grain yield per plant over hybrid check, Aadishakti was observed in DHLB-16A x S-16/08 (36.88 %) followed by DHLB-14A x S-16/06 (34.74 %) and DHLB-16A x S-16/07 (26.29 %).

Badhe *et al.* (2018) conducted an experiment in pearl millet which depicted the hybrid DHLB-18A x K-13/1007 recorded maximum positive and significant heterobeltiosis for grain yield per plant. While, the hybrid DHLB-15A x K-13/999 showed maximum positive and significant heterobeltiosis for number of effective tillers per plant, the hybrid DHLB-16A x K-13/995 registered maximum, positive and significant heterobeltiosis for ear head length. For the trait 1000 grain weight, the hybrid DHLB-17A x K-13/995 showed positive and significant heterobeltiosis. For ear head girth, the maximum positive and significant heterobeltiosis was recorded by the hybrid DHLB-18A x K-13/995. The hybrid DHLB-16A x K-13/1008 registered maximum positive and significant heterobeltiosis for fodder. None of the hybrid showed heterobeltiosis in desirable direction for grain Zn content.

Krishnan *et al.* (2019a) studied considerable high heterosis in certain crosses of pearl millet and revealed that the nature of gene action varied with the genetic makeup of the parents. The hybrids *viz*., ICMA 07777 x 18488 R, ICMA 06777 x 18805 R and ICMA 96222 x 18488 R showed high *per se* performance with highly significant positive heterobeltiosis, standard heterosis for grain yield per plant.

Barathi *et al.* (2020) estimated heterosis in pearl millet which revealed that, out of 60 crosses the cross ICMA 04999 × 2309 recorded significant heterosis over mid parent and better parent in desirable direction for grain yield and fodder yield. The crosses ICMA 04999 × 2310 and ICMA 04999 × 2311 recorded significant mid parent heterosis, heterobeltiosis and standard heterosis for days to 50 % flowering, indicating earliness in flowering. The crosses ICMA 04999 × 2329 and ICMA 97111 × 2311 recorded significant positive heterosis for plant height over mid parent, better parent and standard parent.

Dutta *et al*. (2021) performed heterosis study in 42 diallel-derived hybrids of pearl millet in which grain yield (GY) exhibited an average panmictic mid parent heterosis of 24 per cent, ranging from -1.51 to 64.69 per cent. The hybrids showed an average panmictic mid parent heterosis of 23.70 per cent for GY. Almost 91 per cent of the hybrids showed a positive panmictic mid parent heterosis. While combined across environments, panmictic mid parent heterosis for GY ranged from - 3.47 per cent for hybrid 29 (ICMV IS 92222 x IP8679) to 64.69 per cent for hybrid 21 (Kapelga x PE03942). For single environment analysis, the highest average panmictic mid parent heterosis was observed in Sadoré (68.80 %) followed by Bambey (56.35 %).

2.2 Combining ability

The concept of combining ability has become very popular in the discipline of plant breeding since Davis (1927) suggested the use of inbred variety cross (top cross) as a method of evaluating inbred lines of maize.

Later on, Sprague and Tatum (1942) elaborated it by proposing the concept of general and specific combining ability. Information on relative importance of general and specific combining ability is of value in the formulation of efficient breeding programme particularly in those species which are amenable to commercial production of F_1 hybrid seed. As such the information is useful in selecting superior parents for particular traits. General combining ability is the average performance of a parental line in a series of hybrid combinations with other lines and is controlled by additive genetic variance including additive x additive interaction variance, while specific combining ability is the deviation in the performance of a specific cross from the performance predicted on the basis of general combining ability. The F_1 performance between two parents may not be true indication of the potentialities of the parents but performance of F_1 crosses involving a common parent may be good indication of the potentialities of a particular parent to transmit favourable genes to the progenies. Therefore, general and specific combining ability estimates are likely to be quite useful in self as well as cross-pollinated crops. Additive gene effects are more important, in general combining ability, while specific combining ability is more dependent on genes with dominance and epistatic gene effects are more important.

The choice of parental material in a breeding programme is very important, since it puts a limitation on the possibility of isolating the genotypes outside the framework of the genetic makeup of the parents. The knowledge of combining ability of the parents and crosses is important to achieve this goal.

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

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

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

In diallel selective mating of mungbean, Malhotra *et al.* (1980) suggested that parents on the basis of GCA may result in breaking up some undesirable linkages and release greater genetic variability. They reported the significant mean squares due to GCA and SCA for number of pod clusters per plant and pods per plant.

Ali *et al.* (2001) defined combining ability analysis for grain and biomass yield, time to flowering, plant height, panicle length and productive tillers from an eleven parent diallel cross of pearl millet. Populations ICMV 91059, SenPop, ICMP 91715 and ICMP 929451 constitute a genetically diverse subset of the parents that consistently had the best ranks for grain yield GCA across test environments.

Joshi *et al.* (2001) evaluated a 10 x 10 half diallel excluding reciprocal to study the combining ability for yield and yield attributes in pearl millet. Analysis of variance revealed that mean sum of square due to GCA and SCA were highly significant for all nine characters *viz*., days to 50 per cent flowering, days to maturity, plant height, earhead length, effective tillers per plant, earhead weight, fodder yield, 1000 grain weight and grain yield indicating the importance of both additive and non-additive components of variation in inheritance of these characters. However, ratio of σ^2gca: σ^2sca was less than unity for all character conformed the role of non-additive type of gene action. Top crosses for SCA effect involved either one or more types of combinations good x poor, good x good and poor x poor for different traits.

Singh and Sagar (2001) undertaken genetic study for grain yield and its components in pearl millet in rainfed and irrigated condition. They reported that dominance variance exceeded the additive variance, there by indicating preponderance of dominance gene action for number of productive tillers per plant, ear head weight per plant and grain yield per plant of all the crosses in both the environment.

Yadav *et al.* (2002) examined the combining ability of seven newly developed male sterile lines and eleven testers of forage pearl millet. They found sca estimates were higher for dry fodder yield and effective tillers indicating the predominance of non additive gene effect for these traits.

Yagya *et al.* (2002) determined combining ability in pearl millet and reported variance due to GCA and SCA were significant, showed the importance of both additive and non-additive gene effect in the inheritance of panicle length, panicle girth and grain yield.

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

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

In 11 x11 diallel of diverse restorer lines of pearl millet Rathore *et al.* (2004) examined that variance due to both SCA and GCA were significant for days to flowering, plant height, productive tillers per plants, 500-grain test weight and grain yield per plant indicating importance of both additive and non-additive gene action for panicle girth.

Shanmuganathan *et al.* (2005) evaluated the 55 F_1 and 11 parents of pearl millet during *rabi* 2003 in Coimbatore for grain and stover yield. The variances due to

GCA and SCA were significant. General combining ability variances were higher in magnitude than SCA variances for all characters except leaf breadth, indicating the preponderance of additive gene action. For leaf breadth, both GCA and SCA variances were equal, indicating the prevalence of both additive and nonadditive gene action. The *per se* performance of the parents provided a fairly good indication of their combining ability in most cases, except for panicle width and in general, crosses having high SCA effects have high *per se* performance.

Sushir *et al.* (2005) observed higher GCA effects than SCA effect for number of tillers per plant and ear length and higher SCA for days to 50 per cent flowering, ear girth and grain yield pre plant in pearl millet.

Haussmann *et al.* (2006) studied the medium-maturity, high-tillering population diallel derived from crossing 12 diverse pearl millet populations in all possible combinations. The variance of GCA effects were highly significant for days to 50 per cent flowering, head yield, grain yield, plant height, panicle length panicle circumference, panicle exertion and tillers per hill, while variance of SCA effects was significant for days to 50 per cent flowering, head and grain yield, panicle length and circumference and number of tillers per hill.

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

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

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

Eldie *et al.* (2009) conducted combining ability analysis in line x tester for grain yield and its components in pearl millet, at two locations with 60 crosses. Combining ability analysis showed that non-additive gene effects were important for inheritance of stover, panicle, biomass and grain yields. Combining ability analysis showed that parents, ICMA 97333, ICMA 96222, Baladi yellow, SADC Togo and top cross P_1 were good combiners for high grain yield as well as for most of the other traits measured in this study. However, ICMV 155 x ICMB 99111 exhibited the highest sca in combined analysis across sites.

Dangariya *et al.* (2009) studied the combing ability and gene action involved in respect of yield and its attributers in pearl millet. The estimates of general combining ability (GCA) effects indicated that the parents D-23, SB-220 and J-2467 emerged as good general combiners for grain yield and its components. Out of 45 crosses combinations only five combinations such as J-2467 x J-2474, J-2454 x J-108, SB-220 x D-23, J-2475 x D-23 and J-2340 x D-23 showed significant and positive specific combining ability (SCA) effects for grain yield and other yield attributing characters.

Lakshmana *et al*. (2010b) determined the combining ability of alloplasmic iso-nuclear lines of pearl millet and revealed that the lines with A4 cytoplasmic are significantly better general combiner for grain yield per plant, ear weight, ear length and productive tillers per plant then the lines with A1 and A5 cytoplasm. The pollinators IP-1497, IP-973, IP-872 and IP-10085 proved their utility for breeding high yielding hybrids. Leaf number showed significant positive correlation with node number and ear head thickness.

Vagadiya *et al.* (2010b) observed predictability ratio of GCA and SCA in pearl millet which revealed the preponderance of non-additive gene action in the inheritance of all the traits *viz*., grain yield per plant, plant height, days to flowering, ear head girth, ear head length, number of effective tillers per plant, ear head weight per plant, days to maturity, 1000-grain weight, harvest index, threshing index and fodder yield per plant. Among 48 crosses, 19 displayed significant and positive SCA effects for grain yield. Out of these, three hybrids *viz*., ICMA- 95444 x J-2405, JMSA-20073 x J-

2474 and ICMA-98444 x J-2498 were the most promising having good specific combining ability effects in addition to high *per se* performance.

Lakshamana *et al.* (2011) analysed combining ability for pearl millet and reported majority of characters were under the control of non additive gene action and SCA variances are greater than GCA variances.

Shinde (2011) studied combining ability in 8 x 8 diallel set of pearl millet. Analysis of combining ability revealed that mean sum of square due to GCA and SCA were significant for all the characters in both the season and across the season revealing importance of both additive and non-additive type of gene effects for expression of these traits. Significance of gca x environment for all characters except number of tillers per plant, L:S ratio and oxalic acid, while significant sca x environment for all characters except number of tillers per plant indicated importance of experimentation over environment to asses genetic worth of genotypes. The analysis of variance further revealed that parents *vs*. hybrids differed significantly for all characters except number of tillers per plant. The mean sum of square due to treatment x environment, parent x environment, hybrid x environment and parents vs. hybrids x environment were found significant for majority of characters except number of tillers per plant.

Velu *et al.* (2011) studied combining ability for grain Fe and Zn with ten inbred lines and their full diallel crosses in pearl millet. The general combining ability (GCA) effects of parents and specific combining ability (SCA) effects of hybrids showed significant differences for both of the micronutrients. However, the predictability ratio $[2\sigma^2\ 2gca\ /\ (2\ \sigma^2 gca + \sigma^2 sca)]$ was around unity both for Fe and Zn densities, implying preponderance of additive gene action.

Lv *et al*. (2012) studied the genetic basis underlying breeding strategies and a potential genetic control of general combining ability (GCA) is postulated in pearl millet. They suggested that GCA and the yields of inbred lines might be genetically controlled by different sets of loci on the maize genome that are transmitted into offspring. Different inbred lines might possess different favourable alleles for GCA. In hybrids, loci involved in multiple pathways, which are directly or indirectly associated with yield performance, might be regulated by GCA loci. In addition, a case of GCA mapping using a set of testcross progeny from introgression lines is provided.

Rai *et al.* (2012) determined combining ability in pearl millet with line x tester and observed highly significant differences ($P<0.01$) among the parents and among the hybrids, for both Fe and Zn contents. The variances due to general combining ability (σ^2gca) as the more prominent component and predictability ratio to unity, implying a larger role of additive gene action in controlling both micronutrients.

Govindaraj *et al.* (2013) studied combining ability for grain Fe and Zn densities in pearl millet with two sets of line x tester across two contrasting seasons (environments). They observed grain Fe and Zn densities were largely under additive genetic control and Fe and Zn densities of the inbred lines *per se* and their general combining ability (GCA) were positively and highly significantly correlated. Consistency in the patterns of results across both sets of trials and across the environments for all the parameters implies that these results could be of wider application to the genetic improvement of Fe and Zn densities in pearl millet.

Kanatti *et al.* (2014) studied hybrids of pearl millet with high levels of Fe and Zn densities, involved both parental lines having significant positive general combining ability (GCA) and there were highly significant and high positive correlations between performance *per se* of parental lines and their GCA. There was highly significant and high positive correlation between the Fe and Zn densities, both for performance *per se* and GCA. Fe and Zn densities had highly significant and negative, albeit weak, correlations with grain yield and highly significant and moderate positive correlation with grain weight in hybrids.

Khandagale *et al.* (2014) synthesized 50 hybrids of pearl millet through line x tester mating design and observed significant differences for all the ten characters studied. Among females, 732A was found best general combiner for grain yield and had significant GCA effects for days to 50 per cent flowering, days to maturity, 1000-grain weight and plant height while, in male parent, PT 4801 was the best general combiner followed by PT 4108 and PT 4563 for grain yield per plant. The cross ICMA 88004 x PT 4639 was the best specific combiner for grain yield per plant followed by ICMA 91222 x PT 4520 and ICMA 99222 x PT 4801. They produced significant and desirable SCA effects for most of the traits studied, indicating potential for exploiting hybrid vigour in breeding programme.

Patel *et al.* (2014) evaluated 45 F_1s with ten restorer parents of pearl millet in half diallel for inheritance of grain yield and component characters of pearl millet. The analysis of variance for combining ability revealed that mean squares due to GCA and SCA were significant for all characters, while parents and F_1s were significant for all characters studied except number of effective tillers per plant, thereby suggesting the importance of both additive and non-additive gene effects. However, potence ratio and predictability ratio depicted preponderance of non-additive gene effect for all the characters except number of effective tillers per plant, average ear head length, average ear head and girth.

Singh and Sharma (2014) conducted combining ability study in pearl millet and found that parent GIB 144 showed maximum GCA effects for yield, stem thickness, leaf area, panicle length, panicle-girth and 1000-grain weight, dry weight per plant and harvest index followed by ICMA 93222, GIB 3346 and ICMA 95333. In specific combining ability analysis seven crosses *viz*., ICMA 93222 x GIB 78, ICMA 96111 x GIB 129, ICMA 93222 x GIB 144, ICMA 93222 x GIB 129, ICMA 97333 x GIB 157, ICMA 97333 x GIB 135 and ICMA 95333 x GIB 157 were identified as the best specific combiners for yield and major yield components. Analysis of SCA effects revealed that good combining parents yield better hybrids, because parents with significant positive GCA effects were involved more in selected crosses than those with non-significant GCA effects and negative GCA effects.

Rafiq *et al.* (2016) carried out a study for combining ability analysis of different (A1 A4 and A5) cytoplasms of alloplasmic isonuclear lines of pearl millet. The results revealed that the lines with A4 cytoplasm are significantly better general combiner for grain yield per plant, panicle weight, 1000 grain weight and productive tillers per plant than the lines with A1 and A5 cytoplasm. Among male parents NB 527 was the best general combiner followed by NB 799, NB 714, NB 612 for grain yield per plant. A4 cytoplasmic hybrids are more heterotic than A1 and A5 cytoplasm. The A4 cytoplasm hybrids ICMA 05666 x NB 647, ICMA 05666 x NB 812 and ICMA 05666 x NB 827 best specific combiner for grain yield per plant followed by CMA 07999 x NB652 and ICMA99444 x NB 526 belongs to A5 and A1 cytoplasm respectively.

Jeeterwal *et al.* (2017) studied combining ability in pearl millet which revealed that the parent RIB-3135 followed by RIB-335/74, MIR-525-2 and RIB-192 were found to be uniformly best parent for grain yield per plant. Parent HBL-11 was found to be a better general combiner for days to 50 % flowering, days to maturity, productive tillers per plant, plant height, panicle girth and Fe content. The crosses *viz*., P_5 x P_9 followed by P_4 x P_6 in E_1, P_5 x P_{10} followed by P_1 x P_2 in E_2 and P_6 x P_7 followed by P_2 x P_6 in E_3 were the most promising having good SCA, coupled with high *per se* performance for grain yield and some of its components. Analyses of crosses revealed majority of the superior crosses were involved poor x good or average x poor or average x good and few cases good x good general combiners. The ratio of GCA and SCA revealed preponderance of non- additive gene action in expression of all the characters.

Karvar *et al.* (2017) conducted combining ability study in 48 hybrids of pearl millet produced by line (4) x tester (12) crossing programme. Among the hybrids with positive significant SCA effects for grain yield, the frequency of good x average combiner was more. Among four females three lines DHLB-16A, DHLB-8A and DHLB-14A and among males S-16/07, S-16/08 and S-16/05 are the good general combiners and gave top yielding hybrid combinations. Among ten top performing hybrids, three hybrids *viz.,* DHLB-16A x S-16/08, DHLB-14A x S-16/06 and DHLB-16A x S-16/07 exhibited significant GCA and SCA effects for yield and most of the related traits.

Gavali *et al.* (2018) developed 48 hybrids in pearl millet through line x tester mating design using four male sterile line and twelve restores. Among the females, DHLB-25A was found best general combiner for grain yield and had significant GCA effects for six other characters. For earliness, DHLB-21A was good general combiner as it had significant GCA effects. The lines, DHLB-22A, DHLB-23A were good general combiner for grain iron content (ppm). Among male parents, S-16/105, S-16/85 and S-16/93 were found to be good general combiner for most of the characters under study. The cross DHLB-21 x S-16/107 was the best specific combiner for grain yield per plant. The cross combination DHLB-22A x S-16/109 was the best specific combiner for grain iron content (ppm) followed by DHLB-23 x S-16/89. They produced significant and desirable SCA effects for most of the traits studied.

Maryam (2018) conducted combining ability study in pearl millet which revealed that, majority of the characters are under the control of non-additive gene action. Combinations were obtained from parents with the following general combining ability (*i.e*., High x High, High x Low, Low x High and Low x Low parents). Among the resistant parents, PEO5532, P1449 and DMR15 were excellent general combiners for yield. The cross MOP1 x SOSATC88 was the best specific combiner for grain yield.

Krishnan *et al.* (2019b) conducted line x tester analysis of seven male-sterile lines and five testers of pearl millet. Among the male sterile lines, ICMA 96222 proved to be the best general combiner, followed by ICMA 07777. Whereas 18488 R, was the best of the inbreeds. The cross ICMA 07777 × 18488 R showed significant positive SCA effect. The cross ICMA 06777 × 18805 had good × average combiner parents, high *per se* performance and SCA effect for grain yield per plant, test weight, ear head length and harvest index. The cross ICMA 96222 × 18488 R had good × good combiner parent, significant positive SCA effect for grain yield per plant test weight and ear head length. The magnitude of SCA variances was higher than the GCA variances for all the characters. It indicates nonadditive gene action in the inheritance of the traits. This was further supported by less magnitude of σ^2gca/ σ^2sca ratios.

Kumawat *et al.* (2019) studied combining ability of 50 hybrids of pearl millet in line x tester mating design using 5 male sterile lines and 10 restorers and reported that the ratio of GCA and SCA variance indicated the predominance of non-additive gene action for all the characters. GCA effects revealed that parents like ICMA 843-22, RMS 7A (female), BIB-423, BIB-343, BIB-451 and BIB-407 (male) were good general combiners for grain yield and some contributing characters. On the basis of SCA effects the crosses namely RMS 7A x BIB-407, ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-451, ICMA 88004 x BIB-423 and ICMA 93333 x BIB-439 were identified as superior for seed yield and related traits.

Sharma and Singh (2019) investigated combining ability and gene action analysis in pearl millet. Results revealed that GIB 144, ICMA 93222, GIB 3346 and ICMA 95333 were the best general combiners for yield and its attributes. Seven crosses *viz*., ICMA 93222 × GIB78, ICMA 96111 × GIB129, ICMA 93222 × GIB 144, ICMA

93222 × GIB 129, ICMA 97333 × GIB 157, ICMA 97333 × GIB 135 and ICMA 95333 × GIB 157 exhibited high SCA effects for most of the yield contributing characters.

Barathi *et al.* (2020) evaluated 60 crosses to study combining ability and to predict the gene action in pearl millet. Among parents, the line ICMA 04999 and testers 2325, 2396, 2306, 2337, 2348 and 2394 were the good general combiners for grain yield. The components of variance due to GCA and SCA revealed predominance of non-additive gene action for all the traits. The cross ICMA 04999 × 2309 recorded high significant positive SCA effect, mid parent, better parent heterotic effect and *per se* performance for grain yield.

Dutta *et al.* (2021) performed heterosis study of 42 diallel-derived population hybrids of pearl millet and found that general combining ability (GCA) was significant across test environments as reflected by high heritability estimates and high GCA:SCA variance ratios. Thus, early selection for parental *per se* performance would be rewarding. The parental population from Sudan (IP8679) had strongly negative GCA for GY. Its lack of adaptation contributed to the predominance of additive effects in the present germplasm set. Parental populations PE02987 (Senegal), PE05344 (Mali) and ICMV IS 92222 (Niger) showed large positive GCA for GY. Their offspring, especially PE02987 x PE05344 and Kapelga x ICMV IS 92222, exhibited a high and stable GY across all test environments.

2.3 Gene action for grain yield and its component traits

In segregating generation, it is essential to determine the presence of gene action and genetic variation for characters of importance, because it decides the methods for improvement of characters.

The gene action controlling quantitative characters can be described by the use of gene models. The first attempt to construct a gene model was that of Fisher (1918). In this model, he included dominance at a single locus. He stated that there may be a deviation from simple additive effects between loci, similar to dominance at one locus if more than one locus affected a given character. He called this deviation epistasis. Fisher *et al.* (1932) used this gene model to describe gene action of any number of genes on a given character. Gene models were also developed by Comstock and Robinson (1948) and Mather (1949) to evaluate gene effects. Epistatic effects were assumed to be negligible in these models.

Anderson and Kempthrone (1954), Hayman (1958) believed that epistatic effects could be of significance for quantitative characters. Gene model proposed by Anderson and Kempthrone (1954) was based on the factorial model used in designs of experiments. In this model, the genotypic value was partitioned into additive, dominance and epistatic effects. In an attempt to assess the contribution of gene interaction to continuous variation, developed a gene model based on a theory developed by Fisher *et al.* (1932) and Mather (1949). Hayman (1958) described a general procedure to estimate parameters referring to the additive, dominance, additive x additive, additive x dominance and dominance x dominance effects, also to mean (m).

The knowledge of the nature and relative magnitude of gene action (additive and non-additive) is of prime importance in designing suitable and efficient breeding methodology for the improvement of yield and its components. In segregating generation, it is essential to determine the presence of gene action and genetic variation for characters of importance because it decides the methods for improvement of characters.

Sheoran *et al*. (2000b) studied gene effects for seven quantitative traits in pearl millet *viz*., days to flowering, plant height, number of effective tillers per plant, girth of the ear head, ear length, 1000 grain weight and weight of grains per ear head were evaluated. Dominance gene effects were higher than additive gene effects for all the traits in both locations, except for girth of ear head.

Singh *et al*. (2000) studied six generations of pearl millet (P_1, P_2, F_1, F_2, BC_1 and BC_2) of three crosses i.e. PPMI 318 × PPMI 618, PPMI 318 × PPMI 619 and PPMI 618 × PPMI 619 for estimation of gene action. The least square estimates of the parameters of m, (d), (h), (l), (J) and (l) revealed inadequacy of additive dominance model for diameter of the earhead for cross PPMI 318 × PPMI 618 interallelic interactions. Duplicate epistatic interaction was observed for all the traits indicating thereby the difficulty in direct relating segregating generations for all the characters.

Joshi and Desale (2000) worked out gene effects for seven quantitative characters through generation mean analysis in pearl millet and revealed that complementary type of epistasis played a role in the manifestation of heterosis for grain yield per plant.

Azizi *et al*. (2006) estimated generation mean analysis in corn and suggested that both additive and dominance effects were important for most of the traits, however dominance had a more pronounced effect. Epistasis affected the expression of nine traits in both crosses at three planting densities. Expression of epistasis and genetic parameters differed in the two crosses and were influenced by plant density. Plant densities interacted more strongly with epistasis gene action than with additive or dominance gene action in both crosses.

Godasara *et al*. (2010) conducted an experiment which comprised of six basic generations, *viz*., P_1, P_2, F_1, F_2, BC_1 and BC_2 of four pearl millet crosses. They observed that individual and joint scaling tests indicated the presence of epistasis for all the characters studied, except for number of productive tillers per plant and fodder yield per plant. The nature and magnitude of gene effects indicated, that the nature and magnitude of gene action varied from cross to cross. Hence, each cross has to be handled separately for specific character. The results also indicated the role of either higher order gene interaction or tight linkage for the expression of grain yield per plant, 1000 grain weight and days to maturity.

Wannows *et al*. (2015) evaluated genetic parameters for days to 50 % silking, plant and ear height, ear length, ear diameter, number of rows per ear, number of kernels per row, 100 kernel weight and grain yield per plant using generations means analysis of two yellow maize hybrids (IL.292-06 × IL.565-06, IL.459-06 × IL.362-06) to detect epistasis and estimates of m, d, h, i, j and l parameters. Results showed that the additive x dominance model was adequate to demonstrate the genetic variation and its importance in the inheritance of most studied traits. Non-allelic gene interaction was operating in the control of genetic variation in most studied traits. The signs of [h] and [l] were opposite in most studied traits for the two crosses. Also, the inheritance of all studied traits was controlled by additive and non-additive genetic effects, but dominance gene effects play the major role in controlling the genetic variation of the most studied traits.

Jog *et al*. (2016) investigated nature and magnitude of gene action in six generations for grain yield and its attributing characters in four crosses of pearl millet. On the basis of individual scaling test A, B and C and joint scaling test, the additive-dominance model was found to be adequate for description of variation in generation means for number of nodes per plant, number of effective tillers per plant, grain yield per plant and biological yield per plant in all the four crosses, days to flowering in ICMB-04999 x J-2454; days to maturity and earhead length in crosses ICMB-20071 x J-2480 and ICMB-04999 x J-2454; while, test weight in crosses ICMB-20071 x J-2500 and ICMB-20071 x J-2480. For remaining cases, significance of either all or the three or any of the individual scaling tests A, B or C and significant chi-square values confirming the involvement of digenic interaction parameters in the inheritance of these characters. Study indicated that grain yield per plant and its component characters were mostly governed by additive and non-additive gene effects but the magnitude of dominance effect was higher for almost all the characters. Duplicate type of epistasis played a greater role then complementary epistasis was observed for most of cases.

Vengadessan and Vinayan (2016) revealed that a large part of the genetic variation of grain size in pearl millet was under the epistasis control, particularly interactions of the dominance x dominance and dominance x additive, which were largely significant in both the generation means analysis. The presence of epistasis must imply multiple QTL for grain size. Furthermore, significant epistatic effects, additive x dominance and dominance x dominance were also observed among the detected QTLs. The presence of epistatic interactions through classical genetic analysis and among the detected QTLs for grain size suggested that the marginal effects could be severally biased.

Kumar *et al*. (2017) studied joint scaling test in pearl millet which suggested that nodes per plant and days to physiological maturity were adequate for 3 parameter model. Six parameter models revealed that both additives (d) as well as additive × additive (i) type of gene effects were significant for seed setting in cross R-15134 × R-15762. Duplicate type of epistasis was found for plant height, grain yield per plant in all three crosses of pearl millet, flag leaf length, 1000 seed weight in cross R-16419 × R-15114, tillers per plant, panicle length, seed setting, middle leaf temperature, harvest index in cross R-16419 × R-15114 and tillers per plant, panicle length, flag leaf length, middle leaf temperature, 1000 seed weight in cross of R-15762 × ASRT-111.

Kumar *et al*. (2020) also reported the presence of duplicate epistasis in most of the crosses of pearl millet for all the traits except number of productive tillers per plant indicated prevalence of greater genetic diversity. While, complementary epistasis was restricted to limited crosses for days to flowering, plant height, number of productive tillers per plant, panicle length and grain yield per plant. For grain Fe and Zn content varied non allelic interactions in combination with additive and dominance gene actions played a major role in influencing the trait. However, non-allelic gene interactions with only additive (d) gene actions played a major role in genetic control of grain iron content in crosses J 2340 x 30291, 30127 x J 2556, ICMB 10444 x ICMB 97222 and 30843 x ICMB 98222. Moreover, one cross 30725 x ICMB 05333 showed only additive gene effect and additive x dominance component of genic interaction for grain zinc content.

Kumar *et al*. (2022) conducted a generation mean analysis studies in pearl millet and revealed that the additive and varied non-allelic interactions, dominance and varied types of non-allelic interactions, additive and dominance gene actions were observed in crosses for grain yield per plant and contributing traits presence of duplicate epistasis in most of the crosses for all the traits except number of productive tillers per plant indicated prevalence of greater genetic diversity. While, complementary epistasis was restricted to limited crosses for days to flowering, plant height, number of productive tillers per plant, panicle length and grain yield per plant. However, nonallelic gene interactions with only additive (d) gene actions played a major role in genetic control of grain iron content in crosses J 2340 x 30291, 30127 x J 2556, ICMB 10444 x ICMB 97222 and 30843 x ICMB 98222. Moreover, one cross 30725 x ICMB 05333 showed only additive gene effect and additive 9 dominance component of genic interaction for grain zinc content. This information can be utilized in developing pearl millet lines with high grain Fe and Zn content.

Pujar *et al*. (2022) studied analysis of variances which revealed highly significant mean squares ($p < 0.01$) among different generations for grain Fe and Zn contents in pearl millet. Six-parameter generation mean analyses revealed a predominance of additive genetic effect and a significant ($p < 0.05$) additive-dominant interaction for the grain Fe content. The additive genetic effect for the grain Zn content was also highly significant ($P < 0.01$). However, interaction effects contributed minimally with respect to most of the crosses for the grain Zn content and hence we assume that a simple digenic inheritance pattern holds true for it. Furthermore, we established that narrow-sense heritability was high for the grain Fe content (>61.78 %), whereas it was low to moderate for the grain Zn content (30.60–59.04 %).

2.4 Transgressive segregation

Transgressive segregation refers to the phenomenon through which we get variation in F_2 or later generations outside the range of both the parents. Production of transgressive segregants for yield and its components like grain yield, test weight, earhead girth, earhead length and effective tillers plays a vital role in breeding programme. Although transgressive segregants includes lines which fall outside the range of performance of either parent, but only those being superior to better parents in desirable direction are of practical value. Therefore, a breeder is more concerned with obtaining higher frequency of transgressive segregants in segregating population, as it provides him a better scope for exercising selection to improve productivity. Transgressive breeding aims at improving yield or its contributing characters through transgressive segregation. Such plants are produced by an accumulation of the plus or favorable genes from both the parents as a consequence of recombination. No much published information is available on this aspect in pearl millet. Hence research report on other crops is also reviewed herewith.

Bahl (1979) initiated the work on Kabuli-Deshi introgression of chickpea in 1976 and reported the encouraging results from this line of work. He could isolate early maturing types with determinant in growth habit and better harvest index as compared to standard check variety. He also suggested that three ways instead of single crosses are more useful for introgression of new germplasm into the breeding population.

Patil (1994) carried out investigation in pearl millet in a view to generate transgressive segregants possessing combinations of more number of desirable attributes through crosses among four potential maintained. The study revealed that all the four crosses produced transgressive segregants for all the seven characters. The highest proportion of transgressive segregants (18 to 37 %) was observed for grain yield per plant and also identified 500 individuals simultaneously segregating for desirable traits. On the basis of observed high values of transgressive segregants, he concluded that when desired intensity of a character is not available in the parents, transgressive breeding could successfully be used to extend the limit of expression of the character.

Joshi (1999) observed transgressive segregation in pearl millet and found highest percent recovery of transgressive segregants for grain yield in F_2 generation followed by days to flowering. Least percent segregants were obtained for plant height. High values of transgressive segregants for many characters indicated desire intensity of these characters unavailable in parents, to extend the limits of expression of characters in desirable direction.

Barge *et al.* (2002) observed the transgressive segregation in F_2 populations of pear millet, derived from the four best F_1 of the crosses between 4 temperature-sensitive genic male sterile lines and 4 pollinators during the summer of 1998. Transgressive segregants for grain yield and grains per cm^2 comprised the highest and lowest proportions of the F_2 segregants, respectively. High intensity of expression for number of days to flower, plant height, number of total tillers, number of reproductive tillers, earhead length and girth, grain cm^2 and grain yield in the transgressive segregants was observed.

Girase and Deshmukh (2002) observed the transgressive segregation for all the seven characters in three crosses of chickpea. They observed the highest transgressive segregation for plant height (27 %) followed by pods per plant, fruiting branches per plant and yield per plant in both F_2 and F_3 generations of all the three crosses, except F_3 generation of JG-62 x Vijay. They also reported the simultaneous transgressive segregation for yield in combination with other characters. They reported that the proportion of transgressive segregants were more in backcross population with increasing parent than straight F_2 population.

Pawar *et al*. (2003) observed transgressive segregation in cotton. The F_2 of four diverse cotton (*Gossypium spp.*) crosses were evaluated. They studied five diverse parents involving four crosses. Lines CNHPT-1, CNHPT-254 and PKV-081 were crossed with testers RHC-1488 and GB-20 The F_2 of cross CNHPT-1 x RHC-1488 exhibited the highest frequency of transgressive segregants (70.66 %), followed by CHHPT-254 x

RHC-1488 (62.33 %) for plant height. The F_2 of cross CHHPT-254 x RHC-1488 exhibited only 1.33 per cent transgressive segregants for bolls per plant. The F_2 of cross PKV-081 x GB-20 exhibited the highest frequency of transgressive segregants for seed cotton yield per plant (40.67 %), followed by CNHPT-254 x RHC-1488 (28.67 %). Plant No. 91 (F_2) was the most transgressive segregants in cross one (CNHPT-1 x RHC-1488) for seed cotton yield, recording 56.75 per cent higher seed cotton yield in addition to higher intensity of expression for plant height, sympodia per plant and bolls per plant.

Kotzamanidis (2006) studied the thirteen successful crosses in peanut (*Arachis hypogaea* L.) in 1985 belonging to the crossing schemes *viz.,* Virginia x Spanish, Virginia x Valencia, Valencia x Virginia, Virginia x Virginia, Valencia x Valencia, Valencia x Spanish and seven successful crosses in 1986 belonging to two crossing schemes *viz;* Virginia x Valencia and Virginia x Virginia. Transgressive segregation for yield characters of 100-pod weight and 100-seed weight was studied. Pedigree selection was applied from the F_3 and F_5 generations and segregated material together with the parental varieties were evaluated. Most of the selections that showed transgressive segregation belonged to the cross type Virginia x Spanish. Yield and quality of peanut could be improved by exploiting the phenomenon of transgressive variation occurring in cross between Virginia x Spanish.

Chahota *et al.* (2007) reported that the prediction of expected transgressive segregants in F_2 generation obtained as a ratio of additive genetic effect [d] and additive variance (D) *i.e*. $[d]/\sqrt{D}$ was studied in 28 crosses of lentil generated in a diallel fashion involving four parents each of macrosperma (exotic) and microsperma (Indian) types respectively, resulting in three hybridization groups. The seed material advanced to F_2, F_3 and F_4 generations through single seed descent method was evaluated to determine the observed transgressive segregants for seed yield per plant. The observed frequency of crosses showing more than 20 % transgressive segregants in F_2 to F_4 generations were exhibited in 9 (32 %) crosses, of which 7 (77 %) crosses were of macrosperma x microsperma type.

Kachole *et al.* (2009) generated the transgressants possessing more number of desirable attributes in sorghum. He studied Four crosses viz; SPV 1359 x SPV 1452 (Cross I), SPV 1452 x RSE 907-11 (Cross II), SPV 1359 x RSE 90-7-11 (Cross III) and RSLG 1072 × RSE 90-7-11 (Cross IV) these parents and their F_2 and backcross F_2 were grown in randomized block design with three replications. The studies revealed that transgressive segregants were recorded in each of the four crosses for all the seven characters expect earhead breadth in F_2s and B_2 F_2 generation of cross III and cross IV, respectively. In case of grain yield per plant, the highest proportion of individuals (8.0 to 34.99 %) transgressed beyond the increasing parent, consistently in all the four crosses.

Dhole and Reddy (2011) observed eight transgressive segregants (2.56 %) in the cross-I of mungbean, which ranged from 8.52 to 9.29 g for 100 seed weight. No transgressive segregants were obtained in cross-II and cross-III for 100 seed weight. Among the F_2 populations, the mean seed yield per plant was the highest in the cross-I (3.89 g) followed by the cross-III (2.74 g) and the cross-II (1.88 g). For seed yield per plant, fifteen (4.79 %) and one (0.0027 %) transgressive segregants were recorded in the cross-I (range 7.95 to 11.93 g) and the cross-III (15.01 g), respectively. Transgressive segregants were also reported in mungbean for various characters. Changes in mean value were closely followed by alteration in variances.

Kumari (2011) reported that the number of transgressive segregants were identified mainly for seed yield and its component traits in urdbean in different populations on the basis of superior performance of progenies over the better parent (TAU-1) with one standard deviation value in desirable direction for each of the component traits in F_2 and F_3 generations. The frequency of transgressive segregants in two F_2 populations was higher for seeds per pod and seed weight in both the populations followed by seed yield per plant and there was no much variation in per cent.

Karkute (2013) studied transgressive segregants for all the characters of mungbean in F_2 generation of the three crosses. The highest proportion of transgressive segregants were recorded for pods per plant (46) followed by grain yield per plant (43) pod length (41), followed by number of clusters per plant (40), number of seeds per pod (36) and 100-seed weight (28) irrespective of crosses. They also observed the simultaneous transgressive segregants for grain yield in combination with other character.

Sathya *et al.* (2014) evaluated 200 RILs of pearl millet and noted that 52 lines were early flowering and 43 lines were early maturity as compared to parents. A total of 133 shorter transgressed inbreds was observed (<175.00 cm). RILs with more number of productive tillers have direct contribution towards yield. Thus, more number of productive tillers was recorded in 39 lines. With regard to ear head length, 177 lines (>23.00 cm), ear head girth 15 lines (>12.50 cm), single ear head weight 31 lines (>49.50 g), single ear head grain weight 19 lines (32.50 g) and for 1000 grain weight 18 lines (>12.95 g) outperformed the parent.

Badhe *et al.* (2017) studied transgressive segregation analysis in pearl millet, revealed that, F_2 generation of three crosses RHRBI-138 x S/12–30074, RHRBI-138 x S/12-30088 and DHLBI-967 x S/12-30088 produced desirable transgressive sergregants for the characters days to flowering, days to maturity, plant height, effective tillers per plant, ear head length, ear head girth, 1000-grain weight and grain yield per plant. The plant numbers 224 in cross RHRBI-138 x S/12–30074, 141 in cross RHRBI-138 x S/12-30088 and 149 in cross DHLBI-967 x S/12-30088 were identified as most promising transgressive sergeants.

Dahat *et al*. (2017) isolated desirable transgressive segregants in wheat for twelve characters in three crosses. The proportion of transgressive segregation was found to be 51 to 55 per cent for grain yield per plant. In most of the segregants, grain yield per plant of better parent was transgressed simultaneously with transgression of one or more characters. The cross PHS-0622 × MP-4080 showed more number of transgressive segregants for length of spike and grain per spike which are important components of grain yield per plant. The most promising transgressive segregants possessing higher per cent performance for grain yield per plant and one or more desirable traits were F_2 Plant No. 89 of cross LOK-62 × PHS-0622, Plant No. 112 of cross PHS-0622 × MP-4080 and Plant No. 36 of cross DI-9 × PHS-0622.

Raval *et al*. (2018) carried out studies on genetic variability, heritability and genetic advance of 720 plants in F_2 populations of four chickpea crosses. High mean performance, wider range of variation, high heritability coupled with moderate to high expected genetic advance as per cent of mean was observed for number of branches per plant, number of pods per plant and seed yield per plant in GJG 0315 x ICCV 96029, GJG 0107 x GCP 105 and GJG 0719 x SAKI 9516 of F_2 populations, which indicated the predominant role of additive gene action in the expression of these three traits. Moderate heritability and low genetic advance was recorded for number of branches per plant, number of pods per plant and seed yield per plant in GAG 0419 x JCP 245.

2.5 Inheritance of rust resistance

Rust (*Puccinia substriata* var. *indica Ramachar & Cumm*) has become a disease of considerable importance in recent years because it severely affects both forage and fodder value. It also causes substantial reduction in grain yield. Understanding the inheritance of rust resistance in pearl millet helps to develop rust resistant pearl millet genotypes. The available literature concerning the inheritance of rust resistance in pearl millet and related crops are presented below.

Andrews *et al*. (1985) observed 3 resistant: 1 susceptible ratio in F_2 population of pearl millet and the backcrosses involving susceptible male sterile lines as recurrent parents showed a reasonably good fit to a 1 resistant: 1 susceptible indicating that resistance is conferred by a single dominant gene and susceptibility by its recessive allele and assigned gene symbol Rpp1 and rpp1 for these genes.

Hanna *et al*. (1985) reported that resistance was dominant over susceptibility in *Pennisetum americanum* (L.).

Sokhi *et al*. (1987) observed that resistance to rust is governed by single dominant gene in line P-1564 and by two dominant gene exhibiting complementary action in line 700481-23-2 in pearl millet.

Ramamoorti *et al*. (1995) studied rust inheritance pattern in different generations of twenty crosses of pearl millet and found the dominant trait with monogenic control.

Panna *et al*. (1996) reported that the resistance against rust in pearl millet was found under the control of a single dominant gene in the entries and was found to be governed by two genes (1 dominant, 1 recessive) and the segregation pattern in F_2 of the cross 7042-1-4-4 x 70048127-5-2 showed duplicate gene action.

Ramamoorti and Jehangir (1996) reported that rust resistance is monogenically dominant over susceptibility in the crosses involving rust susceptible and a rust resistant inbred of pearl millet.

Wilson (1997) studied the expression and inheritance of partial rust resistance of pearl millet inbreeds *viz*., 700481-21-8 and ICMP 501 crossed to moderately susceptible Tift 383 were evaluated in seedling assays in the greenhouse and in generation mean and single-seed descent populations in the field. In generation mean analyses, additive genetic effects were significant in the cross of 700481-21-8 × Tift 383, whereas additive, dominance and dominance × dominance epistatic effects were significant for ICMP 501×Tift 383. The number of genes conferring partial resistance was estimated to be two for 700481-21-8 and 2.5 for ICMP 501. Higher levels of resistance were observed in progeny derived from ICMP 501. Because segregation of resistance differed among progeny derived from 700481-21-8 and ICMP 501, the genetic basis for resistance probably differs between the two inbreeds.

Sharma *et al*. (2009) reported eight lines (1 B-line, 7 R-lines) of pearl millet that showed resistance (≤10 % rust severity) in the field screen were evaluated in the greenhouse by artificial inoculation of potted seedlings to confirm their resistance. One B-line (ICMB 96222) and three R-lines (ICMR 0699, ICMP 451-P8 and ICMP 451-P6) were resistant while the other four R-lines were susceptible. The four confirmed resistant lines could be useful resistance sources for breeding rust resistant hybrid parental lines and their hybrids.

Lakshmana *et al*. (2010a) studied inheritance of rust resistance in pearl millet in which segregations pattern of F_2 revealed that, out of 432 F_2 plants of cross P-2933l x 81B, 320 were resistant and 112 were susceptible. In the cross IP-6240-3 x 81B, out of 320 plants, 246 were resistant and 88 were susceptible, similarly in the cross 700481-1-5-3 x 81B, out of 340 plants, 248 were resistant and 92 were susceptible. The segregation pattern in all the three reciprocal crosses showed a good fit to the monogenic ratio of 3:1 with chi-square values of 0.20, 0.60 and 0.72, respectively.

Sharma *et al*. (2020) screened 305 accessions of *Pennisetum violaceum*, a wild relative of pearl millet, under greenhouse conditions against a local isolate of *P. substriata* var. *indica*. Single plant selections from nine accessions (IP 21629, 21645, 21658, 21660, 21662, 21711, 21974, 21975 and 22038) were found highly resistant to rust (0 % rust severity) after four generations of pedigree selection and subsequent screening.

3. MATERIAL AND METHODS

The present investigation entitled "Genetic studies for quantitative traits and inheritance of rust resistance in pearl millet [*Pennisetum glaucum* (L.) R. Br.]" aimed at studying heterosis and combining ability, gene action for grain yield contributing traits, transgressive segregation and inheritance of rust resistance in pearl millet was conducted during *Kharif*-2019 and *Kharif*-2021 at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri. The details of the materials used, the experimental approach and statistical methods followed for conduct of experiment are described below.

3.1 Experimental Material

The experimental material for the present study comprised of nine inbred lines obtained from Bajra Research Scheme, College of Agriculture, Dhule. The details of these inbreds are given below (Table 3.1).

Table 3.1. Salient features of the pearl millet inbred lines used in the study

Sr. No.	Code	Inbred/Parent	Feature
1	P_1	DHLBI-1103	Synchronous tillering, early
2	P_2	DHLBI-967	Mid-tall, profuse tillering
3	P_3	DHLBI-1013	Rich in Fe, good restorer
4	P_4	DHLBI-1708	Synchronous tillering, mid tall
5	P_5	DHLBI-18963	Long and broad earhead, bold grains
6	P_6	DHLBI-181181	Long earhead, good restorer, bold grains.
7	P_7	DHLBI-181138	Broad earhead, bold grains, rich in Fe
8	P_8	DHLBI-1035	Synchronous tillering, long and compact earhead
9	P_9	DHLBI-1603	Very compact earhead, rich in Fe

Table 3.2. Details of six generations with respect to two crosses for generation mean analysis

Generation	Cross-I	Cross-II
P_1	DHLBI-1103	DHLBI-1708
P_2	DHLBI-1035	DHLBI-181138
F_1	DHLBI-1103 x DHLBI-1035	DHLBI-1708 x DHLBI-181138
F_2	F_1 selfed	F_1 selfed
B_1	F_1 × DHLBI-1103	F_1 × DHLBI-1708
B_2	F_1 × DHLBI-1035	F_1 × DHLBI-181138

Table 3.3. **Details of three generations with respect to two crosses for transgressive segregation study**

Generation	Cross-I	Cross-II
P_1	DHLBI-1708	DHLBI-1708
P_2	DHLBI-181138	DHLBI-18963
F_2	F_1 selfed (DHLBI-1708 x DHLBI-181138)	F_1 selfed (DHLBI-1708 x DHLBI-18963)

Table 3.4. **Details of six generations with respect to three crosses for study of inheritance of rust resistance**

Generation	Cross-I	Cross-II	Cross-III
P_1	DHLBI-967 (S)	DHLBI-1035 (R)	DHLBI-1013 (R)
P_2	DHLBI-1035 (R)	DHLBI-1103 (S)	DHLBI-1035 (R)
F_1	DHLBI-967 x DHLBI-1035 (S x R)	DHLBI-1035 x DHLBI-1103 (R x S)	DHLBI-1013 x DHLBI-1035 (R x R)
F_2	F_1 selfed	F_1 selfed	F_1 selfed
B_1	F_1 × DHLBI-967	F_1 × DHLBI-1035	F_1 × DHLBI-1013
B_2	F_1 × DHLBI-1035	F_1 × DHLBI-1103	F_1 × DHLBI-1035

3.1.1 Methodology

3.1.1.1 Hybridization

Sowing of crossing block was carried out at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri and during which thirty six crosses were attempted in 9 x 9 half diallel fashion, excluding reciprocals during summer-2019. For the development of hybrids, protogynous condition was used. When female flowers were fully opened early in the morning then these flowers pollinated with male pollen grains and earheads were covered using butter paper bag. Among the 36 crosses, two crosses *viz*., DHLBI-1708 x DHLBI-181138 and DHLBI-1708 x DHLBI-18963 were selected on the basis of heterosis and SCA effects for transgressive segregation study (Table 3.3). To study generation mean analysis two crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138 were selected (Table 3.2). For inheritance of rust resistance studies another three crosses were selected *viz.,* DHLBI-967 x DHLBI-1035, DHLBI-1035 x DHLBI-1103 and DHLBI-1013 x DHLBI-1035 (Table 3.4) with four parents, two with resistance to rust (DHLBI-1035 and DHLBI-1013) and another two susceptible to rust disease (DHLBI-967 and DHLBI-1103).

Similarly, for generation mean analysis and inheritance of rust resistance, part of F_1 seeds harvested from above crosses were sown during *Kharif*-2019 and selfing of F_1s and backcrosses were done to get F_2, B_1 and B_2 generations, respectively.

3.2 Conduct of experiments

3.2.1 Experiment I: Heterosis and combining ability studies

The resulting 36 hybrids along with nine inbreds and one standard check *viz.,* Phule Aadishakti were sown in a Randomized Block Design with three replications during *Kharif* 2019. Randomization of each entry was done. Each entry was sown in one row of 3 m length spaced at 50 cm. Plants were spaced at 15 cm within a row. Three to four seeds per hill were dibbled. Thinning was done at 21 days after sowing keeping one healthy seedling per hill. Additional dummy guard rows were also sown on both sides of each replication to avoid border effects. All the routine cultural practices were followed to grow a good crop.

3.2.2 Experiment II: Generation mean analysis for grain yield and its components

The experiment was conducted in Randomised Block Design with three replications, six generations consisting parents (P_1 and P_2), F_1s, F_2s, B_1s and B_2s of the two crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138. Sowing was carried out during *Kharif* 2021 at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri. Among the six generations each of the parents (P_1 and P_2) and F_1s was represented by single row, B_1s and B_2s represented by two rows and F_2s by four rows of 3 m length spaced at 50 cm apart with 15 cm distance between plants in a row. All cultural practices were followed to have a satisfactory crop growth.

3.2.3 Experiment III: Identification of transgressive segregants for quantitative traits

The experimental materials consist of six treatments (four parents, two F_2 populations) were grown. Among the treatments, two rows of parents, twenty rows of F_2 generations with 3 m row length were grown at 50 cm x 15 cm spacing. The recommended dose of fertilizer 50:25:25 NPK kg/ha was applied as a basal dose. The operations like gap filling, weeding and loosening of soil were carried out regularly in the experimental plot as per the need of the crop.

3.2.4 Experiment IV: Inheritance of rust resistance

The generations *viz.*, P_1, P_2, F_1, F_2, B_1 and B_2 of following crosses were grown without replication at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri to study inheritance of rust resistance in pearl millet. All treatments were sown with 3 m row length and spaced at 50 cm between rows with 15 cm distance between plants for field screening. Each parent, F_1, B_1 and B_2 are represented in four rows while, F_2 were in twenty rows of each. For green house screening phytotron green house facility at Department of Agricultural Botany, M.P.K.V., Rahuri was used.

Sr. No.	Name of cross	Cross type
1.	DHLBI-967 x DHLBI-1035	Susceptible x Resistant
2.	DHLBI-1035 x DHLBI-1103	Resistant x Susceptible
3.	DHLBI-1013 x DHLBI-1035	Resistant x Resistant

Screening techniques:

All the parents, three F_1s, three F_2s, three B_1s and three B_2s were screened for *Puccinia substriata* var *indica* in the natural field and greenhouse conditions as per Singh *et al. (*1997).

A. Field screening

1. Grown test lines in central four rows and a highly rust susceptible line as spreader or infector rows on every first row and fifth row.
2. Inoculated the spreader row by dispensing 2 ml of the urediniospore suspension into the whorls of the plants 20-25 days after seedling emergence.
3. Alternately, sprayed the inoculated seedlings both in test lines and susceptible checks with urediniospore suspension twice at 25 and 40 days after emergence and irrigated the crop to provide high humidity for 2-3 days.
4. Recorded rust severity on individual plants in a line (if segregating material) or entire line 25-40 days after inoculation (at the grain-filling stage) using a modified Cobb scale.
5. Recorded rust severity on lower leaves and top 4 leaves separately to indicate the disease progress.

B. Greenhouse screening

1. Plastic root trainer with 25 cavities/each trainer were filled with autoclaved soil-sand-coco pit and FYM mix (2:1:1 volume).
2. Seed of test lines (different generations) and susceptible check were grown in root trainer (4 seeds/cavity) in greenhouse and maintained at 30 ± 1 °C.

Table 3.5. Rust severity rating scale (0-5) recorded as per Singh *et al.* (1997)

Grade	Rust severity rating scale	Type
0	0	Immune/highly resistance (HR)
1	0.1-20	Resistant (R)
2	20.1-40	Moderately resistant (MR)
3	40.1-60	Moderately susceptible (MS)
4	60.1-80	Susceptible (S)
5	80.1-100	Highly susceptible (HS)

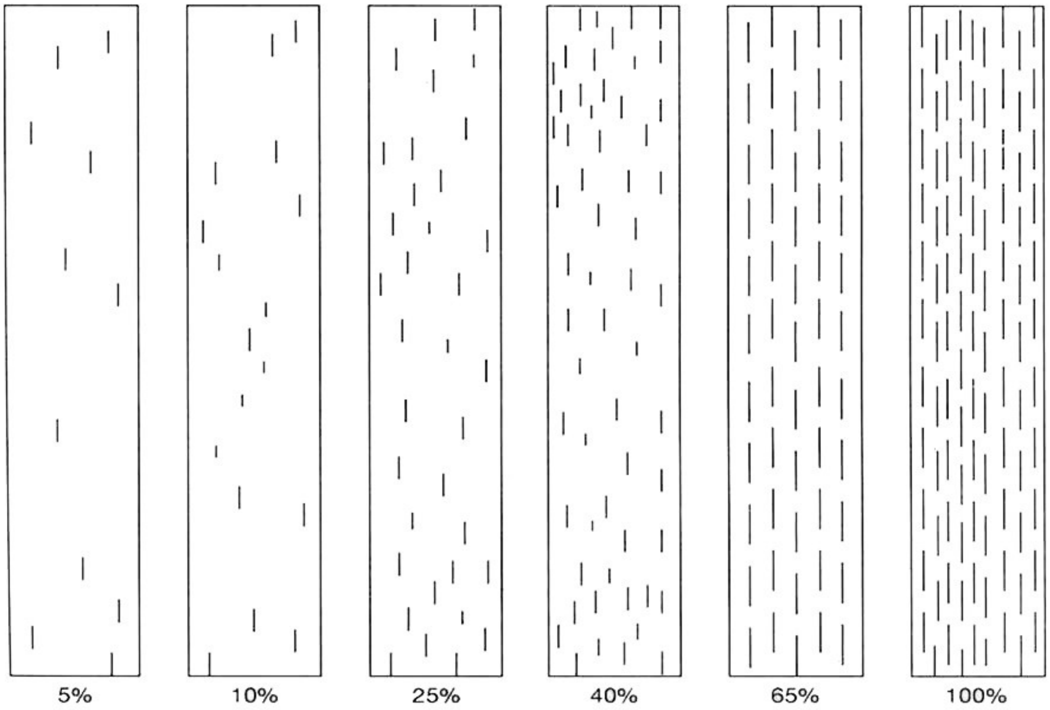

Fig 1. Rust severity rating scale (Singh *et al.* 1997)

3. Plastic root trainer was irrigated adequetly and test seedlings were grown for 10-12 days.

4. The grown seedlings (15 days old) were spray-inoculated with an aqueous uridial suspension of *Puccinia substriata* var *indica* and exposed to high humidity (>90% RH) under misting for 10 days.
5. Recorded rust infection types 12 days after inoculation.

3.3 Recording of experimental observations

3.3.1 Experiment I and II

Observations were recorded on randomly selected five plants from each treatment in each replication. For experiment II five plants of parents and F_1, twenty plants of B_1 and B_2 and forty plants of F_2 form each replication were selected and observations recorded on following traits.

1. Days to 50 per cent flowering

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

2. Days to maturity

The number of days required from sowing to the physiological maturity of the grain on the observational plants was considered as days to maturity.

3. Plant height (cm)

Plant height was measured from soil surface to tip of ear of main shoot at maturity.

4. Number of effective tillers/plant

The number of grains bearing tillers on the sample plants.

5. Earhead length (cm)

The length of earhead from base to tip of main shoot was measured.

6. Earhead girth (cm)

The maximum girth at the centre of ear of main shoot was measured.

7. 1000 grain weight (g)

1000 grains from the bulks of five plants were counted and weighed.

8. Grain yield per plant (g)

The total grain yield of the selected plants was harvested separately from individual plant with effective tillers and average grain yield per plant was recorded.

9. Grain quality characters : Micronutrients grain Fe and Zn (mg/kg)

Laboratory analysis of micronutrients

3.3.1.1 Grain analysis for micronutrients (Fe and Zn)

Representative grain samples from the middle of the ear head of the plants were collected at harvesting stage. The grains were manually cleaned to avoid any contamination of the grains with dust particles and any other extraneous matter. The samples were dried in an oven at 70^0C, ground to fine powder using sample mill consisting of hard plastic and used for micronutrient analysis. A known quantity (0.2 g) of grain samples powder were digested following wet digestion of the dried grain sample material with triacid mixture HNO_3:$HClO_4$:H_2SO_4 in the ratio of 9:3:1 and this acid extract was used for determination of Fe and Zn on Automic Absorption Spectrophotometer (Lindsay and Norvell, 1978).

3.3.2 Experiment III

For experiment-III of transgressive segregation study, five plants in parents and six hundred plants in F_2s were selected and observations were recorded on following traits.

1. Days to flowering

The number of days required for emergence of stigma on the earhead of the main shoot.

2. Days to maturity

The number of days required from sowing to the physiological maturity of the grain on the observational plants was considered as days to maturity.

3. Plant height (cm)

Plant height was measured from soil surface to tip of ear of main shoot at maturity.

4. Number of effective tillers/plant

The number of grains bearing tillers on the plants.

5. Earhead length (cm)

The length of earhead from base to tip of main shoot was measured.

6. Earhead girth (cm)

The maximum girth at the centre of ear of main shoot was measured.

7. 1000 grain weight (g)

1000 grains from the bulks of five plants were counted and weighed.

8. Grain yield per plant (g)

The total grain yield of the selected plants was harvested separately from individual plant and grain yield per plant was recorded.

3.3.3 Experiment IV

All the plants from each generation of three crosses were scored for rust disease intensity at different stages by using the 0-5 scale given by Singh *et al. (*1997).

3.4 Statistical analysis

The mean values of randomly selected observational plants for different characters were used for statistical analysis. The following statistical parameters were calculated.

3.4.1 Analysis of variance (ANOVA)

The data collected from the experiments for all the characters were subject to statistical analysis. The 'Null hypothesis' that there was no genotypic difference in the population under study was tested. The analysis of variance for randomized block design (RBD) was carried out separately for each character as per the Panse and Sukhatme (1995) as presented in Table 3.6.

Table 3.6. Analysis of variance (ANOVA)

S.N.	Sources	D.F.	S.S.	Expected M.S.S	M.S.S	Cal. F value
1.	Replications	(r-1)	RSS	$\sigma^2 e + t\sigma^2 r$	Mr	Mr/ME
2.	Treatments	(t-1)	TrSS	$\sigma^2 e + r\sigma^2 t$	Mt	Mt/ME
3.	Error	(r-1).(t-1)	ESS	$\sigma^2 e$	ME	-
4.	Total	(rt-1)	TSS	-		-

Where,

r = Number of replications

t = Number of treatments

df = Degrees of freedom

SS = Sum of square

RSS = Replications sum of square

TrSS = Treatments sum of square

ESS = Error sum of square
ME = Error mean sum of square
TSS = Total sum of square
MSS = Mean sum of square
M_r = Replication mean sum of square
M_t = Treatment mean sum of square

Standard error (SE), critical difference (CD) and co-efficient of variation (CV) were calculated as follows.

$$SE(\pm) = \sqrt{Me/r}$$

$$CD = SE \times \sqrt{2} \times t \text{ value (at error d.f.)}$$

Where,

Me = Error mean sum of squares

Table ‘t’ value at error degrees of freedom at 5 and 1 per cent level of significance. The characters, which are significant, were only subjected for further statistical analysis.

3.4.2 Experiment I: Heterosis and Combining Ability

i. Heterosis

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

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

Where,

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

$\overline{F_1}$ = Mean performance of F_1
$\overline{P_1}$ = Mean performance of parent 1
$\overline{P_2}$ = Mean performance of parent 2
$\overline{MP}$ = Mean performance of both the parents

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

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

$\overline{BP}$ = Mean performance of better parent

The standard error of difference for heterobeltiosis was calculated as follows:

$$S.E.(d) = \sqrt{\frac{2Me}{r}}$$

Where,

Me = Error mean squares

r = Number of replications

c. Standard Heterosis

It was calculated as the deviation of F_1 from the standard check variety and expressed on per cent basis by the following formula:

$$\text{Standard Heterosis (\%)} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where,

$\overline{F_1}$ = Mean performance of F_1.

$\overline{SC}$ = Mean performance of standard check (Phule Adishakti)

The standard error of difference for standard heterosis was calculated as follows:

$$S.E.(d) = \sqrt{\frac{2Me}{r}}$$

Where,

Me = Error mean square

r = Number of replications

In above two cases of heterosis, critical differences were computed by multiplying respective standard error of differences with respective 't' Table value for error degree of freedom at 0.05 and 0.01 probability level.

ii. Combining ability analysis

The combining ability analysis was carried out according to Model-I (Fixed effect), Method-2 (Parents and one set of F_1s without reciprocals) of Griffing (1956). In this model, experimental material was regarded as a population about which inferences are to be drawn and combining ability effects of parents and hybrids could be compared when parents and hybrids themselves are used as a tester to identify good combiner. In Model-I, it was assumed that genotypes and replication effects were constant but error (environmental and other uncontrollable components) effect was normally and independently distributed mean zero and common variance σ^2e. The following is the mathematical model for the combining ability in Model-I.

Analysis of variance for combining ability

The analysis was done according to Griffing (1956) Model I (fixed effect model), Method II (parents and F_1s excluding reciprocals).

The mathematical model for combining ability analysis was assumed to be:

$X_{ij} = \mu + g_i + g_j + S_{ij} + 1/bc \ \Sigma \Sigma \ e_{ijk}$

i and j = 1, 2, …. , p

k = 1, 2,.. …b

Where,

p = Number of parents

b = Number of replications

c = Number of observations for each of the plots

μ = Population mean

g_i = gca effect of i^{th} parent

g_j = gca effect of j^{th} parent

s_{ij} = sca effects of the cross between i^{th} and j^{th} parent

e_{ijk} = Environmental effect pertaining to the ijk^{th} observation on ij^{th} individual in k^{th} block with i^{th} as female parent and j^{th} as male parent

Assumption for model I

1. $\sum_{i=1}^{i} gi = 0$

2. $\sum_{j=1}^{i} Sij = 0$

Table 3.7. Analysis of variance

Sources	D.F.	Sum of squares
Replications	(r-1)	$\frac{\Sigma Y^2_{..k}}{n(n+2)/2} - \frac{Y^2_{..}}{n(n+1)\, r/2}$
Treatments	(t-1)	$\frac{(\Sigma Y_{ij})^2}{r} - \frac{Y^2}{n(n+1)\, r/2}$
Parents	(n-1)	$\sum_{i=j} Y^2_{ij} - \frac{[(\sum_{i=j} Y_{ij})]^2}{nr}$
Crosses	(c-1)	$\frac{\sum_{i=j} Y^2_{ij}}{r} - \frac{[(\sum_{i=j} Y_{ij})]^2}{n(n+1)\, r/2}$
Parents *Vs* Crosses	(t-n-c+1)	Treat. S.S. – Parent S.S. – Crosses S.S.
Error	(t-1)(r-1)	Total S.S. –Treat. S.S. – Replication S.S.
Total	(tr-1)	$\Sigma Y^2_{ijk} - \frac{Y^2}{n(n+1)\, r/2}$

Where,

r = Number of replications
t = Number of treatments
n = Number of parents
c = Number of crosses

The mean sum of squares was tested against the error variance by ‘F’ test.

Table 3.8. Analysis of variance for combining ability

Sources	D.F.	S.S.	M.S.S.	Expected mean S.S.
GCA	(n-1)	Sg	Mg	$\sigma^2 e + \frac{(n+2)}{(n-1)} \sum_i g_i^2$
SCA	$\frac{n(n-1)}{2}$	Ss	Ms	$\sigma^2 e + \frac{2}{n(n+1)} \sum_i \sum_j S_{ij}^2$
Error	M	Se	Me	$\sigma^2 e$

Where,

M = $(r^{-1})\ (g^{-1})$

Me = Error mean squares

The sum of squares were calculated as :

$$Sg = \frac{1}{(n+2)} \left[\sum_{i} (Xi. + Xii)^2 - 4/n\ X^2 ..\right]$$

$$Ss = \sum_{i \le j} \sum Xij^2\ \frac{1}{(n+2)} \sum_{i} (Xi. + Xii)^2 + \frac{2}{(n+1)\ (n+2)}\ X^2 ..$$

Sg = Sum of square due to GCA

Ss = Sum of square due to SCA

n = Number of parents

Xij = Value of cross between ith and jth parent

Xi = Total of ith array in diallel Table

$Xi.$ = Total of ith column in diallel table

$X...$ = Grand total of n^2 values of diallel

Mg and Ms were calculated by dividing the respective sum of squares with corresponding degrees of freedom while error mean square (M'e) was calculated by dividing error mean square by number of replications

$$M'e = \frac{Me}{\sigma^2 er}$$

The following F ratios were used for testing the GCA and SCA effects.

i. To test the difference between GCA effects

$$F\ [(n-1);\ M] = \frac{Mg}{M'e}$$

ii. To test the difference between SCA effects

$$F\ [n(n-1)/2;\ M] = \frac{Ms}{M'e}$$

Computation of GCA and SCA effects

The individual effects were estimated as follows

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

2. GCA estimates of parent I

$$gi = \frac{1}{(n+2)} \left[(Xi. + Xii) - \frac{2}{n} X...\right]$$

3. SCA estimates of cross Xij

$$Sij = Xij - \frac{1}{(n+2)} \left[(Xi. + Xii + X.j + Xjj) + \frac{2}{(n+1)(n+2)} X...\right]$$

Standard error (S.E.) for estimates

To test the significance of GCA and SCA estimates and the difference between each of the two estimates were computed using following formulae.

$$\text{S.E. for GCA effects (gi)} = \sqrt{\frac{(n-1)}{n(n+2)} M'e}$$

$$\text{S.E. for SCA effects (Sij)} = \sqrt{\frac{n^2 + n + 2}{(n+1)(n+2)} M'e} \qquad (i \neq j)$$

$$\text{(S.E.) (gi – gj)} = \sqrt{\frac{2M'e}{(n+2)}} \qquad (i \neq j)$$

(S.E.) difference between two SCA effects in different arrays is given by,

$$\text{(S.E.) (Sij – Sik)} = \sqrt{\frac{2(n+1)}{(n+2)} M'e} \qquad (i \neq j, k;\ j \neq i)$$

Critical differences were estimated as given above.

3.4.3 Experiment II: Generation mean analysis

1. Sampling variance of generation means

The generation means were subjected to sampling variation, which can be estimated by normal statistical procedures. Replication wise variance among the individuals within each generation was estimated and then pooled over replications. The estimates of the variance of a generation mean (X) were obtained by dividing the variance within a generation by the total number of individuals in that generation.

2. Scaling tests

Adequacy of additive dominance effect was detected by individual scaling test, three tests of scale were carried out to detect the presence or absence of epistasis by using formulae given by Mather (1949) and Hayman and Mather (1955).

$A = 2\ \overline{B}_1 - \overline{P}_1 - \overline{F}_1$

$B = 2\ \overline{B}_2 - \overline{P}_2 - \overline{F}_1$

$C = 4\ \overline{F}_2 - 2\ \overline{F}_1 - \overline{P}_1 - \overline{P}_2$

$D = 2\ \overline{F}_2 - \overline{B}_1 - \overline{B}_2$

Where,

$\overline{P}_1$ = Mean of P_1

$\overline{P}_2$ = Mean of P_2

$\overline{F}_1$ = Mean of F_1

$\overline{F}_2$ = Mean of F_2

$\overline{B}_1$ = Mean of B_1

$\overline{B}_2$ = Mean of B_2

To test the significance of these four tests their variances were calculated as

$VA = 4V\ \overline{B}_1 + V\ \overline{P}_1 + V\ \overline{F}_1$

$VB = 4V\ \overline{B}_2 + V\ \overline{P}_2 + V\ \overline{F}_1$

$VC = 16V\ \overline{F}_2 + 4V\ \overline{F}_1 + V\ \overline{P}_1 + V\ \overline{P}_2$

$VD = 4\ V\ \overline{F}_2 + V\ \overline{B}_1 + V\ \overline{B}_2$

Where,

VA = Variance of A

VB = Variance of B

VC = Variance of C

VD = Variance of D

$V\overline{P}_1$ = Variance of mean of P_1

$V\overline{P}_2$ = Variance of mean of P_2

$V\bar{F}_1$ = Variance of mean of F_1

$V\bar{F}_2$ = Variance of mean of F_2

Square roots of these variances provided their respective standard error which was used to test the significance as below.

S.E. of A = $\sqrt{VA}$

S.E. of B = $\sqrt{VB}$

S.E. of C = $\sqrt{VC}$

S.E. of D = $\sqrt{VD}$

‘t’ values for scaling tests

It is the ratio of value of scaling test to the S.E. of the scaling test.

$$t(A) = \frac{A}{S.E.(A)}$$

$$t(B) = \frac{A}{S.E.(B)}$$

$$t(C) = \frac{A}{S.E.(C)}$$

$$t(D) = \frac{A}{S.E.(D)}$$

The calculated values of ‘t’ is compared with tabulated ‘t’ value 1.96 at 5 per cent level of significance. If calculated value is higher than 1.96; then it is considered significant and vice versa. The type of epistasis revealed by the significance of specific scale as given below,

1. The significance of A and B scales indicates the presence of all the three types of non-allelic interaction *viz.,* additive x additive (i), additive x dominance (j) and dominance × dominance (l).
2. The significance of C scale suggests that dominance x dominance (l) type of non-allelic interaction.
3. The significance of D scale reveals that additive x additive (i) type of gene interaction.

4. The significance of both C and D scales indicates additive x additive (i) and dominance x dominance (l) type of gene interactions.

3. Six parameters model (Hayman, 1958)

Components of generation means were analysed for two crosses using six basic generations *viz.,* P_1, P_2, F_1, F_2, B_1 and B_2. Whenever, the model was found inadequate, Hayman (1958) six parameter model was used to estimate the different gene effects.

Various notations used for the various gene effects by Hayman (1958).

Where:

Gene effects	Notations
Mean	m
Additive	d
Dominance	h
Additive × Additive	i
Additive × Dominance	j
Dominance × Dominance	l

The estimates of m, d, h, i, j and l were calculated by using the means of six populations.

$m = \bar{F}_2$

$d = \bar{B}_1 - \bar{B}_2$

$h = \bar{F}_1 - 4\,\bar{F}_2 - ½\,\bar{P}_1 - ½\,\bar{P}_2 + 2\bar{B}_1 + 2\,\bar{B}_2$

$i = 2\,\bar{B}_1 + 2\,\bar{B}_2 - 4\,\bar{F}_2$

$j = \bar{B}_1 + ½\,\bar{P}_1 - \bar{B}_2 + ½\,\bar{P}_2$

$l = \bar{P}_1 + \bar{P}_2 + 2\,\bar{F}_1 + 4\,\bar{F}_2 - 4\,\bar{B}_1 + 4\,\bar{B}_2$

The variances of these gene effects were obtained as:

$Vm = V\bar{F}_2$

$Vd = V\bar{B}_1 + V\bar{B}_2$

$Vh = ¼\,V\bar{P}_1 + ¼\,V\bar{P}_2 + V\bar{F}_1 + 16\,V\bar{F}_2 + 4\,V\bar{B}_1 + 4\,V\bar{B}_2$

$Vi = 16\,V\bar{F}_2 + 4V\bar{B}_1 + 4V\bar{B}_2$

$Vj = ¼\,V\bar{P}_1 + ¼\,V\bar{P}_2 + V\bar{B}_1 + V\bar{B}_2$

$$Vl = V\bar{P}_1 + V\bar{P}_2 + 4\ V\bar{F}_1 + 16\ V\bar{F}_2 + 16\ V\bar{B}_1 + 16\ V\bar{B}_2$$

Estimation of standard error

$\text{S.E.}\ (m) = \sqrt{Vm}$

$\text{S.E.}\ (d) = \sqrt{Vd}$

$\text{S.E.}\ (h) = \sqrt{Vh}$

$\text{S.E.}\ (i) = \sqrt{Vi}$

$\text{S.E.}\ (j) = \sqrt{Vj}$

$\text{S.E.}\ (l) = \sqrt{Vl}$

Estimates of 't' values for gene action

It is the ratio of the estimate of different genetic effects to their standard errors. It is used to test significance of the values of different genetic effects and calculated as below.

$t\ (m) = m/\text{S.E.}(m)$

$t\ (d) = d/\text{S.E.}(d)$

$t\ (h) = h/\text{S.E.}(h)$

$t\ (i) = i/\text{S.E.}(i)$

$t\ (j) = j/\text{S.E.}(j)$

$t\ (l) = l/\text{S.E.}(l)$

The calculated values of 't' were to be compared with 1.96 and 2.57 which were the tabulated values of 't' at 5 per cent and 1 per cent of significance, respectively.

Note:

When scaling test is non-significant i.e. when epistasis is absent, then three parameters model suggested by Mather (1949) was used, i.e.

$m = \frac{1}{2}\bar{P}_1 + \frac{1}{2}\bar{P}_2 + 4\bar{F}_2 - 2\bar{B}_1 - 2\bar{B}_2$

$d = \frac{1}{2}\bar{P}_1 + \frac{1}{2}\bar{P}_2$

$h = 6\bar{B}_1 + 6\bar{B}_2 - 8\bar{F}_2 - F_1 - 3/2\bar{P}_1 - 3/2\bar{P}_2.$

3.4.4 Experiment III : Transgressive segregation

The data on individual plant for each character was pooled together and means, standard deviations, standard error of means, variances and standard varieties were estimated as per the formulae given below.

$$\textbf{Mean } (\overline{X}) = \frac{\sum_{i=1}^{N} (Xi)}{N}$$

Where,

N = Number of individuals observed for particular character

Xi = Value of an individual from the sample

$$\textbf{Standard deviation } (\sigma) = \sqrt{\frac{\sum (Xi - \overline{X})^2}{N}}$$

Where,

Xi = $(Xi-\overline{X})$ an individual deviation

$\overline{X}$ = Mean of sample

$\sum (xi)^2 = \sum Xi^2 - \sum (Xi)^2 / N$

Standard error of mean = б /$\sqrt{n}$

Where,

б= Standard deviation of a sample as a whole

n= Number in the sample

$$\textbf{Variance } (б^2) = \frac{\sum(Xi)^2}{N-1}$$

Where,

Xi = $(X1-\overline{X})$ an individual deviation

$$\textbf{Standard variate} = \frac{Xi - \overline{X}}{б}$$

Where,

Xi = Variate value of i^{th} individual

$\overline{X}$ = Mean of sample

б = Standard deviation

Normal deviation (Limiting value)

The limiting value of standard varieties corresponding to the range of parental means at 5 per cent probability level was calculated so that the segregants showing deviation beyond this limiting value would be the transgressants. Transgressive segregants showing significant deviation only in desirable direction were considered for drawing inferences about transgression. The limiting value/ normal deviation value was calculated as per the formula given below.

$$\text{N. D. value} = \frac{\overline{P}^{(+)} + 1.96 \text{ x } \text{б } \overline{P}^{(+)} - \overline{X}}{\text{б}}$$

Where,

$\overline{P}^{(+)}$ = Mean of increasing parent

$\text{б}P^{(+)}$ = Standard deviation of increasing parent

$\overline{X}$ = Mean of segregating generation

б = Standard deviation of respective segregating generation

3.4.5 Experiment IV: Inheritance of rust resistance

Chi- square test

The goodness of fit test for Mendelian segregation ratio in the segregating populations was tested by Chi- square test (Fisher, 1930).

$$\chi^2 = \frac{\sum(O - E)^2}{E}$$

Where,

O = observed frequency.

E = expected frequency.

The significance of Chi- square value was tested against Table value with (n-1) degrees of freedom, where ‘n’ is the total number of segregating classes (Stansfield, 1986).

4. RESULTS AND DISCUSSION

The present investigation on “Genetic studies for quantitative traits and inheritance of rust resistance in pearl millet [*Pennisetum glaucum* (L.) R. Br.]” was carried out to know the heterosis and combining ability, to study the gene action, to identify transgressive segregation for various yield contributing traits and inheritance of rust resistance in pearl millet. The results obtained in relation to above objectives are presented here under following heads *viz*.,

4.1 Heterosis and combining ability

4.1.1 Mean performance of inbreds and hybrids

4.1.2 Heterosis

4.1.3 Combining ability analysis

4.1.4 Analysis of variances

4.1.5 Analysis of variance for combining ability

4.1.6 General combining ability effects

4.1.7 Specific combining ability effects

4.1.8 *Per se* performance, SCA effects and heterosis

4.2 Generation Mean Analysis

4.2.1 Analysis of variance

4.2.2 Mean performance of parents and different generations for grain yield and its component traits

4.2.3 Estimates of scaling tests for detecting non-allelic interactions of two crosses for different traits in pearl millet

4.2.4 Estimates of genetic effects of two crosses for gain yield and its component traits in pearl millet

4.3 Transgressive segregation

4.3.1 Cross I- DHLBI-1708 x DHLBI-181138

4.3.1.1 Means, standard deviations, frequency distribution and proportion of desirable transgressive segregants for eight characters in F_2 generation

4.3.1.2 Frequency and percentage of transgressive segregants for grain yield and yield attributing characters in F_2 generation of cross DHLBI-1708 x DHLBI-181138

4.3.2 Cross II- DHLBI 1708 x DHLBI 18963

4.3.2.1 Means, standard deviations, frequency distribution and proportion of desirable transgressive segregants for eight characters in F_2 generation

4.3.2.2 Frequency and percentage of transgressive segregants for grain yield and yield attributing characters in F_2 generation of cross DHLBI-1708 x DHLBI-18963

4.3.3 Promising transgressive segregants having combination of desirable attributes in F_2 generation of two crosses

4.4 Inheritance of rust resistance

4.4.1 Cross-I: DHLBI-967 x DHLBI-1035 (S x R)

4.4.2 Cross-II: DHLBI-1035 x DHLBI-1103 (R x S)

4.4.3 Cross-III: DHLBI-1013 x DHLBI-1035 (R x R)

4.1 Heterosis and combining ability

4.1.1 Mean performance of inbreds and hybrids.

The analysis of variance for ten characters are presented in Table 4.1. The analysis of variance for treatments revealed significant mean sum of squares for all the characters, which suggested that there was significant genetic variation among them. The mean performance of inbreds and their crosses for grain yield and its contributing traits in pearl millet are presented in Table 4.2 and 4.3. Higher values are desirable for all traits under study except for days to 50 % flowering and days to maturity for which lower values are preferred.

4.1.1.1 Days to 50 % flowering

The mean values for days to 50 % flowering of inbreds and crosses ranged between 49.33 days to 60.33 days and 47 days to 62.33 days, respectively. Among all inbreds, DHLBI-1708 took minimum number of days (49.33 days) followed by DHLBI-1103 (49.66 days), than rest of the inbreds. While, inbred DHLBI-181138 (60.33 days) recorded maximum number of days to 50 % flowering. In case of crosses, DHLBI-18963 x DHLBI-181181 was earliest (47.00 days) followed by DHLBI-967 x DHLBI-181181 (47.67 days) and the cross, DHLBI-1103 x DHLBI-1603 (62.33 days) was taken more number of days for 50 % flowering. Among the thirty six crosses, five crosses were found earlier than the check Phule Adishakti (52 days).

Table 4.1. Analysis of variance for ten characters in pearl millet

Sources of variation	d.f.	Mean sum of squares									
		Days to 50 % flowering	**Days to maturity**	**Plant height (cm)**	**Number of effective tillers/plant**	**Earhead length (cm)**	**Earhead girth (cm)**	**1000-grain weight (g)**	**Grain yield per plant (g)**	**Grain Fe (mg/kg)**	**Grain Zn (mg/kg)**
Replication	2	0.47	0.46	24.58	0.0073	0.024	0.14	0.20	4.46	4.42	0.67
Treatment	44	40.28**	39.73**	719.08**	0.42**	29.73**	2.73**	4.70**	263.81**	380.12**	198.85**
Error	88	4.26	3.86	35.24	0.014	1.62	0.19	1.77	13.81	1.80	2.35

*, ** significant at 5 and 1 per cent level of significance, respectively

Table 4.2. **Mean performance of inbreds and their F$_1$'s for ten characters in 9 x 9 half diallel crosses in pearl millet**

Sr. No.	Inbreds/ Crosses	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number effective tillers/plant	Earhead length (cm)
	Inbreds					
1.	DHLBI-1103	49.66	80.00	150.33	2.03	15.88
2.	DHLBI-967	50.66	83.00	154.00	2.30	18.88
3.	DHLBI-1013	57.33	90.00	165.22	2.00	23.11
4.	DHLBI-1708	49.33	81.00	161.66	2.03	19.33
5.	DHLBI-18963	58.00	90.00	172.66	2.21	24.55
6.	DHLBI-181181	51.66	86.00	161.00	1.81	26.62
7.	DHLBI-181138	60.33	91.66	181.00	2.40	23.54
8.	DHLBI-1035	59.00	91.00	163.44	1.74	23.00
9.	DHLBI-1603	59.66	92.66	144.46	1.26	20.44
	Inbred Mean	55.07	87.25	161.53	1.97	21.71
	F$_{1s}$					
10.	DHLBI-1103 x DHLBI-967	51.00	82.67	175.00	2.20	20.33
11.	DHLBI-1103 x DHLBI-1013	55.00	88.00	177.89	2.31	18.89
12.	DHLBI-1103 x DHLBI-1708	52.33	85.67	171.89	2.13	20.78
13.	DHLBI-1103 x DHLBI-18963	55.67	87.33	181.00	2.10	21.78
14.	DHLBI-1103 x DHLBI-181181	56.33	89.00	167.78	2.20	24.22
15.	DHLBI-1103 x DHLBI-181138	56.67	88.00	192.33	2.40	23.67
16.	DHLBI-1103 x DHLBI-1035	53.33	87.66	183.67	2.43	24.67
17.	DHLBI-1103 x DHLBI-1603	62.33	90.33	134.89	1.70	13.78
18.	DHLBI-967 x DHLBI-1013	53.67	87.00	189.81	2.40	23.22
19.	DHLBI-967 x DHLBI-1708	53.67	87.67	182.00	1.72	22.00
20.	DHLBI-967 x DHLBI-18963	57.00	90.00	183.11	2.07	25.33
21.	DHLBI-967 x DHLBI-181181	47.67	79.67	190.00	1.70	27.22
22.	DHLBI-967 x DHLBI-181138	58.00	91.00	199.33	2.00	27.22
23.	DHLBI-967 x DHLBI-1035	55.00	88.33	184.52	1.77	19.89
24.	DHLBI-967 x DHLBI-1603	55.00	89.00	180.89	1.87	22.89

Table 4.2 contd….

Sr. No.	Inbreds/ Crosses	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number effective tillers/plant	Earhead length (cm)
25.	DHLBI-1013 x DHLBI-1708	48.33	81.00	184.00	2.27	24.00
26.	DHLBI-1013 x DHLBI-18963	53.33	87.00	183.11	1.73	26.78
27.	DHLBI-1013 x DHLBI-181181	58.00	90.67	192.11	1.93	27.00
28.	DHLBI-1013 x DHLBI-181138	57.33	89.67	202.20	2.30	24.89
29.	DHLBI-1013 x DHLBI-1035	53.00	87.00	166.44	1.71	23.67
30.	DHLBI-1013 x DHLBI-1603	59.67	91.67	175.33	1.80	25.78
31.	DHLBI-1708 x DHLBI-18963	52.00	84.00	190.55	2.97	21.11
32.	DHLBI-1708 x DHLBI-181181	48.00	81.00	178.67	2.67	26.67
33.	DHLBI-1708 x DHLBI-181138	52.00	86.67	200.71	3.00	25.33
34.	DHLBI-1708 x DHLBI-1035	56.33	86.33	183.89	2.72	25.00
35.	DHLBI-1708 x DHLBI-1603	55.33	89.00	166.66	2.33	23.56
36.	DHLBI-18963 x DHLBI-181181	47.00	77.33	166.00	1.67	28.00
37.	DHLBI-18963 x DHLBI-181138	57.33	90.33	193.33	2.23	24.56
38.	DHLBI-18963 x DHLBI-1035	57.00	89.00	185.67	1.62	25.33
39.	DHLBI-18963 x DHLBI-1603	57.00	89.67	156.33	1.97	27.11
40.	DHLBI-181181 x DHLBI-181138	58.00	88.33	184.44	2.50	27.22
41.	DHLBI-181181 x DHLBI-1035	52.67	87.00	166.00	1.87	27.67
42.	DHLBI-181181 x DHLBI-1603	56.00	89.00	159.00	1.47	23.44
43.	DHLBI-181138 x DHLBI-1035	55.67	87.33	197.33	2.27	27.00
44.	DHLBI-181138 x DHLBI-1603	59.00	91.67	195.00	1.62	24.89
45.	DHLBI-1035 x DHLBI-1603	54.00	87.67	164.00	1.87	24.11
46.	Phule Adishakti (C)	52.00	86.00	188.00	2.03	23.55
	F_1's mean	55.79	87.32	180.13	2.09	24.13
	General Mean	54.89	87.31	176.41	2.07	23.65
	S.E. ±	1.19	1.13	3.39	0.066	0.72

Table 4.3. Mean performance of inbreds and their F_1s for ten characters in 9 x 9 half diallel crosses in pearl millet

Sr. No.	Inbreds/ Crosses	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
	Inbreds					
1.	DHLBI-1103	9.33	11.26	29.96	53.33	31.27
2.	DHLBI-967	10.73	9.91	33.48	48.77	33.15
3.	DHLBI-1013	10.44	11.89	27.24	72.59	50.13
4.	DHLBI-1708	9.77	10.81	29.33	49.20	29.11
5.	DHLBI-18963	10.61	11.61	34.57	60.24	41.24
6.	DHLBI-181181	10.66	11.54	28.63	62.40	44.14
7.	DHLBI-181138	11	12.83	35.72	78.25	50.62
8.	DHLBI-1035	10.66	12.22	24.50	60.31	40.48
9.	DHLBI-1603	9.44	10.85	22.99	70.84	51.58
	Inbred Mean	10.29	11.43	29.60	61.79	41.30
	F_{1s}					
10.	DHLBI-1103 x DHLBI-967	11.00	11.95	44.86	51.62	34.24
11.	DHLBI-1103 x DHLBI-1013	9.44	10.67	44.77	66.10	47.19
12.	DHLBI-1103 x DHLBI-1708	10.11	12.14	42.91	49.61	24.69
13.	DHLBI-1103 x DHLBI-18963	11.00	13.41	45.44	60.58	43.24
14.	DHLBI-1103 x DHLBI-181181	10.67	12.95	42.37	67.49	46.38
15.	DHLBI-1103 x DHLBI-181138	11.67	13.70	48.90	73.19	52.85
16.	DHLBI-1103 x DHLBI-1035	10.33	13.91	47.74	62.02	45.64
17.	DHLBI-1103 x DHLBI-1603	7.56	13.28	25.42	59.34	46.90
18.	DHLBI-967 x DHLBI-1013	11.56	13.57	45.25	64.36	49.36
19.	DHLBI-967 x DHLBI-1708	11.22	10.43	28.33	38.83	34.37
20.	DHLBI-967 x DHLBI-18963	11.11	12.95	42.25	49.16	44.23
21.	DHLBI-967 x DHLBI-181181	11.78	13.45	39.25	53.40	36.44
22.	DHLBI-967 x DHLBI-181138	13.00	11.96	44.49	58.60	49.35
23.	DHLBI-967 x DHLBI-1035	12.00	12.95	23.77	48.21	29.32
24.	DHLBI-967 x DHLBI-1603	11.56	12.80	39.43	54.21	41.75

Table 4.3 Contd….

Sr. No.	Inbreds/ Crosses	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
25.	DHLBI-1013 x DHLBI-1708	10.56	11.51	37.14	56.19	40.44
26.	DHLBI-1013 x DHLBI-18963	10.22	13.23	43.85	63.58	45.66
27.	DHLBI-1013 x DHLBI-181181	10.78	12.33	40.52	70.18	47.29
28.	DHLBI-1013 x DHLBI-181138	11.56	14.29	48.38	87.30	59.70
29.	DHLBI-1013 x DHLBI-1035	11.11	12.26	36.69	60.84	43.03
30.	DHLBI-1013 x DHLBI-1603	11.44	13.26	34.26	69.18	46.46
31.	DHLBI-1708 x DHLBI-18963	10.67	12.90	56.78	61.71	32.46
32.	DHLBI-1708 x DHLBI-181181	10.34	11.79	49.73	63.27	36.32
33.	DHLBI-1708 x DHLBI-181138	11.99	14.01	59.90	84.61	49.44
34.	DHLBI-1708 x DHLBI-1035	10.67	13.90	47.45	54.22	30.19
35.	DHLBI-1708 x DHLBI-1603	11.11	10.29	43.73	61.42	33.45
36.	DHLBI-18963 x DHLBI-181181	10.5	8.78	27.24	60.31	42.65
37.	DHLBI-18963 x DHLBI-181138	10.44	13.79	51.27	70.43	45.22
38.	DHLBI-18963 x DHLBI-1035	9.44	11.18	28.38	52.49	39.80
39.	DHLBI-18963 x DHLBI-1603	11.11	12.83	41.78	66.10	48.55
40.	DHLBI-181181 x DHLBI-181138	11.56	13.55	53.50	78.25	51.53
41.	DHLBI-181181 x DHLBI-1035	11.67	12.99	39.45	50.49	42.88
42.	DHLBI-181181 x DHLBI-1603	10.39	12.29	25.40	62.53	50.02
43.	DHLBI-181138 x DHLBI-1035	10.55	14.16	46.75	83.37	53.53
44.	DHLBI-181138 x DHLBI-1603	13.11	13.30	35.16	89.10	58.49
45.	DHLBI-1035 x DHLBI-1603	10.67	12.41	42.88	72.25	50.43
46.	Phule Adishakti (C)	10.11	13.71	45.12	52.71	37.98
	F_1's mean	10.94	12.64	41.53	63.18	43.70
	General Mean	10.81	12.40	39.15	62.60	43.22
	S.E. ±	0.26	0.37	2.12	0.82	0.91

4.1.1.2 Days to maturity

The variation for days to maturity among inbreds and crosses ranged between 80.00 days to 92.66 days and 77.33 days to 91.67 days, respectively. From the inbreds, DHLBI-1103 was matured significantly earlier (80.00 days), followed by DHLBI-1708 (81.00). Among all the hybrids, DHLBI-18963 x DHLBI-181181 was matured earlier (77.33 days) than the rest of the crosses. While the hybrid, DHLBI-1013 x DHLBI-1603 and DHLBI-181138 x DHLBI-1603 took more number of days for maturity (91.67 days). Out of thirty six hybrids, seven crosses were found earlier in maturity over the check Phule Adishakti (86.00).

4.1.1.3 Plant height (cm)

The maximum plant height in inbreds was recorded by DHLBI-181138 (181 cm), while minimum by DHLBI-1603 (144.46 cm). The hybrids, DHLBI-1013 x DHLBI-181138 (202.20 cm) and DHLBI-1708 x DHLBI-181138 (200.71 cm) found significantly tallest and the hybrid DHLBI-1103 x DHLBI-1603 (134.89 cm) was found dwarf. The height of rest of hybrids ranged between 134.89 to 202.20 cm. Among thirty six crosses, eleven crosses recorded significantly maximum height over the check Phule Adishakti (188.00 cm).

4.1.1.4 Number of effective tillers per plant

For number of effective tillers per plant values of inbreds and crosses ranged between 1.26 to 2.40 and 1.47 to 3.00, respectively. Inbred DHLBI-181138 showed maximum number of effective tillers (2.40). Among the hybrids, DHLBI-1708 x DHLBI-181138 recorded highest (3.00) followed by DHLBI-1708 x DHLBI-18963 (2.97), whereas, DHLBI-181181 x DHLBI-1603 recorded minimum (1.47). Total nineteen crosses, recorded significantly maximum effective tillers over the check Phule Adishakti (2.03).

4.1.1.5 Earhead length (cm)

The longest earhead was found in inbred DHLBI-181181 (26.62 cm) followed by DHLBI-18963 (24.55 cm) compared to inbred mean (21.71 cm), while shortest earhead was found in DHLBI-1103 (15.88 cm). The mean values of inbreds and crosses were ranged from 15.88 cm to 26.62 cm and 13.78 cm to 28.00 cm, respectively. The cross combination DHLBI-18963 x DHLBI-181181 recorded longest earhead length

(28.00 cm) while shortest earhead length was recorded by DHLBI-1103 x DHLBI-1603 (13.78 cm). Among thirty six crosses, twenty five crosses were found significantly superior over the check Phule Adishakti (23.55 cm).

4.1.1.6 Earhead girth (cm)

The maximum earhead girth in inbreds were recorded by DHLBI-967 (10.73 cm), while minimum by DHLBI-1103 (9.33 cm). Among the crosses, DHLBI-181138 x DHLBI-1603 (13.11 cm) followed by DHLBI-967 x DHLBI-181138 (13.00 cm) were found significantly for broad earhead. The earhead girth of rest of crosses ranged between 7.56 cm to 13.11 cm. Out of thirty six hybrids, thirty two hybrids were found to be significant over check Phule Adishakti (10.11 cm).

4.1.1.7 1000-grain weight (g)

For 1000-grain weight, mean values of inbreds and crosses varied between 9.91 g to 12.83 g and 8.78 g to 14.29 g, respectively. Among the inbreds, DHLBI-181138 had shown highest 1000-grain weight i.e., 12.83 g followed by DHLBI-1035 (12.22 g). While the lowest 1000-grain weight was exhibited by the inbred DHLBI-967 (9.91 g).

The cross combination DHLBI-1013 x DHLBI-181138 (14.29 g) followed by DHLBI-181138 x DHLBI-1035 (14.16 g) displayed highest 1000-grain weight as compared to rest of the crosses, while minimum 1000-grain weight was recorded by cross DHLBI-18963 x DHLBI-181181 (8.78 g). The 1000-grain weight of six crosses were found significantly superior as compared to check Phule Adishakti (13.71 g).

4.1.1.8 Grain yield per plant (g)

The variation for grain yield per plant among inbreds and crosses varied between 22.99 g to 35.72 g and 23.77 g to 59.90 g, respectively. The highest grain yield per plant (35.72 g) was recorded by inbred DHLBI-181138, while the lowest grain yield per plant (22.99 g) was recorded in DHLBI-1603. Inbreds DHLBI-18963 (34.57 g) followed by DHLBI-967 (33.48 g) and DHLBI-1103 (29.96 g) had shown higher grain yield per plant over the inbred mean (29.60 g).

The cross combinations, DHLBI-1708 x DHLBI-181138 (59.90 g), DHLBI-1708 x DHLBI-18963 (56.78 g) and DHLBI-181181 x DHLBI-181138 (53.50 g) ranked first, second and third, respectively for grain yield per plant. The cross DHLBI-967 x DHLBI-1035 was the poorest performer for grain yield (23.77 g). Out of thirty six hybrids, twelve hybrids recorded significantly higher grain yield per plant over standard check Phule Adishakti (45.12 g).

4.1.1.9 Grain Fe (mg/kg)

The mean values for grain Fe (Iron) content among inbreds and crosses were ranged between 48.77 to 78.25 and 38.83 to 89.10, respectively. Highest grain Fe was recorded in inbred DHLBI-181138 (78.25). Four inbreds were found superior than inbred mean for this trait. Among thirty six crosses, DHLBI-181138 x DHLBI-1603 (89.10) was found most superior followed by DHLBI-1013 x DHLBI-181138 (87.30), DHLBI-1708 x DHLBI-181138 (84.61) and DHLBI-181138 x DHLBI-1035 (83.37), while lowest grain Fe was recorded in cross DHLBI-967 x DHLBI-1708 (38.83). Among thirty six crosses, twenty nine crosses were recorded significantly higher grain Fe content than check Phule Adishakti (52.71).

4.1.1.10 Grain Zn (mg/kg)

The maximum grain Zn (Zinc) content in inbreds was recorded by DHLBI-1603 (51.58), while minimum by DHLBI-1708 (29.11). Among the hybrids, DHLBI-1013 x DHLBI-181138 (59.70) was found with highest grain Zn content, followed by DHLBI-181138 x DHLBI-1603 (58.49) and DHLBI-181138 x DHLBI-1035 (53.41). and hybrid DHLBI-1103 x DHLBI-1708 (24.69) was lowest. Out of thirty six hybrids, twenty seven hybrids were found significant over Phule Adishakti (37.98).

4.1.2 Heterosis

In present study mean performance of different traits were compared with corresponding mid parent (MP), better parent (BP) and standard check hybrid (Phule Adishakti) and differences are being expressed as per cent heterosis for grain yield and its component traits. In pearl millet, positive heterosis was desirable for all traits studied except days to 50 % flowering and days to maturity where negative heterosis is desirable. The trait wise results of mid parent (MP) i.e. relative heterosis, better parent (BP) i.e. heterobeltiosis and standard heterosis (SH) were observed in thirty six hybrids are given in Table 4.4a to 4.4e.

4.1.2.1 Days to 50 % flowering

In pearl millet, earliness for days to 50 per cent flowering is considered as desirable character. Therefore, the hybrids with negative heterosis for this character are considered as superior. Magnitude of heterosis over the mid-parent ranged from -14.29

per cent (DHLBI-18963 x DHLBI-181181) to 14.02 per cent (DHLBI-1103 x DHLBI-1603). Out of thirty six crosses, seven crosses exhibited significant negative mid parent heterosis. The highest negative mid parent heterosis was observed in DHLBI-18963 x DHLBI-181181 (-14.29 %) followed by DHLBI-1013 x DHLBI-1708 (-9.38 %) and DHLBI-1035 x DHLBI-1603 (-8.99 %). Better parent heterosis was ranged from -18.97 to 9.03 per cent. Out of thirty six crosses, eighteen crosses showed negative significant heterobeltiosis. The cross DHLBI-18963 x DHLBI-181181 (-18.97 %) followed by DHLBI-1013 x DHLBI-1708 (-15.70 %) and DHLBI-1708 x DHLBI-181138 (-13.81 %) exhibited highest negative heterobeltiosis.

Standard heterosis ranged from -9.62 to 19.87 per cent over check Phule Adishakti. The cross DHLBI-18963 x DHLBI-181181 (-9.62 %) exhibited highest negative standard heterosis followed by cross DHLBI-967 x DHLBI-181181 (-8.33 %) and DHLBI-1708 x DHLBI-181181 (-7.69 %). Out of thirty six crosses, only four crosses had shown significant negative standard heterosis over the check Phule Adishakti. The results were in accordance with Singh and Sagar (2001), Vetriventhan *et al.* (2008), Chotaliya *et al*. (2009), Lakshmana *et al*. (2010b), Pawar *et al*. (2015), Badhe *et al.* (2018), Barathi *et al*.,(2020) and Dutta *et al*. (2021).

4.1.2.2 Days to maturity

For earliness, a negative heterosis for days to maturity is desirable and early genotypes could be isolated from advanced generations of these crosses. The average heterosis for days to maturity ranged from -12.12 per cent (DHLBI-18963 x DHLBI-181181) to 7.23 per cent (DHLBI-1103 x DHLBI-181181). Out of thirty six crosses, seven crosses had shown significant negative heterosis over mid inbred.

Better parent heterosis were ranged from -14.07 to 5.76 per cent. Seventeen crosses had shown desirably significant heterobeltiosis over thirty six crosses, out of which DHLBI-18963 x DHLBI-181181 (-14.07 %) exhibited highest negative heterobeltiosis. Standard heterosis for days to maturity ranged from –10.08 to 6.59 per cent over check Phule Adishakti. Five crosses exhibited significant heterosis in desirable direction out of which DHLBI-18963 x DHLBI-181181 (-10.08 %) recorded highest standard heterosis. Similar results were reported earlier by Singh and Sagar (2001), Chotaliya *et al*. (2009), Lakshmana *et al*. (2010b), Vagadiya *et al*. (2010a) and Pawar *et al.* (2015).

Table 4.4a. Per cent heterosis over mid parent, better parent and standard check for days to 50 per cent flowering and days to maturity in pearl millet.

Sr. No.	Crosses	Days to 50 % flowering			Days to maturity		
		MP	BP	SH	MP	BP	SH
1.	DHLBI-1103 x DHLBI-967	1.66	0.66	-1.92	1.43	-0.40	-3.88*
2.	DHLBI-1103 x DHLBI-1013	2.80	-4.07	5.77	3.53*	-2.22	2.33
3.	DHLBI-1103 x DHLBI-1708	5.72	5.37	0.64	6.42**	5.76**	-0.39
4.	DHLBI-1103 x DHLBI-18963	3.41	-4.02	7.05*	2.75	-2.96	1.55
5.	DHLBI-1103 x DHLBI-181181	11.18**	9.03**	8.33*	7.23**	3.49	3.49
6.	DHLBI-1103 x DHLBI-181138	3.03	-6.08*	8.97**	2.52	-4.00*	2.33
7.	DHLBI-1103 x DHLBI-1035	-2.12	-9.61**	2.56	2.53	-2.56	1.93
8.	DHLBI-1103 x DHLBI-1603	14.02**	4.47	19.87**	4.63**	-3.67*	5.04**
9.	DHLBI-967 x DHLBI-1013	-0.62	-6.40*	3.21	0.58	-3.33	1.16
10.	DHLBI-967 x DHLBI-1708	7.33*	5.92	3.21	6.91**	5.62**	1.94
11.	DHLBI-967 x DHLBI-18963	4.91	-1.72	9.62**	4.05*	0.00	4.65*
12.	DHLBI-967 x DHLBI-181181	-6.84*	-7.74*	-8.33*	-5.72**	-7.36**	-7.36**
13.	DHLBI-967 x DHLBI-181138	4.50	-3.87	11.54**	4.20**	-0.73	5.81**
14.	DHLBI-967 x DHLBI-1035	0.30	-6.78*	5.77	1.53	-2.93	2.71
15.	DHLBI-967 x DHLBI-1603	-0.30	-7.82**	5.77	1.33	-3.96*	3.49
16.	DHLBI-1013 x DHLBI-1708	-9.38**	-15.70**	-7.05*	-5.26**	-10.00**	-5.81**
17.	DHLBI-1013 x DHLBI-18963	-7.51**	-8.05**	2.56	-3.33*	-3.33	1.16
18.	DHLBI-1013 x DHLBI-181181	6.42*	1.16	11.54**	3.03	0.74	5.43**
19.	DHLBI-1013 x DHLBI-181138	-2.55	-4.97	10.26**	-1.28	-2.18	4.26*
20.	DHLBI-1013 x DHLBI-1035	-8.88**	-10.17**	1.92	-3.87*	-4.40*	1.16
21.	DHLBI-1013 x DHLBI-1603	1.99	0.00	14.74**	0.36	-1.08	6.59**
22.	DHLBI-1708 x DHLBI-18963	-3.11	-10.34**	0.00	-1.75	-6.67**	-2.33
23.	DHLBI-1708 x DHLBI-181181	-4.95	-7.10*	-7.69*	-2.99	-5.81**	-5.81**
24.	DHLBI-1708 x DHLBI-181138	-5.17	-13.81**	0.00	0.39	-5.45**	0.78
25.	DHLBI-1708 x DHLBI-1035	4.00	-4.52	8.33*	0.39	-5.13**	0.39
26.	DHLBI-1708 x DHLBI-1603	1.53	-7.26*	6.41	2.50	-3.96*	3.49
27.	DHLBI-18963 x DHLBI-181181	-14.29**	-18.97**	-9.62**	-12.12**	-14.07**	-10.08**
28.	DHLBI-18963 x DHLBI-181138	-3.10	-4.97	10.26**	-0.55	-1.45	5.04**
29.	DHLBI-18963 x DHLBI-1035	-2.56	-3.39	9.62**	-1.66	-2.20	3.49
30.	DHLBI-18963 x DHLBI-1603	-3.12	-4.47	9.62**	-1.82	-3.24	4.26*
31.	DHLBI-181181 x DHLBI-181138	3.57	-3.87	11.54**	-0.56	-3.64*	2.71
32.	DHLBI-181181 x DHLBI-1035	-4.82	-10.73**	1.28	-1.69	-4.40*	1.16
33.	DHLBI-181181 x DHLBI-1603	0.60	-6.15*	7.69*	-0.37	-3.96*	3.49
34.	DHLBI-181138 x DHLBI-1035	-6.70**	-7.73**	7.05*	-4.38**	-4.73**	1.55
35.	DHLBI-181138 x DHLBI-1603	-1.67	-2.21	13.46**	-0.54	-1.08	6.59**
36.	DHLBI-1035 x DHLBI-1603	-8.99**	-9.50**	3.85	-4.54**	-5.40**	1.94
	SE(D)±	1.46	1.68	1.68	1.38	1.60	1.60
	CD at 5%	2.90	3.35	3.35	2.76	3.18	3.18
	CD at 1%	3.84	4.44	4.44	3.65	4.22	4.22

*, ** Significant at 5 and 1 per cent level, respectively

Table 4.4b. Per cent heterosis over mid parent, better parent and standard check for plant height and number of effective tillers per plant in pearl millet

Sr. No.	Crosses	Plant height (cm)			Number effective tillers/plant		
		MP	BP	SH	MP	BP	SH
1.	DHLBI-1103 x DHLBI-967	15.01**	13.63**	-6.91**	1.54	-4.35	8.20
2.	DHLBI-1103 x DHLBI-1013	12.75**	7.67*	-5.38*	14.55**	13.61**	13.61**
3.	DHLBI-1103 x DHLBI-1708	10.19**	6.32*	-8.57**	4.92	4.92	4.92
4.	DHLBI-1103 x DHLBI-18963	12.08**	4.83	-3.72	-1.02	-4.98	3.28
5.	DHLBI-1103 x DHLBI-181181	7.78**	4.21	-10.76**	14.29**	8.20	8.20
6.	DHLBI-1103 x DHLBI-181138	16.10**	6.26*	2.30	8.27*	0.00	18.03**
7.	DHLBI-1103 x DHLBI-1035	17.07**	12.37**	-2.30	28.98**	19.67**	19.67**
8.	DHLBI-1103 x DHLBI-1603	-8.48**	-10.27**	-28.25**	3.03	-16.39**	-16.39**
9.	DHLBI-967 x DHLBI-1013	18.92**	14.88**	0.96	11.63**	4.35	18.03**
10.	DHLBI-967 x DHLBI-1708	15.31**	12.58**	-3.19	-20.77**	-25.36**	-15.57**
11.	DHLBI-967 x DHLBI-18963	12.11**	6.05*	-2.60	-8.35*	-10.14*	1.64
12.	DHLBI-967 x DHLBI-181181	20.63**	18.01**	1.06	-17.41**	-26.09**	-16.39**
13.	DHLBI-967 x DHLBI-181138	19.00**	10.13**	6.03*	-14.89**	-16.67**	-1.64
14.	DHLBI-967 x DHLBI-1035	16.25**	12.89**	-1.85	-12.54**	-23.19**	-13.11**
15.	DHLBI-967 x DHLBI-1603	21.21**	17.46**	-3.78	4.67	-18.84**	-8.20
16.	DHLBI-1013 x DHLBI-1708	12.58**	11.36**	-2.13	12.40**	11.48*	11.48*
17.	DHLBI-1013 x DHLBI-18963	8.38**	6.05*	-2.60	-17.66**	-21.57**	-14.75**
18.	DHLBI-1013 x DHLBI-181181	17.78**	16.27**	2.19	1.31	-3.33	-4.92
19.	DHLBI-1013 x DHLBI-181138	16.80**	11.71**	7.55**	4.55	-4.17	13.11**
20.	DHLBI-1013 x DHLBI-1035	1.28	0.74	-11.47**	-8.73*	-14.67**	-16.07**
21.	DHLBI-1013 x DHLBI-1603	13.23**	6.12*	-6.74*	10.41*	-9.83*	-11.31*
22.	DHLBI-1708 x DHLBI-18963	13.99**	10.36**	1.36	39.83**	34.24**	45.90**
23.	DHLBI-1708 x DHLBI-181181	10.74**	10.52**	-4.96	38.53**	31.15**	31.15**
24.	DHLBI-1708 x DHLBI-181138	17.14**	10.89**	6.76*	35.34**	25.00**	47.54**
25.	DHLBI-1708 x DHLBI-1035	13.12**	12.51**	-2.19	43.99**	33.61**	33.61**
26.	DHLBI-1708 x DHLBI-1603	8.89**	3.09	-11.35**	41.01**	14.43**	14.43**
27.	DHLBI-18963 x DHLBI-181181	-0.50	-3.86	-11.70**	-17.22**	-24.59**	-18.03**
28.	DHLBI-18963 x DHLBI-181138	9.33**	6.81*	2.84	-3.11	-6.94	9.84*
29.	DHLBI-18963 x DHLBI-1035	10.48**	7.53**	-1.24	-18.14**	-26.85**	-20.49**
30.	DHLBI-18963 x DHLBI-1603	-1.41	-9.46**	-16.84**	13.14**	-11.01*	-3.28
31.	DHLBI-181181 x DHLBI-181138	7.86**	1.90	-1.89	18.58**	4.17	22.95**
32.	DHLBI-181181 x DHLBI-1035	2.33	1.56	-11.70**	4.97	2.75	-8.20
33.	DHLBI-181181 x DHLBI-1603	4.11	-1.24	-15.43**	-4.86	-19.27**	-27.87**
34.	DHLBI-181138 x DHLBI-1035	14.58**	9.02**	4.96	9.50*	-5.56	11.48*
35.	DHLBI-181138 x DHLBI-1603	19.83**	7.73**	3.72	-11.82**	-32.64**	-20.49**
36.	DHLBI-1035 x DHLBI-1603	6.53*	0.34	-12.77**	24.17**	7.28	-8.20
	SE(D)±	4.19	4.84	4.84	0.08	0.09	0.09
	CD at 5%	8.34	9.63	9.63	0.15	0.18	0.18
	CD at 1%	11.05	12.76	12.76	0.21	0.24	0.24

*, ** Significant at 5 and 1 per cent level, respectively

4.1.2.3 Plant height (cm)

Out of thirty six crosses, thirty crosses recorded significant average heterosis in positive direction. The heterosis over better parent ranged from -10.27 (DHLBI-1103 x DHLBI-1603) to 18.01 per cent (DHLBI-967 x DHLBI-181181). Out of thirty six crosses, twenty five crosses exhibited significant heterobeltiosis in desirable direction for this trait. The range of standard heterosis over the check Phule Adishakti was -28.25 (DHLBI-1103 x DHLBI-1603) to 7.55 per cent (DHLBI-1013 x DHLBI-181138). Out of thirty six crosses, only three crosses exhibited significant standard heterosis in desirable direction for plant height. The highest standard heterosis in was found in cross DHLBI-1013 x DHLBI-181138 (7.55 %) followed by DHLBI-1708 x DHLBI-181138 (6.76 %) and DHLBI-967 x DHLBI-181138 (6.03 %). These findings are in agreement with the Sheoran *et al.* (2000a), Izge *et al.* (2007), Chotaliya *et al.* (2009), Lakshmana *et al.* (2010b) and Barathi *et al*. (2020).

4.1.2.4 Number of effective tillers per plant

Average heterosis for number of effective tillers per plant ranged from -20.77 to 43.99 per cent. The cross DHLBI-1708 x DHLBI-1035 (43.99 %) exhibited highest positive average heterosis followed by DHLBI-1708 x DHLBI-1603 (41.01 %) and DHLBI-1708 x DHLBI-18963 (39.83 %).

Heterobeltiosis ranged from -32.64 per cent (DHLBI-181138 x DHLBI-1603) to 34.24 per cent (DHLBI-1708 x DHLBI-18963). Out of thirty six crosses, eight crosses shown significant heterobeltiosis in desirable direction for this trait. Standard heterosis over check hybrid Phule Adishakti ranged from -27.87 (DHLBI-181181 x DHLBI-1603) to 47.54 per cent (DHLBI-1708 x DHLBI-181138). Fourteen crosses showed standard heterosis in desirable direction. The highest significant standard heterosis recorded in the cross, DHLBI-1708 x DHLBI-181138 (47.54 %), followed by cross DHLBI-1708 x DHLBI-18963 (45.90 %) and DHLBI-1708 x DHLBI-1035 (33.61 %). These results are in conformity with the earlier findings of Manga and Dubey (2004), Izge *et al.* (2007), Chotaliya *et al.* (2009), Bhadalia *et al.* (2011), Bachkar *et al.* (2014), Karvar *et al.* (2017) and Badhe *et al.* (2018).

4.1.2.5 Earhead length (cm)

The range of heterosis for earhead length over mid parent, better parent and standard check were -24.15 to 28.28, -32.61 to 15.58 and -41.50 to 18.86 per cent, respectively. The cross DHLBI-967 x DHLBI-181138 manifested highest significant positive heterosis over mid parent (28.28 %) and better parent (15.58 %). While, standard heterosis (18.86 %) was observed for cross DHLBI-18963 x DHLBI-181181. Among thirty six crosses, twenty six, eight and eleven crosses showed positive heterotic effect over mid parent, better parent and standard check, respectively. These findings are in accordance with Sheoran *et al.* (2000a), Singh and Sagar (2001), Manga and Dubey (2004) and Chotaliya *et al*. (2009).

4.1.2.6 Earhead girth (cm)

Out of thirty-six hybrids, nineteen hybrids recorded significant average heterosis in desirable direction. The heterosis over better parent ranged from -19.98 per cent (DHLBI-1103 x DHLBI-1603) to 19.15 per cent (DHLBI-181138 x DHLBI-1603). Out of thirty-six crosses, ten crosses exhibited positively significant heterobeltiosis for this trait. The range of standard heterosis over the check Phule Adishakti was -25.26 per cent (DHLBI-1103 x DHLBI-1603) to 29.67 per cent (DHLBI-181138 x DHLBI-1603). Out of thirty-six crosses, nineteen crosses exhibited positively significant standard heterosis for this trait. The highest standard heterosis in desirable direction was shown by cross DHLBI-181138 x DHLBI-1603 (29.67 %) followed by DHLBI-967 x DHLBI-181138 (28.59 %) and DHLBI-967 x DHLBI-1035 (18.69 %). The similar results were earlier reported by Sheoran *et al.* (2000a), Chotaliya *et al.* (2009), Bhadalia *et al.* (2011), Bachkar *et al.* (2014), Salagarkar and Wali (2016) and Badhe *et al.* (2018).

4.1.2.7 1000-grain weight (g)

The magnitude of heterosis for 1000-grain weight over the mid parent was ranged from -24.13 per cent (DHLBI-18963 x DHLBI-181181) to 25.41 per cent (DHLBI-967 x DHLBI-181181). The cross DHLBI-967 x DHLBI-181181 (25.41 %) exhibited highest positive average heterosis followed by DHLBI-967 x DHLBI-1013 (24.45 %) and DHLBI-967 x DHLBI-1603 (23.24 %). The range of heterobeltiosis was from -24.37 per cent (DHLBI-18963 x DHLBI-181181) to 17.90 per cent (DHLBI-1103 x DHLBI-1603). Out of thirty-six crosses, seventeen crosses shown highest significant

Table 4.4c. Per cent heterosis over mid parent, better parent and standard check for earhead length and earhead girth in pearl millet

Sr. No.	Crosses	Earhead length (cm)			Earhead girth (cm)		
		MP	BP	SH	MP	BP	SH
1.	DHLBI-1103 x DHLBI-967	16.93**	7.64	-13.68**	9.67**	2.52	8.84*
2.	DHLBI-1103 x DHLBI-1013	-3.13	-18.26**	-19.81**	-4.52	-9.60**	-6.59
3.	DHLBI-1103 x DHLBI-1708	17.99**	7.48	-11.79**	5.81	3.41	0
4.	DHLBI-1103 x DHLBI-18963	7.68	-11.32**	-7.56	10.31**	3.68	8.80*
5.	DHLBI-1103 x DHLBI-181181	13.95**	-9.03*	2.83	6.68*	0.03	5.51
6.	DHLBI-1103 x DHLBI-181138	20.00**	0.48	0.47	14.74**	6.03	15.40**
7.	DHLBI-1103 x DHLBI-1035	26.85**	7.25	4.71	3.35	-3.09	2.21
8.	DHLBI-1103 x DHLBI-1603	-24.15**	-32.61**	-41.50**	-19.51**	-19.98**	-25.26**
9.	DHLBI-967 x DHLBI-1013	10.59*	0.49	-1.42	9.13**	7.67*	14.31**
10.	DHLBI-967 x DHLBI-1708	15.11**	13.79*	-6.61	9.41**	4.53	10.98**
11.	DHLBI-967 x DHLBI-18963	16.60**	3.15	7.53	4.11	3.51	9.89**
12.	DHLBI-967 x DHLBI-181181	19.60**	2.23	15.55**	10.11**	9.75**	16.52**
13.	DHLBI-967 x DHLBI-181138	28.28**	15.58**	15.57**	19.61**	18.15**	28.59**
14.	DHLBI-967 x DHLBI-1035	-5.05	-13.54**	-15.58**	12.17**	11.80**	18.69**
15.	DHLBI-967 x DHLBI-1603	16.38**	11.95*	-2.83	14.55**	7.67*	14.31**
16.	DHLBI-1013 x DHLBI-1708	13.09**	3.85	1.88	4.4	1.05	4.42
17.	DHLBI-1013 x DHLBI-18963	12.35**	9.04*	13.67**	-2.93	-3.68	1.09
18.	DHLBI-1013 x DHLBI-181181	8.57*	1.40	14.62**	2.13	1.09	6.63
19.	DHLBI-1013 x DHLBI-181138	6.68	5.68	5.66	7.75**	5.03	14.31**
20.	DHLBI-1013 x DHLBI-1035	2.65	2.41	0.47	5.26	4.19	9.89**
21.	DHLBI-1013 x DHLBI-1603	18.36**	11.54*	9.42*	15.07**	9.54**	13.19**
22.	DHLBI-1708 x DHLBI-18963	-3.80	-14.04**	-10.39*	4.64	0.53	5.51
23.	DHLBI-1708 x DHLBI-181181	16.04**	0.15	13.20**	1.14	-3.06	2.24
24.	DHLBI-1708 x DHLBI-181138	18.14**	7.56	7.54	15.37**	8.94**	18.56**
25.	DHLBI-1708 x DHLBI-1035	18.11**	8.70	6.13	4.37	0.03	5.51
26.	DHLBI-1708 x DHLBI-1603	18.43**	15.21**	0.00	15.64**	13.67**	9.92**
27.	DHLBI-18963 x DHLBI-181181	9.41**	5.16	18.86**	-0.78	-1.03	4.39
28.	DHLBI-18963 x DHLBI-181138	2.09	0.00	4.25	-3.36	-5.09	3.3
29.	DHLBI-18963 x DHLBI-1035	6.54	3.16	7.54	-11.22**	-11.44**	-6.59
30.	DHLBI-18963 x DHLBI-1603	20.49**	10.41*	15.10**	10.80**	4.71	9.89**
31.	DHLBI-181181 x DHLBI-181138	8.49*	2.23	15.55**	6.68*	5.03	14.31**
32.	DHLBI-181181 x DHLBI-1035	11.50**	3.91	17.45**	9.41**	9.41**	15.40**
33.	DHLBI-181181 x DHLBI-1603	-0.40	-11.96**	-0.48	3.32	-2.59	2.74
34.	DHLBI-181138 x DHLBI-1035	15.98**	14.62**	14.60**	-2.58	-4.09	4.39
35.	DHLBI-181138 x DHLBI-1603	13.14**	5.68	5.66	28.24**	19.15**	29.67**
36.	DHLBI-1035 x DHLBI-1603	10.97**	4.81	2.33	6.13*	0.06	5.54
	SE(D)±	0.90	1.04	1.04	0.31	0.35	1.04
	CD at 5%	1.79	2.06	2.06	0.61	0.71	2.06
	CD at 1%	2.37	2.73	2.73	0.81	0.94	2.73

*, ** Significant at 5 and 1 per cent level, respectively

Table 4.4d. Per cent heterosis over mid parent, better parent and standard check for 1000-grain weight and grain yield per plant in pearl millet

Sr. No.	Crosses	1000-grain weight (g)			Grain yield per plant (g)		
		MP	BP	SH	MP	BP	SH
1.	DHLBI-1103 x DHLBI-967	12.83**	6.04	-12.84**	41.43**	34.01**	-0.56
2.	DHLBI-1103 x DHLBI-1013	-7.86*	-10.29*	-22.15**	56.51**	49.39**	-0.78
3.	DHLBI-1103 x DHLBI-1708	10.01**	7.78	-11.41**	44.72**	43.18**	-4.91
4.	DHLBI-1103 x DHLBI-18963	17.25**	15.50**	-2.14	40.81**	31.43**	0.70
5.	DHLBI-1103 x DHLBI-181181	13.53**	12.19**	-5.54	44.60**	41.38**	-6.10
6.	DHLBI-1103 x DHLBI-181138	13.74**	6.81	-0.02	48.89**	36.89**	8.39
7.	DHLBI-1103 x DHLBI-1035	18.42**	13.80**	1.46	75.30**	59.31**	5.81
8.	DHLBI-1103 x DHLBI-1603	20.08**	17.90**	-3.09	-4.02	-15.18	-43.67**
9.	DHLBI-967 x DHLBI-1013	24.45**	14.07**	-1.02	49.04**	35.16**	0.29
10.	DHLBI-967 x DHLBI-1708	0.71	-3.48	-23.88**	-9.79	-15.38	-37.21**
11.	DHLBI-967 x DHLBI-18963	20.30**	11.48**	-5.54	24.17**	22.22*	-6.36
12.	DHLBI-967 x DHLBI-181181	25.41**	16.55**	-1.87	26.40**	17.24	-13.00
13.	DHLBI-967 x DHLBI-181138	5.16	-6.81	-12.77**	28.56**	24.52**	-1.40
14.	DHLBI-967 x DHLBI-1035	17.04**	5.97	-5.52	-18.01	-29.00**	-47.32**
15.	DHLBI-967 x DHLBI-1603	23.24**	17.87**	-6.64	39.65**	17.78	-12.60
16.	DHLBI-1013 x DHLBI-1708	1.39	-3.22	-16.03**	31.32**	26.64*	-17.68*
17.	DHLBI-1013 x DHLBI-18963	12.56**	11.24**	-3.48	41.89**	26.84**	-2.81
18.	DHLBI-1013 x DHLBI-181181	5.26	3.70	-10.02**	45.04**	41.52**	-10.20
19.	DHLBI-1013 x DHLBI-181138	15.60**	11.38**	4.26	53.68**	35.43**	7.23
20.	DHLBI-1013 x DHLBI-1035	1.69	0.33	-10.55**	41.84**	34.70**	-18.68**
21.	DHLBI-1013 x DHLBI-1603	16.60**	11.52**	-3.23	36.40**	25.77*	-24.07**
22.	DHLBI-1708 x DHLBI-18963	15.06**	11.08**	-5.89	77.72**	64.25**	25.84**
23.	DHLBI-1708 x DHLBI-181181	5.47	2.14	-14.01**	71.61**	67.56**	10.22
24.	DHLBI-1708 x DHLBI-181138	18.53**	9.20*	2.21	84.15**	69.66**	32.76**
25.	DHLBI-1708 x DHLBI-1035	20.74**	13.78**	1.43	76.30**	61.78**	5.16
26.	DHLBI-1708 x DHLBI-1603	-5.02	-5.22	-24.93**	67.17**	49.11**	-3.07
27.	DHLBI-18963 x DHLBI-181181	-24.13**	-24.37**	-35.92**	-13.79	-21.19*	-39.62**
28.	DHLBI-18963 x DHLBI-181138	12.86**	7.51*	0.63	45.88**	43.52**	13.64*
29.	DHLBI-18963 x DHLBI-1035	-6.21	-8.54*	-18.46**	-3.90	-17.90*	-37.09**
30.	DHLBI-18963 x DHLBI-1603	14.17**	10.45*	-6.42	45.15**	20.85*	-7.41
31.	DHLBI-181181 x DHLBI-181138	11.23**	5.64	-1.12	66.25**	49.74**	18.57**
32.	DHLBI-181181 x DHLBI-1035	9.37**	6.33	-5.20	48.52**	37.80**	-12.56
33.	DHLBI-181181 x DHLBI-1603	9.72*	6.47	-10.36**	-1.59	-11.28	-43.71**
34.	DHLBI-181138 x DHLBI-1035	13.05**	10.37**	3.31	55.25**	30.85**	3.61
35.	DHLBI-181138 x DHLBI-1603	12.33**	3.69	-2.94	19.75*	-1.59	-22.07**
36.	DHLBI-1035 x DHLBI-1603	7.53*	1.53	-9.48**	42.50**	26.43**	-4.97
	SE(D)±	0.41	0.47	0.47	2.62	3.04	3.04
	CD at 5%	0.82	0.95	0.95	5.22	6.03	6.03
	CD at 1%	1.09	1.26	1.26	6.92	7.99	7.99

*, ** Significant at 5 and 1 per cent level, respectively

heterobeltiosis in desirable direction for this traits. None of the cross found significant over standard check and was ranged from -35.92 per cent to 4.26 per cent. DHLBI-1013 x DHLBI-181138 (4.26 %) and DHLBI-181138 x DHLBI-1035 (3.31 %) had shown highest positive standard heterosis. Similar results were recorded by Manga and Dubey (2004), Izge *et al*. (2007), Chotaliya *et al*. (2009), Salagarkar and Wali (2016), Badhe *et al*. (2018) and Dutta *et al*. (2021).

4.1.2.8 Grain yield per plant (g)

The magnitude of heterosis over mid-parent for grain yield per plant ranged from -18.01 per cent (DHLBI-967 x DHLBI-1035) to 84.15 per cent (DHLBI-1708 x DHLBI-181138). A total of thirty hybrids recorded significant positive heterosis over mid parent. The cross DHLBI-1708 x DHLBI-181138 (84.15 %) exhibited highest significant average heterosis followed by DHLBI-1708 x DHLBI-18963 (77.72 %) and DHLBI-1708 x DHLBI-1035 (76.30 %). The range in heterobeltiosis varied from -29.00 per cent (DHLBI-967 x DHLBI-1035) to 69.66 per cent (DHLBI-1708 x DHLBI-181138). Twenty-seven hybrids recorded significant positive heterosis over better parent. The cross DHLBI-1708 x DHLBI-181138 (69.66 %) exhibited highest significant heterosis over better parent.

The range of heterosis over standard checks, Phule Adishakti was from -47.32 per cent (DHLBI-967 x DHLBI-1035) to 32.76 per cent (DHLBI-1708 x DHLBI-181138). Among thirty-six hybrids, four hybrids recorded positively significant heterosis over Phule Adishakti. The highest standard heterosis in desirable direction was recorded in the cross DHLBI-1708 x DHLBI-181138 (32.76 %). These results are in conformity with the earlier findings of the Yadav (2006), Izge *et al.* (2007), Vetriventhan *et al.* (2008), Chotaliya *et al.* (2009), Lakshmana *et al.* (2010b), Bhadalia *et al.* (2011), Bachkar *et al.* (2014), Mungra *et al.* (2014), Pawar *et al.* (2015), Patel *et al*. (2016), Acharya *et al.* (2017), Badhe *et al.* (2018), Krishnan *et al.* (2019a) and Barathi *et al.* (2020).

4.1.2.9 Grain Fe (mg/kg)

Average heterosis for grain Fe content was ranged from -20.75 to 32.53 per cent. The cross DHLBI-1708 x DHLBI-181138 (32.53 %) exhibited highest positive average heterosis followed by DHLBI-181138 x DHLBI-1035 (20.14 %) and DHLBI-181138 x DHLBI-1603 (19.34 %). Heterobeltiosis ranged from -25.32 per cent (DHLBI-

Table 4.4e. Per cent heterosis over mid parent, better parent and standard check for grain Fe and grain Zn content per plant in pearl millet

Sr. No.	Crosses	Grain Fe (mg/kg)			Grain Zn (mg/kg)		
		MP	BP	SH	MP	BP	SH
1.	DHLBI-1103 x DHLBI-967	1.10	-3.22	-2.07	6.30	3.28	-9.84**
2.	DHLBI-1103 x DHLBI-1013	4.99**	-8.94**	25.41**	15.94**	-5.88*	24.25**
3.	DHLBI-1103 x DHLBI-1708	-3.24	-6.98**	-5.88**	-18.24**	-21.05**	-35.00**
4.	DHLBI-1103 x DHLBI-18963	6.69**	0.57	14.94**	19.25**	4.82	13.84**
5.	DHLBI-1103 x DHLBI-181181	16.62**	8.15**	28.03**	22.99**	5.06	22.11**
6.	DHLBI-1103 x DHLBI-181138	11.06**	-6.73**	38.86**	29.08**	4.41	39.15**
7.	DHLBI-1103 x DHLBI-1035	9.15**	2.84	17.67**	27.23**	12.76**	20.18**
8.	DHLBI-1103 x DHLBI-1603	-4.43**	-16.24**	12.57**	13.22**	-9.07**	23.49**
9.	DHLBI-967 x DHLBI-1013	6.06**	-11.34**	22.10**	18.52**	-1.55	29.96**
10.	DHLBI-967 x DHLBI-1708	-20.75**	-21.09**	-26.34**	10.38**	3.66	-9.51**
11.	DHLBI-967 x DHLBI-18963	-9.81**	-18.39**	-6.73**	18.90**	7.24*	16.46**
12.	DHLBI-967 x DHLBI-181181	-3.93*	-14.42**	1.32	-5.73*	-17.46**	-4.06
13.	DHLBI-967 x DHLBI-181138	-7.89**	-25.32**	11.18**	17.81**	-2.52	29.93**
14.	DHLBI-967 x DHLBI-1035	-11.62**	-20.07**	-8.54**	-20.36**	-27.56**	-22.79**
15.	DHLBI-967 x DHLBI-1603	-9.35**	-23.47**	2.85	-1.46	-19.06**	9.93**
16.	DHLBI-1013 x DHLBI-1708	-7.73**	-22.59**	6.60**	2.05	-19.34**	6.48
17.	DHLBI-1013 x DHLBI-18963	-4.27**	-12.42**	20.62**	-0.08	-8.94**	20.21**
18.	DHLBI-1013 x DHLBI-181181	3.97**	-3.32*	33.14**	0.33	-5.67*	24.52**
19.	DHLBI-1013 x DHLBI-181138	15.59**	11.25**	65.63**	18.50**	17.93**	57.18**
20.	DHLBI-1013 x DHLBI-1035	-8.44**	-16.19**	15.42**	-5.03*	-14.17**	13.30**
21.	DHLBI-1013 x DHLBI-1603	-3.53**	-4.69**	31.25**	-8.65**	-9.93**	22.32**
22.	DHLBI-1708 x DHLBI-18963	12.77**	2.45	17.08**	-7.73*	-21.29**	-14.53**
23.	DHLBI-1708 x DHLBI-181181	13.37**	1.38	20.03**	-0.86	-17.73**	-4.38
24.	DHLBI-1708 x DHLBI-181138	32.53**	7.82**	60.51**	24.01**	-2.33	30.17**
25.	DHLBI-1708 x DHLBI-1035	-0.98	-10.10**	2.87	-13.23**	-25.41**	-20.50**
26.	DHLBI-1708 x DHLBI-1603	2.32	-13.30**	16.52**	-17.11**	-35.16**	-11.94**
27.	DHLBI-18963 x DHLBI-181181	-1.65	-3.35	14.42**	-0.11	-3.39	12.29**
28.	DHLBI-18963 x DHLBI-181138	1.55	-10.25**	33.62**	-1.56	-10.67**	19.05**
29.	DHLBI-18963 x DHLBI-1035	-12.92**	-12.97**	-0.42	-2.59	-3.50	4.80
30.	DHLBI-18963 x DHLBI-1603	0.86	-6.69**	25.41**	4.60	-5.88*	27.82**
31.	DHLBI-181181 x DHLBI-181138	11.09**	-0.28	48.45**	8.76**	1.80	35.69**
32.	DHLBI-181181 x DHLBI-1035	-17.72**	-19.10**	-4.22*	1.34	-2.86	12.90**
33.	DHLBI-181181 x DHLBI-1603	-6.14**	-11.73**	18.64**	4.51*	-3.02	31.70**
34.	DHLBI-181138 x DHLBI-1035	20.14**	6.24**	58.16**	17.53**	5.76*	40.95**
35.	DHLBI-181138 x DHLBI-1603	19.34**	13.54**	69.04**	14.47**	13.40**	54.01**
36.	DHLBI-1035 x DHLBI-1603	10.17**	1.99	37.07**	9.56**	-2.23	32.78**
	SE(D)±	0.95	1.09	1.09	1.08	1.25	1.25
	CD at 5%	1.88	2.18	2.18	2.15	2.48	2.48
	CD at 1%	2.50	2.88	2.88	2.85	3.29	3.29

*, ** Significant at 5 and 1 per cent level, respectively

967 x DHLBI-181138) to 13.54 per cent (DHLBI-181138 x DHLBI-1603). Out of thirty six crosses, five crosses had shown highest significant positive heterobeltiosis in desirable direction for this trait. Standard heterosis over check Phule Adishakti ranged from -26.34 per cent (DHLBI-967 x DHLBI-1708) to 69.04 per cent (DHLBI-181138 x DHLBI-1603). Twenty six crosses had shown standard heterosis in desirable direction. The highest significant standard heterosis recorded in the cross, DHLBI-181138 x DHLBI-1603 (69.04 %), followed by cross DHLBI-1013 x DHLBI-181138 (65.63). These findings are in agreement with the Govindraj (2011), Velu *et al.* (2011) and Kanatti *et al.* (2014).

4.1.2.10 Grain Zn (mg/kg)

Out of thirty six crosses, seventeen crosses recorded significant average heterosis in positive direction. The heterosis over mid parent ranged from -20.36 per cent (DHLBI-967 x DHLBI-1035) to 29.08 per cent (DHLBI-1103 x DHLBI-181138). The range of better parent heterosis was from -35.16 (DHLBI-1708 x DHLBI-1603) to 17.93 (DHLBI-1013 x DHLBI-181138). Out of thirty six crosses, five crosses exhibited positive and significant heterobeltiosis for grain Zn content. The range of standard heterosis over the check Phule Adishakti was -35.00 per cent (DHLBI-1103 x DHLBI-1708) to 57.18 per cent (DHLBI-1013 x DHLBI-181138). Out of thirty six crosses, twenty five crosses exhibited positive and significant standard heterosis for this trait. Maximum positive significant standard heterosis was recorded by cross DHLBI-1013 x DHLBI-181138 (57.18 %) followed by DHLBI-181138 x DHLBI-1603 (54.01 %) and DHLBI-181138 x DHLBI-1035 (40.95 %). The similar results were reported earlier by Govindraj (2011), Velu *et al.* (2011) and Kanatti *et al.* (2014).

The deviation from progeny means to parental means are measured by heterosis performance. The average heterosis, heterobeltiosis and standard heterosis were used to derive the heterosis. According to Kadambavanasundaram (1980), the economic exploitation of hybrid vigour should only focus on the heterotic performance over the standard hybrid. The nature and magnitude of heterosis are important for determining the optimum cross combinations and for using them to produce good transgressive segregants. The heterosis over standard check is significantly vital since as the superiority of new hybrid over existing standard check is always desirable.

The cross DHLBI-1708 x DHLBI-181138 which evinced highest heterobeltiosis and standard heterosis for grain yield per plant and desirably significant heterosis for plant height, number of tillers per plant, earhead girth, grain Fe and grain Zn content followed by the cross DHLBI-1708 x DHLBI-18963, which showed desirable significant standard heterosis for grain yield per plant, number of effective tillers per plant and grain Fe content. The cross DHLBI-181181 x DHLBI-181138 found promising as it exhibited desirable significant standard heterosis for grain yield per plant, days to flowering, number of effective tillers per plant, earhead length, earhead girth, grain Fe and grain Zn content (Table 4.5a and Table 4.5b). It means that these crosses could be exploited for isolating desirable genotypes in pearl millet by selecting desirable transgressive segregants.

The crosses DHLBI-1708 x DHLBI-181138, DHLBI-1708 x DHLBI-18963 and DHLBI-181181 x DHLBI-181138 were top ranked on the basis of magnitude of *per se* performance, significant standard heterosis for most of the important yield contributing traits. Though, above mentioned crosses have been proven their superiority over better parent as well as standard check for most of the traits, the *per se* performance may be kept in mind while selecting a particular cross for grain yield and its components for their exploitation.

4.1.3 Combining ability analysis

4.1.4 Analysis of variance

The result of analysis of variance carried out to test the significant differences among the various genotypes which are furnished in Table 4.6. The mean sum of square due to treatments, inbreds and hybrids were highly significant for the all the characters studied in the present investigation. It indicates that presence of sustainable genetic variability among treatments with regards to characters under investigation. The mean sum of square due to inbred *v/s* hybrids were found to be significant for all characters except for days to 50 per cent flowering and days to maturity. These findings are in agreement with earlier reports of Dangariya *et al.* (2009), Shinde (2011), Rai *et al.* (2012), Govindraj *et al*. (2013), Khandagale *et al.* (2014) and Gavali *et al.* (2018).

Table 4.5a. Three best promising crosses showing significant heterobeltiosis in desirable direction for different characters in pearl millet.

Sr. No.	Characters	Number of sig. crosses	Heterobeltiosis (%)	Crosses
1	Days to 50 % flowering	18	-18.97**	DHLBI-18963 x DHLBI-181181
			-15.70**	DHLBI-1013 x DHLBI-1708
			-13.81**	DHLBI-1708 x DHLBI-181138
2	Days to maturity	17	-14.07**	DHLBI-18963 x DHLBI-181181
			-10.00**	DHLBI-1013 x DHLBI-1708
			-7.36**	DHLBI-967 x DHLBI-181181
3	Plant height	25	18.01**	DHLBI-967 x DHLBI-181181
			17.46**	DHLBI-967 x DHLBI-1603
			16.27**	DHLBI-1013 x DHLBI-181181
4	Number of effective tillers per plant	8	34.24**	DHLBI-1708 x DHLBI-18963
			33.61**	DHLBI-1708 x DHLBI-1035
			31.15**	DHLBI-1708 x DHLBI-181181
5	Earhead length	8	15.58**	DHLBI-967 x DHLBI-181138
			15.21**	DHLBI-1708 x DHLBI-1603
			14.62**	DHLBI-181138 x DHLBI-1035
6	Earhead girth	10	19.15**	DHLBI-181138 x DHLBI-1603
			18.15**	DHLBI-967 x DHLBI-181138
			13.67**	DHLBI-1708 x DHLBI-1603
7	1000-grain weight	17	17.90**	DHLBI-1103 x DHLBI-1603
			17.87**	DHLBI-967 x DHLBI-1603
			16.55**	DHLBI-967 x DHLBI-181181
8	Grain yield per plant	27	69.66**	DHLBI-1708 x DHLBI-181138
			67.56**	DHLBI-1708 x DHLBI-181181
			64.25**	DHLBI-1708 x DHLBI-18963
9	Gain Fe	5	13.54**	DHLBI-181138 x DHLBI-1603
			11.25**	DHLBI-1013 x DHLBI-181138
			8.15**	DHLBI-1103 x DHLBI-181181
10	Grain Zn	5	17.93**	DHLBI-1013 x DHLBI-181138
			13.40**	DHLBI-181138 x DHLBI-1603
			12.76**	DHLBI-1103 x DHLBI-1035

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

Table 4.5b. Three best promising crosses showing significant standard heterosis over (Phule Adishakti) in desirable direction for different characters in pearl millet

Sr. No.	Characters	Number of sig. crosses	Standered heterosis (%)	Crosses
1	Days to 50 % flowering	4	-9.62**	DHLBI-18963 x DHLBI-181181
			-8.33*	DHLBI-967 x DHLBI-181181
			-7.69*	DHLBI-1708 x DHLBI-181181
2	Days to maturity	5	-10.08**	DHLBI-18963 x DHLBI-181181
			-5.81**	DHLBI-1708 x DHLBI-181181
			-5.81**	DHLBI-1013 x DHLBI-1708
3	Plant height	3	7.55**	DHLBI-1013 x DHLBI-181138
			6.76**	DHLBI-1708 x DHLBI-181138
			6.03**	DHLBI-967 x DHLBI-181138
4	Number of effective tillers per plant	14	47.54**	DHLBI-1708 x DHLBI-181138
			45.90**	DHLBI-1708 x DHLBI-18963
			33.61**	DHLBI-1708 x DHLBI-1035
5	Earhead length	11	18.86**	DHLBI-18963 x DHLBI-181181
			17.45**	DHLBI-181181 x DHLBI-1035
			15.55**	DHLBI-967 x DHLBI-181138
6	Earhead girth	19	29.67**	DHLBI-181138 x DHLBI-1603
			28.59**	DHLBI-967 x DHLBI-181138
			18.69**	DHLBI-967 x DHLBI-1035
7.	1000-grain weight	-	-	-
8	Grain yield per plant	4	32.76**	DHLBI-1708 x DHLBI-181138
			25.84**	DHLBI-1708 x DHLBI-18963
			18.57**	DHLBI-181181 x DHLBI-181138
9	Gain Fe	26	69.04**	DHLBI-181138 x DHLBI-1603
			65.63**	DHLBI-1013 x DHLBI-181138
			60.51**	DHLBI-1708 x DHLBI-181138
10	Grain Zn	25	57.18**	DHLBI-1013 x DHLBI-181138
			54.01**	DHLBI-181138 x DHLBI-1603
			40.95**	DHLBI-181138 x DHLBI-1035

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

4.1.5 Analysis of variance for combining ability

The analysis of variance for combining ability (general combing ability and specific combining ability) for ten characters following Griffings (1956) Model-I, method 2, along with σ^2gca, σ^2sca and σ^2gca/σ^2sca is presented in Table 4.7. The analysis of variance for combining ability (general and specific combining ability) divulged that the variance due to parents i.e. general combining ability (GCA) effects were highly significant for all the characters. The variance due to crosses i.e. specific combining ability (SCA) effects were highly significant for all the characters. This suggested that both the additive and non- additive gene effects were important in the inheritance of all the ten characters. However, σ^2gca/ σ^2sca ratio was less than one for all the characters except grain Fe and Zn, suggesting predominance of non-additive gene effects in control of the studied characters. The similar results were earlier reported by Joshi *et al.* (2001), Rathore *et al.* (2004), Dangariya *et al.* (2009), Vagadiya *et al.* (2010b), Govindaraj *et al.* (2013) and Kumawat *et al*. (2019).

4.1.6 General combining ability effects

The relative importance of general combining ability and specific combining ability in plant breeding has been assessed using a different methodology. The ratio of combining ability variance (σ^2gca/ σ^2sca) determines the type of gene action engaged in the expression of characters and enable inferences about optimum allocation of resources in hybrid breeding. The analysis of combining ability split genetic variance into variance due to general combining ability, which is a measure of additive gene action and variance due to specific combining ability, which is a measure of non-additive gene action.

In Table 4.8, the estimates of general combining ability effects of nine inbreds on quantitative traits in pearl millet are shown. All observed characters in the pearl millet for which positive GCA effects are important, with the exception of days to 50 % flowering and days to maturity, for which negative GCA effects are desirable. Most of the inbreds showed the significant differences for all the traits. The character wise GCA effects of the inbreds are presented in table 4.8.

Table 4.6 Analysis of variance for ten characters in 9 x 9 half diallel crosses in pearl millet

Sources of variation	d.f.	Mean sum of squares									
		Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tillers/plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
Replication	2	0.47	0.46	24.58	0.0073	0.024	0.14	0.20	4.46	4.42	0.67
Treatment	44	40.28**	39.73**	719.08**	0.42**	29.73**	2.73**	4.70**	263.81**	380.12**	198.85**
Parents	8	64.14**	70.98**	372.81**	0.34**	33.13**	1.12**	2.21**	57.62**	330.44**	223.02**
Hybrids	35	35.92**	33.72**	605.14**	0.44**	26.17**	2.92**	4.50**	230.55**	401.15**	195.44**
Parents *Vs.* Hybrid	1	1.66	0.90	7475.41**	0.30**	127.21**	9.00**	31.41**	3077.22**	41.40**	124.66**
Error	88	4.26	3.86	35.24	0.014	1.62	0.19	0.34	13.81	1.80	2.35
Total	134	16.03	15.58	259.61	0.14	10.83	1.02	1.77	95.76	126.06	66.84

*, ** Significant at 5 and 1 per cent level, respectively

Table 4.7. Analysis of variance for combining ability of ten characters in pearl millet

Sources of variation	d.f.	Mean sum of squares									
		Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tillers/plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
GCA	8	38.74**	36.47**	654.00**	0.35**	32.88**	2.02**	2.13**	123.47**	535.83**	277.17**
SCA	36	7.80**	8.08**	147.61**	0.092**	4.80**	0.66**	1.44**	80.04**	35.79**	19.42**
Error	88	1.42	1.28	11.74	0.38	0.54	0.06	0.11	4.60	0.60	0.78
σ^2gca		3.39	3.19	58.38	0.032	2.94	0.17	0.18	10.81	48.65	25.12
σ^2sca		6.37	6.79	135.86	0.088	4.26	0.60	1.32	75.43	35.18	18.63
σ^2gca/ σ^2sca		0.53	0.47	0.42	0.36	0.68	0.29	0.14	0.14	1.38	1.34

*, ** Significant at 5 and 1 per cent level, respectively

Table 4.8. Estimates of general combining ability effects of inbreds for ten characters in pearl millet

Sr. No	Inbreds	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tillers/plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
1.	DHLBI-1103	-0.32	-1.22**	-7.19**	0.07**	-3.33**	-0.69**	0.05	0.98	-2.94**	-2.60**
2.	DHLBI-967	-1.47**	-1.07**	2.59**	-0.03*	-0.97**	0.59**	-0.39**	-1.54*	-10.28**	-4.26**
3.	DHLBI-1013	0.41	0.81*	3.38**	-0.02	0.35	-0.05	0.08	-0.56	4.89**	4.28**
4.	DHLBI-1708	-2.89**	-2.71**	1.59	0.25**	-0.86**	-0.17*	-0.49**	3.01**	-5.52**	-8.42**
5.	DHLBI-18963	0.35	0.14	1.84	0.004	1.14**	-0.21**	-0.16	1.33*	-2.20**	-0.72**
6.	DHLBI-181181	-1.96**	-1.74**	-3.47**	0.10**	2.56**	0.08	-0.27**	-1.53*	0.15	0.86**
7.	DHLBI-181138	2.38**	2.11**	14.77**	0.22**	1.39**	0.70**	0.95**	6.20**	13.88**	8.09**
8.	DHLBI-1035	0.86*	0.93**	-0.52	-0.09**	0.62**	-0.03	0.38**	-2.67**	-2.23**	-1.49**
9.	DHLBI-1603	2.65**	2.75**	-13.01**	-0.35**	-0.92**	-0.21**	-0.17**	-5.23**	4.25**	4.26**
	SE(gi)	0.33	0.32	0.97	0.018	0.20	0.07	0.10	0.61	0.22	0.25
	CD at 5%	0.67	0.64	1.93	0.037	0.41	0.14	0.20	1.21	0.43	0.50
	CD at 1%	0.88	0.86	2.58	0.049	0.55	0.19	0.27	1.63	0.58	0.66

*, ** Significant at 5 and 1 per cent level, respectively

4.1.6.1 Days to 50 per cent flowering

Inbreds which flowered earlier with negative GCA values are preferred. For days to 50 per cent flowering, the inbreds DHLBI-1708 (-2.89), DHLBI-181181 (-1.96) and DHLBI-967 (-1.47) were good general combiners as they displayed significant negative general combining ability effects. Whereas, DHLBI-1603 (2.65), DHLBI-181138 (2.38) and DHLBI-1035 (0.86) displayed significant positive general combining ability effects hence considered as poor general combiner for earliness. Inbreds DHLBI-1103 (-0.32), DHLBI-1013 (0.41) and DHLBI-18963 (0.35) found as average general combiner for the days to 50 percent flowering.

4.1.6.2 Days to maturity

For days to maturity, significant negative GCA effects were recorded by inbreds DHLBI-1708 (-2.71), DHLBI-181181(-1.74), DHLBI-1103 (-1.22) and DHLBI-967 (-1.07). While, DHLBI-1603 (2.75), DHLBI-181138 (2.11), DHLBI-1035 (0.93) and DHLBI-1013 (0.81) displayed significant positive GCA effect and hence considered as poor general combiner. Inbred DHLBI-18963 (0.14) found as positive but non-significant, hence considered as average general combiner.

4.1.6.3 Plant height (cm)

Inbreds which are taller and having positive values of GCA are preferred. The inbreds, DHLBI-181138 (14.77), DHLBI-1013 (3.38) and DHLBI-967 (2.59) were observed to be the best combiners for tallness since they displayed significant positive general combining ability effects for plant height. In contrast, DHLBI-1603 (-13.01), DHLBI-1103 (-7.19) and DHLBI-181181 (-3.47) showed significant negative GCA effect for plant height and are considered as poor combiners. Inbreds DHLBI-1708, DHLBI-18963 and DHLBI-1035 are average combiner.

4.1.6.4 Number of effective tillers per plant

Out of nine inbreds, four inbreds exhibited positive significant GCA effects. DHLBI-1708 (0.25), DHLBI-181138 (0.22), DHLBI-181181 (0.10) and DHLBI-1103 (0.07) had more favorable genes for number of effective tillers as exhibited by their significant positive general combining ability effects. Inbreds DHLBI-1603 (-0.35), DHLBI-1035 (-0.09) and DHLBI-967 (-0.03) had displayed the highest significant negative GCA effects, so considered as the poor general combiners for this trait.

Whereas, inbreds DHLBI-1013 (-0.02) and DHLBI-18963 (0.004) were found to be average general combiners.

4.1.6.5 Earhead length (cm)

The inbreds, DHLBI-181181 (2.56), DHLBI-181138 (1.39), DHLBI-18963 (1.14) and DHLBI-1035 (0.62) were observed to be the good combiner for earhead length since they had significant positive general combining ability effects. In contrast, DHLBI-1103 (-3.33), DHLBI-967 (-0.97), DHLBI-1603 (-0.92) and DHLBI-1708 (-0.86) had significant negative GCA effect for earhead length and were considered as poor general combiner for the same trait. Inbred, DHLBI-1013 was found as average combiner for earhead length.

4.1.6.6 Earhead girth (cm)

The general combining ability effects of inbreds for earhead girth showed that the inbreds, DHLBI-181138 (0.70) and DHLBI-967 (0.59) were good general combiner. However, DHLBI-1103 (-0.69), DHLBI-18963 (-0.21), DHLBI-1603 (-0.21) and DHLBI-1708 (-0.17) had negatively significant GCA effects and observed to be poor combiners for earhead girth. Remaining three inbreds were found as an average general combiner for earhead girth.

4.1.6.7 1000-grain weight (g)

The inbreds, DHLBI-181138 (0.95) and DHLBI-1035 (0.38) were observed good general combiners for 1000-grain weight as they showed significant positive general combining ability effects. Significant negative gca effects for 1000-grain weight were observed in four inbreds namely, DHLBI-1708 (-0.49), DHLBI-967 (-0.39), DHLBI-181181 (-0.27) and DHLBI-1603 (-0.17). Whereas, three inbreds were found to be average general combiners for 1000-grain weight.

4.1.6.8 Grain yield per plant (g)

The estimates of general combining ability effects revealed that only three inbreds *viz*., DHLBI-181138 (6.20), DHLBI-1708 (3.01) and DHLBI-18963 (1.33) were good general combiners as they had displayed significant positive GCA effects for grain yield per plant. Whereas, the inbreds DHLBI-1603 (-5.23), DHLBI-1035 (-2.67), DHLBI-181181 (-1.53) and DHLBI-967 (-1.54) with significant negative GCA effect was found as poor general combiners. Remaining two inbreds were found as an average combiner for the grain yield per plant.

4.1.6.9 Grain Fe (mg/kg)

For grain Fe content, significant positive general combining ability effects were recorded by inbreds, DHLBI-181138 (13.88), DHLBI-1013 (4.89) and DHLBI-1603 (4.25) and considered as good general combiner. Whereas, inbreds DHLBI-967 (-10.28), DHLBI-1708 (-5.52), DHLBI-1103 (-2.94), DHLBI-1035(-2.23) and DHLBI-18963 (-2.20) displayed significant negative GCA effects and hence considered as poor general combiner. Inbred, DHLBI-181181 (0.15) found as positive but non-significant, hence considered as average general combiner.

4.1.6.10 Grain Zn (mg/kg)

The inbreds, DHLBI-181138 (8.09), DHLBI-1013 (4.28), DHLBI-1603 (4.26) and DHLBI-181181 (0.86) were observed good general combiners for grain Zn content as they showed positively significant general combining ability effects. Significant negative GCA effects for this trait were observed in five inbreds namely, DHLBI-1708 (-8.42), DHLBI-967 (-4.26), DHLBI-1103 (-2.60), DHLBI-1035 (-1.49) and DHLBI-18963 (-0.72).

Early generation genotype evaluation becomes more effective when general combining ability variations are larger than specific combining ability variances and promising hybrids may be identified and selected based on their prediction from general combining ability effects. A general combining ability performance of relatively later inbreds can be predicted by using a general combining ability of an inbred in an early generation Lv *et al.* (2012). The scientific basis for this observation is that the general combining ability which is controlled by heritable genetic material and which is transmitted to its progeny. By releasing hybrids more efficiently and carrying fewer materials in breeding processes, this increases the effectiveness and lowers the cost of hybrid cultivar improvement.

High *per se* performance along with high general combining ability is a sign of an extraordinary best inbred with reservoir of superior genes. Therefore, for parental selection, mean performance and general combining ability effects both are considered. None of the inbreds included in the study had an overall good general combiner for all ten characters, based on the relative magnitude and sign of general combining ability effect.

In the present investigation highly significant differences were obtained for general combining ability effects for all the ten characters studied, it was found that the inbred DHLBI-181138 was good general combiner for eight characters, i.e. plant height, number of effective tillers per plant, earhead length, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn and also had high *per se* performance for grain yield per plant. Inbreds, DHLBI-1708 and DHLBI-18963 were also found good general combiners along with good *per se* performance for grain yield and yield contributing characters indicating scope for their exploitation in future breeding programme to isolate desirable transgressive segregants for grain yield and its components. Therefore, inbreds shown high mean performance with desirable general combining ability effects and these specific features might be used in subsequent crossing programmes in order to achieve various pearl millet trait. The results of the present investigation are in accordance with the information given by various workers Joshi *et al.* (2001), Yagya *et al.* (2002), Lakshamana *et al.* (2003), Shanmuganathan *et al.* (2005), Izge *et al.* (2007), Dangariya *et al.* (2009), Lakshmana *et al.* (2010b), Vagadiya *et al.* (2010b), Velu *et al.* (2011), Kanatti *et al.* (2014), Khandagale *et al.* (2014), Singh and Sharma (2014), Karvar *et al.* (2017), Gavali *et al.* (2018), Krishnan *et al.* (2019b), Kumawat *et al.* (2019), Sharma and Singh (2019), Barathi *et al.* (2020) and Dutta *et al.* (2021).

4.1.7 Specific combining ability effects (SCA)

It is not advisable to choose hybrids based on their *per se* performance, as hybrids with excellent *per se* performance may not always have high levels of heterosis. As a result, a key factor in the selection of hybrids is specific combining ability effect. High estimations of specific combining ability could result from the combination of favorable genes from genetically distinct inbreds. The importance of both additive x additive and additive x dominance type of gene interactions in bringing out the high specific combining ability effect. Therefore, specific combining ability effects of cross combination along with gene action and appropriate breeding method for improvement of grain yield and its contributing characters are discussed here. In pearl millet, positively significant specific combining ability effects are desirable for all the traits studied except for days to 50 % flowering and days to maturity for which negative specific combining ability effects are desirable. The results of specific combining ability effects of thirty six crosses for yield and yield contributing characters in pearl millet is presented in Table 4.9.

4.1.7.1 Days to 50 % flowering

Among the thirty six crosses, nine crosses exhibited negatively significant SCA effects for earliness. The highest negative SCA effects were found in cross DHLBI-18963 x DHLBI-181181 (-6.24) followed by DHLBI-1035 x DHLBI-1603 (-4.36) and DHLBI-1013 x DHLBI-1708 (-4.03). While cross combination DHLBI-1103 x DHLBI-1603 (5.15) had highest positively significant SCA effects.

4.1.7.2 Days to maturity

The cross combinations, DHLBI-18963 x DHLBI-181181 (-8.38), DHLBI-967 x DHLBI-181181 (-4.83) and DHLBI-1013 x DHLBI-1708 (-4.41) showed highest negatively significant specific combining ability effects for days to maturity. While the highest positively significant SCA effect was observed in cross DHLBI-1103 x DHLBI-181181 (4.64). Among the thirty six crosses, six crosses exhibited negatively significant SCA effects.

4.1.7.3 Plant height (cm)

Estimates of specific combining ability effects indicated that out of thirty six crosses, fifteen crosses showed positively significant SCA effects and five crosses showed significant negative specific combining ability effects for this character. The highest positively significant SCA effect was registered by crosses DHLBI-181138 x DHLBI-1603 (16.82) followed by DHLBI-1013 x DHLBI-181181 (15.78) and DHLBI-1103 x DHLBI-1035 (14.96).

4.1.7.4 Number of effective tillers per plant

Out of the thirty six crosses, fourteen crosses exhibited positively significant SCA effect. The crosses, DHLBI-1708 x DHLBI-18963 (0.60), DHLBI-1708 x DHLBI-1035 (0.45) and DHLBI-1708 x DHLBI-181138 (0.42) recorded highest magnitude of positively significant SCA effects for number of effective tillers per plant.

4.1.7.5 Earhead Length (cm)

Among thirty six crosses under study, twelve hybrids recorded positively significant SCA effects for earhead length. The hybrids, DHLBI-1103 x DHLBI-1035 (3.72), DHLBI-18963 x DHLBI-1603 (3.23) and DHLBI-967 x DHLBI-181138 (3.14) recorded highest magnitude of positively significant SCA effect for earhead length.

4.1.7.6 Earhead girth (cm)

Specific combining ability effects for earhead girth were significant in sixteen crosses; among them eleven crosses exhibited positively significant specific combining ability effects. Highest positively significant SCA effects was observed in the cross combination DHLBI-181138 x DHLBI-1603 (1.80) followed by DHLBI-1103 x DHLBI-18963 (1.10) and DHLBI-1013 x DHLBI-1603 (0.89).

4.1.7.7 1000-grain weight (g)

Specific combining ability effects were positively significant in fifteen crosses. Highest positively significant SCA effects was observed in the cross combination DHLBI-967 x DHLBI-181181 (1.70) followed by DHLBI-967 x DHLBI-1013 (1.46) and DHLBI-1708 x DHLBI-1035 (1.16).

4.1.7.8 Grain yield per plant (g)

Among thirty six crosses, eighteen crosses displayed positively significant SCA effects for grain yield per plant. The highest positively significant SCA effects were exhibited by crosses DHLBI-1708 x DHLBI-18963 (13.29), DHLBI-1708 x DHLBI-181138 (11.53) and DHLBI-181181 x DHLBI-181138 (9.66).

4.1.7.9 Grain Fe (mg/kg)

The estimates of specific combining ability effects revealed that among thirty six crosses, thirteen crosses were shown positively significant SCA effects for grain Fe (iron) content, the highest SCA effect was observed in crosses DHLBI-1708 x DHLBI-181138 (13.34), DHLBI-181138 x DHLBI-1035 (8.80) and DHLBI-181138 x DHLBI-1603 (8.05).

4.1.7.10 Grain Zn (mg/kg)

For grain Zn content, sixteen cross combinations exhibited positively significant SCA effects. The cross combination DHLBI-1708 x DHLBI-181138 (6.54) showed highest magnitude of positively significant SCA effect followed by DHLBI-1103 x DHLBI-1035 (6.51) and DHLBI-967 x DHLBI-1013 (6.11). The cross DHLBI-967 x DHLBI-1035 (-8.14) shown highest magnitude of significant negative SCA effect.

Among thirty six crosses, SCA effects for grain yield per plant indicated that, the top yielding cross was DHLBI-1708 x DHLBI-18963 evinced high significant SCA effects for grain yield as well as desirably significant SCA effect for plant height, number of effective tillers per plant, 1000-grain weight and grain Fe content. The cross DHLBI-1708 x DHLBI-181138 exhibited significant SCA effect in desirable direction for days to 50 per cent flowering, plant height, number of effective tillers per plant, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn content. The cross combination, DHLBI-181181 x DHLBI-181138 displayed significant SCA effect in desirable direction for number of effective tillers per plant and grain yield per plant.

The aforementioned cross combinations showed high mean performance and found promising with significant SCA effects for more number of characters with good gca x good gca or poor gca x good gca or poor gca x poor gca type combinations. This indicated additive, dominance and additive x additive gene effects were predominant in the expression of the respective traits and also suggested synergy among inbreds. Therefore, single plant selection could be used in segregating generations to isolate superior lines from such combinations due to the possibility of gene fixation. This suggested that information on GCA effects should be supplemented by SCA effects of cross combination to predict the transgressive types possibly be available in segregating generations. Selection is rapid if the GCA effects of the inbreds and SCA effects of the crosses are in the same direction.

Further crosses involving good x good general combining parent with high SCA effect can be handled by simple varietal improvement programme for respective characters. The results in the present investigation are in accordance with the findings reported by various workers Joshi *et al.* (2001), Singh and Sagar (2001), Yagya *et al.* (2002), Rathore *et al.* (2004), Shanmuganathan *et al*. (2005), Sushir *et al*. (2005), Haussmann *et al*. (2006), Pachade (2006), Izge *et al*. (2007), Eldie *et al*. (2009), Dangariya *et al*. (2009), Vagadiya *et al*. (2010b), Velu *et al.* (2011), Rai *et al.* (2012), Govindaraj *et al*. (2013), Kanatti *et al.* (2014), Khandagale *et al.* (2014), Singh and Sharma (2014), Jeeterwal *et al.* (2017), Karvar *et al*. (2017), Gavali *et al.* (2018), Barathi *et al*. (2020) and Dutta *et al*. (2021).

Table 4.9. Estimates of specific combining ability effects of crosses for ten characters in pearl millet

Sr. No.	Crosses	Days to 50 % flowering	Days to maturity	Plant height (cm)	No. effective tillers/plant	Earhead length (cm)
1.	DHLBI-1103 x DHLBI-967	-2.06	-2.35*	3.17	0.12*	0.97
2.	DHLBI-1103 x DHLBI-1013	0.061	1.10	5.28	0.18**	-1.78**
3.	DHLBI-1103 x DHLBI-1708	0.69	2.28*	1.06	-0.29**	1.31
4.	DHLBI-1103 x DHLBI-18963	0.78	1.10	9.92**	-0.05	0.31
5.	DHLBI-1103 x DHLBI-181181	3.75**	4.64**	2.01	0.15*	1.34*
6.	DHLBI-1103 x DHLBI-181138	-0.24	-0.20	8.32*	0.03	1.94**
7.	DHLBI-1103 x DHLBI-1035	0.72	-1.64	14.96**	0.37**	3.72**
8.	DHLBI-1103 x DHLBI-1603	5.15**	1.49	-21.32**	-0.12*	-5.62**
9.	DHLBI-967 x DHLBI-1013	-0.12	-0.04	7.42*	0.39**	0.18
10.	DHLBI-967 x DHLBI-1708	3.18**	4.13**	1.39	-0.60**	0.17
11.	DHLBI-967 x DHLBI-18963	-3.27**	3.61**	2.25	0.02	1.50*
12.	DHLBI-967 x DHLBI-181181	-3.75**	-4.83**	14.46**	-0.23**	1.97**
13.	DHLBI-967 x DHLBI-181138	2.24*	2.64*	5.55	-0.25**	3.14**
14.	DHLBI-967 x DHLBI-1035	0.75	1.16	6.03	-0.17**	-3.41**
15.	DHLBI-967 x DHLBI-1603	-1.03	0.01	14.89**	0.15*	1.12
16.	DHLBI-1013 x DHLBI-1708	-4.03**	-4.41**	2.60	-0.06	0.84
17.	DHLBI-1013 x DHLBI-18963	-2.27*	-1.26	1.46	-0.32**	1.62*
18.	DHLBI-1013 x DHLBI-181181	4.69**	4.28**	15.78**	-0.01	0.43
19.	DHLBI-1013 x DHLBI-181138	-0.30	-0.56	7.62*	0.03	-0.51
20.	DHLBI-1013 x DHLBI-1035	-3.12**	-2.04	-12.83**	-0.24**	-0.95
21.	DHLBI-1013 x DHLBI-1603	1.75	0.80	8.54**	0.08	2.68**
22.	DHLBI-1708 x DHLBI-18963	-0.30	-0.74	10.69**	0.60**	-2.83**
23.	DHLBI-1708 x DHLBI-181181	-2.00	-1.86	4.12	0.40**	1.31
24.	DHLBI-1708 x DHLBI-181138	-2.33*	-0.04	7.92*	0.42**	1.14
25.	DHLBI-1708 x DHLBI-1035	3.51**	0.80	6.40*	0.45**	1.58*
26.	DHLBI-1708 x DHLBI-1603	0.72	1.64	1.66	0.29**	1.67*
27.	DHLBI-18963 x DHLBI-181181	-6.24**	-8.38**	-8.79**	-0.31**	0.64
28.	DHLBI-18963 x DHLBI-181138	-0.24	0.77	0.29	-0.06	1.63*
29.	DHLBI-18963 x DHLBI-1035	0.93	0.61	7.93*	-0.36**	-0.08
30.	DHLBI-18963 x DHLBI-1603	-0.84	-0.53	-8.91**	0.21**	3.23**
31.	DHLBI-181181 x DHLBI-181138	2.72*	0.64	-3.27	0.31**	-0.38
32.	DHLBI-181181 x DHLBI-1035	-1.09	0.49	-6.42*	-0.01	0.83
33.	DHLBI-181181 x DHLBI-1603	0.45	0.67	-0.93	-0.18**	-1.85**
34.	DHLBI-181138 x DHLBI-1035	-2.42*	-3.01**	6.66*	0.07	1.33*
35.	DHLBI-181138 x DHLBI-1603	-0.87	-0.50	16.82**	-0.34**	0.75
36.	DHLBI-1035 x DHLBI-1603	-4.36**	-3.32**	1.11	0.21**	0.75
	SE ±	1.09	1.03	3.13	0.06	0.67
	CD at 5 %	2.16	2.06	6.22	0.11	1.33
	CD at 1 %	2.91	2.75	8.35	0.16	1.78

*, ** Significant at 5 and 1 per cent level, respectively

Table 4.9 Contd…

Sr. No.	Crosses	Earhead girth (cm)	1000-grain weight (g)	Grain yield /plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
1.	DHLBI-1103 x DHLBI-967	0.29	-0.12	6.27**	1.94**	-2.12*
2.	DHLBI-1103 x DHLBI-1013	-0.61**	-1.86**	5.19*	1.25	2.27**
3.	DHLBI-1103 x DHLBI-1708	0.17	0.19	-0.24	-4.82**	-7.51**
4.	DHLBI-1103 x DHLBI-18963	1.10**	1.12**	3.97*	2.82**	3.33**
5.	DHLBI-1103 x DHLBI-181181	0.46*	0.75*	3.76	7.37**	4.88**
6.	DHLBI-1103 x DHLBI-181138	0.84**	0.31	2.56	-0.65	4.12**
7.	DHLBI-1103 x DHLBI-1035	0.25	1.08**	9.18**	4.29**	6.51**
8.	DHLBI-1103 x DHLBI-1603	-2.34**	1.00**	-9.49**	-4.87**	2.01*
9.	DHLBI-967 x DHLBI-1013	0.19	1.46**	8.20**	6.84**	6.11**
10.	DHLBI-967 x DHLBI-1708	-0.01	-1.10**	-12.29**	-8.27**	3.83**
11.	DHLBI-967 x DHLBI-18963	-0.08	1.08**	3.31	-1.26	5.99**
12.	DHLBI-967 x DHLBI-181181	0.28	1.70**	3.17	0.63	-3.92**
13.	DHLBI-967 x DHLBI-181138	0.88**	-1.01**	0.66	-7.90**	-2.28**
14.	DHLBI-967 x DHLBI-1035	0.62**	0.55	-11.17**	-2.18**	-8.14**
15.	DHLBI-967 x DHLBI-1603	0.35	0.94**	7.04**	-2.26**	-1.48
16.	DHLBI-1013 x DHLBI-1708	-0.03	-0.48	-4.46*	-6.08**	1.35
17.	DHLBI-1013 x DHLBI-18963	-0.32	0.90**	3.93*	-2.02**	-1.12
18.	DHLBI-1013 x DHLBI-181181	-0.06	0.11	3.45	2.22**	-1.08
19.	DHLBI-1013 x DHLBI-181138	0.09	0.86**	3.58	5.61**	4.08**
20.	DHLBI-1013 x DHLBI-1035	0.38	-0.60	0.78	-4.73**	-2.98**
21.	DHLBI-1013 x DHLBI-1603	0.89**	0.95**	0.89	-2.87**	-5.32**
22.	DHLBI-1708 x DHLBI-18963	0.24	1.15**	13.29**	6.53**	-1.61*
23.	DHLBI-1708 x DHLBI-181181	-0.38	0.13	9.10**	5.73**	0.65
24.	DHLBI-1708 x DHLBI-181138	0.64**	1.15**	11.53**	13.34**	6.54**
25.	DHLBI-1708 x DHLBI-1035	0.06	1.16**	7.96**	-0.92	-3.11**
26.	DHLBI-1708 x DHLBI-1603	0.68**	-1.45**	6.80**	-0.21	-5.62**
27.	DHLBI-18963 x DHLBI-181181	-0.12	-3.21**	-11.71**	-0.54	-0.72
28.	DHLBI-18963 x DHLBI-181138	0.85**	0.60	4.58*	-4.16**	-5.38**
29.	DHLBI-18963 x DHLBI-1035	-1.12**	-1.45**	-9.42**	-5.98**	-1.20
30.	DHLBI-18963 x DHLBI-1603	0.72**	0.75*	6.52**	1.14	1.77*
31.	DHLBI-181181 x DHLBI-181138	-0.04	0.46	9.66**	1.30	-0.65
32.	DHLBI-181181 x DHLBI-1035	0.80**	0.47	4.50*	-10.34**	0.28
33.	DHLBI-181181 x DHLBI-1603	-0.30	0.31	-6.99**	-4.77**	1.66*
34.	DHLBI-181138 x DHLBI-1035	-0.93**	0.43	4.06*	8.80**	3.70**
35.	DHLBI-181138 x DHLBI-1603	1.80**	0.12	-4.97*	8.05**	2.90**
36.	DHLBI-1035 x DHLBI-1603	0.09	-0.21	8.02**	7.32**	4.43**
	SE ±	0.23	0.31	1.96	0.70	0.80
	CD at 5 %	0.46	0.61	3.90	1.41	1.60
	CD at 1 %	0.61	0.83	5.23	1.86	2.13

*, ** Significant at 5 and 1 per cent level, respectively

4.1.8 *Per se* performance, SCA effects and Heterosis

Pearl millet production has been transformed by the commercial exploitation of heterosis. The crosses reflect higher productivity without significantly more expenditure on other inputs. Exploiting hybrid vigour has therefore emerged as a key component of pearl millet improvement programmes. *Per se* performance, SCA effects and the extent of heterosis are crucial for maximising hybrid vigour. It might not be effective to choose based solely on one of these factors. High *per se* performance hybrid performance need not always translate into high SCA effect and vice versa. Selection must therefore take into account all three criteria (Izge *et al*., 2007 and Barathi *et al*., 2020).

On the basis of *per se* performance, heterosis and SCA effects it revealed that cross, DHLBI-1708 x DHLBI-181138 was identified as superior, which ranked first for *per se* performance, with highest magnitude of heterobeltiosis, standard heterosis and high SCA effects for grain yield per plant. Cross combinations DHLBI-1708 x DHLBI-18963 (good x good) and DHLBI-181181 x DHLBI-181138 (poor x good) showed significant SCA effects for four and two yield, yield contributing and quality characters, respectively. These crosses ranked second and third in mean performance and also exhibited high magnitude of heterobeltiosis and standard heterosis for grain yield per plant. The crosses DHLBI-18963 x DHLBI-181138 (good x good) and DHLBI-1708 x DHLBI-181181 (good x average) ranked fourth and fifth in *per se* which also expressed higher magnitude of heterobeltiosis, standard heterosis and positive SCA effects for grain yield per plant (Table 4.10). Similar results were also reported by Izge *et al*. (2007), Kanatti *et al*. (2014), Karvar *et al.* (2017) and Krishnan *et al.* (2019b).

The *per se* performance, GCA effects of inbreds, SCA effects of hybrids and heterotic performance for yield and its principal components in the cross combinations *viz*., DHLBI-1708 x DHLBI-181138, DHLBI-1708 x DHLBI-18963, DHLBI-181181 x DHLBI-181138, DHLBI-18963 x DHLBI-181138 and DHLBI-1708 x DHLBI-181181 appeared to be the most promising. Therefore, the desired size of the F_2 population of these crosses can be increased in order to obtain superior transgressive segregants from these crosses and they may be used in subsequent breeding programmes through biparental mating or diallel selective mating (Jenson, 1970) as multiple parents input into the central gene pool for isolating high yielding lines from advance generations. Malhotra *et al*. (1980) demonstrated that diallel selective mating among the inbreds on the basis of GCA effects may break up some undesirable linkages and as a result, result in the release of greater genetic variability.

Table 4.10. Best performing crosses based on mean performance, heterosis and SCA effects for yield

Sr. No.	Hybrid	*Per se*	Heterosis over			SCA effects	GCA effects	Sig. desirable SCA effects for other characters
			MP	BP	SH			
1	DHLBI-1708 x DHLBI-181138	59.90	84.15**	69.66**	32.76**	11.53**	Good x Good	DF, PH, NWT, EG, TW, Fe, Zn
2	DHLBI-1708 x DHLBI-18963	56.78	77.72**	64.25**	25.84**	13.29**	Good x Good	PH, NET, TW, Fe
3	DHLBI-181181 x DHLBI-181138	53.50	66.25**	49.74**	18.57**	9.66**	Poor x Good	NET
4	DHLBI-18963 x DHLBI-181138	51.27	45.88**	43.52**	13.64**	4.58*	Good x Good	EL, EG
5	DHLBI-1708 x DHLBI-181181	49.73	71.61**	67.56**	10.22	9.10**	Good x Average	NET, Fe

*, ** Significant at 5 and 1 per cent level, respectively

Whereas,

DF = Days to 50 % flowering
DM = Days to maturity
PH = Plant height
NET = No. of effective tillers per plant
EL = Earhead length
EG = Earhead girth
TW = 1000-grain weight
GYPP = Grain yield per plant
Fe = Grain Fe
Zn = Grain Zn

4.2 Generation mean study for grain yield and its components

4.2.1 Analysis of variance

Analysis of variance was carried out for traits associated with grain yield for six different generations of pearl millet in two crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138 (Table 4.11). The genotypes differed significantly for all the characters, which indicated significant amount of variability present in the material selected for present investigation.

4.2.2 Mean performance of parents and different generations for grain yield and its component traits

The mean values for parents, F_1, F_2, B_1 and B_2 generations of two crosses *viz.,* DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138 for ten different characters of pearl millet are presented in (Table 4.12).

4.2.2.1 Days to 50 per cent flowering

The range of variation for days to 50 % flowering was 51.60 to 58.33 days in cross DHLBI-1103 x DHLBI-1035. Among the inbreds, DHLBI-1103 (52.00) was earliest followed by DHLBI-1035 (58.33). Among the different segregating generations, the days to 50 % flowering recorded in F_1 (51.60), F_2 (57.08), B_1 (52.66) and B_2 (56.66) for the cross DHLBI-1103 x DHLBI-1035.

The days to 50 % flowering were ranged from 50.00 to 59.66 days in cross DHLBI-1708 x DHLBI-181138. The inbred DHLBI-181138 recorded (59.67) days to 50 % flowering, whereas inbred DHLBI-1708 (51.66) was early in days to 50 % flowering. Among the segregating generations, days to 50 % flowering recorded in F_1 (50.00), F_2 (50.13), B_1 (51.33) and B_2 (56.33) for the cross DHLBI-1708 x DHLBI-181138.

4.2.2.2 Days to maturity

Days to maturity ranged from 83.33 to 89.66 days. The inbred DHLBI-1103 (85.00) was earliest followed by DHLBI-1035 (89.66). Among the different generations, days to maturity recorded in F_1 (83.33), F_2 (88.81), B_1 (84.00) and B_2 (87.33) for the cross DHLBI-1103 x DHLBI-1035.

The days to maturity were ranged from 83.00 to 91.00 days in cross DHLBI-1708 x DHLBI-181138. The inbred DHLBI-181138 recorded (91.00) days for physiological maturity, whereas inbred DHLBI-1708 (84.66) was early in maturity. Among the different generations, the days to maturity recorded in F_1 (83.00), F_2 (82.98), B_1 (83.33) and B_2 (87.33) for the cross DHLBI-1708 x DHLBI-181138.

4.2.2.3 Plant height (cm)

Plant height was ranged from 156.20 to 190.53 cm in DHLBI-1103 x DHLBI-1035 cross. Among the inbreds, DHLBI-1035 (166.26 cm) recorded as tallest and inbred DHLBI-1103 had 156.20 cm. From the different generations of the cross, plant height was recorded in F_1 (190.53 cm), F_2 (183.85 cm), B_1 (177.98 cm) and B_2 (184.78 cm).

In the cross DHLBI-1708 x DHLBI-181138, among the inbreds and different generations F_1 (206.53 cm) recorded highest value of plant height followed by B_2 (190.75 cm), B_1 (185.70 cm), F_2 (185.33 cm), P_2 (181.06 cm) and P_1 (160.33 cm).

4.2.2.4 Number of effective tillers per plant

Number of effective tillers per plant was ranged from 1.73 to 2.53 in the cross DHLBI-1103 x DHLBI-1035. Among the inbreds, DHLBI-1103 (2.00) recorded maximum productive tillers per plant and DHLBI-1035 had 1.73. Among the different generations of the cross, F_1 (2.53) recorded highest value of effective tillers per plant followed by B_1 (2.47), F_2 (1.81) and B_2 (1.72).

Among the different generations of the cross DHLBI-1708 x DHLBI-181138, F_1 (3.00) recorded highest value of effective tillers per plant followed by B_2 (2.68), P_2 (2.27), B_1 (2.03), F_2 (1.84) and P_1 (1.73).

4.2.2.5 Earhead length (cm)

The earhead length was ranged from 15.06 to 23.60 cm. Among the inbreds, DHLBI-1035 recorded maximum (21.20 cm) earhead length followed by DHLBI-1103 (15.06 cm). Among the different generations the maximum earhead length was recorded in F_1 (23.60 cm), F_2 (21.50 cm), B_1 (18.87 cm) and B_2 (21.53 cm) of the cross DHLBI-1103 x DHLBI-1035.

The earhead length was varied among the inbreds and crosses. The earhead length ranged from 18.87 to 24.80 cm in DHLBI-1708 x DHLBI-181138 cross. The inbred DHLBI-181138 had maximum earhead length (22.60 cm) followed by DHLBI-1708 (18.87 cm). Among the different generations, maximum earhead length was recorded by F_1 (24.80 cm), F_2 (23.55 cm), B_2 (23.00 cm) and B_1 (19.91 cm) of the cross DHLBI-1708 x DHLBI-181138.

4.2.2.6 Earhead girth (cm)

Earhead girth was ranged from 9.13 cm to 10.46 cm in the cross, DHLBI-1103 x DHLBI-1035. Among the different generations, earhead girth was recorded in P_1 (9.13 cm), P_2 (9.40 cm), F_1 (10.46 cm), F_2 (9.40 cm), B_1 (9.18 cm) and B_2 (10.05 cm) of the cross DHLBI-1103 x DHLBI-1035.

In cross DHLBI-1708 x DHLBI-181138, among the inbreds and different generations F_1 (12.46 cm) recorded highest value of earhead girth followed by B_2 (12.18 cm), P_2 (11.33 cm), F_2 (10.79 cm), P_1 (9.93 cm) and B_1 (9.90 cm).

4.2.2.7 1000-grain weight (g)

The range of variation for 1000-grain weight was 11.64 to 13.43 g in the cross DHLBI-1103 x DHLBI-1035. Among the inbreds, DHLBI-1035 (12.41 g) had highest 1000-grain weight followed by DHLBI-1103 (11.64 g). Among the different generation of the cross DHLBI-1103 x DHLBI-1035, 1000-grain weight was recorded by F_1 (13.43 g), F_2 (12.13 g), B_1 (12.33 g) and B_2 (12.87 g).

1000-grain weight was ranged from 10.92 to 14.44 g in cross, DHLBI-1708 x DHLBI-181138. Among the different generations the 1000-grain weight was recorded by P_1 (10.92 g), P_2 (13.11 g), F_1 (14.44 g), F_2 (14.26 g), B_1 (11.02 g) and B_2 (13.42 g) of the cross DHLBI-1708 x DHLBI-181138.

4.2.2.8 Grain yield per plant (g)

Grain yield per plant is the most important parameter in pearl millet, grain yield per plant among the inbreds and crosses ranged from 26.49 to 47.38 g in cross DHLBI-1103 x DHLBI-1035. Among the inbreds, DHLBI-1103 (29.07 g) recorded maximum grain yield, followed by DHLBI-1035 (26.49 g). Among the different generations of cross DHLBI-1103 x DHLBI-1035, the grain yield per plant was recorded by F_1 (47.38 g), F_2 (40.26g), B_1 (43.37 g) and B_2 (37.40 g).

The grain yield per plant was ranged from 27.56 to 57.55 g in cross DHLBI-1708 x DHLBI-181138. The inbred DHLBI-181138 recorded (39.68 g) maximum grain yield per plant followed by inbred DHLBI-1708 (27.56 g). Among the different generations, grain yield per plant was recorded in F_1 (57.55 g), F_2 (47.92 g), B_1 (39.08 g) and B_2 (51.28 g) of the cross DHLBI-1708 x DHLBI-181138.

4.2.2.9 Grain Fe (mg/kg)

Grain Fe content was ranged from 50.62 to 62.89 mg/kg in cross DHLBI-1103 x DHLBI-1035. Among the inbreds, DHLBI-1035 (56.56 mg/kg) recorded highest value of grain Fe content followed by DHLBI-1103 (50.62 mg/kg). From the different generations of the cross DHLBI-1103 x DHLBI-1035 grain Fe content was recorded in F_1 (62.89 mg/kg), F_2 (51.77 mg/kg), B_1 (53.98 mg/kg) and B_2 (58.20 mg/kg).

Table 4.11. Analysis of variance for six generations of two crosses for grain yield and its component traits in pearl millet

Sr. No.	Name of characters	Cross I DHLBI-1103 x DHLBI-1035		Cross II DHLBI-1708 x DHLBI-181138	
		Mean sum of squares		Mean sum of squares	
		Treatments	Error	Treatments	Error
	DF	**5**	**10**	**5**	**10**
1.	Days to 50 % flowering	26.27**	1.21	46.26**	1.80
2.	Days to maturity	20.69**	1.93	30.90**	3.07
3.	Plant height (cm)	503.22**	1.02	672.75**	4.26
4.	Number of effective tillers per plant	0.40**	0.01	0.73**	0.02
5.	Earhead length (cm)	26.46**	0.28	15.41**	0.56
6.	Earhead girth (cm)	0.85**	0.11	3.10**	0.11
7.	1000-grain weight (g)	1.14**	0.16	7.18**	0.14
8.	Grain yield per plant (g)	191.59**	1.06	300.01**	8.83
9.	Grain Fe (mg/kg)	61.67**	0.42	632.41**	2.54
10.	Grain Zn (mg/kg)	72.41**	2.32	290.48**	3.63

*, ** Significant at 5 and 1 per cent level, respectively

In the cross DHLBI-1708 x DHLBI-181138, among the inbreds and segregating generations F_1 (85.07 mg/kg) exhibited the highest value of grain Fe content followed by P_2 (77.76 mg/kg), B_2 (69.47 mg/kg), B_1 (56.61 mg/kg), F_2 (54.01 mg/kg) and P_1 (48.33 mg/kg).

4.2.2.10 Grain Zn (mg/kg)

Grain Zn ranged from 37.22 to 50.46 mg/kg. Among the inbreds, DHLBI-1035 recorded maximum (41.85 mg/kg) grain Zn content than the DHLBI-1103 (37.52 mg/kg). Among the different generations the grain Zn content was recorded in F_1 (50.46 mg/kg), F_2 (37.22 mg/kg), B_1 (39.37 mg/kg) and B_2 (42.76 mg/kg) of the cross DHLBI-1103 x DHLBI-1035.

The grain Zn ranged from 27.33 to 53.37 mg/kg. The inbred DHLBI-181138 had maximum grain Zn (50.27 mg/kg) followed by DHLBI-1708 (27.33 mg/kg). Among the different generations the grain Zn content was recorded in F_1 (53.37 mg/kg), F_2 (36.34 mg/kg), B_1 (35.11 mg/kg) and B_2 (45.37 mg/kg) of the cross DHLBI-1708 x DHLBI-181138.

Table 4.12. Mean performance & standard error for six generations of ten characters in pearl millet for grain yield in two crosses

Name of cross	**Generations**	**Days to 50 % flowering**	**Days to maturity**	**Plant height (cm)**	**No. of effective tillers/plant**	**Earhead length (cm)**	**Earhead girth (cm)**	**1000-grain weight (g)**	**Grain yield per plant (g)**	**Grain Fe (mg/kg)**	**Grain Zn (mg/kg)**
DHLBI-1103 x DHLBI-1035 (Cross I)	**P$_1$**	52.00 (0.19)	85.00 (0.22)	156.20 (0.66)	2.00 (0.10)	15.06 (0.31)	9.13 (0.36)	11.64 (0.34)	29.07 (1.02)	50.62 (0.58)	37.52 (1.23)
	P$_2$	58.33 (0.33)	89.66 (0.45)	166.26 (0.56)	1.73 (0.12)	21.20 (0.34)	9.40 (0.23)	12.41 (0.28)	26.49 (1.36)	56.56 (0.87)	41.85 (1.47)
	F$_1$	51.60 (0.27)	83.33 (0.27)	190.53 (0.95)	2.53 (0.13)	23.60 (0.29)	10.46 (0.35)	13.43 (0.24)	47.38 (1.90)	62.89 (0.66)	50.46 (0.62)
	F$_2$	57.08 (0.13)	88.81 (0.15)	183.85 (0.36)	1.81 (0.07)	21.50 (0.24)	9.40 (0.14)	12.13 (0.16)	40.26 (1.14)	51.77 (0.38)	37.22 (0.49)
	B$_1$	52.66 (0.16)	84.00 (0.21)	177.98 (0.30)	2.47 (0.69)	18.87 (0.17)	9.18 (0.11)	12.33 (0.15)	43.37 (1.10)	53.98 (0.38)	39.37 (0.53)
	B$_2$	56.66 (0.16)	87.33 (0.22)	184.78 (0.17)	1.72 (0.07)	21.53 (0.16)	10.05 (0.12)	12.87 (0.12)	37.40 (1.01)	58.20 (0.37)	42.76 (0.65)
DHLBI-1708 x DHLBI-181138 (Cross II)	**P$_1$**	51.66 (0.33)	84.66 (0.33)	160.33 (0.51)	1.73 (0.12)	18.87 (0.31)	9.93 (0.21)	10.92 (0.18)	27.56 (1.33)	48.33 (0.59)	27.33 (0.68)
	P$_2$	59.66 (0.33)	91.00 (0.44)	181.06 (0.69)	2.27 (0.12)	22.60 (0.30)	11.33 (0.19)	13.11 (0.22)	39.68 (2.07)	77.76 (0.98)	50.27 (0.55)
	F$_1$	50.00 (0.22)	83.00 (0.22)	206.53 (1.45)	3.00 (0.14)	24.80 (0.31)	12.46 (0.19)	14.44 (0.31)	57.55 (2.19)	85.07 (0.54)	53.37 (0.70)
	F$_2$	50.13 (0.19)	82.98 (0.27)	185.33 (0.97)	1.84 (0.05)	23.55 (0.22)	10.79 (0.10)	14.26 (0.25)	47.92 (1.49)	54.01 (1.12)	36.34 (0.93)
	B$_1$	51.33 (0.16)	83.33 (0.27)	185.70 (0.22)	2.03 (0.07)	19.91 (0.18)	9.90 (0.10)	11.02 (0.10)	39.08 (1.19)	56.61 (0.45)	35.11 (0.64)
	B$_2$	56.33 (0.16)	87.33 (0.16)	190.75 (0.36)	2.68 (0.07)	23.00 (0.25)	12.18 (0.11)	13.42 (0.11)	51.28 (0.95)	69.47 (0.33)	45.37 (0.68)

Note-Figures in parentheses indicate standard error.

4.2.3 Estimates of scaling tests for detecting non-allelic interactions of two crosses for different traits of pearl millet.

The presence or absence of gene interactions in the inheritance of yield contributing traits were examined using scaling tests (Mather, 1949). A, B, C and D scaling tests were used to evaluate the adequacy of the additive dominance model and the significance of these tests suggested the existence of non-allelic interactions. The significance of A and B scales indicated that the presence of all the three types of non-allelic interaction *viz*., additive x additive (i), additive x dominance (j) and dominance x dominance (l). The significance of C suggests dominance x dominance (l) type of interaction and significance of D suggests additive x additive (i) type of interaction. The significance of any one of the scaling tests indicates inadequacy of simple additive dominance model. The Chi square (χ^2) values were also found significant for all the characters in both the crosses.

The results on scaling test (A, B, C and D) in respect of yield and yield contributing traits have been tabulated in Table 4.13.

4.2.3.1 Days to 50 % flowering

For the days to 50 % flowering, the scaling tests, ‘A’ (1.73), ‘B’ (3.40), ‘C’ (14.80) and ‘D’ (4.83) were positively significant in cross DHLBI-1103 x DHLBI-1035, while scaling test ‘B’ (3.00) was positively significant in cross DHLBI-1708 x DHLBI-181138. While scaling tests ‘C’ (-10.80) and ‘D’ (-7.40) were negatively significant. The adequacy of additive dominance model was tested by using joint scaling test as per Cavalli, (1952) which was highly significant in both crosses, indicating presence of non-allelic interactions.

4.2.3.2 Days to maturity

In case of days to maturity scaling tests ‘B’ (1.66), ‘C’ (13.93) and ‘D’ (6.30) were positively significant in cross DHLBI-1103 x DHLBI-1035. Scaling tests ‘C’ (-9.73) and ‘D’ (-4.70) scaling tests were negatively significant in cross DHLBI-1708 x DHLBI-181138. The joint scaling test was found highly significant for days to maturity in both the crosses, indicating inadequacy of additive dominance model to explain all the genetic variation.

Table 4.13. Estimates of individual and joint scaling test for grain yield and its component traits in two crosses of pearl millet (Cross-I : DHLBI-1103 x DHLBI-1035 and Cross-II: DHLBI-1708 x DHLBI-181138)

Sr. No.	Name of Characters	Crosses	Scaling test				Chi square (χ^2)
			A	B	C	D	
1.	Days to 50 per cent flowering	C-I	1.73**	3.40**	14.80**	4.83**	342.16**
		C-II	1.00	3.00**	-10.80**	-7.40**	293.34**
2.	Days to maturity	C-I	-0.33	1.66*	13.93**	6.30**	299.46**
		C-II	-1.00	0.67	-9.73**	-4.70**	76.11**
3.	Plant height (cm)	C-I	9.23**	12.77**	31.90**	4.95**	172.18**
		C-II	4.53**	-6.10**	-13.13**	-5.78**	90.28**
4.	Number of effective tillers per plant	C-I	0.40	-0.83**	-1.53**	-0.55**	38.48**
		C-II	-0.67*	0.10	-2.63**	-1.03**	74.77**
5.	Earhead length (cm)	C-I	-0.93	-1.73**	2.53**	2.60**	29.23**
		C-II	-3.83**	-1.40*	3.13**	4.18**	90.72**
6.	Earhead girth (cm)	C-I	-1.23**	0.23	-1.86	-0.43	9.91*
		C-II	2.60**	0.57	-3.03**	-0.50*	81.91**
7.	1000-grain weight (g)	C-I	-0.40	-0.10	-2.38**	-0.94*	8.50*
		C-II	-3.32**	-0.70	4.16**	4.09**	128.17**
8.	Grain yield per plant (g)	C-I	10.28**	0.91	10.69	-2.25	12.83**
		C-II	-6.94*	5.33	9.32	5.46	11.70**
9.	Grain Fe (mg/kg)	C-I	-5.60**	-3.04*	-25.90**	-8.65**	149.75**
		C-II	-20.17	-23.89	-80.18	-18.06**	644.88**
10.	Grain Zn (mg/kg)	C-I	-9.24**	-6.79**	-31.41**	-7.69**	112.86**
		C-II	-11.08**	-12.91**	-39.56**	-7.79**	148.50**

*, ** Significant at 5 and 1 per cent level, respectively

4.2.3.3 Plant height (cm)

Scaling test ‘A’ (9.23 and 4.53) was positively significant in both the crosses (DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138) for plant height. Scaling tests ‘B’ (12.77 and -6.10), ‘C’ (31.90 and -13.13) ‘D’ (4.95 and -5.78) were positively and negatively significant in both the crosses, respectively. The joint scaling test for plant height was found to be significant in both the crosses, indicating inadequacy of additive dominance model to explain all the genetic variation.

4.2.3.4 Number of effective tillers per plant

For the number of effective tillers per plant, the scaling tests ‘B’ (-0.83), ‘C’ (-1.53) and ‘D’ (-0.55) were negatively significant in the cross, DHLBI-1103 x DHLBI-1035. and scaling tests ‘A’ (-0.67), ‘C’ (-2.63) and ‘D’ (-1.03) were negatively significant in cross DHLBI-1708 x DHLBI-181138. Estimates of genetic effects for number of effective tillers per plant by joint scaling test indicated that inadequacy of additive dominance model to explain all the genetic variations as the chi-square values of both the crosses were significant.

4.2.3.5 Earhead length (cm)

For earhead length, scaling tests ‘B’ (-1.73), ‘C’ (2.53) and ‘D’ (2.60) were significant in the cross DHLBI-1103 x DHLBI-1035. In the cross DHLBI-1708 x DHLBI-181138, scaling tests ‘A’ (-3.83), ‘B’ (-1.40), ‘C’ (3.13) and ‘D’ (4.18) were significant. The joint scaling test for earhead length was found to be significant in both the crosses, indicating inadequacy of additive dominance model to explain all the genetic variations.

4.2.3.6 Earhead girth (cm)

For earhead girth, scaling test ‘A’ (-1.23) was significant and scaling tests ‘B’, ‘C’ and ‘D’ were non-significant in cross DHLBI-1103 x DHLBI-1035. Scaling tests ‘A’ (2.60), ‘C’ (-3.03) and ‘D’ (-0.50) were significant in cross DHLBI-1708 x DHLBI-181138. The joint scaling test for earhead girth was found significant in both the crosses, indicating inadequacy of additive dominance model to explain all the genetic variations.

4.2.3.7 1000-grain weight (g)

For 1000-grain weight scaling tests ‘C’ (-2.38) and ‘D’ (-0.94) were negatively significant in the cross DHLBI-1103 x DHLBI-1035. Scaling tests ‘A’ (-3.32), ‘C’ (4.16) and ‘D’ (4.09) were significant in cross DHLBI-1708 x DHLBI-181138. The adequacy of additive-dominance model was tested using joint scaling test, which was highly significant in both the crosses for 1000-grain weight indicating presence of non-allelic interaction.

4.2.3.8 Grain yield per plant (g)

For grain yield per plant scaling test ‘A’ (10.28 and -6.94) was positively and negatively significant in DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138 crosses, respectively. The adequacy of additive-dominance model was tested using joint scaling test, which was highly significant in both the crosses for grain yield per plant indicating the presence of non-allelic interaction.

4.2.3.9 Grain Fe (mg/kg)

Scaling test ‘A’ (-5.60), ‘B’ (-3.04), ‘C’ (-25.90) and ‘D’ (-8.65) were negatively significant in the cross DHLBI-1103 x DHLBI-1035 for grain Fe. Scaling tests ‘D’ (18.06) was negatively significant in the cross DHLBI-1708 x DHLBI-181138. The joint scaling test for grain Fe was found significant in both the crosses, indicating inadequacy of additive dominance model.

4.2.3.10 Grain Zn (mg/kg)

For the grain Zn content, the scaling tests ‘A’ (-9.24 and -11.08), ‘B’ (-6.79 and -12.91), ‘C’ (-31.41 and -39.56) and ‘D’ (-7.69 and -7.79) were negatively significant in both the crosses (DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138), respectively. Estimates of genetic effects for this trait by joint scaling test indicated inadequacy of additive dominance model to explain all the genetic variations as the chi-square values of all the crosses were significant.

4.2.4 Estimates of genetic effects of two crosses for gain yield and its component traits in pearl millet

The six generations of both the crosses were used to estimate the gene effects *viz*., (m), (d), (h), (i), (j) and (l) for grain yield and its contributing traits in pearl millet. Wherever, the scaling tests and joint scaling test were highly significant indicating inadequacy of the simple additive-dominance model to explain the genetic control.

The estimates of m (mean), major genetic effects additive [d] and dominance [h] and non-allelic gene interactions (i, j and l) based on six parameter model (Hayman, 1958) for grain yield and its contributing traits (Table 4.14).

The parameter [m] was significant in both the crosses (DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138) for all the characters which were studied for grain yield and its contributing traits in pearl millet.

The gene effects estimated by using perfect fit model in respect of traits associated with grain yield in pearl millet has been presented in Table 4.14 and discussed traits wise below.

4.2.4.1 Days to 50 % flowering

The estimates of genetic parameters in the cross DHLBI-1103 x DHLBI-1035, observed that ‘d’ (-4.00) and ‘h’ (-13.23) were negatively significant. The interaction components ‘i’ (-9.67) and ‘j’ (-0.83) were estimated negatively significant, while component ‘l’ (4.53) was positively significant. Opposite sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis.

In the cross DHLBI-1708 x DHLBI-181138, estimates of genetics parameters, it was observed that ‘d’ (-5.00) and ‘h’ (9.13) were negatively and positively significant respectively. The interaction component ‘i’ (14.80) was observed positively significant, while ‘j’ (-1.00) and ‘l’ (-18.80) were estimated negatively significant. Opposite sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis.

In both the crosses, the additive [d] and dominance [h] gene effects were highly significant with predominance of dominance [h] gene effect, one of them in negative directional dominance. Significance of additive and dominance components indicated the importance of additive and dominance gene effects and the role of additive and non-additive gene action in inheritance of days to 50 per cent flowering traits and with the opposite sign of dominance [h] and dominance x dominance [l] components were observed which indicated the presence of duplicate type of epistasis. It has been earlier reported by Sheoran *et al*. (2000b), Singh *et al*. (2000), Wannows *et al*. (2015), Jog *et al*. (2016), Kumar *et al*. (2017) and Kumar *et al*. (2022).

Table 4.14. Estimates of genetic effects for different traits of grain yield and its component traits in two crosses of pearl millet. [Cross-I: DHLBI-1103 x DHLBI-1035 and Cross-II: DHLBI-1708 x DHLBI-181138]

Name of character	Cross	Genetic components						Type of epistasis
		m	d	h	i	j	l	
Days to 50 per cent flowering	**C-I**	57.08** (0.13)	-4.00** 0.23	-13.23** (0.77)	-9.67** (0.70)	-0.83** (0.30)	4.53** (1.25)	D
	C-II	50.13** (0.19)	-5.00** (0.23)	9.13** (0.93)	14.80** (0.88)	-1.00** (0.33)	-18.80** (1.35)	D
Days to Maturity	**C-I**	88.81** (0.15)	-3.33 (0.31)	-16.60** (0.93)	12.60** (0.86)	-1.00* (0.40)	11.27** (1.55)	D
	C-II	82.98** (0.27)	-4.00** (0.31)	4.57** (1.29)	9.40** (1.25)	-0.83* (0.42)	-9.07** (1.79)	D
Plant height (cm)	**C-I**	183.86** (0.36)	-6.80** (0.34)	19.40** (1.92)	-9.90** (1.61)	-1.77** (0.55)	-12.10** (2.90)	D
	C-II	185.33** (0.97)	-5.05** (0.42)	47.40** (4.24)	11.56** (3.95)	5.32** (0.60)	-10.00** (5.19)	D
No. of effective tillers per plant	**C-I**	1.82** (0.07)	0.75** (0.10)	1.77** (0.38)	1.10** (0.35)	0.62** (0.13)	-0.67 (0.58)	D
	C-II	1.84** (0.03)	-0.65** (0.01)	3.08** (0.33)	2.08** (0.30)	-0.38** (0.13)	-1.50** (0.56)	D
Earhead length (cm)	**C-I**	21.50** (0.24)	-2.66** (0.23)	0.27 (1.13)	-5.20** (1.07)	0.40 (0.33)	7.87** (1.53)	C
	C-II	23.55** (0.22)	-3.08** (0.31)	-4.30** (1.13)	-8.37** (1.07)	-1.22** (0.38)	13.60** (1.70)	D
Earhead girth (cm)	**C-I**	9.40** (0.14)	-0.87** (0.16)	2.07** (0.76)	0.87 (0.64)	-0.73** (0.27)	0.13 (1.19)	C
	C-II	10.79** (0.10)	-2.28** (0.15)	2.83** (0.55)	1.00* (0.5)	-1.58** (0.20)	1.03 (0.86)	C
1000-grain weight (g)	**C-I**	12.13** (0.16)	-0.54** (0.18)	3.28** (0.81)	1.88* (0.74)	-0.15 (0.29)	-1.37* (1.18)	D
	C-II	14.27** (0.25)	-2.40** (0.15)	-5.76** (1.10)	-8.18** (1.04)	-1.31** (0.21)	12.20** (1.36)	D
Grain yield per plant (g)	**C-I**	40.26** (1.14)	5.98** (1.49)	20.11** (5.84)	0.51 (5.46)	4.69** (1.72)	-11.70 (8.60)	D
	C-II	47.92** (1.49)	-12.20** (1.52)	13.00* (7.18)	-10.93 (6.71)	-6.12** (1.96)	12.54** (9.91)	C
Grain Fe (mg/kg)	**C-I**	51.77** (0.38)	-4.22** (0.52)	26.59** (2.04)	17.29** (1.86)	-1.26 (0.74)	-8.69** (3.09)	D
	C-II	54.01** (1.12)	-12.85** (0.56)	58.14** (4.70)	36.11** (4.63)	1.86* (0.80)	7.94 (5.26)	C
Grain Zn (mg/kg)	**C-I**	37.22** (0.49)	-3.39** (0.84)	26.15** (2.82)	15.38** (2.58)	-1.22 (1.28)	0.65 (4.52)	C
	C-II	36.35** (0.93)	-10.26** (0.93)	29.84** (4.26)	15.57** (4.17)	0.91 (1.03)	8.42 (5.52)	C

*, ** Significant at 5 and 1 per cent level, respectively

Among the interactions, additive x additive [i] and additive x dominance [j] components found negatively significant while component dominance x dominance [l] found positively significant in Ist cross and components additive x dominance [j] and dominance x dominance [l] negatively significant, while component additive x additive [i] positively significant in IInd cross indicates that the presence of non-allelic interactions in both the crosses. The dominance x dominance [l] component was higher in magnitude followed by additive x additive [i] and additive x dominance [j] which was in relatively lower magnitude which indicates preponderance of dominance [h] component and dominance x dominance [l] for the expression of days to 50 per cent flowering trait. Similar results were already recorded by Singh *et al.* (2000), Godasara *et al.* (2010), Wannows *et al.* (2015), Jog *et al.* (2016), Kumar *et al.* (2017) and Kumar *et al.* (2020).

4.2.4.2 Days to maturity

The estimates of genetic parameters in the cross DHLBI-1103 x DHLBI-1035, revealed that 'd' (-3.33) was negatively non-significant and 'h' (-16.60) was negatively significant. The interaction components 'i' (12.60) and 'l' (11.27) were positively significant while component 'j' (-1.00) was negatively significant. Opposite sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis.

In the cross DHLBI-1708 x DHLBI-181138, the estimates of genetic parameters, it was observed that 'd' (-4.00) and 'h' (4.57) were negatively and positively significant, respectively. The interaction component 'i' (9.40) estimated positively significant and component 'j' (-0.83) and 'l' (-9.07) were observed negatively significant. Opposite sign was observed for genetic component dominance 'h' and dominance x dominance 'l', with presence of duplicate epistasis.

It was observed that additive [d] and dominance [h] components were significant with the greater magnitude of dominance [h] component in desirable direction than the additive [d] component in both the crosses, indicated the preponderance of dominance gene effect for days to maturity in pearl millet with opposite sign of dominance [h] and dominance x dominance [l] components indicating the presence of duplicate epistasis in both the cross. On the basis of these results it was suggested that, the inheritance of days to maturity in pearl millet is governed by non-additive gene action.

It was observed that all the three interaction *viz*., additive x additive [i], additive x dominance [j] and dominance x dominance [l] were found to be significant in both the crosses among these, additive x additive [i] was estimated in higher magnitude with duplicate type of epistasis gene action based on the opposite sign of dominance [h] and dominance x dominance [l] components. Importance of both additive and dominance gene effects were earlier reported by Sheoran *et al*. (2000b), Godasara *et al*. (2010), Wannows *et al*. (2015), Jog *et al*. (2016), Vengadessan and Vinayan (2016), Kumar *et al*. (2020) and Kumar *et al.* (2022).

4.2.4.3 Plant height (cm)

In cross DHLBI-1103 x DHLBI-1035 the estimates of genetic parameters ‘d’ (-6.80) and ‘h’ (19.40) were negatively and positively significant, respectively. The interaction components ‘i’ (-9.90), ‘j’ (-1.77) and ‘l’ (-12.10) were negatively significant and opposite sign was observed for genetic components i.e. dominance [h] and dominance x dominance [l], with presence of duplicate epistasis.

In the estimates of genetic parameters in cross DHLBI-1708 x DHLBI-181138, it was observed that, ‘d’ (-5.05) and ‘h’ (47.40) component were negatively and positively significant, respectively. The interaction components ‘i’ (11.56), ‘j’ (5.32) and ‘l’ (-10.00) were positively and negatively significant, respectively. Opposite sign was observed for genetic component i.e. dominance [h] and dominance x dominance [l], with presence of duplicate epistasis.

The gene effect of additive [d] and dominance [h] components were estimated negatively and positively significant and dominance [h] component recorded in higher magnitude than additive [d] component in both the crosses and with the evidence of duplicate epistasis based on the opposite sign of dominance [h] and dominance x dominance [l] components. Significance of additive and dominance components indicated the importance of additive and dominance gene effects and the role of additive and non-additive gene action in inheritance of plant height. From the interaction components additive x additive [i], additive x dominance [j] and dominance x dominance [l] gene effects were estimated highly significant in desirable direction, with the predominance of dominance x dominance [l] gene effect in 1^{st} cross and additive x additive [i] gene effect in 2^{nd} cross for plant height in pearl millet for both the crosses. Importance of both additive and dominance gene effects were reported by Sheoran *et al.* (2000b), Godasara *et al.* (2010), Wannows *et al.* (2015) and Vengadessan and Vinayan (2016).

4.2.4.4 Number of effective tillers per plant

From the estimates of genetic parameters, it was observed that additive gene effect [d] (0.75) and dominance gene effect 'h' (1.77) were positively significant in cross DHLBI-1103 x DHLBI-1035. The interaction components additive x additive [i] (1.10) and [j] additive x dominance (0.62) were estimated positively significant. Dominance x dominance [l] component was estimated non-significant. Opposite sign observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis for number of effective tillers per plant.

In the estimates of genetic parameters in the cross DHLBI-1708 x DHLBI-181138, additive gene effect [d] (-0.65) and dominance gene effect [h] (3.08) recorded negatively and positively significant, respectively. The interaction component additive x additive [i] (2.08) was positively significant and additive x dominance [j] (-0.38) and dominance x dominance [l] (-1.50) were negatively significant. Duplicate gene interaction based on the opposite signs of [h] and [l] components was noticed in this cross combination.

The gene effect of additive [d] and dominance [h] components were estimated significant and dominance [h] component recorded in higher magnitude in desirable direction than additive [d] in both the crosses, indicated the preponderance of dominance gene effect for number of effective tillers per plant in pearl millet with opposite sign of dominance [h] and dominance x dominance [l] components were observed which indicated the presence of duplicate epistasis in both the crosses. Based on these results it was suggested that the inheritance of number of effective tillers per plant in pearl millet is governed by non-additive gene action.

The interaction components additive x additive [i], additive x dominance [j] and dominance x dominance [l] estimated highly significant in both the crosses except dominance x dominance [l] in cross-I with the predominance of additive x additive [i] component, hence predominance of dominance [h] with additive x additive [i] interaction played importance role in the expression of this trait. Similar results were earlier reported by Wannows *et al.* (2015), Jog *et al.* (2016), Kumar *et al.* (2017), Kumar *et al.* (2020) and Pujar *et al.* (2022).

4.2.4.5 Earhead length (cm)

In cross DHLBI-1103 x DHLBI-1035, the genetic parameter additive [d] (-2.66) was negatively significant while dominance [h] (0.27) component was observed non-significant. The interaction component additive x additive [i] (-5.20) and dominance x dominance [l] (7.87) was negatively and positively significant respectively, while additive x dominance [j] (0.40) was non-significant. Similar sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of complementary epistasis.

For estimates of genetic parameters in cross DHLBI-1708 x DHLBI-181138, it was observed that, both additive [d] (-3.08) and dominance [h] (-4.30) components were negatively significant. The interaction components additive x additive [i] (-8.37) and additive x dominance [j] (-1.22) were negatively significant and dominance x dominance [l] (13.60) component was positively significant. Opposite sign observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis for earhead length.

The gene effect of additive [d] and dominance [h] components were estimated negatively significant and non-significant, respectively. The additive [d] component recorded with higher magnitude in desirable direction than dominance [h] component in the I cross (DHLBI-1103 x DHLBI-1035), whereas, dominance gene effect was found significant with greater in magnitude in the cross II (DHLBI-1708 x DHLBI-181138). It was reported that, the expression of earhead length is due to inheritance of both additive and dominance gene effect in both crosses.

Among the interaction components it was observed that all the three interaction *viz*., additive x additive [i], additive x dominance [j] and dominance x dominance [l] were found to be significant except additive x dominance [j] in cross I (DHLBI-1103 x DHLBI-1035), among these dominance x dominance [l] was estimated in higher magnitude with complementary epistasis in cross I based on the similar sign of dominance [h] and dominance x dominance [l] components, while duplicate type of epistasis based on the opposite sign of dominance [h] and dominance x dominance [l] components in cross II. Similar findings were reported by Joshi and Desale (2000), Jog *et al.* (2016), Vengadessan and Vinayan (2016), Kumar *et al.* (2020) and Pujar *et al.* (2022).

4.2.4.6 Earhead girth (cm)

The estimates of genetic parameters in cross DHLBI-1103 x DHLBI-1035, the additive [d] (-0.87) and dominance component [h] (2.07) were observed negatively and positively significant. The interaction components additive x additive [i] (0.87) and dominance x dominance [l] (0.13) component were non-significant. and additive x dominance [j] (-0.73) was negatively significant. Similar sign observed for genetic component dominance [h] and dominance x dominance [l], with presence of complementary epistasis.

In cross DHLBI-1708 x DHLBI-181138, additive component [d] (-2.28) was negatively significant while dominance component [h] (2.83) observed positively significant. The interaction components additive x additive [i] (1.00) and additive x dominance [j] (-1.58) were positively and negatively significant, respectively and dominance x dominance [l] (1.03) component was estimated non-significant. Similar sign observed for genetic component dominance [h] and dominance x dominance [l], with presence of complementary epistasis for earhead girth.

The gene effect of additive [d] and dominance [h] components were estimated negatively and positively significant and dominance [h] component recorded higher in magnitude than additive [d] component in both the crosses and with the evidence of complementary epistasis based on the similar sign of dominance [h] and dominance x dominance [l] components. Significance of additive and dominance components indicated the importance of additive and dominance gene effects and the role of additive and non-additive gene action in inheritance of earhead girth. From the interaction components additive x dominance [j] in cross I and additive x additive (i) and additive x dominance [j] in cross II gene effects were estimated highly significant in desirable direction, with the predominance of additive x dominance [j] gene effect for earhead girth in pearl millet for both the crosses.

Importance of both additive and dominance gene effects were earlier reported by Sheoran, *et al.* (2000b), Godasara *et al.* (2010), Wannows *et al.* (2015), Kumar *et al.* (2020), Pujar *et al*. (2022) and Kumar *et al.* (2022).

4.2.4.7 1000-grain weight (g)

From the estimates of genetic parameters in cross DHLBI-1103 x DHLBI-1035, it was observed that additive gene effect [d] (-0.54) and dominance gene effect 'h' (3.28) were negatively and positively significant, respectively. The interaction components additive x additive [i] (1.88) and dominance x dominance [l] (-1.37) were estimated positively and negatively significant, respectively. The component [j] additive x dominance (-0.15) was estimated non-significant. Opposite sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis for 1000-grain weight.

In the estimates of genetic parameters in the cross DHLBI-1708 x DHLBI-181138, additive gene effect [d] (-2.40) and dominance gene effect [h] (-5.76) were recorded negatively significant. The interaction components additive x additive [i] (-8.18) and additive x dominance [j] (-1.31) were negatively significant and dominance x dominance [l] (12.20) was positively significant. Duplicate gene interaction based on the opposite signs of [h] and [l] components was noticed in this cross combination.

It was observed that additive [d] and dominance [h] components were significant with the greater magnitude of dominance [h] component than the additive [d] component in both the crosses, indicated the preponderance of dominance gene effect for 1000-grain weight in pearl millet. While presence of duplicate epistasis based on opposite sign of dominance [h] and dominance x dominance [l] components. On the basis of these results it was suggested that, the inheritance of 1000-grain weight in pearl millet is governed by non-additive gene action.

It was observed that all the three interaction *viz*., additive x additive [i], additive x dominance [j] and dominance x dominance [l] were found to be significant in both the crosses except additive x dominance [j] in cross I and among these interactions, dominance x dominance [l] was estimated in higher magnitude with duplicate type of epistatic gene action based on the opposite sign of dominance [h] and dominance x dominance [l] components. Importance of both additive and dominance gene effects were earlier reported by Sheoran *et al.* (2000b), Godasara *et al.* (2010), Jog *et al.* (2016), Wannows *et al.* (2015), Jog *et al.* (2016), Vengadessan and Vinayan (2016), Kumar *et al.* (2020) and Kumar *et al.* (2022).

4.2.4.8 Grain yield per plant (g)

For the estimates of genetic parameters in cross DHLBI-1103 x DHLBI-1035, it was observed that additive gene effect [d] (5.98) and dominance gene effect 'h' (20.11) were positively significant. The interaction components additive x additive [i] (0.51) and dominance x dominance [l] (-11.70) were estimated non-significant. Additive x dominance [j] (4.69) component was estimated positively significant. opposite sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis for grain yield per plant.

In cross DHLBI-1708 x DHLBI-181138, additive component [d] (-12.20) was negatively significant while dominance component [h] was observed positively significant (13.00). The interaction component additive x additive [i] (-10.93) was non-significant. The components additive x dominance [j] (-6.12) and dominance x dominance [l] (12.54) were negatively and positively significant, respectively. Similar sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of complementary epistasis for grain yield per plant.

The estimates of additive [d] and dominance [h] gene effects were positively significant in both the crosses, except cross I (DHLBI-1103 x DHLBI-1035) for additive gene effect was negatively significant indicated their importance in the expression of grain yield per plant in pearl millet. Significance of additive [d] and dominance [h] components with higher magnitude in desirable direction of dominance [h] components indicated the preponderance of dominance [h] gene effect for governing grain yield per plant. The magnitude of dominance gene effect was higher in desirable direction than additive gene effect, indicated the predominance of non-additive gene action in the inheritance of this trait in both the crosses.

In cross I (DHLBI-1103 x DHLBI-1035) the interaction component additive x dominance [j] was estimated highly significant with opposite sign of dominance [h] and dominance x dominance [l] components indicated the presence of duplicate type of epistasis. The gene effects in this cross were observed dominance [h] with dominance x dominance interaction effects in higher magnitude with duplicate epistasis, indicated the non-additive gene action played important role in the inheritance of grain yield per plant in pearl millet.

The interaction components additive x dominance [j] and dominance x dominance [l] was estimated significant in the cross II [DHLBI-1708 x DHLBI-181138]. It was indicated that the preponderance of dominance x dominance [l] gene effect followed by the additive x additive [i] and additive x dominance gene effects for grain yield per plant in pearl millet based on the results. Kumar *et al.* (2020) reported significance of additive, dominance and additive x additive interaction for this trait. Presence of epistasis as indicated by non-additive gene action was also reported by Sheoran *et al.* (2000b), Godasara *et al.* (2010), Wannows *et al.* (2015), Jog *et al.* (2016), Vengadessan and Vinayan (2016), Kumar *et al.* (2017), Pujar *et al.* (2022) and Kumar *et al.* (2022).

4.2.4.9 Grain Fe (mg/kg)

In cross DHLBI-1103 x DHLBI-1035, additive component [d] (-4.22) was negatively significant, while dominance component [h] (26.59) component was observed positively significant. The interaction components additive x additive [i] (17.29) and dominance x dominance [l] (-8.69) were positively and negatively significant, respectively and the component additive x dominance [j] (-1.26) was non-significant. Opposite sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of duplicate epistasis.

In cross DHLBI-1708 x DHLBI-181138 additive component [d] (-12.85) and dominance component [h] (58.14) were observed negatively and positively significant, respectively. The interaction components additive x additive [i] (36.11) and additive x dominance [j] (1.86) were estimated positively significant while dominance x dominance [l] (7.94) component was non-significant. Similar sign was observed for genetic component dominance [h] and dominance x dominance [l], indicating the presence of complementary epistasis.

The gene effect of additive [d] and dominance [h] components were estimated highly significant while dominance [h] component recorded with higher magnitude in desirable direction than additive [d] in both the crosses. It was reported that, the expression of this character is due to inheritance of dominance gene effect in both the crosses.

Among the interaction components it was observed that interactions *viz*., additive x additive [i], additive x dominance [j] and dominance x dominance [l] were found to be significant except additive x dominance [j] in cross I (DHLBI-1103 x DHLBI-1035) and dominance x dominance [l] in cross II (DHLBI-1708 x DHLBI-181138), among these additive x additive [i] was estimated in higher magnitude with duplicate type of epistasis based on the opposite sign of dominance [h] and dominance x dominance [l] components, gene action in cross I and in cross II complementary type of epistasis based on the similar sign of dominance [h] and dominance x dominance [l] components. Similar results were earlier reported by Kumar *et al.* (2020), Pujar *et al.* (2022) and Kumar *et al.* (2022).

4.2.4.10 Grain Zn (mg/kg)

In cross DHLBI-1103 x DHLBI-1035, the additive component [d] (-3.39) was negatively significant, while dominance [h] (26.15) component was observed positively significant. The interaction component additive x additive [i] (15.38) was positively significant. The other component additive x dominance [j] (-1.22) and dominance x dominance [l] (0.65) components were non-significant. Similar sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of complementary epistasis.

In the estimates of genetic parameters in cross DHLBI-1708 x DHLBI-181138, it was observed that, additive component [d] (-10.26) was negatively significant and dominance component [h] (29.84) was positively significant. The interaction component additive x additive [i] (15.57) was positively significant and additive x dominance [j] (0.91) and dominance x dominance [l] (8.42) components were positively non-significant. Similar sign was observed for genetic component dominance [h] and dominance x dominance [l], with presence of complementary epistasis for grain Zn content.

It was observed that additive [d] and dominance [h] components were negatively and positively significant and dominance [h] component recorded with greater magnitude in desirable direction than additive [d] in both the crosses, indicated the preponderance of dominance gene effect for grain Zn in pearl millet with similar sign of dominance [h] and dominance x dominance [l] components indicating the presence of complementary epistasis in both the crosses.

Among the interaction components in this cross it was observed that interaction additive x additive [i] was found to be significant and recorded with greater magnitude in desirable direction than additive x dominance [j] and dominance x dominance [l] in both the crosses. The interaction components additive x dominance [j] and dominance x dominance [l] were found to be non-significant. Importance of both additive and dominance gene effects were reported by Kumar *et al.* (2020), Pujar *et al.* (2022) and Kumar *et al.* (2022).

Although the generation mean approach is useful for identifying and quantifying gene interactions like as dominance, epistasis and additive interactions, but it has some limitations. The estimations of additive x additive and dominance x dominance gene effects are more seriously biased by linkage effects and epistasis gene effects. The distribution of positive and negative gene effects in the parents may result in varying degrees of cancellation of effects in the expression of the generation means, therefore drawing conclusions based solely on the magnitude of additive effects is not advised. In the presence of significant epistasis effects, estimates of additive and dominance gene effects could be biased (Hayman, 1958). The magnitudes of additive gene effects may not always correspond to the magnitudes of additive variance for the same reason. The combined estimates of dominance [h] and dominance x dominance [l] could be thought of as the best representations of the sign and magnitude of individual [h] and [l], respectively, because they are independent of the degree of gene distribution. Consequently, they are practically the only variables that can be utilised in a safe manner to determine the type of epistasis that may have an influence on the observed performance of generations (Mather and Jinks, 1971). For the same reason, focus has been paid on the traits controlled by these gene effects in order to recommend a breeding strategy that will result in a higher expression of those traits.

The sign associated with the estimates of additive x additive [i], additive x dominance [j] and dominance x dominance [l] types of epistasis indicates the direction in which the gene effects affects the mean of population (Azizi *et al.*, 2006). The magnitude of dominance x dominance [l] was relatively higher when compared to additive x additive [i] and additive x dominance [j] which indicated that the gene responsible for the inheritance of these traits were highly or partially dispersed conforming polygenic nature of the characters. Among the major gene effects, [h] component was much higher than the [d] component and in desirable direction in both the crosses for most of the traits in pearl millet. The estimates of [h] and [l] are observed similar sign indicating complementary epistasis for some characters, whereas, opposite sign observed in most of the characters, indicating the duplicate type of epistasis.

Due to the presence of duplicate epistasis in the included crosses, which reduces the manifestation of heterosis, the higher magnitude of dominant gene effects and dominance gene interactions identified for the majority of the traits in the current study could not be utilised for heterosis breeding. Therefore, if dominance and epistasis effects were first reduced by a few generations of selfing, selection for grain yield traits would be beneficial. However, interactions will not aid in selection during the early segregating generations. Until a high level of gene fixation is reached and genetic variation within a population becomes largely dominant, it should be delayed to later or advanced generations.

Based on limited material and number of generations used in this study the additive, dominance and epistatic gene effects were found to contribute significantly for the inheritance of various characters studied for grain yield and its contributing traits in pearl millet. With few exceptions, the dominant effects whether significant or not, outperformed the corresponding additive effects in both crosses for significant yield contributing characters, indicating the presence of either overdominance or complete dominance. Numerous researchers have noted that non-additive components predominate in the inheritance of grain yield and its component traits in pearl millet. Thus, the results of the current study show that the inheritance of grain yield was largely determined by interallelic interactions at the digenic level. Because of this, breeders should use breeding techniques that can mop up the genes to create superior gene constellations that interact favourably.

Despite the fact that all of the gene action components were found to be controlling all of the characters, including grain yield, dominance (h) effect, which is comprised of epistatic interactions, was found to be predominant for the majority of the significant traits studied. The epistasis in both of the crosses included both complementary and duplicate types. As a result, improvement may be anticipated by first utilising both additive and dominance genetic variance, i.e., by incorporating mild selection intensity in earlier generations and intense selection intensity in later generations where additive genetic variance is estimated to be of higher magnitude. To remove unfavourable linkages and accumulate favourable additive genes, the early generation isolates may be interbred.

4.3 Transgressive segregation

Frequency distribution and proportion of desirable transgressive segregants for eight agronomic characters, individually and for combination of characters along with grain yield per plant have been reported cross wise *viz.,* DHLBI 1708 x DHLBI 181138 and DHLBI 1708 x DHLBI 18963. The result of each cross was presented separately as below.

4.3.1 Cross I- DHLBI-1708 x DHLBI-181138

4.3.1.1 Means, standard deviations, frequency distribution and proportion of desirable transgressive segregants for eight characters in F_2 generation

Frequency distribution and proportion of desirable transgressive segregants for eight agronomic traits of cross I (DHLBI 1708 x DHLBI 181138) are given in Table 4.15 and 4.16.

1. Days to flowering

As evident from Table 4.15, out of the two parental lines, DHLBI 1708 flowered earlier (48.93 days) as compared to DHLBI 181138 (60.00 days), while mean of F_2 population for days to flowering was 49.50 days. Days to flowering was ranged from 43 to 47 days in transgressive segregants (Table 4.16). The transgressive segregants observed for days to flowering in F_2 generation were 11.67 per cent (70 plants) in desirable direction (Table 4.15). Threshold value for days to flowering was 47.08.

2. Days to maturity

The data showed that days required for maturity for inbreds DHLBI 1708 and DHLBI 181138 were 83.47 and 91.00 days, respectively (Table 4.15). In F_2

generation, it was 82.03 days. The transgressive segregants observed for days to maturity in F_2 generation was 12.00 per cent (72 plants) which ranged from 73 to 80 days (Table 4.16). Threshold value for this trait was 80.75.

3. Plant height (cm)

Inbred DHLBI 1708 was dwarf with 161.60 cm height as compared to DHLBI 181138 which was 176.60 cm. In F_2 generation the average plant height was 178.20 cm (Table 4.15). The transgressive segregants in terms of tall plants were 13.33 per cent (80 plants) which ranged from 185 to 205 cm (Table 4.16). Threshold value for plant height was 183.52.

4. Number of effective tillers per plant

Out of the two inbreds, DHLBI 181138 (2.20) had more number of effective tillers as compared to DHLBI 1708 (1.80), while mean of F_2 population for number of effective tillers was 2.34 (Table 4.15). Number of effective tillers was ranged from 4 to 5 in transgressive segregants (Table 4.16). In cross, 5.17 per cent (31 plants) of F_2 population was transgressed in desirable direction for effective tillers per plant. Threshold value for number of effective tillers per plant was 3.28.

5. Earhead length (cm)

The earhead length in parental lines DHLBI 1708 was 19.00 cm while in DHLBI 181138 was 22.23 cm. The average transgressive segregation in F_2 generation for earhead length was 22.74 cm (Table 4.15). Transgressive segregants in F_2 in terms of long earhead length than higher inbred was 16.17 per cent (97 plant) with a range of 25 to 29 cm (Table 4.16). Threshold value for earhead length was 24.27.

6. Earhead girth (cm)

The earhead girth in DHLBI 1708 and DHLBI 181138 was 9.80 and 10.97 cm, respectively. In the F_2 generation the average earhead girth was 11.10 cm (Table 4.15). The transgressive segregants in terms of earhead girth in F_2 were 13.67 per cent (82 plants) with a range of 13 to 16 cm (Table 4.16). Threshold value for this trait was 12.37.

Table 4.15. Mean, Standard deviation, frequency distribution and percentage of desirable transgressive segregants (T.S.) in different generations of the cross DHLBI 1708 x DHLBI 181138 for the traits

Sr. No	Generations	Mean ± SE.	S.D.													Frequency Total	N.D. value	Percentage of T.S.
				-5	-4	-3	-2	-1	0	1	2	3	4	5	Total TS			
	Days to flowering																	
1.	DHLBI 1708 (+)	48.93 ± 0.17	0.94	0	0	0	4	66	134	193	107	78	18	0	**70**	600	-0.88	11.67
2.	DHLBI 181138 (-)	60.00 ± 0.26	1.44															
3.	F_2	49.50 ± 0.11	2.75															
	Days to maturity																	
1.	DHLBI 1708 (+)	83.47 ± 0.26	1.41	0	0	0	48	24	340	112	52	24	0	0	**72**	600	-0.35	12.00
2.	DHLBI 181138 (-)	91.00 ± 0.17	0.91															
3.	F_2	82.03 ± 0.15	3.77															
	Plant height (cm)																	
1.	DHLBI 1708 (+)	161.60 ± 0.35	1.94	0	0	2	22	59	437	59	11	8	2	0	**80**	600	0.64	13.33
2.	DHLBI 181138 (-)	176.60 ± 0.64	3.53															
3.	F_2	178.20 ± 0.34	8.34															
	Number of effective tillers per plant																	
1.	DHLBI 1708 (+)	1.80 ± 0.07	0.41	0	0	0	0	64	505	30	1	0	0	0	**31**	600	1.27	5.17
2.	DHLBI 181138 (-)	2.20 ± 0.10	0.55															
3.	F_2	2.34 ± 0.03	0.74															
	Earhead length (cm)																	
1.	DHLBI 1708 (+)	19.00 ± 0.19	1.02	0	0	0	14	78	411	66	26	5	0	0	**97**	600	0.71	16.17
2.	DHLBI 181138 (-)	22.23 ± 0.19	1.04															
3.	F_2	22.74 ± 0.09	2.16															
	Earhead girth (cm)																	
1.	DHLBI 1708 (+)	9.80 ± 0.15	0.81	0	0	0	2	31	485	73	8	1	0	0	**82**	600	1.06	13.67
2.	DHLBI 181138 (-)	10.97 ± 0.13	0.72															
3.	F_2	11.10 ± 0.05	1.20															
	1000-grain weight (g)																	
1.	DHLBI 1708 (+)	10.02 ± 0.12	0.68	0	0	0	2	37	458	53	47	3	0	0	**103**	600	0.65	17.17
2.	DHLBI 181138 (-)	13.36 ± 0.17	0.91															
3.	F_2	14.04 ± 0.07	1.67															
	Grain yield per plant (g)																	
1.	DHLBI 1708 (+)	26.80 ± 0.79	4.32	0	0	0	0	56	427	75	36	5	1	0	**117**	600	0.46	19.50
2.	DHLBI 181138 (-)	38.18 ± 1.46	8.02															
3.	F_2	46.81 ± 0.63	15.31															

(+) = Increasing inbred N.D. = Normal Deviation (-) = Decreasing inbred S.D. = Standard Deviation

Table 4.16. Threshold value, frequency and range in values of transgressive segregants for eight agronomic characters in F_2 generation of the cross DHLBI-1708 x DHLBI-181138

Sr. No.	Characters	Threshold value	Transgressive segregation	
			F_2 Generation	
			Frequency	Range
1.	Days to flowering	47.08	70.00	43 to 47
2.	Days to maturity	80.75	72.00	73 to 80
3.	Plant height (cm)	183.52	80.00	185 to 205
4.	Number of effective tillers per plant	3.28	31.00	04 to 05
5.	Earhead length (cm)	24.27	97.00	25 to 29
6.	Earhead girth (cm)	12.37	82.00	13 to16
7.	1000-grain weight (g)	15.13	103.00	15.15 to 19.5
8.	Grain yield per plant (g)	53.90	117.00	53.95 to 113

7. 1000-grain weight (g)

The data presented in the Table 4.15, showed that 1000-grain weight in inbreds DHLBI 1708 and DHLBI 181138 were 10.02 g and 13.36 g, respectively. In F_2 generation 1000-grain weight was 14.04 g. The transgressive segregants observed for 1000-grain weight in F_2 generation were 17.17 per cent (103 plants) with the range of 15.15 to 19.5 g (Table 4.16). Threshold value for 1000-grain weight was 15.13.

8. Grain yield per plant (g)

The grain yield (g) in parental line DHLBI 1708 was 26.80 g while DHLBI 181138 yielded 38.18 g (Table 4.15). In F_2 generation average value of transgressive segregants for this trait was 46.81 g. Transgressive segregants in F_2 in terms of higher grain yield than higher inbred was 19.50 per cent (117 plants) with a range of 53.95 to 113 g (Table 4.16). Threshold value for grain yield was 53.90.

4.3.1.2 Frequency and percentage of transgressive segregants for grain yield and yield attributing characters in F_2 generation of cross DHLBI-1708 x DHLBI-181138

The data on frequency and percentage of transgressive segregants for grain yield and other characters along with yield is summarized in Table 4.17. The transgression of grain yield along with five other characters took place in one combinations. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering, days to maturity, number of effective tillers per plant, earhead length and 1000-grain weight (0.17 %).

There were two character combinations in which the transgression of grain yield was found to be associated with transgression of four other characters. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering, days to maturity, plant height and earhead girth (0.17 %).
2. Grain yield per plant with days to flowering, days to maturity, plant height and 1000-grain weight (0.17 %).

There were three character combinations in which the transgression of grain yield was found to be associated with transgression of three other characters. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering, days to maturity and plant height (0.34 %).
2. Grain yield per plant with days to flowering, plant height and number of effective tillers per plant (0.17 %).
3. Grain yield per plant with plant height, earhead length and 1000-grain weight (0.17 %).

There were thirteen character combinations in which the transgression of yield was found to be associated with transgression of two other characters. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering and days to maturity (0.17 %).
2. Grain yield per plant with days to flowering and earhead length (0.17 %).
3. Grain yield per plant with days to flowering and 1000-grain weight (0.34 %).
4. Grain yield per plant with days to maturity and earhead length (0.34 %).
5. Grain yield per plant with days to maturity and 1000-grain weight (0.34 %).
6. Grain yield per plant with plant height and earhead length (0.34 %).
7. Grain yield per plant with plant height and 1000-grain weight (0.17 %).
8. Grain yield per plant with number of effective tillers per plant and earhead length (0.17 %).
9. Grain yield per plant with number of effective tillers per plant and earhead girth (0.34 %).
10. Grain yield per plant with number of effective tillers per plant and 1000-grain weight (0.17 %).
11. Grain yield per plant with earhead length and earhead girth (0.17 %).
12. Grain yield per plant with earhead length and 1000-grain weight (0.17 %).
13. Grain yield per plant with earhead girth and 1000-grain weight (0.51 %).

There were seven character combinations in which the transgression of yield was found to be associated with transgression of only one character. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering (0.68 %).
2. Grain yield per plant with days to maturity (1.19 %).
3. Grain yield per plant with plant height (1.19 %).
4. Grain yield per plant with number of effective tillers per plant (0.85 %).
5. Grain yield per plant with earhead length (1.53 %).
6. Grain yield per plant with earhead girth (0.68 %).
7. Grain yield per plant with 1000-grain weight (1.7 %)

The proportion of the transgressive segregants in F_2 generation was occurred for grain yield per plant alone was 7.48 per cent.

Table 4.17. **Frequency and percentage of simultaneous transgressive segregation (T.S) for grain yield and yield attributing characters in F_2 generation of the cross DHLBI-1708 x DHLBI-181138**

Sr. No.	Character combination	Transgressive segregants	
		Frequency	Percentage
	Grain yield with		
1	Days to flowering + days to maturity + number of effective tillers per plant + earhead length + 1000-grain weight	1	0.17
2	Days to flowering + days to maturity + plant height + earhead girth	1	0.17
3	Days to flowering + days to maturity + plant height + 1000-grain weight	1	0.17
4	Days to flowering + days to maturity + plant height	2	0.34
5	Days to flowering + plant height + number of effective tillers per plant	1	0.17
6	Plant height + earhead length + 1000-grain weight	1	0.17
7	Days to flowering + days to maturity	1	0.17
8	Days to flowering + earhead length	1	0.17
9	Days to flowering + 1000-grain weight	2	0.34
10	Days to maturity + earhead length	2	0.34
11	Days to maturity + 1000-grain weight	2	0.34
12	Plant height + earhead length	2	0.34
13	Plant height + 1000-grain weight	1	0.17
14	Number of effective tillers per plant + earhead length	1	0.17
15	Number of effective tillers per plant + earhead girth	2	0.34
16	Number of effective tillers per plant + 1000-grain weight	1	0.17
17	Earhead length + earhead girth	1	0.17
18	Earhead length + 1000-grain weight	1	0.17
19	Earhead girth + 1000-grain weight	3	0.51
20	Days to flowering	4	0.68
21	Days to maturity	7	1.19
22	Plant height	7	1.19
23	Number of effective tillers per plant	5	0.85
24	Earhead length	9	1.53
25	Earhead girth	4	0.68
26	1000-grain weight	10	1.7
27	Grain yield per plant	44	7.48
	Total	**117**	**19.50**

4.3.2 Cross II- DHLBI 1708 x DHLBI 18963

4.3.2.1 Means, standard deviations, frequency distribution and proportion of desirable transgressive segregants for eight characters in F_2 generation

Frequency distribution and proportion of desirable transgressive segregants for eight agronomic characters of cross II (DHLBI 1708 x DHLBI 18963) are given in Table 4.18 and 4.19.

1. Days to flowering

From the two parental inbred lines, DHLBI 1708 was early flowered in 48.93 days and DHLBI 18963 was late, which took 58.33 days for flowering, while mean of F_2 population for days to flowering was 50.55 days (Table 4.18). Days to flowering was ranged from 42 to 46 days in transgressive segregants. The transgressive segregants observed for days to flowering in F_2 generation were 13.50 per cent (81 plants) in desirable direction (Table 4.19). Threshold value for days to flowering was 47.00.

2. Days to maturity

The data showed that days required for maturity for inbreds DHLBI 1708 and DHLBI 18963 were 82.00 and 89.60 days, respectively (Table 4.18). In F_2 generation it was 84.84 days. The transgressive segregants observed for days to maturity in F_2 generation were 13.83 per cent (83 plants) which ranged from 75 to 80 days (Table 4.19). Threshold value for this trait was 80.45.

3. Plant height (cm)

Inbred DHLBI 1708 was dwarf with 160.20 cm height as compared to DHLBI 18963 which was 177.40 cm. In F_2 generation the average plant height was 176.20 cm (Table 4.18). The transgressive segregants in terms of tall plants were 13.67 per cent (82 plants) which ranged from 182 to 192 cm (Table 4.19). Threshold value for plant height was 181.20.

4. Number of effective tillers per plant

Out of the two inbreds, DHLBI 18963 (2.13) had more number of effective tillers as compared to DHLBI 1708 (1.77), while mean of F_2 population for number of effective tillers was 1.99 (Table 4.18). Number of effective tillers was ranged from 3 to 4 in transgressive segregants (Table 4.19). In cross DHLBI-1708 x DHLBI-18963, 16.00 per cent (96 plants) of F_2 population were transgressed in desirable direction for effective tillers per plant. Threshold value for number of effective tillers per plant was 2.99.

Table 4.18. Mean, Standard deviation, frequency distribution and percentage of desirable transgressive segregants (T.S.) in different generations of the cross DHLBI 1708 x DHLBI 18963 for the traits

Sr. No	Generations	Mean ± SE.	S.D.													Frequency Total	N.D. value	Percentage of T.S.
				-5	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**Total TS**			
	Days to flowering																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	48.93 ± 0.17 58.33 ± 0.21 50.55 ± 0.13	1.02 1.12 3.22	0	0	0	3	78	130	71	146	98	74	0	**81**	600	-1.10	13.50
	Days to maturity																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	82.00 ± 0.14 89.60 ± 0.15 84.84 ± 0.17	0.79 0.81 4.19	0	0	8	17	58	115	28	75	24	134	141	**83**	600	-1.05	13.83
	Plant height (cm)																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	160.20 ± 0.44 177.40 ± 0.35 176.20 ± 0.19	2.40 1.94 4.54	0	6	4	27	95	386	72	7	3	0	0	**82**	600	1.10	13.67
	Number of effective tillers per plant																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	1.77 ± 0.08 2.13 ± 0.06 1.99 ± 0.02	0.43 0.35 0.59	0	0	0	0	104	400	94	2	0	0	0	**96**	600	1.40	16.00
	Earhead length (cm)																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	19.00 ± 0.19 24.80 ± 0.18 25.03 ± 0.10	1.02 1.00 2.36	0	0	0	34	54	407	67	35	3	0	0	**105**	600	0.73	17.50
	Earhead girth (cm)																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	9.50 ± 0.09 9.57 ± 0.11 10.07 ± 0.04	0.51 0.63 0.98	0	0	0	4	16	479	96	5	0	0	0	**101**	600	0.74	16.83
	1000-grain weight (g)																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	10.05 ± 0.13 11.64 ± 0.14 12.21 ± 0.05	0.69 0.78 1.24	0	0	0	0	35	454	98	8	5	0	0	**111**	600	0.77	18.50
	Grain yield per plant (g)																	
1. 2. 3.	DHLBI 1708 (+) DHLBI 18963 (-) F_2	26.21 ± 0.72 36.97 ± 1.13 43.21 ± 0.48	3.93 6.17 11.64	0	0	0	1	44	432	91	18	14	0	0	**123**	600	0.50	20.50

(+) = Increasing inbred N.D. = Normal Deviation (-) = Decreasing inbred S.D. = Standard Deviation

Table 4.19. Threshold value, frequency and range in values of transgressive segregants for eight agronomic characters in F_2 generation of the cross DHLBI-1708 x DHLBI-18963

Sr. No.	Characters	Threshold Value	Transgressive segregation	
			F_2 Generation	
			Frequency	Range
1.	Days to 50 % flowering	47.00	81.00	42 to 46
2.	Days to maturity	80.45	83.00	75 to 80
3.	Plant height (cm)	181.20	82.00	182 to 192
4.	Number of effective tillers per plant	2.99	96.00	03 to 04
5.	Earhead length (cm)	26.75	105.00	27 to 31
6.	Earhead girth (cm)	10.79	101.00	11 to 13
7.	1000-grain weight (g)	13.17	111.00	13.20 to 17.60
8.	Grain yield per plant (g)	49.07	123.00	49.10 to 84.34

5. Earhead length (cm)

The earhead length in parental inbred lines DHLBI 1708 was 19.00 cm while in DHLBI 18963 was 24.80 cm. In F_2 segregating generation the average earhead length was 25.03 cm (Table 4.18). The transgressive segregants in terms of earhead length in F_2 were 17.50 per cent (105 plants) with a range of 27 to 31 cm (Table 4.19). Threshold value for earhead length was 26.75.

6. Earhead girth (cm)

The earhead girth in DHLBI 1708 and DHLBI 18963 was 9.50 and 9.57 cm, respectively. In the F_2 segregating generation the average earhead girth was 10.07 cm (Table 4.18). The transgressive segregants in terms of earhead girth in F_2 were 16.83 per cent (101 plants) with a range of 11 to 13 cm (Table 4.19). Threshold value for this trait was 10.79.

7. 1000-grain weight (g)

The data presented in the Table 4.18, showed that 1000-grain weight in inbreds DHLBI 1708 and DHLBI 18963 were 10.05 g and 11.64 g, respectively. In F_2 generation 1000-grain weight was 12.21 g. The transgressive segregants observed for

1000-grain weight in F_2 generation were 18.50 per cent (111 plants) with the range of 13.20 to 17.60 g (Table 4.19). Threshold value for 1000-grain weight was 13.17.

8. Grain yield per plant (g)

The grain yield per plant (g) in parental inbred line DHLBI 1708 was 26.21 g while DHLBI 18963 yielded 36.97 g (Table 4.18). In F_2 average value of transgressive segregants for this trait was 43.21 g. Transgressive segregants in F_2 in terms of higher grain yield than higher inbred was 20.50 per cent (123 plants) with a range of 49.10 to 84.34 g (Table 4.19). Threshold value for grain yield was 49.07.

4.3.2.2 Frequency and percentage of transgressive segregants for grain yield and yield contributing traits in F_2 generation of cross DHLBI-1708 x DHLBI-18963

The data on frequency and percentage of transgressive segregants for grain yield and other characters along with yield is summarized in Table 4.20. The transgression of grain yield along with five other characters took place in one character combination. Such combination along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering, days to maturity, number of effective tillers per plant, earhead girth and 1000-grain weight (0.17 %).

There were four character combinations in which the transgression of grain yield was found to be associated with transgression of four other characters. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering, days to maturity, number of effective tillers per plant and 1000-grain weight (0.17 %).
2. Grain yield per plant with days to flowering, number of effective tillers per plant, earhead length and 1000-grain weight (0.17 %).
3. Grain yield per plant with days to maturity, plant height, number of effective tillers per plant and earhead girth (0.17 %).
4. Grain yield per plant with plant height, earhead length, earhead girth and 1000-grain weight (0.17 %).

Table 4.20. **Frequency and percentage of simultaneous transgressive segregation (T.S.) for grain yield and yield attributing characters in F_2 generation of the cross DHLBI-1708 x DHLBI-18963**

Sr. No.	Character combination	Transgressive segregants	
		Frequency	Percentage
	Grain yield with		
1.	Days to flowering + days to maturity + number of effective tillers per plant + earhead girth + 1000-grain weight	1	0.17
2.	Days to flowering + days to maturity + number of effective tillers per plant + 1000-grain weight	1	0.17
3.	Days to flowering + number of effective tillers per plant + earhead length + 1000-grain weight	1	0.17
4.	Days to maturity + plant height + number of effective tillers per plant + earhead girth	1	0.17
5.	Plant height + earhead length + earhead girth + 1000-grain weight	1	0.17
6.	Days to flowering + days to maturity + plant height	1	0.17
7.	Days to flowering + days to maturity + number of effective tillers per plant	1	0.17
8.	Days to flowering + days to maturity + 1000-grain weight	1	0.17
9.	Days to flowering + plant height + earhead length	2	0.34
10.	Days to flowering + number of effective tillers per plant + 1000-grain weight	1	0.17
11.	Days to maturity + number of effective tillers per plant + earhead girth	1	0.17
12.	Days to maturity + earhead length + earhead girth	1	0.17
13.	Earhead length + earhead girth + 1000-grain weight	1	0.17
14.	Days to flowering + days to maturity	1	0.17
15.	Days to flowering + number of effective tillers per plant	3	0.51
16.	Days to flowering + 1000-grain weight	1	0.17
17.	Days to maturity + plant height	1	0.17
18.	Days to maturity + number of effective tillers per plant	3	0.51
19.	Days to maturity + earhead length	1	0.17
20.	Days to maturity + 1000-grain weight	3	0.51
21.	Plant height + number of effective tillers per plant	2	0.34
22.	Plant height + earhead girth	1	0.17
23.	Plant height + 1000-grain weight	3	0.51
24.	Number of effective tillers per plant + earhead length	2	0.34
25.	Number of effective tillers per plant + 1000-grain weight	4	0.68

Table 4.20 contd…..

Sr. No.	Character combination	Transgressive segregants	
		Frequency	**Percentage**
26.	Earhead length + earhead girth	2	0.34
27.	Earhead length + 1000-grain weight	1	0.17
28.	Days to flowering	3	0.51
29.	Days to maturity	4	0.68
30.	Plant height	6	1.02
31.	Number of effective tillers per plant	7	1.19
32.	Earhead length	11	1.87
33.	Earhead girth	4	0.68
34.	1000-grain weight	5	0.85
35.	Grain yield per plant	41	6.97
	Total	**123**	**20.50**

There were eight character combinations in which the transgression of grain yield was found to be associated with transgression of three other characters. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering, days to maturity and plant height (0.17 %).
2. Grain yield per plant with days to flowering, days to maturity and number of effective tillers per plant (0.17 %).
3. Grain yield per plant with days to flowering, days to maturity and 1000-grain weight (0.17 %).
4. Grain yield per plant with days to flowering, plant height and earhead length (0.34 %).
5. Grain yield per plant with days to flowering, number of effective tillers per plant and 1000-grain weight (0.17 %).
6. Grain yield per plant with days to maturity, number of effective tillers per plant and earhead girth (0.17 %).
7. Grain yield per plant with days to maturity, earhead length and earhead girth (0.17 %).

8. Grain yield per plant with earhead length, earhead girth and 1000-grain weight (0.17 %).

There were fourteen character combinations in which the transgression of yield was found to be associated with transgression of two other characters. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering and days to maturity (0.17 %).
2. Grain yield per plant with days to flowering and number of effective tillers per plant (0.51 %).
3. Grain yield per plant with days to flowering and 1000-grain weight (0.17 %).
4. Grain yield per plant with days to maturity and plant height (0.17 %).
5. Grain yield per plant with days to maturity and number of effective tillers per plant (0.51 %).
6. Grain yield per plant with days to maturity and earhead length (0.17 %).
7. Grain yield per plant with days to maturity and 1000-grain weight (0.51 %).
8. Grain yield per plant with plant height and number of effective tillers per plant (0.34 %).
9. Grain yield per plant with plant height and earhead girth (0.17 %).
10. Grain yield per plant with plant height and 1000-grain weight (0.51 %).
11. Grain yield per plant with number of effective tillers per plant and earhead length (0.34 %).
12. Grain yield per plant with number of effective tillers per plant and 1000-grain weight (0.68 %).
13. Grain yield per plant with earhead length and earhead girth (0.34 %).
14. Grain yield per plant with earhead length and 1000-grain weight (0.17 %).

There were seven character combinations in which the transgression of yield was found to be associated with transgression of only one character. Such combinations along with the percentage of transgressive segregants in F_2 generation are given below.

1. Grain yield per plant with days to flowering (0.51 %).
2. Grain yield per plant with days to maturity (0.68 %).

3. Grain yield per plant with plant height (1.02 %).
4. Grain yield per plant with number of effective tillers per plant (1.19 %).
5. Grain yield per plant with earhead length (1.87 %).
6. Grain yield per plant with earhead girth (0.68 %).
7. Grain yield per plant with 1000-grain weight (0.85 %).

The proportion of the transgressive segregants in F_2 generation was occurred for grain yield per plant alone was 6.97 per cent.

4.3.3 Promising transgressive segregants having combination of desirable attributes in F_2 generation of two crosses

In the cross DHLBI-1708 x DHLBI-181138, plant no.124 was found to be most promising transgressive segregants for grain yield per plant as it has given 197 per cent more grain yield per plant. In addition to that, it was transgressed simultaneously for days to flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, earhead girth and 1000-grain weight than the increasing inbred (Table 4.21). The promising transgressive segregant for cross DHLBI-1708 x DHLBI-18963 which out yielded over the increasing inbred by 123 per cent more grain yield per plant. It had shown simultaneous transgression for days to flowering, days to maturity, number of effective tillers per plant, earhead girth and 1000-grain weight in desired direction (Table 4.21).

From the results, it can be suggested that the most promising transgressive segregants listed in Table 4.21 need to be evaluated further. If the segregants confirm their superiority in further generations may be considered for multi-location evaluation for release as a variety or may be used as a inbred in future breeding programme.

As per the plant breeders view, transgressive segregation is a crucial tool for crop improvement. Due to segregation and recombination, in certain cases transgressive segregants are produced in F_2 or later generations by accumulation of favourable genes from the inbreds involved in hybridization. Kabuli-Deshi introgression research was started by Bahl (1979), who later reported encouraging findings. In contrast to standard check varieties, he was able to identify early maturing types with determinant growth habits and harvest indices. He added that three ways are preferable to a single cross for the introgression of new germplasm into breeding populations.

Table 4.21. Promising transgressive segreagants having combinations of desirable attributes

Generation	Plant No.	Days to flowering	Days to maturity	Plant height (cm)	Effective tillers/ plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield/plant (g)	% yield increased over increasing parent
Cross-1 DHLBI-1708 x DHLBI-181138										
F_2		45*	75*	181*	5*	25*	11*	17.02*	113*	197
DHLBI-1708	124	48.93	83.47	161.60	1.80	19	9.80	10.02	26.80	
DHLBI-181138		60	91.00	176.60	2.20	22.23	10.97	13.36	38.18	
Cross-2 DHLBI-1708 x DHLBI-18963										
F_2		45*	77*	177	3*	24	12*	16*	82.45*	123
DHLBI-1708	160	48.93	82	160.20	1.77	19	9.50	10.05	26.21	
DHLBI-18963		57.87	89.60	177.40	2.13	24.80	9.57	11.64	36.97	

* Intensity of expression of character higher than the increasing parent

It is interesting to note that in the present study, the desirable transgressive segregants were recorded in each of the two crosses in F_2 generations for all the eight characters (Table 4.15 and 4.19). In case of F_2 generation the highest proportion of individuals transgressed beyond the increasing parent for grain yield per plant (19.50 to 20.50 per cent). Transgressive segregants were 11.67 to 13.50 per cent for days to flowering, 12.00 to 13.83 per cent to days to maturity, 13.33 to 13.67 per cent for plant height, 5.17 to 16.00 per cent for number of effective tillers per plant, 16.17 to 17.50 per cent for earhead length, 13.67 to 16.83 per cent for earhead girth and 17.17 to 18.50 per cent for 1000-grain weight in two crosses.

Similar findings were also reported by Patil (1994) and also observed transgressive segregants in pear millet for grain yield per plant (18-37 %) followed by earhead girth, earhead length, 1000-grain weight, days to flowering, effective tillers per plant and least percent in plant height. Joshi (1999) reported highest proportion of transgressive segregants in pearl millet for total number of tillers, number of productive tillers, earhead length, earhead girth, 1000-grain weight and grain yield per plant. Barge *et al. (*2002) found highest proportion of the individuals (33 to 57 %) in F_2 for grain yield per plant which transgressed beyond the increasing parent, followed by days to flowering, total tillers per plant, earhead length, productive tillers per plant, earhead girth and 1000-grain weight in pearl millet. Pawar (2003) observed the proportion of transgressive segregants 22 to 41 per cent for seed cotton yield per plant. In most of the segregants, seed cotton yield of better inbred was transgressed simultaneously with transgression of one or more other characters.

Girase and Deshmukh (2002) reported transgressive segregants in chickpea for all seven characters like plant height, plant spread, fruiting branches per plant, pods per plant, seeds per pod, 100-seed weight and yield per plant. They observed the highest transgressive segregation for plant height (27 %) followed by pods per plant, fruiting branches per plant and yield per plant in both F_2 and F_3 generation of all the three crosses. Dhole and Reddy (2011) reported eight transgressive segregants (2.56 %) were recorded for seed weight. Kumari (2011) reported transgressive segregants in two F_2 populations which were higher for seeds per pod and seed weight followed by seed yield. Sathya *et al.* (2014) identified 22 lines out of 200 RIL population which were isolated and outperformed the parents for individual grain yield per plant in pearl millet and also for days to flowering, days to maturity, plant height, number of productive tillers per plant, head length, earhead girth and 1000 grain weight. Karkute *et al.* (2016) recorded highest proportion of transgressive segregants for pods per plant (46) grain yield per plant (43) pod length (41), followed by number of clusters per plant (40), number of seeds per pod (36) and 100-seed weight (28) in gram. Badhe *et al.* (2017) produced desirable transgressive sergeants for the characters days to flowering, days to maturity, plant height, effective tillers per plant, ear head length, ear head girth, 1000-grain weight and grain yield per plant.

4.4 Inheritance of rust resistance

In the present investigation, two rust susceptible (DHLBI-967 and DHLBI-1103) and two rust resistant inbreds (DHLBI-1035 and DHLBI-1013) were selected for study. Three types of crosses *viz*., susceptible x resistant (Cross-I: DHLBI-967 x DHLBI-1035), resistant x susceptible (Cross-II: DHLBI-1035 x DHLBI-1103) and resistant x resistant (Cross-III: DHLBI-1013 x DHLBI-1035) were attempted. Total of three F_1 their F_2, B_1 and B_2 generations were developed subsequently. The experiment was conducted along with the F_1, F_2, B_1 and B_2 generations and inbreds were scored for their reaction to rust under greenhouse condition and field conditions.

4.4.1 Cross-I: DHLBI-967 x DHLBI-1035 (S x R)

The results revealed that in Cross-I: DHLBI-967 x DHLBI-1035 all plants of the susceptible inbred DHLBI-967 (Greenhouse condition 41 plants, Field condition 40 plants) showed susceptibility to rust (score ≥ 3) and spore count at field condition of P_1 is 6 x 10^7/ml, while for resistant inbred DHLBI-1035 all plants (Greenhouse condition 40 plants, Field condition 40 plants) were resistant (score of ≤ 2). Similarly, all plants of F_1 of Cross-I were resistant (score of ≤ 2) under greenhouse (45 plants) and field (40 plants) conditions.

In, F_2 generation of Cross-I, 216 plants were screened at greenhouse condition, of which 159 plants showed resistance (score of ≤ 2) and 57 plants showed susceptibility (score ≥ 3). Out of 379 F_2 plants at field screening, 288 were resistant and 91 were susceptible for rust and spore count was 9.6 x 10^7/ml. The segregation of F_2 at both conditions *viz*., greenhouse and field condition showed good fit to the monogenic ratio of 3:1 with chi-square values of 0.22 and 0.20, respectively.

B_1 population of Cross-I showed segregation with respect to rust resistance and susceptibility, while in B_2 all plants of both conditions were found resistant. B_1 generation of Cross-I, at greenhouse condition out of 74 plants, 41 plants were resistant and 33 were susceptible with chi-square value 0.86. In field condition, 58 plants of B_1 were screened, out of that 26 plants showed resistance and 32 showed susceptibility for rust and whereas spore count was 8.8 x 10^7/ml with chi-square value 0.62. The segregation showed goodness of fit of 1:1 ratio for both the conditions for B_1 population of Cross-I which confirms the monogenic ratio of 3:1 for rust inheritance.

4.4.2 Cross-II: DHLBI-1035 x DHLBI-1103 (R x S)

In Cross-II (R x S: DHLBI-1035 x DHLBI-1103) all plants of inbred DHLBI-1035 showed resistance (score of ≤ 2) to rust at greenhouse condition (47 plants) and field condition (40), while all plants of inbred DHLBI-1103 were susceptible (score $\geq$ 3) to rust at greenhouse condition (43 plants) and field condition (38) with the spore count of 8.8 x 10^7/ml. Similarly, all plants of F_1 of Cross-II were resistant (score of ≤ 2) under greenhouse (49 plants) and field condition (40 plants).

In greenhouse condition, for Cross-II, out of 243 plants of F_2, 179 were resistant, while 64 were susceptible with chi-square value of 0.23. Out of 392, plants of F_2 305 were resistant and 87 were susceptible with chi-square value 1.64 at field condition and spore count was 6.8 x 10^7/ml. The segregation in F_2 at both the conditions for Cross-II fit to the monogenic ratio 3:1 which confirmed by growing the B_1 and B_2 populations.

All the plants of B_1 populations of Cross-II at both the conditions were found to be resistant, while B_2 populations of both conditions showed segregation with respect to rust resistance and susceptibility. Out of total 89 plants of B_2, 42 were resistant while 47 were susceptible at greenhouse condition. In field condition 29 resistant and 27 susceptible plants were observed out of total 56 plants of B_2 and spore count was 1.1 x 10^8 /ml. The segregation of B_2 at both conditions *viz*., greenhouse condition and field condition showed good fit to the ratio of 1:1 with chi-square values of 0.28 and 0.07, respectively.

4.4.3 Cross-III: DHLBI-1013 x DHLBI-1035 (R x R)

In Cross-III, DHLBI-1013 x DHLBI-1035 (R x R) all resistant plants were observed for P_1, P_2, F_1, their F_2, B_1 and B_2 in both conditions (Greenhouse F_2: 203 plants and Field F_2:368 plants).

There was no significance difference between the F_1 of Cross-I (DHLBI-967 x DHLBI-1035), Cross-II (DHLBI-1035 x DHLBI-1103) and Cross-III (DHLBI-1013 x DHLBI-1035) under greenhouse and field condition for rust resistance, indicated that the resistance is governed by dominant gene in the inheritance of rust resistance in pearl millet. Andrews *et al.* (1985), Sokhi *et al.* (1987), Ramamoorthi *et al.* (1995) and Panna *et al.* (1996) also reported similar results for rust resistance in pearl millet was govern by dominant gene.

The segregation pattern of F_2 generation in Cross-I and Cross-II of greenhouse and field condition had good fit to the monogenic ratio of 3: 1 (Table 4.22). Similar results were also reported by Hanna *et al.* (1985), Panna *et al.* (1996), Ramamoorti and Jehangir (1996) and Sharma *et al.* (2009) on F_2 plants of pearl millet.

In the B_1 population of Cross-I and B_2 of Cross-II segregation pattern of greenhouse and field condition was 1 resistant and 1 susceptible; while in B_2 population of Cross-I and B_1 of Cross-II of green house and field condition, all the plants were resistant. These results confirm single gene control of resistance. Andrews *et al.* (1985) and Ramamoorti and Jehangir (1996) also observed similar ratio in their studies.

Table 4.22. Inheritance of rust disease resistance in pearl millet

Cross	Envt.	Generation	No. of observed plant			No. of expected plant		Expected ratio (3:1)		χ^2	P
			R	S	Total	R	S	R	S		
Cross-I (S x R) DHLBI-967 x DHLBI-1035	**Green house**	P_1	0	41	41	-	-	-	-	-	-
		P_2	40	0	40	-	-	-	-	-	-
		F_1	45	0	45	-	-	-	-	-	-
		F_2	159	57	216	162	54	3	1	0.22	0.63
		B_1	41	33	74	37	37	1	1	0.86	0.35
		B_2	71	0	71	-	-	-	-	-	-
	Field	P_1	0	40	40	-	-	-	-	-	-
		P_2	40	0	40	-	-	-	-	-	-
		F_1	40	0	40	-	-	-	-	-	-
		F_2	288	91	379	284.25	94.75	3	1	0.20	0.65
		B_1	26	32	58	29	29	1	1	0.62	0.41
		B_2	55	0	55	-	-	-	-	-	-
Cross-II (R x S) DHLBI-1035 x DHLBI-1103	**Green house**	P_1	47	0	47	-	-	-	-	-	-
		P_2	0	43	43	-	-	-	-	-	-
		F_1	49	0	49	-	-	-	-	-	-
		F_2	179	64	243	182.25	60.75	3	1	0.23	0.62
		B_1	81	0	81	-	-	-	-	-	-
		B_2	42	47	89	6.5	6.5	1	1	0.28	0.60
	Field	P_1	40	0	40	-	-	-	-	-	-
		P_2	0	38	38	-	-	-	-	-	-
		F_1	40	0	40	-	-	-	-	-	-
		F_2	305	87	392	294	98	3	1	1.64	0.23
		B_1	51	0	51	-	-	-	-	-	-
		B_2	29	27	56	28	28	1	1	0.07	0.81
Cross-III (R x R) DHLBI-1013 x DHLBI-1035	**Green house**	P_1	51	0	51	-	-	-	-	-	-
		P_2	54	0	54	-	-	-	-	-	-
		F_1	59	0	59	-	-	-	-	-	-
		F_2	203	0	203	-	-	-	-	-	-
		B_1	76	0	76	-	-	-	-	-	-
		B_2	81	0	81	-	-	-	-	-	-
	Field	P_1	40	0	40	-	-	-	-	-	-
		P_2	40	0	40	-	-	-	-	-	-
		F_1	40	0	40	-	-	-	-	-	-
		F_2	368	0	368	-	-	-	-	-	-
		B_1	51	0	51	-	-	-	-	-	-
		B_2	53	0	53	-	-	-	-	-	-

5. SUMMARY AND CONCLUSIONS

The present investigation entitled "Genetic studies for quantitative traits and inheritance of rust resistance in pearl millet [*Pennisetum glaucum* (L.) R. Br.]" was designed and executed to study the heterosis and combining ability, gene action, identification of transgressive segregants and inheritance of rust resistance in pearl millet with following objectives:

1. To estimate the extent of heterosis, general and specific combining ability of parents and their crosses for quantitative traits.
2. To study gene action for grain yield and its components.
3. To identify transgressive segregants for quantitative traits.
4. To study the inheritance of rust resistance in pearl millet.

The heterosis and combining ability studies involved nine diverse inbreds of pearl millet and their 36 F_1 derived through diallel mating system. Study of gene action for quantitative characters was carried out with two crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138. Estimation of transgressive segregation for quantitative characters was carried out with selected two crosses *viz.,* DHLBI-1708 x DHLBI-181138 and DHLBI-1708 x DHLBI-18963. Whereas, another three crosses were selected *viz*., DHLBI-967 x DHLBI-1035, DHLBI-1035 x DHLBI-1103 and DHLBI-1013 x DHLBI-1035 involving susceptible and resistant parents to study inheritance of rust resistance. All the experiments were conducted at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri during *Kharif*-2019 and *Kharif*-2021. Data was recorded on ten quantitative traits *viz;* Days to 50 % flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn. The heterosis and combing ability, gene action study and transgressive segregation study were estimated using standard procedures. All the plants from each generation of three crosses were scored for rust disease intensity at different stages by using the 0-5 scale.

The salient features of the results obtained are summarized as below:

5.1 Heterosis and combining ability

The analysis of variance for treatments revealed significant mean sum of squares for all the characters, which indicated presence of ample amount of genetic variability among treatments. The levels of heterosis were found high thereby indicating good amount of heterosis for the characters.

The cross combination DHLBI-1708 x DHLBI-181138 exhibited high *per se* performance and highly significant standard heterosis for grain yield per plant, plant height, number of effective tillers per plant, earhead girth, grain Fe and grain Zn content. The other cross combinations DHLBI-1708 x DHLBI-18963, DHLBI-181181 x DHLBI-181138 and DHLBI-18963 x DHLBI-181181, exhibited high *per se* performance with highly significant better parent and standard heterosis for grain yield and yield contributing characters with quality characters.

Analysis of variance for combining ability revealed that the mean sum of squares due to GCA and SCA were highly significant for all the characters. However, σ^2gca/ σ^2sca ratio was less than one for all the characters except grain Fe and Zn, suggesting predominance of non-additive gene effects in control of the studied characters.

Among all nine inbreds the estimates of GCA effects showed that the inbred DHLBI-181138 was good general combiner for eight characters, i.e. plant height, number of effective tillers per plant, earhead length, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn and also had high *per se* performance for grain yield per plant. Inbreds, DHLBI-1708 and DHLBI-18963 were also found good general combiners along with good *per se* performance for grain yield and yield contributing characters and identified as superior inbred for grain yield and its components.

With respect to estimates of specific combining ability effect for grain yield, it was observed that the hybrid DHLBI-1708 x DHLBI-18963 evinced highly significant SCA effects for grain yield as well as for plant height, number of effective tillers per plant, 1000-grain weight and grain Fe content.

The other cross combinations *viz*., DHLBI-1708 x DHLBI-181138, DHLBI-181181 x DHLBI-181138 DHLBI-18963 x DHLBI-181138 and DHLBI-1708 x DHLBI-181181 showed high SCA effects along with high mean performance for grain yield derived from either good x good, poor x good and good x average general combiner indicated the predominance of inter allelic gene action for respective characters.

Perusal the *per se* performance, GCA effects of inbreds, SCA effects of hybrids and heterotic performance for yield and its principal components in the cross combinations *viz*., DHLBI-1708 x DHLBI-181138, DHLBI-1708 x DHLBI-18963, DHLBI-181181 x DHLBI-181138, DHLBI-18963 x DHLBI-181138 and DHLBI-1708 x DHLBI-181181 were appeared to be the most promising.

5.2 Generation mean study for grain yield and its components

The mean of six generations in both the crosses indicated that, the F_1 means were higher than mid parental mean values which is comparable to better parent mean values in significant direction with respects to all the traits in present investigation which indicating the presence of over dominance. In both the crosses, F_2 means were lower than the F_1 mean. The mean of backcross populations tended towards their respective parents. These results indicated that the predominance of non-additive gene action which includes both dominance as well as epistatic interactions.

The F_1 and segregating generations evolved from the cross combination DHLBI-1708 x DHLBI-181138 exhibited the higher mean values for grain yield and its contributing characters. Based on the substantial information obtained from mean performance of parents and segregating generations the parents, DHLBI-181138 and DHLBI-1103 could be considered in developing high grain yielding hybrids. From the present investigation the cross DHLBI-1708 x DHLBI-181138 could expect to be most promising for grain yield among both the crosses.

In both the crosses, individual scaling test and joint scaling test were significant for all the characters indicating the inadequacy of simple additive-dominance model, justifying the use of six parameters model for detection of gene interactions.

The generation mean analysis revealed the significance of additive, dominance and epistasis gene effects were found operating the gene actions for grain yield and its contributing traits in pearl millet in both the crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x DHLBI-181138.

The estimates of additive [d] and dominance [h] gene effects were significant in both the crosses *viz*., DHLBI-1103 x DHLBI-1035 and DHLBI-1708 x

DHLBI-181138 which indicated their importance in the expression of grain yield per plant in pearl millet. Significance of additive [d] and dominance [h] components with higher magnitude in desirable direction of dominance [h] components indicated the preponderance of dominance [h] gene effect for governing grain yield per plant. The magnitude of dominance gene effect was higher in desirable direction than additive gene effect, indicated the predominance of non-additive gene action in the inheritance of this trait in both the crosses.

In cross I (DHLBI-1103 x DHLBI-1035) the interaction component additive x dominance [j] was estimated highly significant with opposite sign of dominance [h] and dominance x dominance [l] components indicated the presence of duplicate type of epistasis. The gene effects in this cross were observed dominance [h] with dominance x dominance interaction effects in higher magnitude with duplicate epistasis, indicated the non-additive gene action played important role in the inheritance of grain yield per plant in pearl millet.

The interaction components additive x dominance [j] and dominance x dominance [l] was estimated significant in the cross II [DHLBI-1708 x DHLBI-181138]. It was indicated that the preponderance of dominance x dominance [l] gene effect followed by the additive x additive [i] and additive x dominance gene effects for grain yield per plant in pearl millet based on the present results.

5.3 Transgressive segregation

Desirable transgressive segregants were observed for all the characters in each of the two crosses. In case of F_2 generation the highest proportion of individuals transgressed beyond the increasing parent for grain yield per plant (19.50 to 20.50 per cent). Transgressive segregants were 11.67 to 13.50 per cent for days to flowering, 12.00 to 13.83 per cent to days to maturity, 13.33 to 13.67 per cent for plant height, 5.17 to 16.00 per cent for number of effective tillers per plant, 16.17 to 17.50 per cent for earhead length, 13.67 to 16.83 per cent for earhead girth and 17.17 to 18.50 per cent for 1000-grain weight in two crosses *viz*., DHLBI 1708 x DHLBI 181138 and DHLBI 1708 x DHLBI 18963, respectively.

The plant number 124 of DHLBI-1708 x DHLBI-181138 and 160 of DHLBI-1708 x DHLBI-18963 in F_2 generation was reported to be the most promising transgressive segregants. It produced 197 per cent in DHLBI-1708 x DHLBI-181138 and 123 per cent in DHLBI-1708 x DHLBI-18963 more grain yield than respective increasing parent. These transgressants needs to be evaluated in further generations for consistency in their performance.

5.4 Inheritance of rust resistance

The F_2 population of Cross-I (S x R: DHLBI-967 x DHLBI-1035) and Cross-II (R x S: DHLBI-1035 x DHLBI-1103) had good fit to segregation ratio of 3R: 1S in greenhouse and field conditions. The monogenic dominant ratio was confirmed with backcross generation i.e. B_1 of Cross-I (S x R) and B_2 of Cross-II (R x S) which had good fit to the 1R: 1S in greenhouse and field conditions. However, in Cross III (R x R: DHLBI-1013 x DHLBI-1035) all resistant plants were observed for F_2 and backcross generation in both conditions.

5.5 Conclusion

5.5.1 Heterosis and combining ability

1. The analysis of variance for treatments revealed significant mean sum of squares for all the characters, which suggested that there was significant genetic variation among them.
2. The cross DHLBI-1708 x DHLBI-181138 was identified as superior, which ranked first in *per se* performance, with highest magnitude of heterobeltiosis and standard heterosis for grain yield per plant followed by DHLBI-1708 x DHLBI-18963**,** DHLBI-181181 x DHLBI-181138 and DHLBI-18963 x DHLBI-181138.
3. The analysis of variance for general and specific combining ability revealed that the variance due to parents and their crosses were highly significant for all the characters. However, σ^2gca/ σ ^{2}sca ratio was less than one for all the characters except grain Fe and Zn, suggesting predominance of non-additive gene effects in control of the studied characters.
4. On the basis of estimates of GCA effects, the parent DHLBI-181138 was good general combiner for all characters except days to 50 % flowering and days to maturity while parent DHLBI-181181 was good general combiner for days to 50 % flowering, days to maturity, number of effective tillers per plant, earhead length and grain Zn. Whereas parent, DHLBI-1708 was good general combiner

for days to 50 % flowering, days to maturity, number of effective tillers per plant and grain yield per plant. These parents had good *per se* performance for most of the characters indicating great potential and should be included in further breeding programme for pearl millet improvement.

5. Among thirty six crosses, DHLBI-1708 x DHLBI-18963 evinced high significant SCA effects for grain yield as well as for plant height, number of effective tillers per plant, 1000-grain weight and grain Fe contain. Whereas, DHLBI-1708 x DHLBI-181138 exhibited significant SCA effect in desirable direction for days to 50 per cent flowering, plant height, number of effective tillers per plant, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn content. The cross combination, DHLBI-181181 x DHLBI-181138 displayed significant SCA effect in desirable direction for number of effective tillers per plant and grain yield per plant. These crosses involved one good general combiner parent and other either good or poor general combiner parent. From the heterosis and combining ability studies, out of 36 crosses, DHLBI-1708 x DHLBI-181138, DHLBI 1708 x DHLBI 18963, DHLBI-181181 x DHLBI-181138, DHLBI-18963 x DHLBI-181138 and DHLBI-1708 x DHLBI-181181 appeared as promising. The desirable transgressive segregants may be obtained from these crosses.

5.5.2 Generation mean analysis

1. The estimates of A, B, C and D scaling tests and joint scaling test were significant in both the crosses for ten characters with few exceptions. The significance of these crosses for various characters indicated inadequacy of additive-dominance model.
2. For grain yield and yield components, the dominant component (h) and dominance x dominance (l) gene interaction was found significant for most of the characters *viz.,* days to 50 % flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, 1000-grain weight, grain yield per plant and grain Fe, these characters can be improved by hybrid development or by recurrent selection for SCA.
3. Additive gene action along with additive x additive (i) followed by dominance (h) was found significant for the characters *viz*., days to 50 % flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, earhead

girth, 1000-grain weight, grain Fe and grain Zn. For improvement of these characters, one should follow the simple selection in early segregating generations.

5.5.3 Transgressive segregation for grain yield and its components

1. Desirable transgressive segregants were observed for all the characters in both the crosses.
2. In general, highest proportion of individuals transgressed beyond the increasing parent recorded for grain yield per plant followed by 1000-grain weight, earhead girth, earhead length, number of effective tillers per plant, plant height, days to maturity and days to flowering. Better parent was found to transgressed simultaneously with transgression of one or more other characters.
3. Simultaneous transgression of grain yield per plant with days to flowering, days to maturity, plant height, number of effective tillers per plant, earhead length and 1000-grain weight was observed more frequently. It may be due to the dependency of grain yield per plant on these characters or existence of linkage drag among the genes of these characters, enabling genes of these traits to move together.
4. The most promising transgressive segregants plant number 124 of cross DHLBI-1708 x DHLBI-181138 and plant number 160 of cross DHLBI-1708 x DHLBI-18963 could be evaluated for further improvement and development of new inbred lines.
5. On the basis of observed high values of transgressive segregants, it is concluded that, when the desired intensity of a character is not available in the parents, transgressive breeding can be successfully used to extend the limit of expression of character. This could be possible by accumulation of favorable or plus genes, in hybrid derivatives from both parents involved in hybridization due to segregation and recombination.

5.5.4 Inheritance of rust resistance

1. There was no significant difference between the F_1 of Cross I (DHLBI-967 x DHLBI-1035), Cross II (DHLBI-1035 x DHLBI-1103) and Cross III (DHLBI-1013 x DHLBI-1035) for rust resistant, indicating that same gene is responsible in three crosses for inheritance of rust resistance in pearl millet.

2. The F_1's of the all three crosses showed resistant to rust disease, which indicated that the resistance is governed by dominant gene.
3. The F_2 data of both crosses i.e. DHLBI-967 x DHLBI-1035 and DHLBI-1035 x DHLBI-1103 was good fitted in 3:1 (resistant: susceptible) ratio which indicated the involvement of single dominant gene which was confirmed from data of back crosses.
4. All the plants were resistant in F_1, F_2 and back cross progenies in Cross III R x R (DHLBI-1013 x DHLBI-1035) showing that the gene for resistance is the same in both the parents.

Future breeding strategy

Based on the results obtained from the present study following future breeding strategies are suggested for improvement of pearl millet.

1. The parents, DHLBI-181138, DHLBI-1708 and DHLBI-181181 were found good general combiners along with good *per se* performance for most of the characters which should be further utilized in breeding programme for developing high yielding and early maturing varieties.
2. The crosses DHLBI-1708 x DHLBI-181138, DHLBI-1708 x DHLBI-18963, DHLBI-181181 x DHLBI-181138, DHLBI-18963 x DHLBI-181138 and DHLBI-1708 x DHLBI-181181 which exhibits high *per se* performance, heterosis and SCA effects could be exploited for obtaining desirable transgressive segregants from segregating generations to develop the new parental lines or in hybrid development programme.
3. Transgressive segregants *viz*., plant number 124 of cross DHLBI-1708 x DHLBI-181138 and plant number 160 of cross DHLBI-1708 x DHLBI-18963 could be advanced and utilized for further evaluation and selection in subsequent generations.
4. The resistant plants identified for rust resistance in F_2 generations of three crosses should be utilized for development of rust resistant variety in pearl millet.
5. The population developed for rust resistance can be used for identification of molecular markers linked to rust resistance.

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*Originals not seen

7. APPENDIX

Meteorological data during the experimental period

Month	Met. Week	Date	Temp.		Humidity		Rain Fall (mm)	Rainy day	Sun shine (hrs)	Wind velo. (km/h)	Eva. (mm)
			Max	Min	Max	Min					
Jan 19	1	01-07	29.3	8.8	42	23	0	0	9.1	0.1	4.4
	2	08-14	28.5	8.9	57	28	0	0	8.2	0.2	4.3
	3	15-21	29.4	11.3	58	31	0	0	8.3	0.3	4.5
	4	22-28	27.2	10.3	60	42	0	0	6.8	0.9	4.5
	5	29-04	27.7	10.4	53	29	0	0	7.7	7	4.7
Feb 19	6	05-11	27.8	9	54	29	0	0	8.3	1	4.5
	7	12-18	31.8	14.1	55	28	0	0	8	0.7	5.4
	8	19-25	34.6	15.9	50	24	0	0	9.6	0.8	6
	9	26-04	31.9	13	47	20	0	0	9.7	1.4	6.1
Mar 19	10	05-11	33.3	14.1	45	20	0	0	9.2	0.9	6.4
	11	12-18	35.5	15.1	51	16	1	0	8.6	0.9	6.6
	12	19-25	36.4	16.1	46	15	0	0	8.9	1.6	7.3
	13	26-01	39.3	18.8	40	13	0	0	8.9	1.6	8.4
April 19	14	02-08	39.7	19.9	38	14	3	0	9.2	2.5	9.3
	15	09-15	40.4	21.2	35	13	0	0	9	2.1	9.3
	16	16-22	37.1	19.2	45	19	4.4	1	9.4	2.7	8.9
	17	23-29	41.2	24	32	12	0	0	10.5	2.5	11.1
	18	30-06	39.1	20.7	37	16	0	0	10.3	4.2	10.5
May 19	19	07-13	39.3	21.7	44	17	0	0	10.5	3.3	12.1
	20	14-20	40	21.8	34	14	0	0	10.8	4.6	13.7
	21	21-27	41.2	25.6	35	16	0	0	10.9	4.4	14.7
	22	28-03	41.1	23.5	39	19	0	0	10.5	5.4	13.4
June 19	23	04-10	39.1	26.1	51	30	7	1	6.1	5.4	11.9
	24	11-17	37	24.9	59	35	0.4	0	9.5	8.3	10.9
	25	18-24	36.1	24.3	70	40	18.2	1	7.8	6.2	10.9
	26	25-01	31.4	23.8	81	60	51.4	2	2.8	2	4.6
July 19	27	02-08	30.6	23.5	79	63	37	2	1.3	4.9	4.3
	28	09-15	32.1	23.6	76	56	3.8	1	4.7	7.2	5.3
	29	16-22	33.8	23.2	71	51	32	2	7.8	6.4	5.9
	30	23-29	30.5	23.6	78	68	18.4	2	2.3	4.1	3.3
	31	30-05	27	22.8	88	77	47.8	5	0.2	4.8	1.9
Aug 19	32	06-12	28	23.3	80	68	3.6	0	2	8.2	3.6
	33	13-19	31	22.5	75	59	1.4	0	8.4	6.9	5.4
	34	20-26	32.5	21.3	72	47	0	0	7.9	4.1	6.2
	35	27-02	32	23	75	56	87.2	4	5.9	4.1	4.8
Sept 19	36	03-09	30	23.3	77	71	3	0	1.8	3.6	4.3
	37	10-16	28.8	22.5	78	68	21.6	2	1.3	4.6	3.7
	38	17-23	29.8	21.7	89	71	84.2	4	4.2	1.6	3.7
	39	24-30	30.2	21.9	83	67	36.6	3	4.9	0.8	3.3

Appendix contd…..

Month	Met. Week	Date	Temp.		Humidity		Rain Fall (mm)	Rainy day	Sun shine (hrs)	Wind velo. (km/h)	Eva. (mm)
			Max	Min	Max	Min					
Oct 19	40	01-07	31.1	21.1	80	59	7.8	1	6.1	1.1	5
	41	08-14	31.7	24.1	77	50	2.8	0	7.1	0.7	4.9
	42	15-21	28.2	18.6	81	68	52.4	3	5	1.4	3.6
	43	22-28	25.7	20.8	87	79	141.8	6	2.4	1.3	1.6
	44	29-04	30.4	21	84	58	4	1	6.1	1.1	5
Nov 19	45	05-11	31.1	18.4	76	46	23.4	1	9	0.6	5.4
	46	12-18	29.7	16.7	73	48	0	0	7.5	0.8	5.6
	47	19-25	30	15.2	74	45	0	0	7.8	0.3	5.4
	48	26-02	30.5	15.9	74	44	0	0	7.3	0.2	4.9
Dec 19	49	03-09	28.8	16.4	71	47	0	0	5.4	0.3	4.9
	50	10-16	29.6	16.3	74	42	2.8	1	7.8	0.3	4.9
	51	17-29	28	15.8	78	47	0	0	5.1	0.4	4.3
	52	24-31	27.1	16.6	77	48	1.4	0	4.4	0.8	4.1
Jan 21	1	01-07	27.71	17.67	85.71	44.43	0.80	0.00	4.77	3.16	27.71
	2	08-14	28.17	18.30	92.14	44.29	0.76	2.94	6.10	2.89	28.17
	3	15-21	30.11	17.03	84.43	36.71	0.83	0.00	7.96	3.29	30.11
	4	22-28	30.17	14.16	86.29	35.00	0.54	0.00	8.83	3.01	30.17
	5	29-04	28.49	12.61	81.43	33.86	0.90	0.00	8.27	2.79	28.49
Feb 21	6	05-11	28.34	11.10	79.57	26.71	1.21	0.00	9.60	2.90	28.34
	7	12-18	30.43	15.34	79.00	30.71	0.81	0.00	8.63	3.13	30.43
	8	19-25	29.20	15.04	85.00	34.29	1.61	1.03	8.91	3.34	29.20
	9	26-04	33.11	16.37	74.57	21.29	0.97	0.00	9.80	4.41	33.11
Mar 21	10	05-11	34.97	15.56	70.71	19.71	1.03	0.00	9.21	5.40	34.97
	11	12-18	35.91	17.27	70.00	20.71	1.04	0.00	8.74	6.29	35.91
	12	19-25	33.74	19.37	77.00	31.00	1.30	3.34	7.36	4.83	33.74
	13	26-01	37.40	18.46	70.14	14.43	1.21	0.00	9.46	6.50	37.40
April 21	14	02-08	37.80	21.24	67.86	15.29	2.69	0.00	9.49	7.31	37.80
	15	09-15	36.97	23.79	60.29	19.43	2.06	0.00	7.79	6.50	36.97
	16	16-22	37.71	23.46	57.43	16.43	2.23	0.00	9.71	7.94	37.71
	17	23-29	38.43	24.96	50.29	16.57	2.11	0.00	9.39	8.73	38.43
	18	30-06	36.77	25.31	60.29	25.29	1.83	0.29	7.01	8.16	36.77
May 21	19	07-13	38.49	26.21	62.86	24.29	1.67	0.00	8.97	9.86	38.49
	20	14-20	35.57	26.19	68.29	38.14	6.60	0.37	5.24	7.13	35.57
	21	21-27	37.06	25.43	69.71	28.14	5.10	0.00	7.94	7.54	37.06
	22	28-03	36.71	25.46	75.71	37.86	3.03	1.17	6.50	7.86	36.71
June 21	23	04-10	32.40	24.90	78.00	52.43	1.84	3.03	5.10	5.93	32.40
	24	11-17	33.86	25.41	76.14	45.29	6.11	0.91	6.01	8.23	33.86
	25	18-24	33.09	24.73	76.29	45.86	5.99	1.29	6.01	6.83	33.09
	26	25-01	30.26	23.90	85.86	61.71	2.96	12.46	3.40	4.49	30.26

Appendix contd…..

Month	Met. Week	Date	Temp.		Humidity		Rain Fall (mm)	Rainy day	Sun shine (hrs)	Wind velo. (km/h)	Eva. (mm)
			Max	Min	Max	Min					
July 21	27	02-08	34.14	25.14	75.71	45.29	3.34	0.00	8.37	7.51	34.14
	28	09-15	30.31	23.76	91.29	68.14	1.80	16.94	2.27	4.46	30.31
	29	16-22	30.06	23.86	85.29	65.57	2.26	6.23	3.03	4.17	30.06
	30	23-29	30.09	24.66	82.29	59.00	6.93	0.40	3.60	4.80	30.09
	31	30-05	24.37	23.59	82.86	66.71	6.69	0.69	2.13	4.43	24.37
Aug 21	32	06-12	31.29	24.17	80.14	57.57	3.20	0.17	5.54	5.29	31.29
	33	13-19	29.63	22.70	88.00	67.71	2.36	4.94	2.91	4.66	29.63
	34	20-26	27.80	22.23	93.43	68.00	0.86	6.97	4.21	3.37	27.80
	35	27-02	29.34	22.87	88.29	65.86	1.14	11.60	4.67	4.49	29.34
Sept 21	36	03-09	29.60	23.04	91.57	67.14	2.61	16.77	4.34	3.51	29.60
	37	10-16	29.80	23.89	84.00	63.71	4.86	1.09	4.29	4.23	29.80
	38	17-23	28.89	23.09	87.14	68.86	1.83	7.37	3.64	3.74	28.89
	39	24-30	28.94	22.46	92.14	69.43	1.30	8.40	1.69	3.17	28.94
Oct 21	40	01-07	31.17	22.66	94.14	65.14	0.97	9.03	7.67	5.06	31.17
	41	08-14	30.77	22.74	92.29	59.43	0.70	3.63	6.13	4.91	30.77
	42	15-21	32.29	20.73	84.71	39.43	0.87	0.00	8.31	5.47	32.29
	43	22-28	32.09	18.50	83.57	32.00	1.27	0.00	9.81	5.80	32.09
	44	29-04	31.31	18.19	79.14	36.14	1.23	0.00	8.56	5.26	31.31
Nov 21	45	05-11	30.74	17.39	84.00	33.00	1.60	0.00	7.71	4.71	30.74
	46	12-18	30.43	19.63	83.57	50.29	1.77	0.00	5.67	4.69	30.43
	47	19-25	30.80	21.70	90.71	54.14	1.31	7.20	5.44	4.43	30.80
	48	26-02	27.09	16.70	83.43	52.57	1.14	3.31	5.37	3.69	27.09
Dec 21	49	03-09	26.20	17.39	92.71	54.43	0.93	6.77	4.71	2.97	26.20
	50	10-16	28.17	15.89	87.29	46.29	0.64	0.00	5.67	3.83	28.17
	51	17-29	27.83	12.61	90.57	39.00	0.44	0.00	7.34	4.20	27.83
	52	24-31	27.55	13.84	91.38	46.38	0.43	0.00	6.28	3.70	27.55

8. VITAE

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DOCTOR OF PHILOSOPHY (AGRICULTURE)
IN
AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)
2023

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