Biological Forum – An International Journal **15(11): 339-348(2023)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Towards Superior Pearl millet [*Pennisetum glaucum* (L.) R. Br.] Varieties: Unraveling Combining Ability and Heterosis for Improved Grain Yield

Gajjar K.D.[1*], Patel M.S.[2], Zala H.N.[3], Prajapati N.N.[4] and Patel Y.N.[4]
[1]Gujarat Biotechnology Research Centre, Department of Science and Technology, Gandhinagar (Gujarat), India.
[2]Pulses Research Station, S.D. Agricultural University, Sardarkrushinagar (Gujarat), India.
[3]Department of Genetics and Plant Breeding, C.P. College of Agriculture, Sardarkrushinagar (Gujarat), India.
[4]Centre for Crop Improvement, S.D. Agricultural University, Sardarkrushinagar (Gujarat), India.

(Corresponding author: Gajjar K.D.[*])
(Received: 12 September 2023; Revised: 08 October 2023; Accepted: 20 October 2023; Published: 15 November 2023)
(Published by Research Trend)

ABSTRACT: The research aimed to conduct a comprehensive genetic analysis in pearl millet [*Pennisetum glaucum* (L.) R. Br.], focusing on per se performance, heterosis extent, general combining ability of parents, and specific combining ability of hybrids concerning yield and its component characters. A set of 37 genotypes, including 28 hybrids derived from a diallel mating design with 8 parental lines and a standard check (GHB 1129), constituted the experimental material. The study, conducted at the Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University, Gujarat, during the kharif season of 2021, involved the recording of thirteen observations encompassing various agronomic traits. Analysis of variance for parents and hybrids demonstrated highly significant mean squares for all characters, indicating substantial genetic variability within the experimental material. Comparisons between parents and hybrids revealed significant heterosis across all characters. Notably, parent 08444 B exhibited promising per se performance for grain yield per plant, panicle length, panicle weight, and test weight. In contrast, parent 2889 B displayed promise for plant height, number of productive tillers per plant, test weight, iron content, and zinc content. Among the 28 hybrids, crosses 08444 B × 05888 B and 08444 B × 15388 R demonstrated superior per se performance for panicle length, panicle weight, and grain yield per plant, suggesting their potential for enhancing grain yield and related attributes in pearl millet. Hybrids exhibited significant heterosis, ranging from low to high, over mid parent, better parent, and standard check in the desired direction for all traits, except for days to flowering, panicle diameter, and days to maturity. Combining ability analysis revealed highly significant variance for both *gca* and *sca* for all characters. The predominance of non-additive gene action was indicated by the ratio of σ^2gca/σ^2sca being less than unity. Among the parents, 05888 B, 08444 B, and 15388 R were identified as the best combiners for grain yield per plant and other component traits based on *gca* effects. Specific combining ability effects highlighted significant contributions from crosses, with 08444 B × 15388 R and 08444 B × 05888 B showing notable *sca* in the desirable direction for grain yield per plant and other important characters. At present, emphasis in pearl millet breeding is given on developing diverse hybrids, nutrition rich open-pollinated varieties and populations having multiple disease resistance. In this direction, it is necessary to develop new superior male sterile lines, restorers and inbreds having high combining ability, wide variability and disease resistance, which requires the good knowledge of gene action. These findings provide valuable insights for developing superior hybrids and inbreds in pearl millet.

Keywords: Pearl millet, Heterosis, Hybrid, Grain yield per plant and Combining ability.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) holds a significant position within the family Poaceae (Gramineae) and the genus *Pennisetum*. Known by various names such as bajra, bajri, cat tail millet, spiked millet, and bulrush millet, this highly cross-pollinated crop exhibits protogynous flowering and a wind-borne pollination mechanism. These biological characteristics make pearl millet conducive to hybrid development and the commercial exploitation of heterosis. Widely recognized as a staple food crop in India, pearl millet ranks fourth in acreage after rice, wheat, and sorghum, and is the sixth most important cereal globally. Believed to have originated in tropical Western Africa approximately 4000 years ago, pearl millet is diploid (2n=2x=14) and subsequently differentiated into two races: the globosum race moving to the western side and the typhoides race reaching Eastern Africa before spreading to India and Southern Africa some 2000–3000 years ago (Krishnaswamy, 1951).

Cultivated on over 27 million hectares in challenging environments of Africa (17 million hectares) and Asia (10 million hectares), India boasts the largest pearl millet cultivation area, covering 9 million hectares (Rai *et al*., 2012). In India, the pearl millet region is divided into three agro-climatic zones based on rainfall patterns and latitude, namely the arid zone (A1 zone), A zone, and B zone. Farmers in these diverse zones exhibit varying preferences for plant and grain traits, necessitating periodic re-evaluation by plant breeders. India stands as the world's largest producer of pearl millet, contributing significantly to the country's agriculture. Gujarat, for instance, cultivates pearl millet in 26 out of 33 districts, covering an area of 4.46 lakh hectares with a production of 10.56 lakh tonnes and an average productivity of 2368 kg/ha (Anonymous, 2022). Pearl millet is primarily grown as a dry-land dual-purpose grain and fodder crop (Basavaraj *et al*., 2010). Endowed with high photosynthetic efficiency and adaptability to various soil types, pearl millet is a quick-growing, short-duration, drought, and heat-tolerant crop. Its drought resistance, coupled with exceptional grain production in adverse conditions, positions pearl millet as a vital cereal in tropical and subtropical regions. Nutritionally rich, pearl millet is a high-energy cereal containing carbohydrates (70%), protein (14.0%), fat (5.7%), fiber (2.0%), and essential vitamins and minerals. Studies indicate its potential to combat iron deficiency, making it a candidate for inclusion in the smart food project. Despite its nutritional benefits, pearl millet is often referred to as the "Poor man's crop," primarily consumed by the economically disadvantaged due to its affordability and high energy content.

The protogynous flowering of pearl millet results in high cross-pollination, exceeding 85%, making it highly heterozygous. This unique floral biology enables the use of various breeding techniques, ranging from population improvement to strict pedigree selection and heterosis breeding. Three gene pools have been identified, each with specific compatibility and crossability characteristics. Historically undervalued, the improvement of pearl millet gained momentum with the introduction of the first widely used cytoplasmic male sterile line, tift 23A, in the 1960s. This breakthrough facilitated the development of grain hybrids in India, leading to the release of hybrids like "HB–1" in 1965 (Athwal, 1965). Subsequent developments in cytoplasmic genetic male sterility systems enabled the production of hybrids with increased drought tolerance, resistance to biotic stress, and improved yield efficiency (Burton, 1983). Heterosis, or hybrid vigor, emerged as a powerful genetic tool for enhancing pearl millet yield, revolutionizing its commercial cultivation in India.

Genetic variability is a fundamental prerequisite for crop breeding, enabling the development of improved varieties to meet the demands of a growing population. Pearl millet's grain yield and micronutrient content, influenced by both genotype and environmental conditions during grain filling, are critical traits for improvement (Acharya, 2022). Associations between these traits and other quality parameters provide valuable insights into developing high-yielding lines with elevated micronutrient content. In the context of heterosis breeding, the study and evaluation of diverse potential lines and hybrid combinations for grain yield, yield components, and resistance to downy mildew are essential. Identifying potential hybrid combinations through a thorough understanding of heterotic behavior is paramount for successful genetic improvement in pearl millet (Singh *et al.,* 2017).

This study employs a half-diallel mating design to estimate general combining ability and specific combining ability in pearl millet. The half-diallel analysis, popular for assessing gene action and combining ability, provides insights into the potential of new hybrids for polygenic inheritance. The efficient partitioning of genetic variances into additive and non-additive components enhances the formulation of effective breeding programs and allows for the simultaneous evaluation of a large number of germplasm lines. In summary, this research aims to elucidate the GCA and SCA of pearl millet inbred lines for grain yield and other agronomic traits under normal and downy mildew-infested conditions. By employing a robust half-diallel analysis, this study contributes to the understanding of the genetic factors influencing pearl millet's performance and aids in the identification of superior hybrids for sustainable pearl millet cultivation (Adeoti *et al*., 2017).

METHODOLOGY

The study, was conducted during the *kharif* 2021 at the Centre for Crop Improvement, S. D. Agricultural University, Sardarkrushinagar, North Gujarat. Eight restorer parents, 28 F_1 crosses, and one standard check (GHB 1129) formed the experimental material. This included 37 genotypes developed through diallel mating excluding reciprocals. The genotypes were planted in a randomized block design (RBD) with three replications. Hybridization was performed in a crossing block during the summer of 2021. Given the protogynous nature of pearl millet, care was taken to prevent external pollen contamination during hybridization. Hybridization was conducted in the morning, using hand pollination. For genetically pure seeds, each parental genotype was selfed. Proper labeling was maintained for individual parental lines and F1 seeds. Normal and favourable weather conditions during the crop season were recorded by the Department of Agricultural Meteorology, S. D. Agricultural University. The soil type at the experimental site is sandy loam with a pH of 7.5. The study employed a comprehensive methodology to ensure accurate data collection and robust genetic analysis of pearl millet.

A. Observations recorded

Observations on grain yield and its contributing traits were recorded from five randomly selected and competitive plants per genotype in each replication.

1. Days to flowering and Days to maturity: Recorded on a plot basis.
2. Plant Height (cm): Measured from the base of the plant to the tip of the panicle at maturity.
3. Number of Productive Tillers per Plant: Counted from randomly selected plants.

4. Panicle Length (cm): Measured from the base to the tip of the main shoot at harvesting.
5. Panicle Diameter (mm): Measured at the maximum thickness using vernier caliper.
6. Panicle Weight (g): Weighed after sun drying.
7. Grain Yield per Plant (g): Harvested, threshed, cleaned, and sun-dried grains weighed.
8. Test Weight (g): Weight of 1000 grains measured from the grain sample.
9. Harvest Index (%): Calculated as Grain yield of plant divided by Total biological yield of the plant, multiplied by 100.
2. Iron Content and Zinc Content (mg/kg): Determined by atomic absorption spectrophotometry.

B. Statistical analysis

The observations on various traits recorded and mean values were subjected to statistical analysis to test the significance of variation observed among different progenies. Analysis of variance for the experiment conducted as per RBD was carried out by following the popular method Panse and Sukhatme (1978). Relative heterosis, Heterobeltiosis and Standard heterosis is calculated as suggested by Briggle (1963); Fonseca and Patterson (1968); Meredith and Bridge (1972) respectively. The variation among the hybrids was further partitioned into sources attributed to general combining ability and specific combining ability components in accordance with the procedure suggested by Griffing (1956).

RESULTS AND DISCUSSION

The experimental consequences achieved from the present research with experimental material of 8 parental lines, 28 F_1 hybrids and 1 check by diallel excluding reciprocals mating design is presented with discussion. While interpreting the data, the positive effect of heterosis, combining ability and mean performance were considered as favourable for the characters *viz.*, grain yield per plant, plant height, number of effective tillers per plant, panicle length, panicle diameter, panicle weight, test weight, harvest index, Fe content and Zn content. On the other hand, negative effects were considered favourable for the characters, *viz.*, days to flowering and days to maturity. An examination of mean values for different hybrids and their parents (Table 2) highlights key characteristics among the eight parents. Specifically, parents 7042 S, 15636 R, and 05888 B exhibited early flowering, while parents 15636 R, 7042 S, and 07111 B matured earlier. For plant height, the top performers among the eight parents were 2889 B, 08444 B, and 15388 R, recording the highest values. Parents 15388 R, 2889 B, and 7042 S displayed the maximum number of productive tillers per plant, with 15388 R leading in this aspect. Notably, parents 08444 B and 2889 B emerged as the best performers for panicle length, panicle weight, grain yield per plant, and test weight. In contrast, parent 15636 R, although early in flowering and maturity, exhibited lower performance for plant height, number of productive tillers per plant, panicle length, panicle diameter, panicle weight, and grain yield per plant. The parents 30177 HP, 15388 R, and 07111 B were identified as top performers for panicle diameter, while 08444 B and 07111 B excelled in grain yield per plant. Harvest index showcased the superior performance of parents 05888 B, 07111 B, and 08444 B. Finally, parents 05888 B, 15388 R, and 2889 B demonstrated excellence in Fe and Zn content (Bachkar *et al.*, 2014; Mithleshkumar, 2019).

The top-performing hybrids (Table 2), namely 08444 B × 15388 R, 15636 R × 15388 R, and 08444 B × 05888 B, exhibited superior grain yield per plant among the twenty-eight hybrids. Specifically, the cross 08444 B × 05888 B demonstrated higher performance across various traits, including plant height, number of productive tillers per plant, panicle length, panicle weight, and overall grain yield per plant. Furthermore, the parents involved in these successful crosses not only displayed high yield but also excelled in at least one additional yield attribute. This suggests a strong potential for these parent combinations to consistently pass on favorable traits to their offspring. Additionally, hybrids such as 15636 R × 15388 R, 05888 B × 15636 R, and 2889 B × 30177 HP exhibited early flowering and maturity, with the former being particularly superior in grain yield per plant. Notably, certain hybrids, like 15636 R × 15388 R, demonstrated a dwarf plant height while maintaining a higher grain yield per plant. The highest performance for plant height was observed in hybrids 07111 B × 05888 B and 05888 B × 15388 R. Hybrid 08444 B × 15388 R ranked first for grain yield per plant and showed superior performance in panicle length, panicle weight, and iron content. Specific crosses, such as 30177 HP × 15388 R and 15388 R × 7042 S, excelled in panicle diameter. Combinations like 30177 HP × 7042 S, 07111 B × 2889 B, and 08444 B × 30177 HP emerged as top rankers for test weight. Harvest index was notable in hybrids 05888 B × 15636 R, 05888 B × 2889 B, and 07111 B × 15636 R. Finally, hybrids 15388 R × 7042 S and 08444 B × 7042 S exhibited the best performance for iron and zinc content (Chittora and Patel 2017; Reshma *et al.*, 2017).

Table 3 highlights the superior standard heterotic crosses, with the most notable being 08444 B × 15388 R, 15636 R × 15388 R, 08444 B × 05888 B, 05888 B × 7042 S, and 05888 B × 15636 R, showcasing the highest heterosis over the standard check GHB 1129 for grain yield per plant. Specifically, 08444 B × 15388 R displayed significant standard heterosis for plant height, test weight, panicle weight, and Fe content, along with favorable heterobeltiosis for days to maturity, panicle diameter, panicle weight, Fe content, and Zn content. Similarly, 15636 R × 15388 R exhibited standard heterosis and heterobeltiosis for days to flowering, days to maturity, panicle weight, test weight, and harvest index. This reveals that heterotic hybrids for grain yield demonstrate significant and positive heterosis for multiple yield traits, aligning with findings from previous studies. The examination of Table 4.20 underscores that 08444 B × 15388 R, followed by 15636 R × 15388 R and 08444 B × 05888 B, not only manifested the highest standard heterosis but also displayed significant heterosis over the standard check for various yield-contributing characters. Notably, 15636 R × 15388 R, while exhibiting highly significant positive heterosis for grain yield per plant, also showed negative and significant heterobeltiosis for plant height, suggesting its potential as a dwarf, high-yielding hybrid for commercial cultivation, pending further evaluation across diverse environments. Understanding the cause of heterosis for seed yield is crucial. Previous studies by Whitehouse *et al*. (1958); Williams and Gilbert (1960) proposed that seed yield does not have a specific gene system but is rather an outcome of the interactive effects of multiple yield components. Combinational heterosis, where favorable associations among yield components contribute to seed yield, has been reported in pearl millet (Hagberg, 1953). The present study compared the four most heterotic crosses with the heterotic response of other yield components, emphasizing the importance of evaluating the practical utility of heterosis over the better parent or standard check variety. The ultimate goal was to identify combinations that exhibit high heterobeltiosis for better transgressive segregants and characterize parents for their future use in breeding programs (Nandaniya *et al.*, 2016; Rafiq and Kumar 2016; Acharya and Khanpara 2017; Badhe and Patil 2018).

The general combining ability effects of the parents (Table 4) revealed that none of the parent was found to be good general combiner for all the characters. Among the 8 parents, the parents *viz.* 05888 B, 08444 B and 15388 R were found good general combiner for grain yield per plant (Fig. 1). Apart from grain yield per plant, the parent 05888 B was also good combiner for days to flowering, days to maturity, plant height, number of productive tillers per plant, panicle length, panicle weight, grain yield per plant and harvest index. Likewise parent 15388 R was also good combiner for number of productive tillers per plant, panicle diameter, panicle weight, grain yield per plant, Fe content and Zn content. Whereas, the parent 08444 B was also good combiner for plant height, panicle length, panicle weight, grain yield per plant and test weight. Moreover, the parent 2889 B was also good combiner for plant height, number of productive tillers per plant, Fe content and Zn content. As far as earliness was concern, the parents 05888 B, 15636 R and 7042 S were found good general combiners for days to flowering, and 07111 B, 05888 B and 15636 R for days to maturity. From the result, it was observed that the parents 08444 B, 05888 B and 2889 B were good general combiners for plant height. For the number of productive tillers per plant, the parents 05888 B, 2889 B, 15388 R and 7042 S were recorded as good combiners. The parents 08444 B and 05888 B had good potential for panicle length. The good general combiners for panicle diameter were 07111 B, 30177 HP and 15388 R. The parents 05888 B, 08444 B and 15388 R were noticed good general combiners for panicle weight and grain yield per plant. It was observed from the present investigation that parents 08444 B, 30177 HP and 7042 S having good general combining ability for test weight. The parents 05888 B and 15636 R were found good general combiners for harvest index. The parents 2889 B and 15388 R were found good general combiners for Fe and Zn content. Thus, the parents were good general combiner for grain yield per plant also showed good general combiner for other traits (Karvar and Pawar 2017; Thribhuvan *et al.,* 2023).

The results of specific combining ability (Table 5) indicated that out of twenty-eight crosses, eleven crosses exhibited highly significant and positive *sca* effects and thirteen had highly significant but negative *sca* effects for grain yield per plant. The highest *sca* effect for grain yield per plant was manifested by 15636 R × 15388 R and the least by 07111 B × 15388 R (Fig. 2). Being higher manifested and highly significant and positive *sca* effect for grain yield per plant, the cross 15636 R × 15388 R also exhibited significant *sca* effect in desired direction for days to flowering, days to maturity, plant height, number of productive tillers per plant, panicle length, panicle diameter, panicle weight, grain yield per plant, test weight and harvest index. The summary of *sca* effects narrated in Table 6 revealed that none of crosses showed consistently significant and desirable *sca* effects for all characters. However, the crosses manifested desired *sca* effect of grain yield per plant also manifested significant and positive *sca* effects for other yield attributing characters. The superior crosses 15636 R × 15388 R, 08444 B × 15388 R and 05888 B × 7042 S possessed poor × good, good × good and good × poor general combiner parents, respectively. These crosses could be used for commercial F_1 hybrid after evaluation over environments. Considering the *gca* effects of parents involved for the expression of *sca* effects in a particular hybrid the other crosses namely 2889 B × 30177 HP, 07111 B × 30177 HP and 05888 B × 15636 R depicted poor × average, poor × average and good × poor combiner of parents, respectively. These hybrids expressed significant and positive *sca* effect by involving poor and average parents could be due to better complementation between favourable alleles of the parents involved. The *gca* effects of the parents and *sca* effects of their crosses in the present study indicated that the crosses between two poor general combiners were not always the worst for their *sca* effects. The *sca* effects of certain crosses in the undesirable direction could be due to the failure of desirable alleles of the parents to co-operate. As a result, a cross from good general combiner parents may also exhibit poor *sca* effects. Table 6 revealed that there was high degree of correspondence between *per se* performance and *sca* effects of hybrids as well as estimates of heterosis.

Table 1: Analysis of variance (Mean square) for parents and hybrids for grain yield and its component characters in pearl millet.

Source of variation	Degree of freedom	Mean sum of square					
		Days to flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle diameter (mm)
Replications	2	2.58	2.53	12.50	0.03	2.60	1.03
Genotypes	35	108.45**	97.09**	2265.15**	0.99**	27.49**	42.11**
Parents (P)	7	53.61**	34.29**	2456.77**	1.36**	27.61**	43.35**
Hybrids (H)	27	124.85**	115.19**	2005.40**	0.91**	24.42**	42.62**
P *vs* H	1	49.29**	48.21**	7936.30**	33.78**	109.51**	19.46**
Error	70	1.93	1.96	39.72	0.03	5.01	1.02

Table 1 Cont…

Source of variation	Degree of freedom	Mean sum of square					
		Panicle weight (g)	Grain yield per plant (g)	Test weight (g)	Harvest index (%)	Fe content (mg/kg)	Zn content (mg/kg)
Replications	2	0.04	0.90	0.17	3.17	61.53	73.84
Genotypes	35	1664.41**	842.08**	11.28**	214.92**	1424.98**	788.87**
Parents (P)	7	445.11**	176.03**	9.74**	166.48**	902.05**	629.02**
Hybrids (H)	27	1739.56**	899.00**	11.96**	203.33**	1602.19**	815.26**
P *vs* H	1	8170.28**	3967.32**	3.56**	867.01**	300.51**	1195.22**
Error	70	5.44	3.25	0.48	4.71	39.75	28.28

* and ** indicates significant at P = 0.05 and P = 0.01 levels, respectively.

Table 2: Mean performance of genotypes for yield and yield attributing characters in pearl millet.

Sr. No.	Genotypes	Days to flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle diameter (mm)
1.	07111 B	53.33	88.33	117.57	2.00	18.37	23.70
2.	08444 B	54.67	90.33	162.23	2.13	24.30	20.00
3.	05888 B	51.00	90.67	145.67	1.80	19.13	22.93
4.	2889 B	60.33	91.00	186.63	3.07	23.20	23.52
5.	30177 HP	56.33	90.00	112.87	1.87	17.77	29.49
6.	15636 R	49.67	81.67	108.47	1.73	16.63	16.62
7.	15388 R	57.33	92.67	153.90	3.47	22.40	25.88
8.	7042 S	47.67	87.33	114.60	2.93	16.77	22.48
9.	07111 B × 08444 B	59.33	86.00	184.17	1.80	24.83	27.16
10.	07111 B × 05888 B	59.00	86.33	192.23	2.80	25.83	27.77
11.	07111 B × 2889 B	52.33	82.00	133.42	2.80	20.70	22.99
12.	07111 B × 30177 HP	54.33	84.00	138.53	1.53	21.90	27.19
13.	07111 B × 15636 R	62.67	91.33	157.60	2.93	23.10	24.24
14.	07111 B × 15388 R	58.33	94.67	124.33	2.40	18.30	23.02
15.	07111 B × 7042 S	49.67	82.67	143.50	1.67	21.87	18.59
16.	08444 B × 05888 B	49.67	83.33	225.87	3.33	30.30	28.18
17.	08444 B × 2889 B	61.33	93.33	158.27	2.87	22.47	19.26
18.	08444 B × 30177 HP	56.33	89.67	179.23	2.27	24.20	25.83
19.	08444 B × 15636 R	63.67	94.00	162.63	1.67	22.90	20.70
20.	08444 B × 15388 R	59.33	90.00	185.70	2.00	25.20	27.58
21.	08444 B × 7042 S	55.67	89.33	154.73	1.60	21.57	19.67
22.	05888 B × 2889 B	59.33	86.33	163.63	2.20	21.63	22.23
23.	05888 B × 30177 HP	49.67	81.33	174.13	2.27	23.50	23.19
24.	05888 B × 15636 R	45.33	78.00	177.90	1.67	23.87	25.25
25.	05888 B × 15388 R	59.00	88.00	191.23	2.87	25.00	21.82
26.	05888 B × 7042 S	55.67	84.00	155.30	2.47	21.13	18.59
27.	2889 B × 30177 HP	45.67	80.33	149.90	2.40	18.20	30.45
28.	2889 B × 15636 R	49.67	81.67	160.10	1.87	22.33	21.65
29.	2889 B × 15388 R	54.67	87.33	125.30	1.47	18.17	17.57
30.	2889 B × 7042 S	62.00	95.33	146.23	2.33	20.57	22.92
31.	30177 HP × 15636 R	65.67	101.00	99.23	1.27	15.63	22.04
32.	30177 HP × 15388 R	62.33	96.67	157.33	2.07	21.60	31.97
33.	30177 HP × 7042 S	49.67	83.33	171.97	1.80	23.77	24.57
34.	15636 R × 15388 R	42.33	78.00	149.70	2.80	22.87	27.17
35.	15636 R × 7042 S	46.00	81.67	147.03	2.80	21.67	24.10
36.	15388 R × 7042 S	63.00	97.33	124.90	2.80	19.70	29.08
37.	GHB 1129	50.00	85.33	167.37	2.73	22.77	27.07
	General mean	54.92	87.68	154.15	2.28	21.73	23.96
	Parental mean	53.79	89.00	137.74	2.38	19.82	23.08
	Hybrid mean	55.42	87.39	158.36	2.24	22.24	24.10
	Parent range	47.67-60.33	81.67-92.67	108.47-186.63	1.73-3.47	16.63-24.30	16.62-29.49
	Hybrid range	42.33-65.67	78.00-101.00	99.23-225.87	1.27-3.33	15.63-30.30	17.57-31.97
	S.Em. ±	0.80	0.81	3.64	0.10	1.29	0.58
	CD at 5%	2.24	2.26	10.19	0.28	3.62	1.63
	CV %	2.52	1.59	4.10	7.54	10.31	4.23

Table 2 Conti….

Sr. No.	Genotypes	Panicle weight (g)	Grain yield per plant (g)	Test weight (g)	Harvest index (%)	Fe content (mg/kg)	Zn content (mg/kg)
1.	07111 B	40.07	23.83	5.09	30.18	48.09	17.27
2.	08444 B	46.88	28.98	9.73	27.27	35.95	29.41
3.	05888 B	21.60	13.14	6.17	35.46	77.13	49.41
4.	2889 B	24.38	14.27	10.55	17.80	62.09	50.83
5.	30177 HP	15.25	9.14	7.23	22.78	29.63	9.57
6.	15636 R	13.22	7.02	7.82	20.68	61.47	32.07
7.	15388 R	21.99	11.67	7.09	14.86	66.58	39.82
8.	7042 S	16.18	10.04	8.58	14.95	34.80	27.27
9.	07111 B × 08444 B	67.17	42.95	9.19	28.95	71.62	48.63
10.	07111 B × 05888 B	24.96	16.81	5.65	19.81	39.99	38.96
11.	07111 B × 2889 B	23.31	12.66	11.14	21.20	73.88	39.47
12.	07111 B × 30177 HP	65.79	42.76	8.85	33.01	52.16	33.79
13.	07111 B × 15636 R	16.58	9.74	6.86	43.05	50.95	45.59
14.	07111 B × 15388 R	14.50	7.39	5.24	25.43	46.13	35.71
15.	07111 B × 7042 S	12.02	6.46	7.21	23.34	55.43	30.16
16.	08444 B × 05888 B	79.44	55.36	7.92	24.94	19.42	5.86
17.	08444 B × 2889 B	29.93	17.83	5.53	35.26	40.13	30.30
18.	08444 B × 30177 HP	44.39	29.73	10.93	30.38	28.88	21.82
19.	08444 B × 15636 R	24.95	16.44	6.45	27.18	45.05	36.03
20.	08444 B × 15388 R	86.25	60.05	9.56	29.24	89.37	53.97
21.	08444 B × 7042 S	21.89	12.98	7.98	15.99	92.63	66.40
22.	05888 B × 2889 B	49.78	32.31	9.02	44.05	34.60	33.27
23.	05888 B × 30177 HP	69.39	46.21	8.91	30.23	45.13	17.19
24.	05888 B × 15636 R	75.77	51.87	8.09	46.91	62.46	52.53
25.	05888 B × 15388 R	76.25	45.59	9.34	31.60	84.48	55.65
26.	05888 B × 7042 S	80.09	53.65	7.60	35.75	38.77	33.68
27.	2889 B × 30177 HP	67.80	47.65	9.62	37.65	81.15	55.57
28.	2889 B × 15636 R	40.87	18.32	7.60	26.20	62.17	50.78
29.	2889 B × 15388 R	46.07	26.73	4.90	38.83	76.26	53.77
30.	2889 B × 7042 S	28.49	17.28	4.77	17.68	44.21	34.66
31.	30177 HP × 15636 R	20.17	11.51	6.47	24.80	71.52	48.66
32.	30177 HP × 15388 R	38.03	27.13	8.31	31.34	73.34	57.35
33.	30177 HP × 7042 S	35.09	17.02	12.01	15.34	39.28	37.37
34.	15636 R × 15388 R	79.09	56.48	10.74	38.82	23.28	13.39
35.	15636 R × 7042 S	43.50	23.58	9.57	29.35	19.93	13.57
36.	15388 R × 7042 S	22.75	15.04	10.69	28.44	105.22	74.71
37.	GHB 1129	65.60	41.23	7.69	30.26	70.52	59.34
	General mean	41.88	26.51	8.11	28.35	55.51	38.75
	Parental mean	24.95	14.76	7.78	23.00	51.97	31.96
	Hybrid mean	45.87	29.34	8.22	29.81	55.98	39.96
	Parent range	13.22-46.88	7.02-28.98	5.09-10.55	14.86-35.46	29.63-77.13	9.57-50.83
	Hybrid range	12.02-86.25	6.46-60.05	4.77-12.01	15.34-46.91	19.42-105.22	5.86-74.71
	S.Em. ±	1.35	1.04	0.40	1.25	3.64	3.07
	CD at 5%	3.77	2.91	1.12	3.51	10.19	8.60
	CV %	5.66	6.91	8.49	7.67	11.44	13.93

Table 3: Summary of table showing heterosis range and number of significant crosses for all characters.

Traits	Heterosis range			No. of significant			No. of +ve significant			No. of -ve significant		
	MP	BP	SC	MP	BP	SC	MP	BP	SC	MP	BP	SC
Days to flowering	-21.71 to 23.90	-26.16 to 17.50	-15.33 to 31.33	25	19	23	15	8	19	10	11	4
Days to maturity	-11.23 to 17.67	-15.83 to 12.22	-8.59 to 18.36	25	25	20	8	7	12	17	18	8
Plant height (cm)	-26.41 to 51.20	-32.86 to 50.06	-40.71 to 34.95	25	23	21	19	13	7	6	10	14
No. of productive tillers per plant	-55.10 to 69.49	-57.69 to 56.25	-53.66 to 21.95	22	23	19	8	4	1	14	19	18
Panicle length (cm)	-20.32 to 39.52	-21.70 to 35.02	-31.33 to 33.09	15	10	5	14	7	1	1	3	4
Panicle diameter (mm)	-28.88 to 31.26	-32.12 to 22.88	-35.09 to 18.12	21	20	21	13	7	3	8	13	18
Panicle weight (g)	-57.25 to 349.18	-70.00 to 270.77	-81.67 to 31.49	28	26	24	20	18	6	8	8	18
Grain yield per plant (g)	-61.84 to 504.35	-72.88 to 383.81	-84.32 to 45.64	26	26	26	20	18	8	6	8	18
Test weight (g)	-50.16 to 51.90	-54.80 to 39.98	-38.04 to 56.11	20	18	20	13	7	13	7	11	7
Harvest index (%)	-39.65 to 137.74	-44.14 to 118.13	-49.32 to 55.00	22	20	18	18	11	8	4	9	10
Fe content (mg/kg)	-65.65 to 161.85	-74.82 to 157.68	-72.46 to 49.20	20	19	20	12	6	4	8	13	16
Zn content (mg/kg)	-85.12 to 151.73	-88.13 to 125.79	-90.12 to 25.91	21	19	20	15	9	1	6	10	19

Table 4: Estimation of general combining ability (gca) effects of parents for various characters in pearl millet.

Parents		Days to flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle diameter (mm)
07111 B		0.68 **	-0.61 *	-7.51 **	-0.05	-0.21	0.35 *
08444 B		1.92 **	1.66 **	19.11 **	-0.06 *	2.47 **	-0.65 **
05888 B		-1.58 **	-2.11 **	18.76 **	0.08 *	1.42 **	-0.20
2889 B		1.02 **	-0.14	2.61 *	0.16 **	-0.49	-1.07 **
30177 HP		0.08	0.66 **	-8.80 **	-0.31 **	-1.10 **	2.94 **
15636 R		-2.08 **	-2.07 **	-11.29 **	-0.20 **	-0.97 *	-1.65 **
15388 R		1.82 **	2.76 **	-1.77	0.29 **	0.03	1.51 **
7042 S		-1.85 **	-0.14	-11.11**	0.09 **	-1.15 **	-1.24 **
Range	**Min.**	-2.08	-2.11	-11.29	-0.31	-1.15	-1.65
	Max.	1.92	2.76	19.11	0.29	2.47	2.94
S.Em.±		0.24	0.24	1.08	0.03	0.38	0.17
Positive		5	3	3	4	3	3
Positive significant		4	3	3	4	2	3
Negative		3	5	5	4	5	5
Negative Significant		3	3	4	3	3	4

* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.

Table 4: Conti…

Parents		Panicle weight (g)	Grain yield per plant (g)	Test weight (g)	Harvest index (%)	Fe content (mg/kg)	Zn content (mg/kg)
07111 B		-6.65 **	-4.85 **	-0.88 **	0.05	-0.94	-3.68 **
08444 B		7.68 **	5.84 **	0.39 **	-0.82 *	-3.68 **	-2.18 *
05888 B		12.79 **	9.32 **	-0.42 **	4.95 **	-1.67	-0.76
2889 B		-3.60 **	-3.36 **	0.06	0.18	4.08 **	5.59 **
30177 HP		0.02	0.54	0.65 **	-0.64	-4.51 **	-5.27 **
15636 R		-4.36 **	-3.29 **	-0.17	2.30 **	-3.75 **	-1.89 *
15388 R		3.60 **	2.68 **	-0.01	-0.13	13.54 **	8.06 **
7042 S		-9.48 **	-6.88 **	0.39 **	-5.89 **	-3.07 **	0.15
Range	**Min.**	-9.48	-6.88	-0.88	-5.89	-4.51	-5.27
	Max.	12.79	9.32	0.65	4.95	13.54	8.06
S.Em.±		0.40	0.31	0.12	0.37	1.08	0.91
Positive		4	4	4	4	2	3
Positive significant		3	3	3	2	2	2
Negative		4	4	4	4	6	5
Negative Significant		4	4	2	2	4	4

* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.

Table 5: Estimation of specific combining ability (sca) effects for various characters in pearl millet.

Sr. No.	Hybrids	Days to flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle diameter (mm)
1.	07111 B × 08444 B	1.68 **	-2.80 **	18.80 **	-0.36 **	0.86	3.58 **
2.	07111 B × 05888 B	4.84 **	1.30 *	27.20 **	0.50 **	2.92 **	3.74 **
3.	07111 B × 2889 B	-4.42 **	-5.00 **	-15.46 **	0.42 **	-0.31	-0.16
4.	07111 B × 30177 HP	-1.49 *	-3.80 **	1.05	-0.38 **	1.50	0.03
5.	07111 B × 15636 R	9.01 **	6.27 **	22.62 **	0.91 **	2.57 *	1.67 **
6.	07111 B × 15388 R	0.78	4.77 **	-20.17 **	-0.11	-3.23 **	-2.72 **
7.	07111 B × 7042 S	-4.22 **	-4.33 **	8.35 **	-0.64 **	1.52	-4.39 **
8.	08444 B × 05888 B	-5.72 **	-3.97 **	34.22 **	1.05 **	4.70 **	5.15 **
9.	08444 B × 2889 B	3.34 **	4.07 **	-17.23 **	0.50 **	-1.22	-2.89 **
10.	08444 B × 30177 HP	-0.72	-0.40	15.14 **	0.37 **	1.12	-0.34
11.	08444 B × 15636 R	8.78 **	6.67 **	1.04	-0.34 **	-0.31	-0.88
12.	08444 B × 15388 R	0.54	-2.17 **	14.59 **	-0.50 **	0.99	2.85 **
13.	08444 B × 7042 S	0.54	0.07	-7.04 *	-0.70 **	-1.46	-2.32 **
14.	05888 B × 2889 B	4.84 **	0.83	-11.52 **	-0.31 **	-1.00	-0.37
15.	05888 B × 30177 HP	-3.89 **	-4.97 **	10.39 **	0.23 **	1.48	-3.42 **
16.	05888 B × 15636 R	-6.06 **	-5.57 **	16.65 **	-0.48 **	1.71	3.22 **
17.	05888 B × 15388 R	3.71 **	-0.40	20.46 **	0.23 **	1.85	-3.37 **
18.	05888 B × 7042 S	4.04 **	-1.50 *	-6.13 *	0.03	-0.84	-3.85 **
19.	2889 B × 30177 HP	-10.49 **	-7.93 **	2.31	0.28 **	-1.92	4.71 **
20.	2889 B × 15636 R	-4.32 **	-3.87 **	15.00 **	-0.37 **	2.09 *	0.49
21.	2889 B × 15388 R	-3.22 **	-3.03 **	-29.32 **	-1.26 **	-3.08 **	-6.74 **
22.	2889 B × 7042 S	7.78 **	7.87 **	0.96	-0.19 *	0.50	1.36 **
23.	30177 HP × 15636 R	12.61 **	14.67 **	-34.46 **	-0.50 **	-4.00 **	-3.13 **
24.	30177 HP × 15388 R	5.38 **	5.50 **	14.12 **	-0.18 *	0.97	3.65 **
25.	30177 HP × 7042 S	-3.62 **	-4.93 **	38.10 **	-0.25 **	4.32 **	-1.00 *
26.	15636 R × 15388 R	-12.46 **	-10.43 **	8.98 **	0.44 **	2.10 *	3.43 **
27.	15636 R × 7042 S	-5.12 **	-3.87 **	15.66 **	0.64 **	2.09 *	3.11 **
28.	15388 R × 7042 S	7.98 **	6.97 **	-15.99 **	0.15	-0.88	4.93 **
S.Em.±		0.73	0.73	3.30	0.09	1.17	0.53
Range		-12.46 to 12.61	-10.43 to 14.67	-34.46 to 38.1	-1.26 to 1.05	-4.0 to 4.70	-6.74 to 5.15
No. of significant		24	24	24	25	10	22
No. of +ve significant		12	9	15	11	7	12
No. of -ve significant		12	15	9	14	3	10

* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.

Table 5: Cont…

Sr. No.	Hybrids	Panicle weight (g)	Grain yield per plant (g)	Test weight (g)	Harvest index (%)	Fe content (mg/kg)	Zn content (mg/kg)
1.	07111 B × 08444 B	24.91 **	15.86 **	1.55 **	1.42	21.16 **	16.31 **
2.	07111 B × 05888 B	-22.40 **	-13.76 **	-1.17 **	-13.49 **	-12.49 **	5.22 *
3.	07111 B × 2889 B	-7.66 **	-5.23 **	3.84 **	-7.32 **	15.66 **	-0.62
4.	07111 B × 30177 HP	31.20 **	20.96 **	0.96 **	5.30 **	2.52	4.56
5.	07111 B × 15636 R	-13.63 **	-8.22 **	-0.21	12.40 **	0.56	12.98 **
6.	07111 B × 15388 R	-23.66 **	-16.55 **	-1.99 **	-2.79 **	-21.56 **	-6.85 **
7.	07111 B × 7042 S	-13.07 **	-7.91 **	-0.42	0.89	4.36	-4.49
8.	08444 B × 05888 B	17.75 **	14.10 **	-0.17	-7.48 **	-30.32 **	-29.37 **
9.	08444 B × 2889 B	-15.37 **	-10.75 **	-3.04 **	7.60 **	-15.36 **	-11.29 **
10.	08444 B × 30177 HP	-4.53 **	-2.75 **	1.77 **	3.54 **	-18.02 **	-8.91 **
11.	08444 B × 15636 R	-19.59 **	-12.20 **	-1.90 **	-2.59 *	-2.61	1.92
12.	08444 B × 15388 R	33.76 **	25.43 **	1.06 **	1.89	24.41 **	9.91 **
13.	08444 B × 7042 S	-17.53 **	-12.08 **	-0.92 **	-5.60 **	44.29 **	30.25 **
14.	05888 B × 2889 B	-0.64	0.25	1.26 **	10.62 **	-22.90 **	-9.73 **
15.	05888 B × 30177 HP	15.36 **	10.26 **	0.57	-2.38 *	-3.78	-14.95 **
16.	05888 B × 15636 R	26.12 **	19.74 **	0.56	11.36 **	12.79 **	17.01 **
17.	05888 B × 15388 R	18.64 **	7.49 **	1.65 **	-1.53	17.52 **	10.18 **
18.	05888 B × 7042 S	35.56 **	25.11 **	-0.49	8.39 **	-11.58 **	-3.88
19.	2889 B × 30177 HP	30.16 **	24.37 **	0.79 *	9.81 **	26.49 **	17.08 **
20.	2889 B × 15636 R	7.61 **	-1.13	-0.41	-4.57 **	6.76 *	8.91 **
21.	2889 B × 15388 R	4.85 **	1.30	-3.27 **	10.48 **	3.55	1.95
22.	2889 B × 7042 S	0.35	1.42	-3.80 **	-4.91 **	-11.88 **	-9.26 **
23.	30177 HP × 15636 R	-16.71 **	-11.84 **	-2.13 **	-5.16 **	24.69 **	17.65 **
24.	30177 HP × 15388 R	-6.80 **	-2.19 **	-0.45	3.81 **	9.22 **	16.38 **
25.	30177 HP × 7042 S	3.33 **	-2.74 **	2.85 **	-6.43 **	-8.23 **	4.31
26.	15636 R × 15388 R	38.64 **	30.99 **	2.80 **	8.35 **	-41.61 **	-30.96 **
27.	15636 R × 7042 S	16.12 **	7.66 **	1.23 **	4.64 **	-28.34 **	-22.86 **
28.	15388 R × 7042 S	-12.59 **	-6.86 **	2.19 **	6.16 **	39.66 **	28.33 **
	S.Em.±	1.22	0.94	0.36	1.14	3.30	2.78
	Range	-23.66 to 38.64	-16.55 to 30.99	-3.8 to 3.84	-13.49 to 12.4	-41.61 to 44.29	-30.96 to 30.25
	No. of significant	26	24	20	24	22	21
	No. of +ve significant	14	11	12	13	11	12
	No. of -ve significant	12	13	8	11	11	9

* and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.

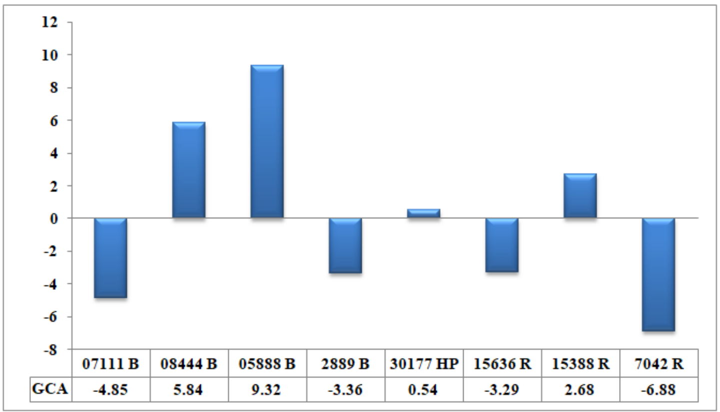

Fig. 1. Diagrammatically representation of general combining ability effects of parents for grain yield per plant.

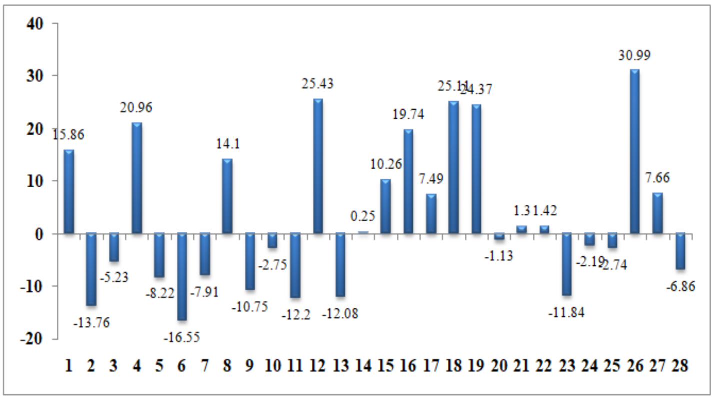

Fig. 2. Graphical representation of specific combining ability effects of hybrids for grain yield per plant.

Table 6: The best specific combinations for grain yield per plant along with *gca* effect of their parents and desirable *sca* effects for yield attributing traits.

Best performing hybrids based on *sca* effect	Grain yield per plant (g)	*sca* effect	*gca* effect		Heterosis over GHB 1129 (%)	Significant and desirable *sca* effect for other traits
			Female	Male		
15636 R × 15388 R	56.48	30.99 **	-3.29 **	2.68 **	36.97 **	DF, DM, PH, PTPP, PL, PD, PW, GY, TW, HI
08444 B × 15388 R	60.05	25.43 **	5.84 **	2.68 **	45.64 **	DM, PH, PD, PW, GY, TW, Fe, Zn
05888 B × 7042 S	53.65	25.11 **	9.32 **	-6.88 **	30.11 **	DM, PW, GY, HI
2889 B × 30177 HP	47.65	24.37 **	-3.36 **	0.54	15.57 **	DF, DM, PTPP, PD, PW, GY, TW, HI, Fe, Zn
07111 B × 30177 HP	42.76	20.96 **	-4.85 **	0.54	20.96 **	DF, DM, PW, GY, TW, HI
05888 B × 15636 R	51.87	19.74 **	9.32 **	-3.29 **	19.74 **	DF, DM, PH, PD, PW, GY, HI, Fe, Zn

DF: Days to flowering, DM: Days to maturity, PH: Plant height, PTPP: Productive tiller per plant, PL: panicle length, PD: Panicle diameter, PW: Panicle weight, GY: Grain yield per plant, TW: Test weight, HI: Harvest index, Fe: Iron content, Zn: Zinc content

Plate 1: Two most promising hybrids in relation to *per se* value, *sca* effect and heterosis for grain yield per plant and useful component characters.

CONCLUSIONS

The comprehensive analysis of variance for both parents and hybrids underscored the substantial genetic variability present in the pearl millet population under investigation. The parents exhibited significant diversity in key agronomic traits, with 08444 B and 2889 B emerging as promising contributors to desirable characteristics. Among the hybrids, 08444 B × 05888 B and 08444 B × 15388 R displayed superior per se performance for panicle traits and grain yield, indicating their potential for enhancing grain yield and associated attributes in pearl millet. Overall, these findings contribute valuable insights to the on-going efforts in pearl millet breeding, offering prospects for the development of improved varieties with enhanced yield and nutritional attributes.

Acknowledgement. I extend my heartfelt gratitude to all those who have been instrumental in the successful completion of this research endeavor. I would like to acknowledge the support of my colleagues and fellow researchers who shared their expertise and perspectives. My sincere thanks are also due to Centre for Crop Improvement, SDAU for providing the necessary resources and facilities. I am indebted to my family for their unwavering support and understanding throughout the course of this research

Conflict of Interest. None.

REFERENCES

Acharya, Z. R. (2022). Genetic analysis of maintainer and pollen fertility restorer lines for yield and its component traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Ph.D. (Agri.) thesis (Unpublished). Sardarkrushinagar Dantiwada Agricultural University, Dantiwada, Gujarat.

Acharya, Z. R. and Khanpara, M. D. (2017). Exploitation of heterosis in Pearl millet [*Pennisetum glaucum* (L.) R. Br.] for yield and its component traits by using male sterile line. *International Journal of Current Microbiology and Applied Sciences*, *6*(12), 750-759.

Adeoti, K., Djedatin, G., Ewedje, E., Beule, T., Santoni, S., Rival, A. and Jaligot, E. (2017). Assessment of genetic diversity among cultivated Pearl millet (*Pennisetum glaucum*, Poaceae) accessions from Benin, West Africa. *African Journal of Biotechnology*, *16*(15), 782-790.

Anonymous (2022). Project Co-ordinator, AICRP on pearl millet review, Mandor, Jodhpur.

Athwal, D. S. (1965). Hybrid Bajra-1 marks a new era. *Indian Farming, 15,* 6-7.

Bachkar, R. M., Pole, S. P. and Patil, S. N. (2014). Heterosis for grain yield and its components in pearl millet (*Pennisetum glaucum* L.). *Indian Journal of Dryland Agricultural Research and Development*, *29*(1), 40-44.

Badhe, P. L. and Patil, H. T. (2018). Heterosis for yield and morpho-nutritional traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Electronic Journal of Plant Breeding, 9*(2), 759-762.

Basavaraj, G., Parthasarathy, R. P., Bhagavatula, S. and Ahmed, W. (2010). Availability and utilization of pearl millet in India. *Journal of SAT Agricultural Research*, *8*, 1-6.

Briggle, L. W. (1963). Heterosis in Wheat - A Review. *Crop Science*, *3*, 407-412.

Burton, G. W. (1983). Breeding pearl millet. *Plant Breeding Review, 1*, 162-182.

Chittora, A. and Patel, J. A. (2017). Estimation of heterosis for grain yield and yield components in pearl millet (*Pennisetum glaucum* (L.) R. Br.). *International Journal of Current Microbiology and Applied Sciences*, *6*(3), 412-418.

Fonseca, S. and Patterson, F. L. (1968). Hybrid vigour in a seven-parent diallel cross in common winter wheat (*Triticum aestivum* L.). *Crop Science*, *8*(1), 85-88.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing system. *Australian Journal of Biological Science, 9*, 463-493.

Hegberg, A. (1953). Heterosis in F_1 combinations in *Galeopsis*. *Hereditas*, *38,* 473-477.

Jethva, A. S., Raval, L., Madariya, R. B., Mehta, D. R. and Mandavia, C. (2012). Heterosis for grain yield and its related characters in pearl millet. *Electronic Journal of Plant Breeding, 3*(3), 848-852.

Karvar, S. H. and Pawar, V. Y. (2017). Heterosis and combining ability in pearl millet. *Electronic Journal of Plant Breeding*, *8*(4), 1197-1215.

Krishnaswamy, N. (1951). Origin and distribution of cultivated plants of south Asian millets. *Indian Journal of Genetics*, *17,* 67-74.

Mithleshkumar, (2019). Delineation of gene action and molecular analysis for grain micronutrients concentration, yield and related traits in pearl millet. Ph.D. (Agri) thesis (Unpublished). Sardarkrushinagar Dantiwada Agricultural University, Dantiwada, Gujarat.

Meredith, W. R. and Bridge, R. R. (1972). Heterosis and gene action in cotton *Gossypium hirsutum*. *Crop Science, 12*, 304-310.

Nandaniya, K. U., Mungra, K. D. and Sorathiya, J. S. (2016). Estimation of heterosis in pearl millet [*Pennisetum glaucum* (L.)] for yield and quality traits. *Electronic Journal of Plant Breeding*, *7*(3), 758-760.

Panse, V. G. and Sukhatme, P. V. (1985). Statistical methods for agricultural workers. ICAR, New Delhi. 4th Edition. pp. 97-156.

Rafiq, S. M. and Sunil kumar, B. (2016). Heterosis studies in diverse cytoplasmic male sterility sources of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Plant Archives*, *16***(**1), 343-348.

Rai, K. N., Yadav, O. P., Gupta, S. K., Mahala, R. S. and Gupta, S. K. (2012). Emerging research priorities in pearl millet. *Journal of SAT Agricultural Research*, *10*, 1-5.

Reshma, M. R., Patel, M. S., Gami, R.A., Bhadauriya, H. S. and Patel, Y. N. (2017). Genetic Analysis in pearl millet [*Pennisetum glaucum* (L) R. Br.]. *International Journal of Current Microbiology and Applied Sciences*, *6*(11), 900-907.

Singh, S. (2017). Pearl millet genes hold key to climate-proof cereals. *Science and Development Net's Asia & Pacific desk.* Retrieved from https://www.scidev.net/asia-pacific/farming/news/pearl-millet-climate-change-resilient-crops.html

Thribhuvan, S. P., Sankar, M. S., Singh, A. M., Mallik, M., Singhal, T. J. K., Meena and Satyavathi, C. T. (2023). Combining ability and heterosis studies for grain iron and zinc concentrations in pearl millet [*Cenchrus americanus* (L). Morrone]. *Frontiers in Plant Science*, *13*, 1029436.

Whitehouse, R. H. N., Thompson J. B. and Ribiero (1958). Studies on the breeding of self-pollinated cereals. The use of diallel cross analysis in yield prediction. *Euphytica*, *7*, 147-169.

Williams, W. and Gilbert, N. (1960). Heterosis and the inheritance of yield in tomato. *Heredity*, *14*, 133-149.

How to cite this article: Gajjar K.D., Patel M.S., Zala H.N., Prajapati N.N. and Patel Y.N. (2023). Towards Superior Pearl millet [*Pennisetum glaucum* (L.) R. Br.]Varieties: Unraveling Combining Ability and Heterosis for Improved Grain Yield. *Biological Forum – An International Journal, 15*(11): 339-348.