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Deciphering heterosis and inbreeding depression of grain yield, its contributing traits and quality parameters from parents, hybrids and segregating generations in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract
The present investigation pertaining to study of heterosis and inbreeding depression for grain yield, its contributing traits and quality parameters in ten morphologically diverse parents were taken to produce F_1 hybrids and its subsequent segregating generations. Cross 98222 B × 15550 R, 1202 B × 16317 R and 05888 B × 16066 R showed positive and significant relative and better parent heterosis along with negative and significant inbreeding depression for grain yield per plant. Crosses depicted high heterosis followed by low inbreeding depression indicates the presence of non-additive type of gene action. Higher and lower mean of F_2 than mean of F_1 indicated presence of additive gene action and non additive gene action, respectively. In case of negative characters, crosses with significant and negative heterosis as well as significant and positive inbreeding depression is more desirable for early flowering, short plant height, early maturity and low tannin content in pearl millet.

Keywords: Inbreeding depression, quality parameters, F_1 hybrids, segregating generations

Introduction

Pearl millet is the most important cereal crop of arid and semi-arid tropics of Asia and Afica, having great yield potential. It is believed to be originated from North-Western Africa. It is highly cross pollinated with protogynous nature leads to outcrossing between range of 70% to 80% (Burton, 1974) [3]. It is diploid (2n = 2 × = 14) crop belongs to family *poaceae* and genus *pennisetum.* Pearl millet is rightly termed as "nutricereal" as it is a good source of energy, carbohydrate, protein, fat, ash, dietary fiber, iron and zinc. Pearl millet is rich in fat content (5 mg/100 g) with better fat digestibility and rich in unsaturated fatty acids (75%) with higher content of nutritionally important n-3 fatty acids. Development of micronutrient rich pearl millet hybrids and varieties with enhanced levels of Fe and Zn is taken up as priority leading to mainstreaming of bio-fortification in pearl millet and now it is a routine affair. In relation to yield, quality traits have also important role for increasing value addition because pearl millet grain is richer source of iron (18-87 ppm) and zinc (22-88 ppm) (Devart *et al.* 2011) [4]. India is the largest pearl millet growing country contributing 42 percent of production in the world. It was grown on 7.54 million ha with an average production of 10.36 million tonnes with productivity of 1374 kg/ha (Anonymous, 2020[a]) [1]. The major pearl millet growing states are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana which account for more than 90 percent of pearl millet acreage in the country and commonly grown in rainy season. In Gujarat, pearl millet covers an area of 4.49 lakh hectares and production of 10.9 lakh tonnes with productivity of 2425 kg/ha (Anonymous, 2020[b]) [2]. Banaskantha, Anand, Kheda, Kachchh, Mehsana, Bhavnagar and Gandhinagar are major pearl millet growing districts of Gujarat.

For any crop improvement programme, the ultimate aim of plant breeder is to increase the productivity. Nature and magnitude of heterosis is one of the important aspects for selection of the right parents for crosses and also help in identification of superior cross combinations that may produce desirable transgressive segregants in advanced generations. The estimates of heterosis and inbreeding depression together provide information about the type of gene action involved in the expression of various quantitative traits. Inbreeding means mating together of individuals which are related to each other by ancestry. It is measured as coefficient of inbreeding, which is the 'probability that two genes at any locus in individual are identical by decent'. Inbreeding depression refers to decrease in fitness and vigour due to inbreeding. Its results due to fixation of unfavourable recessive genes in F_2 generation.

Estimation of heterosis and inbreeding depression

Heterosis expressed as percent increase or decrease of F_1 hybrid over its mid-parent (relative heterosis) (Turner, 1952) [12] and better or superior parent (heterobeltiosis) (Fonseca and Patterson, 1968) [5] were computed as follow:

1) Relative heterosis (%) $= \frac{\overline{F1} - \overline{MP}}{\overline{MP}} \times 100$

2) Heterobeltiosis (%) $= \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \times 100$

Where,
$\overline{F_1}$ = Mean performance of F_1 hybrid
$\overline{MP}$ = Mean value of parents [($P_1 + P_2$) / 2] of a hybrid
$\overline{BP}$ = Mean performance of better parent of respective cross

The standard error and calculated't' values for mid parent heterosis and heterobeltiosis was computed as below,

S.E. (M.P.) = (3 M e / 2 r)0.5
S.E. (B.P.) = (2 Me / r)0.5

Where,
Me = Error mean square

r = Number of replications

The test of significance for heterobeltiosis was done by usual 't' test.

$$t_{(RH)} = \frac{\overline{F_1} - \overline{MP}}{S.E.\ \overline{MP}} \text{ for relative heterosis}$$

$$t_{(HB)} = \frac{\overline{F_1} - \overline{BP}}{S.E.\ \overline{BP}} \text{ for heterobeltiosis}$$

The test of significance of the relative heterosis and heterobeltiosis were carried out by comparing the calculated values of 't' with the tabulated values 't' at 5 percent (1.960) and 1 percent (2.576) levels of significance.
The inbreeding depression (ID) in F_2 generation was calculated as per method described by Warner (1952) [12] using the following formula,

$$\text{Inbreeding depression (\%)} = \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \text{x100}$$

Where,

$\overline{F_1}$ = Mean of F_1 generation
$\overline{F_2}$ = Mean of F_2 generation

Standard error and 't' value for test of significance for inbreeding depression were estimated as under:

$$\text{S.E. for inbreeding depression} = \sqrt{V_{\bar{F}_1} + V_{\bar{F}_2}}$$

$$t_{\overline{F1} - \overline{F2}} = \frac{\overline{F_1} - \overline{F_2}}{\text{S.E. } (\overline{F_1} - \overline{F_2})}$$

Where,
$\overline{F_1}$ = Mean value of the F_1 hybrid
$\overline{F_2}$ = Mean value of the F_2 generation
$V\overline{F_1}$ = Variance of the F_1 generation
$V\overline{F_2}$ = Variance of the F_2 generation

The significance of the inbreeding depression was tested by comparing the calculated 't' value with the table 't' value at 5 percent (1.960) and 1 percent (2.576) levels of significance.

Materials and Methods

The proposed investigation on "Generation mean analysis in pearl millet [*Pennisetum glaucum* (L.) R. Br.]" was initiated to elicit information on magnitude of gene action, heterosis, inbreeding depression, heritability and genetic advance for seed yield and its component characters. The experimental material consists of ten genotypically and phenotypically diverse parents (five B line namely 05888 B, 98222 B, 01555 B, 1202 B and 02889 B as female parent and five R line namely 15001 R, 16317 R, 15990 R, 15550 R and 16066 R as male parent). All parents were procured from Centre for Crop Improvement (CCI), Sardarkrushinagar Dantiwada Agricultural University (SDAU), Sardarkrushinagar, Gujarat. The F_1 hybrids were developed using crossing of one B line as female parent and one R line as male parent during *kharif* 2020 and subsequently F_1 hybrids along with their both the respective parents were sown in *Summer* 2021 to produce seed for F_2, BC_1 and BC_2 generations. All six genotypes (progenies) of a different six cross (family) were raised in compact family block design (CFBD) with three replications during *kharif* 2021 at Centre for Crop Improvement (CCI), Sardarkrushinagar Dantiwada Agricultural University (SDAU), Sardarkrushinagar, Gujarat. Each replication was divided in to six compact blocks, each consists of single cross and blocks were consisted of six plots of six basic generation of each cross.
A crossing activity carried out when panicle emerging out of the flag leaf in respect of both seed and pollen parents, it was covered with butter paper bags and stapled tightly to avoid contamination of foreign pollens. With the full emergence of stigmas but before shedding its own pollen, the female panicles were pollinated by pollens collected

from the respective male parents. Immediately after pollination, the seed parent panicles were covered by paper bags and labelled properly. Simultaneously the parents were selfed to obtain genetically pure seed. F_2 seed was obtained by selfing F_1's either by covering two panicles of the synchronous tillers of the same hybrid plant to obtain sufficient seeds of F_2. A backcross population (BC_1 and BC_2) was obtained by crossing of F_1 with their respective parents P_1 and P_2. At maturity crossed/selfed panicles were harvested separately and dried. Parents, hybrids and segregating generations used in experiment mentioned in Table 1.

Table 1: Parents, hybrids and segregating generations used in experiment.

Sr. No.	Cross designation	F_1 hybrid	Segregating generations		
			F_2	BC_1	BC_2
1	05888 B (P_1) × 15001 R (P_2)	$P_1 \times P_2$	F_1⊗	$F_1 \times P_1$	$F_1 \times P_2$
2	02889 B (P_1) × 16317 R (P_2)	$P_1 \times P_2$	F_1⊗	$F_1 \times P_1$	$F_1 \times P_2$
3	01555 B (P_1) × 15990 R (P_2)	$P_1 \times P_2$	F_1⊗	$F_1 \times P_1$	$F_1 \times P_2$
4	98222 B (P_1) × 15550 R (P_2)	$P_1 \times P_2$	F_1⊗	$F_1 \times P_1$	$F_1 \times P_2$
5	1202 B (P_1) × 16317 R (P_2)	$P_1 \times P_2$	F_1⊗	$F_1 \times P_1$	$F_1 \times P_2$
6	05888 B (P_1) × 16066 R (P_2)	$P_1 \times P_2$	F_1⊗	$F_1 \times P_1$	$F_1 \times P_2$

⊗ indicate selfing.

Results and Discussion

Analysis of variance for experimental design

Analysis of variance for generation means comprising six generations *viz.*, P_1, P_2, F_1, F_2, BC_1 and BC_2 was computed for fifteen characters for each six crosses of pearl millet [*Pennisetum glaucum* (L.) R. Br.] is presented in Table 2. The analysis of variance between cross (between family) revealed that mean square of the cross differed significantly for all characters. The chi-square for barlett's test of homogeneity of error variances being significant for days to flowering, plant height, iron content and zinc content indicated that necessity to perform analysis of variance separately for each family. The analysis of variance between generations within cross (between progenies within family) revealed that the mean squares due to generations were significant for all the characters under study except plant height for cross 1202 B × 16317 R, ear head length for cross 02889 B × 16317 R, ear head girth for cross 05888 B × 15001 R, 1202 B × 16317 R and 05888 B × 16066 R, days to maturity for cross 05888 B × 15001 R and 02889 B × 16317 R and oil content for all six crosses were recorded with non-significant differences. Significant differences suggested presence of sufficient variation for generation mean values of all the crosses for different traits, there by revealing existence of sufficient variation to analyze and interpret the results in terms of objectives under investigation. The significant variation for all the characters under study might be due to more diversity between the parents of all the six crosses which resulted in high variability among its generations.

Per se performance of six generations of six crosses for different characters of pearl millet

The mean value of character of generation within cross (within family) is important to understand the variation present and also to understand primarily gene effect *viz.*, additive, non-additive, partial dominance, dominance and over-dominance. The mean values of P_1, P_2, F_1, F_2, BC_1 and BC_2 generations for grain yield, its contributing characters and quality parameters in six crosses pearl millet were presented and discussed in Table 3 to 7.

Grain yield is the dependent and complex character so increasing yield is challenging task. Understanding the expression pattern of genes can be rewarding for selection. Among all the parents, the highest grain yield was recorded in 15001 R (33.42 g) followed by 02889 B (29.09 g) and 15990 R (27.01 g) while it was recorded minimum in 01555 B (17.22 g). The highest average value was observed in F_1 of cross 05888 B × 15001 R (40.33 g) followed by cross 01555 B × 15990 R (27.15 g), cross 98222 B × 15550 R (25.15 g) and cross 02889 B × 16317 R (25.13 g). The F_1 of all the crosses recorded significantly higher mean value except for cross 02889 B × 16317 R than both the parents indicating over dominance effect. While, cross 02889 B × 16317 R suggested presence of partial dominance for higher grain yield per plant. The F_2 generation of all the crosses recorded higher mean value except for cross 05888 B × 15001 R than their respective hybrids but F_2 was at par with BC_1 in cross 98222 B × 15550 R indicating inbreeding depression. Average value of backcross generations BC_1 and BC_2 recorded significantly higher in all the crosses than their respective recurrent parent except for cross 05888 B × 15001 R. Similarly, Singh *et al.* (1974) [10] reported similar over dominant gene action in expression of this trait. Godasara *et al.* (2010) [7], Suryawanshi *et al.* (2016) [11], Jakhar *et al.* (2017) [9], Kumar *et al.* (2017a) [8] and Goah *et al.* (2020) [6] recorded results in agreement with present results for grain yield per plant for different generations.

The highest mean for number of effective tillers was recorded in female parent namely 1202 B (2.00) of cross 1202 B × 16317 R followed by male parent 15990 R (1.63) of cross 01555 B × 15990 R. In crosses 05888 B × 15001 R, 01555 B × 15990 R, 98222 B × 15550 R and 1202 B × 16317 R, F_1 was found significantly higher mean value than their both parents indicated the over dominance for this trait while F_1 was found significantly intermediate mean value of their respective parents in cross 02889 B × 16317 R and 05888 B × 16066 R indicated the partial dominance for this trait. Mean value of F_2 generations recorded significantly higher than their respective F_1's which indicated the inbreeding depression. In cross 05888 B × 15001 R and 98222 B × 15550 R, mean value of BC_1 was recorded significantly higher than their respective recurrent parent but at par with BC_2.

Among parents, female parent 1202 B in cross 1202 B × 16317 R (25.97 cm) and male parent 15001 R in cross 05888 B × 15001 R (23.69 cm) was recorded maximum earhead length and female parent 01555 B in cross 01555 B × 15990 R (18.03 cm) and male parent 16066 R in cross 05888 B × 16066 R (18.57 cm) was recorded minimum earhead length. Female parent of cross 98222 B × 15550 R was significantly higher than each other but at par with F_1,

BC_1 and BC_2. Female parent of cross 1202 B × 16317 R was significantly higher than each other but at par with F_2 and BC_1. Mean of F_1 in cross 05888 B × 15001 R, 02889 B × 16317 R and 98222 B × 15550 R was found intermediate of both parents indicated partial dominance while in cross 01555 B × 15990 R mean of F_1 was higher and in cross 98222 B × 15550 R and 1202 B × 16317 R mean of F_1 was lower than both parents suggested the presence of over dominance for this trait. The F_2 of cross 1202 B × 16317 R and 05888 B × 16066 R recorded more ear head length and F_2 of other crosses possessed lower ear head length than their respective hybrid indicating presence of inbreeding depression. BC_2 was possessed significantly higher and lower mean value than their respective recurrent parent P_2 in cross 01555 B × 15990 R and cross 05888 B × 16066 R, respectively.

Maximum ear head girth was recorded by female parent 05888 B (26.63 mm) and male parent 15550 R (26.39 mm) while it was minimum for female parent 01555 B (22.87 mm) and male parent 16317 R (24.00 mm). Female parent 05888 B of cross 05888 B × 15001 R was found significantly higher but at par with all other generations. The F_1 was significantly exhibited higher and lower ear head girth than both of the parents in cross 98222 B × 15550 R and 05888 B × 16066 R, respectively indicating over dominance effect. Mean of F_1 and BC_1 was significantly superior but at par with all other generations in cross 05888 B × 16066 R and cross 1202 B × 16317 R, respectively. Mean of BC_1 was significantly superior but at par with F_1 and F_2 in cross 02889 B × 16317 R as well as F_2 and BC_2 in cross 01555 B × 15990 R. Mean value of BC_2 was significantly higher than their respective recurrent parent in cross 1202 B × 16317 R and lower than recurrent parent in cross 02889 B × 16317 R and cross 01555 B × 15990 R for ear head girth.

The highest carbohydrate content was observed for 02889 B (68.96 g/100 g) in cross 02889 B × 16317 R followed by 1202 B (66.32 g/100 g) in cross 1202 B × 16317 R. Mean of female parent of cross 02889 B × 16317 R, 98222 B × 15550 R and 1202 B × 16317 R was significantly superior than all other generations. Mean of male parent of cross 05888 B × 15001 R and cross 01555 B × 15990 R was found significantly higher than other generations but male parent of cross 01555 B × 15990 R was at par with P_1, F_1 and BC_2.

Mean of male parent of cross 05888 B × 15001 R and cross 01555 B × 15990 R was found significantly higher than other generations but male parent of cross 01555 B × 15990 R was at par with P_1, F_1 and BC_2. Average value of F_1 was lower in all crosses than their respective parents except for cross 05888 B × 16066 R suggesting influence of over dominance. F_2 mean value was significantly lower than their respective F_1 but at par with male parent in cross 05888 B × 16066 R indicating inbreeding depression and the presence of additive gene action. Average value of backcross generation was lower than their respective recurrent parent except for BC_1 of cross 05888 B × 15001 R and BC_2 of cross 02889 B × 16317 R and 98222 B × 15550 R.

Tannins (commonly known as tannic acid) are polyphenols which are water soluble. It is known that foods with rich in tannin content are considered to be of low nutritional value. The lowest mean value was observed in 15990 R (100.51 mg/100 g) of cross 01555 B × 15990 R, followed by 98222 B (107.56 mg/100 g) of cross 98222 B × 15550 R. Female parent of cross 98222 B × 15550 R and male parent of cross 01555 B × 15990 R were found significantly lower than all other generations. In case of cross 02889 B × 16317 R and cross 05888 B × 16066 R, F_1 was significantly lower than both parents which suggested the expression of over dominance. The F_2 was found lower than their respective F_1's in crosses 05888 B × 15001 R, 98222 B × 15550 R and 1202 B × 16317 R while it was higher in crosses 02889 B × 16317 R, 01555 B × 15990 R and 05888 B × 16066 R. The mean value of BC_1 of cross 1202 B × 16317 R and BC_2 of cross 05888 B × 15001 R was significantly lower than all other generations but BC_1 of cross 1202 B × 16317 R was at par with F_2 generation.

Maximum mean of iron content among parents was found in 16066 R (89.34 mg/kg) and 05888 B (85.58 mg/kg) of cross 05888 B × 16066 R and 05888 B (85.43 mg/kg) of cross 05888 B × 15001 R while the lowest mean was recorded in 15550 R (59.28 mg/kg) of cross 98222 B × 15550 R. Female parent of cross 05888 B × 15001 R, 02889 B × 16317 R, 01555 B × 15990 R and 1202 B × 16317 R was significantly higher than other generations while male parent of cross 05888 B × 16066 R was significantly higher than other generations.

The mean value of F_1 was lower than respective parents in cross 02889 B × 16317 R, 98222 B × 15550 R, 1202 B × 16317 R and 05888 B × 16066 R which suggested the presence of over dominance except cross 05888 B × 15001 R and 01555 B × 15990 R in which F_1 hybrid mean value was in between two parents suggested the presence of partial dominance. Average value of F_2 generations lowered than their respective F_1 hybrids which indicated the influence of non-additive gene action except cross 02889 B × 16317 R and 1202 B × 16317 R in which it is higher than mean of F_1 generation, so it suggested the influence of additive gene action. Backcross generation BC_1 was significantly lower than their recurrent parent in cross 98222 B × 15550 R. Goah *et al.* (2020) [6] also observed similar results of significant variation between mean values of generations within family.

In case of zinc content, highest mean value was observed in 02889 B (51.29 mg/kg) of cross 02889 B × 16317 R, while lowest mean value was observed in 16317 R (33.01 mg/kg) of cross 02889 B × 16317 R. Female and male parent of cross 02889 B × 16317 R and cross 05888 B × 15001 R was found significantly superior than all other generations but male parent of cross 05888 B × 15001 R was found at par with female parent. F_1 hybrid mean value of zinc content was observed higher than their respective parents in crosses 01555 B × 15990 R, 98222 B × 15550 R and 05888 B × 16066 R as well as lower than their respective parents in cross 05888 B × 15001 R and 1202 B × 16317 R which explains the expression of over dominance while in cross 02889 B × 16317 R, it was intermediate of both respective parents suggested the influence of partial dominance. In all crosses, mean value of F_2 generations for zinc content was lowered than their respective F_1 hybrid except for cross 01555 B × 15990 R indicated the influence of non-additive gene action. BC_2 of cross 1202 B × 16317 R was found significantly higher but at par with P_1 and F_2. Goah *et al.* (2020) [6] also found similar results for zinc content.

Maximum mean value of oil content among parents was observed in 01555 B (5.56%) and minimum mean value observed in 15990 R (4.95%) of cross 01555 B × 15990 R. The mean value of F_1 hybrid was found significantly superior to their respective parents in all crosses (except for cross 05888 B × 15001 R and 1202 B × 16317 R) but at par with other generations of cross 02889 B × 16317 R, 98222 B × 15550 R and 05888 B × 16066 R which suggested presence of over dominance. Average value of F_2 was observed higher in all crosses except for cross 05888 B × 15001 R and 1202 B × 16317 R than the respective hybrid suggested the influence of additive gene action. Average of BC_1 and BC_2 was observed higher than their respective recurrent parent P_1 and P_2 of cross 1202 B × 16317 R and cross 05888 B × 15001 R, respectively.

Protein is essential for regular metabolic activities. The highest and lowest mean value was observed for 05888 B (11.96%) of cross 05888 B × 15001 R and 15990 R (4.51%) of cross 01555 B × 15990 R, respectively. Female parent of cross 05888 B × 15001 R, 01555 B × 15990 R, 98222 B × 15550 R and 05888 B × 16066 R was found significantly superior mean value than all other generations. F_1 hybrid mean value was found intermediate of two parents suggested the presence of partial dominance in all crosses. Average of F_2 generation observed higher than respective F_1 except for crosses 05888 B × 15001 R and 98222 B × 15550 R, which indicated presence of inbreeding depression and additive gene action. BC_1 of cross 02889 B × 16317 R and BC_2 of cross 1202 B × 16317 R were found significantly superior than its respective recurrent parent P_1 and P_2.

Magnitude of heterosis and inbreeding depression

The extent of relative heterosis (RH) and heterobeltiosis (HB) as well as inbreeding depression (ID) were estimated for all the characters under study. The relative heterosis was estimated over mid-parent and heterobeltiosis over better parent in F_1 hybrid and inbreeding depression in F_2 generation for grain yield, its contributing characters and quality parameters in six crosses of pearl millet are presented in Table 8. The presence of high level of heterosis for grain yield and its contributing traits is not only for the developing good hybrids but also to produce transgressive segregants for developing superior homozygous inbred lines in pearl millet.

At the time of selection from any breeding population, grain yield attracts maximum attention of plant breeder. Therefore highest positive and significant heterosis is desirable for grain yield and contributing characters. Total 6 crosses studied, out of these 4 crosses namely 05888 B × 15001 R, 98222 B × 15550 R, 1202 B × 16317 R and 05888 B × 16066 R depicted highest positive and significant relative heterosis and better parent heterosis for grain yield along with some yield attributing characters. In the present experiment, none of single cross showed significant heterosis for all characters. It suggested that the degree and diection of heterosis is varied from character to character and also among different cross combinations.

Heterosis value may be high or low depending upon the mean value of the respective parent. So, there may be chance of getting a cross/hybrid with high mean performance (due to high parental performance) but with low heterotic value. Contrast of these, chance of getting a cross/hybrid with low mean performance but with high heterotic value. It means that choice of best cross/hybrid based on high heterotic value would not be necessarily that these cross/hybrid also give high mean performance. Because mean performance is realized value and heterosis is an estimate, so the mean value would be given preference with high percentage of heterosis during selection of cross combination.

Inbreeding depression based on genetic variability suggested the positive and negative expression of genes in the population which could be fixed for heterosis breeding. The positive and negative value of inbreeding depression indicated the role of dominant and recessive genes in the inheritance of the characters. The direction and magnitude of inbreeding depression differed for grain yield, its contributing traits and quality parameters. Cross 98222 B × 15550 R, 1202 B × 16317 R and 05888 B × 16066 R showed positive and significant relative and better parent heterosis along with negative and significant inbreeding depression for grain yield per plant. Crosses depicted high heterosis followed by low inbreeding depression indicates the presence of non additive type of gene action. Crosses showed negative and significant inbreeding depression for grain yield, its contributing traits and quality parameters can be used to maintain the specific gene pool for further utilization in pearl millet improvement programme.

Cross 01555 B × 15990 R showed positive and significant relative heterosis for number of effective tillers per plant, while cross 02889 B × 16317 R, 98222 B × 15550 R and 05888 B × 16066 R showed negative and significant inbreeding depression for the same character. Cross 05888 B × 15001 R and 02889 B × 16317 R showed positive and significant relative heterosis and cross 1202 B × 16317 R and 05888 B × 16066 R indicated negative and significant inbreeding depression for the ear head length. In case of ear head girth, cross 02889 B × 16317 R and 98222 B × 15550 R showed positive and significant relative heterosis as well as cross 01555 B × 15990 R showed negative and significant inbreeding depression. Out of six cross, none of cross suggested heterosis and inbreeding depression in desired direction for test weight. Cross 05888 B × 15001 R, 01555 B × 15990 R and 1202 B × 16317 R showed positive and significant relative heterosis and better parent heterosis and cross 05888 B × 16066 R showed negative and significant inbreeding depression for harvest index.

In relation to charbohydrate content, cross 05888 B × 16066 R showed positive and significant relative heterosis, while three crosses 05888 B × 15001 R, 98222 B × 15550 R and 1202 B × 16317 R showed negative and significant inbreeding depression. All crosses depicted non significant heterosis so these crosses may not be utilized for objective of high iron content. Both type of heterosis was found positive and significant in cross 01555 B × 15990 R, 98222 B × 15550 R and 05888 B × 16066 R for zinc content means these are considered good for high zinc content and parent of these crosses could be used in development of pearl millet lines with high zinc content.

Table 2: Analysis of variance for six generations in six crosses of pearl millet for grain yield per plant, its contributing characters and quality parameters.

Source of variation	d.f.	Days to flowering	Plant height	Number of effective tiller per plant	Earhead length	Earhead girth	Days to maturity	Test weight	Grain yield per plant
		Mean sum of squares							
Analysis of variance between cross (between family)									
Replications	2	0.099	20.472	0.040**	1.750	2.007*	0.262	0.149**	0.147
Generations	5	10.860**	52.642*	0.089**	7.952**	2.727**	10.198**	0.883**	8.095**
Error	10	0.124	10.900	0.002	0.478	0.312	0.120	0.004	0.239
Chi square		**S**	**S**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Analysis of variance between generations within cross (between progenies within family)									
Cross 1 (05888 B × 15001 R)									
Replications	2	2.42	34.32	0.04*	3.94	4.92	2.65	0.11*	1.09
Generations	5	16.28**	975.76**	0.16**	16.13**	2.53	1.62	0.54**	82.22**
Error	10	0.87	9.75	0.00	1.05	2.69	1.24	0.02	1.56
Cross 2 (02889 B × 16317 R)									
Replications	2	0.71	52.26*	0.09**	2.13	0.00	0.26	0.19	1.10
Generations	5	8.80**	464.19**	0.19**	5.12	7.31**	1.35	0.35*	16.13**
Error	10	1.38	12.07	0.01	1.80	0.88	0.87	0.06	1.55
Cross 3 (01555 B × 15990 R)									
Replications	2	0.86	1.37	0.05	2.51*	7.89*	0.03	0.15	0.58
Generations	5	50.18**	548.88**	0.15**	1.93*	10.88**	18.65**	0.19*	70.78**
Error	10	0.36	11.93	0.01	0.45	1.36	0.66	0.04	2.19
Cross 4 (98222 B × 15550 R)									
Replications	2	0.25	111.42	0.05	4.30	4.12*	0.02	0.09*	1.53
Generations	5	16.09**	393.92**	0.35**	5.55*	5.60**	14.14**	0.19**	58.68**
Error	10	0.07	33.45	0.01	1.48	0.88	1.19	0.01	1.68
Cross 5 (1202 B × 16317 R)									
Replications	2	0.02	227.51	0.04	7.23*	4.00	1.93	0.07	1.65
Generations	5	19.24**	162.43	0.09**	12.60**	1.09	14.62**	0.29*	86.74**
Error	10	0.45	63.30	0.01	1.06	1.09	1.05	0.06	1.94
Cross 6 (05888 B × 16066 R)									
Replications	2	0.01	22.92	0.01	4.70	0.44	0.26	0.39	2.06
Generations	5	19.19**	191.28**	0.23**	25.71**	0.84	17.08**	0.87**	65.03**
Error	10	0.25	12.97	0.03	1.46	0.62	1.04	0.10	1.98
* and **, significant at 5% and 1% level of significance, respectively									

Source of variation	d.f.	Harvest index	Carbohydrate	Tannin	Iron content	Zinc content	Oil content	Protein content
		Mean sum of squares						
Analysis of variance between cross (between family)								
Replications	2	0.990*	0.084	1.136	0.369	0.025	0.005	0.021
Generations	5	20.092**	63.466**	1186.738**	156.307**	12.891**	0.069	2.740**
Error	10	0.156	0.535	1.207	0.117	0.053	0.068	0.036
Chi square		**NS**	**NS**	**NS**	**S**	**S**	**NS**	**NS**
Analysis of variance between generations within cross (between progenies within family)								
Cross 1 (05888 B × 15001 R)								
Replications	2	0.02	2.79	0.42	1.41	0.09	0.48	0.16
Generations	5	9.86**	234.98**	3554.82**	869.16**	13.08**	0.55	9.03**
Error	10	0.58	0.90	20.04	2.23	0.27	0.17	0.23
Cross 2 (02889 B × 16317 R)								
Replications	2	0.87	3.05	10.66	1.25	0.18	0.38	0.44
Generations	5	26.07**	54.34**	3917.26**	326.78**	104.47**	0.07	3.83**
Error	10	0.72	2.85	4.68	1.74	0.12	0.16	0.16
Cross 3 (01555 B × 15990 R)								
Replications	2	1.67	8.07	11.05	0.68	0.56	0.39	0.09
Generations	5	47.21**	51.35**	7279.58**	849.70**	56.84**	0.21	9.18**
Error	10	0.88	3.31	6.68	0.44	0.41	0.13	0.19
Cross 4 (98222 B × 15550 R)								
Replications	2	4.85	0.05	4.52	0.97	0.25	0.04	0.37
Generations	5	26.86**	47.46**	3395.72**	581.72**	39.19**	0.15	2.47**
Error	10	1.46	4.39	6.41	3.11	0.19	0.14	0.27
Cross 5 (1202 B × 16317 R)								
Replications	2	2.58	1.99	5.64	0.74	0.31	0.55	0.04
Generations	5	6.02**	40.69**	2594.36**	591.46**	17.58**	0.26	7.95**
Error	10	0.85	4.57	3.35	0.56	0.89	0.13	0.28
Cross 6 (05888 B × 16066 R)								
Replications	2	0.61	0.56	10.72	0.66	0.32	0.20	0.07
Generations	5	6.03**	88.81**	5454.00**	281.62**	8.17**	0.17	13.88**
Error	10	0.33	3.44	5.99	1.57	1.10	0.17	0.20
* and **, significant at 5% and 1% level of significance, respectively								

Table 3: *Per se* performance of grain yield per plant and number of effective tiller per plant from six generations of six crosses of pearl millet.

Cross	05888 B × 15001 R			02889 B × 16317 R			01555 B × 15990 R			98222 B × 15550 R			1202 B × 16317 R			05888 B × 16066 R		
Grain yield per plant (g)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	26.30	±	0.28	29.09	±	0.59	17.22	±	0.48	23.47	±	0.28	22.27	±	0.37	22.36	±	0.39
P_2	33.42	±	0.32	24.81	±	0.43	27.01	±	0.40	20.13	±	0.27	20.16	±	0.35	20.82	±	0.29
F_1	40.33	±	0.33	25.13	±	0.41	27.15	±	0.54	25.15	±	0.30	24.33	±	0.42	25.06	±	0.34
F_2	28.85	±	0.71	27.09	±	0.71	28.42	±	0.69	31.35	±	0.70	30.16	±	0.56	32.71	±	0.65
BC_1	28.06	±	1.04	29.38	±	1.13	30.17	±	1.27	30.59	±	1.02	32.87	±	1.00	29.44	±	0.87
BC_2	28.00	±	1.06	30.32	±	1.06	30.27	±	1.19	28.93	±	0.54	31.89	±	0.94	29.63	±	0.66
Over all mean	30.83	±	0.72	27.63	±	0.71	26.70	±	0.85	26.60	±	0.75	26.94	±	0.80	26.66	±	0.81
C.D. (P=0.05)	2.27			2.26			2.69			2.36			2.53			2.56		
Number of effective tiller per plant																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	1.17	±	0.07	1.17	±	0.06	1.47	±	0.10	1.50	±	0.09	2.00	±	0.31	1.40	±	0.09
P_2	1.20	±	0.07	1.40	±	0.12	1.63	±	0.12	1.57	±	0.14	1.57	±	0.10	1.50	±	0.09
F_1	1.30	±	0.08	1.23	±	0.09	1.93	±	0.13	1.40	±	0.09	1.50	±	0.10	1.47	±	0.11
F_2	1.44	±	0.05	1.55	±	0.08	1.98	±	0.12	1.98	±	0.11	1.69	±	0.08	1.83	±	0.08
BC_1	1.73	±	0.11	1.58	±	0.10	2.03	±	0.13	2.20	±	0.16	1.72	±	0.10	1.93	±	0.14
BC_2	1.63	±	0.12	1.87	±	0.12	1.90	±	0.14	2.12	±	0.15	1.83	±	0.12	2.07	±	0.15
Over all mean	1.41	±	0.05	1.47	±	0.06	1.82	±	0.06	1.79	±	0.07	1.71	±	0.07	1.7	±	0.10
C.D. (P=0.05)	0.16			0.20			0.21			0.22			0.23			0.33		

Table 4: *Per se* performance of earhead length and earhead girth from six generations of six crosses of pearl millet.

Cross	05888 B × 15001 R			02889 B × 16317 R			01555 B × 15990 R			98222 B × 15550 R			1202 B × 16317 R			05888 B × 16066 R		
Earhead length (cm)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	19.01	±	0.74	23.21	±	0.52	18.03	±	0.56	24.40	±	0.81	25.97	±	0.93	19.27	±	0.60
P_2	23.69	±	0.91	20.12	±	0.56	19.86	±	0.49	20.97	±	0.56	21.58	±	0.55	18.57	±	0.82
F_1	25.01	±	0.82	23.68	±	0.77	20.12	±	0.67	23.21	±	0.49	20.67	±	0.76	17.26	±	0.50
F_2	24.33	±	0.48	23.19	±	0.45	19.87	±	0.40	21.66	±	0.63	24.74	±	0.50	22.01	±	0.44
BC_1	24.82	±	0.57	22.16	±	0.57	19.60	±	0.43	23.96	±	0.80	24.79	±	0.70	23.06	±	0.57
BC_2	24.96	±	0.88	23.17	±	0.62	20.18	±	0.72	23.64	±	0.58	23.63	±	0.99	24.86	±	0.97
Over all mean	23.64	±	0.59	22.59	±	0.77	19.60	±	0.38	22.97	±	0.70	23.56	±	0.59	20.83	±	0.69
C.D. (P=0.05)	1.86			2.44			1.22			2.21			1.87			2.20		
Earhead girth (mm)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	26.18	±	0.80	25.28	±	0.64	22.87	±	0.77	25.05	±	0.52	24.65	±	0.47	26.63	±	0.51
P_2	25.17	±	0.40	26.07	±	0.79	24.66	±	0.37	26.39	±	0.70	24.00	±	0.51	25.86	±	0.55
F_1	25.62	±	0.86	28.86	±	0.51	23.81	±	0.68	28.93	±	0.56	25.14	±	0.51	26.91	±	0.56
F_2	25.57	±	0.39	27.71	±	0.33	26.26	±	0.61	25.37	±	0.48	24.87	±	0.39	26.61	±	0.34
BC_1	23.55	±	0.50	29.33	±	0.47	27.94	±	0.77	26.25	±	0.52	25.78	±	0.45	26.60	±	0.64
BC_2	25.75	±	0.50	27.32	±	0.49	26.62	±	0.74	26.21	±	0.66	24.54	±	0.44	25.55	±	0.52
Over all mean	25.31	±	0.94	27.43	±	0.54	25.35	±	0.67	26.36	±	0.54	24.83	±	0.60	26.35	±	0.45
C.D. (P=0.05)	2.98			1.70			2.12			1.71			1.90			1.44		

Table 5: *Per se* performance of carbohydrate and tannin from six generations of six crosses of pearl millet.

Cross	05888 B × 15001 R			02889 B × 16317 R			01555 B × 15990 R			98222 B × 15550 R			1202 B × 16317 R			05888 B × 16066 R		
Carbohydrate (g/100g)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	47.64	±	0.32	68.96	±	0.35	62.83	±	0.39	59.23	±	0.35	66.32	±	0.53	48.92	±	0.35
P_2	63.16	±	0.60	60.07	±	0.50	63.94	±	0.63	51.71	±	0.34	60.04	±	0.34	55.88	±	0.33
F_1	37.14	±	0.37	61.93	±	0.36	62.34	±	0.52	49.47	±	0.36	55.19	±	0.22	56.05	±	0.49
F_2	54.34	±	0.64	57.07	±	0.65	58.39	±	0.61	53.28	±	0.66	60.40	±	0.53	57.22	±	0.53
BC_1	56.66	±	0.66	58.49	±	0.69	52.75	±	1.01	59.12	±	0.76	62.20	±	0.93	44.09	±	1.06
BC_2	52.54	±	0.47	63.56	±	0.61	61.39	±	1.03	53.56	±	0.76	58.89	±	0.65	47.76	±	0.55
Over all mean	51.91	±	0.54	61.68	±	0.97	60.27	±	1.05	54.39	±	1.21	60.50	±	1.23	51.65	±	1.07
C.D. (P=0.05)	1.72			3.07			3.31			3.81			3.88			3.37		
Tannin (mg/100g)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	194.56	±	0.50	120.69	±	0.49	125.50	±	0.46	107.56	±	0.68	160.07	±	0.56	200.87	±	0.69
P_2	211.14	±	0.45	121.23	±	0.45	100.51	±	0.73	194.58	±	0.53	129.71	±	0.61	189.98	±	0.55
F_1	201.93	±	0.57	105.49	±	0.62	122.51	±	0.64	194.91	±	0.69	194.69	±	0.70	101.99	±	0.70
F_2	192.67	±	2.71	202.32	±	1.25	197.80	±	1.26	181.30	±	2.70	121.33	±	1.63	116.48	±	1.06
BC_1	201.69	±	5.14	162.94	±	0.83	208.03	±	1.60	190.10	±	1.79	120.51	±	1.13	118.75	±	2.03
BC_2	117.61	±	4.86	125.77	±	1.22	207.56	±	1.64	182.99	±	1.14	128.48	±	4.13	118.87	±	1.18
Over all mean	186.60	±	2.58	139.74	±	1.24	160.31	±	1.49	175.24	±	1.46	142.46	±	1.05	141.15	±	1.41
C.D. (P=0.05)	8.14			3.93			4.70			4.60			3.33			4.45		

Table 6: *Per se* performance of iron content and zinc content from six generations of six crosses of pearl millet.

Cross	**05888 B × 15001 R**			**02889 B × 16317 R**			**01555 B × 15990 R**			**98222 B × 15550 R**			**1202 B × 16317 R**			**05888 B × 16066 R**		
Iron content (mg/kg)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	85.43	±	0.22	77.09	±	0.25	84.66	±	0.36	64.14	±	0.52	82.70	±	0.23	85.58	±	0.28
P_2	64.27	±	0.14	75.51	±	0.26	65.98	±	0.25	59.28	±	0.40	77.27	±	0.30	89.34	±	0.45
F_1	66.01	±	0.16	64.86	±	0.42	67.75	±	0.39	45.01	±	0.43	50.58	±	0.39	73.11	±	0.26
F_2	35.79	±	0.10	65.65	±	0.25	49.00	±	0.68	30.26	±	0.86	56.71	±	0.28	72.31	±	0.33
BC_1	67.00	±	0.44	52.32	±	0.87	47.59	±	0.90	66.33	±	0.67	51.63	±	0.67	64.41	±	0.50
BC_2	48.97	±	0.37	53.74	±	0.73	38.95	±	0.51	60.54	±	0.61	54.35	±	0.64	69.37	±	0.31
Over all mean	61.25	±	0.86	64.86	±	0.76	58.98	±	0.38	54.25	±	1.01	62.20	±	0.43	75.68	±	0.72
C.D. (P=0.05)	2.72			2.40			1.21			3.21			1.37			2.28		
Zinc content (mg/kg)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	44.13	±	0.26	51.29	±	0.22	47.08	±	0.33	35.81	±	0.17	40.04	±	0.24	41.82	±	0.34
P_2	44.78	±	0.28	33.01	±	0.25	42.20	±	0.27	35.97	±	0.20	38.95	±	0.33	41.61	±	0.32
F_1	41.22	±	0.20	41.38	±	0.26	51.04	±	0.31	43.87	±	0.22	35.01	±	0.23	43.81	±	0.32
F_2	39.54	±	0.25	40.82	±	0.20	40.43	±	0.29	40.58	±	0.33	40.10	±	0.34	41.94	±	0.33
BC_1	40.63	±	0.23	39.95	±	0.24	40.43	±	0.37	34.49	±	0.51	35.89	±	0.58	42.05	±	0.41
BC_2	40.93	±	0.50	39.21	±	0.32	41.29	±	0.33	40.04	±	0.32	40.79	±	0.51	38.70	±	0.42
Over all mean	41.87	±	0.30	40.94	±	0.20	43.74	±	0.37	38.45	±	0.25	38.46	±	0.54	41.65	±	0.60
C.D. (P=0.05)	0.95			0.63			1.16			0.80			1.72			1.90		

Table 7: *Per se* performance of oil content and protein content from six generations of six crosses of pearl millet.

Cross	**05888 B × 15001 R**			**02889 B × 16317 R**			**01555 B × 15990 R**			**98222 B × 15550 R**			**1202 B × 16317 R**			**05888 B × 16066 R**		
Oil content (%)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	5.38	±	0.06	5.48	±	0.24	5.56	±	0.17	4.96	±	0.15	5.01	±	0.20	5.05	±	0.19
P_2	5.32	±	0.06	5.14	±	0.16	4.95	±	0.19	5.16	±	0.19	4.95	±	0.14	5.33	±	0.14
F_1	5.25	±	0.19	5.55	±	0.18	5.66	±	0.19	5.63	±	0.18	5.16	±	0.18	5.60	±	0.13
F_2	5.84	±	0.14	5.41	±	0.14	5.39	±	0.11	5.23	±	0.12	5.47	±	0.12	5.51	±	0.12
BC_1	5.95	±	0.20	5.29	±	0.18	5.18	±	0.19	5.31	±	0.15	5.70	±	0.18	5.03	±	0.17
BC_2	6.32	±	0.24	5.49	±	0.17	5.50	±	0.17	5.44	±	0.15	5.49	±	0.17	5.13	±	0.18
Over all mean	5.68	±	0.24	5.39	±	0.23	5.37	±	0.21	5.28	±	0.21	5.29	±	0.21	5.27	±	0.24
C.D. (P=0.05)	0.76			0.73			0.67			0.69			0.67			0.75		
Protein content (%)																		
Generations	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
P_1	11.96	±	0.29	8.00	±	0.28	9.34	±	0.26	10.05	±	0.12	7.05	±	0.15	11.43	±	0.31
P_2	6.79	±	0.27	5.57	±	0.29	4.51	±	0.29	8.75	±	0.11	4.61	±	0.16	5.13	±	0.18
F_1	10.74	±	0.21	6.12	±	0.15	8.34	±	0.30	9.71	±	0.12	6.10	±	0.19	7.26	±	0.16
F_2	9.93	±	0.22	7.85	±	0.16	8.99	±	0.24	8.78	±	0.17	8.35	±	0.20	9.45	±	0.16
BC_1	9.26	±	0.36	8.41	±	0.21	8.49	±	0.29	7.48	±	0.37	8.54	±	0.33	7.51	±	0.29
BC_2	9.26	±	0.28	7.43	±	0.30	8.10	±	0.26	8.60	±	0.28	8.68	±	0.40	8.78	±	0.25
Over all mean	9.66	±	0.27	7.23	±	0.23	7.96	±	0.25	8.89	±	0.30	7.21	±	0.31	8.25	±	0.25
C.D. (P=0.05)	0.87			0.74			0.79			0.95			0.97			0.81		

Table 8: Estimates of relative heterosis (RH %), heterobeltiosis (HB %) and inbreeding depression (ID %) in six crosses of pearl millet for grain yield per plant, its contributing characters and quality parameters.

Estimates (%)	Days to flowering	Plant height	Number of effective tiller per plant	Earhead length	Earhead girth	Days to maturity	Test weight	Grain yield per plant
Cross 1 (05888 B × 15001 R)								
RH %	-7.08**	23.83**	9.86	17.11**	-0.19	-0.83	1.83	35.06**
HB %	-5.05**	32.02**	8.33	5.54	-2.12	-0.74	-2.94	20.69**
ID %	-9.22**	0.39	-10.90	2.71	0.21	-0.10	0.10	28.47**
Cross 2 (02889 B × 16317 R)								
RH %	-2.38*	10.22**	-3.90	9.28*	12.38**	0.24	4.41	-6.73**
HB %	0.13	10.29**	-11.90	1.99	10.67**	0.28	2.10	-13.59**
ID %	-3.59**	-5.88**	-25.68*	2.06	3.96	0.61	2.35	-7.77*
Cross 3 (01555 B × 15990 R)								
RH %	3.81**	-7.83**	24.73*	6.18	0.16	-3.81**	1.98	22.76**
HB %	7.07**	5.65**	18.37	1.27	-3.46	-1.16	0.47	0.51
ID %	16.18**	-8.43**	-2.59	1.22	-10.30**	-0.61	0.93	-4.68
Cross 4 (98222 B × 15550 R)								
RH %	2.99*	16.76**	-8.70	2.34	12.49**	-0.22	-0.81	15.40**
HB %	4.81**	21.13**	-10.64	-4.86	9.63**	0.44	-1.57	7.18**
ID %	-2.60*	13.79**	-41.07**	6.69	12.29**	-6.17	4.27	-24.66**
Cross 5 (1202 B × 16317 R)								
RH %	-1.99	-0.03	-15.89	-13.03**	3.37	0.20	1.88	14.68**
HB %	-0.60	6.09**	-25.00	-20.39**	2.01	0.74	-1.17	9.26**
ID %	8.42**	-6.04**	-12.78	-19.69**	1.09	-1.48	4.17	-23.96**
Cross 6 (05888 B × 16066 R)								
RH %	1.96	-3.14*	1.15	-8.75*	2.54	-6.36**	3.86	16.08**
HB %	2.78*	0.28	-2.22	-10.40*	1.07	-6.07**	-1.38	12.08**
ID %	8.35**	-10.74**	-25.00*	-27.48**	1.11	-1.83	5.98	-30.54**
*** and **, significant at 5% and 1% level of significance, respectively**								

Estimates (%)	Harvest index	Carbohydrate	Tannin	Iron content	Zinc content	Oil content	Protein content
Cross 1 (05888 B × 15001 R)							
RH %	9.97**	-32.96**	-0.45	-11.82**	-7.28**	-1.90	14.53**
HB %	6.75**	-41.19**	3.79**	-22.74**	-7.95**	-2.43	-10.22**
ID %	6.36**	-46.30**	4.59**	45.77**	4.06**	-11.40*	7.47*
Cross 2 (02889 B × 16317 R)							
RH %	-0.88	-4.01**	-12.78**	-14.99**	-1.83*	4.47	-9.77*
HB %	-1.43	-10.19**	-12.59**	-15.86**	-19.32**	1.16	-23.51**
ID %	1.89	7.85**	-91.79**	-1.22	1.35	2.54	-28.18**
Cross 3 (01555 B × 15990 R)							
RH %	6.75**	-1.65	8.41**	-10.05**	14.33**	7.64	20.30**
HB %	4.64**	-2.51	21.89**	-19.97**	8.41**	1.67	-10.80*
ID %	12.92**	6.33**	-61.46**	27.68**	20.79**	4.70	-7.86
Cross 4 (98222 B × 15550 R)							
RH %	4.92**	-10.82**	29.02**	-27.06**	22.25**	11.23*	3.29*
HB %	-0.89	-16.48**	81.22**	-29.82**	21.97**	9.14	-3.41
ID %	11.76 **	-7.72**	6.99**	32.78**	7.50**	7.03	9.56**
Cross 5 (1202 B × 16317 R)							
RH %	5.59**	-12.65**	34.37**	-36.76**	-11.34**	3.69	4.63
HB %	5.32**	-16.79**	50.09**	-38.84**	-12.55**	3.07	-13.49**
ID %	6.09**	-9.45**	37.68**	-12.13**	-14.54**	-5.83	-36.94**
Cross 6 (05888 B × 16066 R)							
RH %	2.21	6.97**	-47.81**	-16.41**	5.02**	7.97*	-12.31**
HB %	-2.34	0.31	-46.31**	-18.17**	4.76**	5.16	-36.50**
ID %	-3.78*	-2.09	-14.21**	1.09	4.26**	1.63	-30.17**
* and **, significant at 5% and 1% level of significance, respectively							

Cross 98222 B × 15550 R and 05888 B × 16066 R showed positive and significant relative heterosis for oil content. For protein content, cross 05888 B × 15001 R, 01555 B × 15990 R and 98222 B × 15550 R showed positive and significant relative heterosis, while remaining three crosses showed negative and significant inbreeding depression.

Negative and significant heterosis with positive and significant inreeding depression is considered good for improvement of negative characters like days to flowering, plant height, days to maturity and tannin content. For days to flowering, cross 05888 B × 15001 R indicated negative and significant relative heterosis and better parent heterosis and three crosses namely 01555 B × 15990 R, 1202 B × 16317 R and 05888 B × 16066 R indicated positive and significant inbreeding depression. So these crosses and parent of these crosses can be utilized for objective of early flowering. In case of plant height, cross 01555 B × 15990 R and 05888 B × 16066 R showed heterosis in desired direction and cross 98222 B × 15550 R showed positive and significant inbreeding depression, it means these favours short plant height. Cross 05888 B × 16066 R showed both type of heterosis in desired direction for days to maturity favours early maturity of hybrids. Low tannin content is desirable for high nutritional value of pearl millet. Cross 02889 B × 16317 R and 05888 B × 16066 R showed negative and significant relative heterosis and better parent heterosis and cross 05888 B × 15001 R, 98222 B × 15550 R and 1202 B × 16317 R showed positive and significant inbreeding depression for tannin content.

Conclusion

Significant heterosis over mid-parent and better parent along with positive and negative inbreeding depression may be attributed to major contribution to dominance (h) and additive × additive (i) gene effects, where selection will be effective only in later generations. crosses showed dominance (h) gene effects, these crosses or parents may be used for heterosis breeding to utilize high SCA effect for development of superior pearl millet hybrids. Crosses showed additive × additive (i) type of gene effects, these may be used for exploitation of heterosis for grain yield and its contributing traits with quality traits as well as in future breeding programme by utilizing biparental mating design and recurrent selection method for development of superior pearl millet lines.

For grain yield and contributing characters, which crosses showing significant and positive relative and better parent heterosis were highly desirable. Cross 98222 B × 15550 R, 1202 B × 16317 R and 05888 B × 16066 R showed positive and significant relative and better parent heterosis along with negative and significant inbreeding depression for grain yield per plant. Crosses depicted high heterosis followed by low inbreeding depression indicates the presence of non-additive type of gene action. Crosses showed negative and significant inbreeding depression for grain yield, its related traits and quality parameters can be used to maintain the specific gene pool for further utilization in pearl millet improvement programme. Higher and lower mean of F_2 than mean of F_1 indicated presence of additive gene action and non additive gene action, respectively. In case of negative characters like days to flowering, plant height, days to matuity and tannin content crosses with significant and negative relative and better parent heterosis and significant and positive inbreeding depression is more desirable for early flowering, short plant height, early maturity and low tannin content, respectively.

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