INNSPUB

Journal of Biodiversity and Environmental Sciences | JBES
ISSN: 2220-6663 (Print); 2222-3045 (Online)
Website: https://www.innspub.net
E-mail contact: info@innspub.net
Vol. 27, Issue: 2, p. 117-124, 2025

REVIEW PAPER OPEN ACCESS

Heterosis breeding, general and specific combining ability and stability studies in pearl millet: Current trends

Ram Avtar*[1], Krishan Pal[1], Kavita Rani[1], Rohit Kumar Tiwari[1], Mahendra Kumar Yadav[2]

[1]*Department GPB, College of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab, India*

[2]*Department of Agriculture, RNB Global University, Bikaner, Rajasthan, India*

Key words: Pearl millet, Heterosis, General combining ability, Specific combining ability, Stability analysis

DOI: https://dx.doi.org/10.12692/jbes/27.2.117-124 [Published: August 17, 2025]

ABSTRACT

Pearl millet (*Pennisetum glaucum* L.) is a vital cereal crop for arid and semi-arid regions, where enhancing productivity and stability remains a breeding priority. Recent advancements in heterosis breeding, combined with comprehensive analyses of general combining ability (GCA) and specific combining ability (SCA), have significantly contributed to the development of high-yielding, stress-tolerant hybrids. By identifying superior parental lines with strong GCA effects, the use of heterosis for grain yield, earliness, biomass output, and nutritional quality has been reinforced. Breeders may choose parents with advantageous allelic combinations for both additive and non-additive genetic effects thanks to the increased precision of combining ability prediction provided by molecular markers and genomic selection. Utilizing multi-environment trials, stability analysis guarantees hybrids' tolerance to changing climatic and edaphic conditions, which is essential for reducing yield variations. To address issues of food security and nutrition, current research trends center on combining high-throughput phenotyping, genomic technologies, and bio-fortification techniques with heterosis breeding. Breeders may create hybrids with high yield potential and consistent performance in a variety of conditions by integrating stability criteria with GCA and SCA research. Utilizing climate-resilient germplasm, taking use of untapped genetic variety, and using genomic-assisted breeding to create hybrids quickly are all promising avenues for the future. To ensure sustainable production in marginal agro-ecosystems, a methodical strategy that incorporates heterosis, combining ability, and stability studies will be essential in speeding up pearl millet development.

***Corresponding Author:** Ram Avtar ✉ ram27781@gmail.com

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a vital cereal crop cultivated extensively in arid and semi-arid regions of Asia and Africa, owing to its remarkable resilience to drought, heat, and low soil fertility. For millions of smallholder farmers, it is a staple meal, fodder, and source of income, especially in marginal areas where other cereals frequently fail. Pearl millet makes up a sizable portion of India's coarse cereal land and makes a large contribution to both animal feeding systems and food security. It is a prime target for genetic enhancement initiatives because of its high nutritional content, quick growth cycle, and flexibility. A staple meal for millions of people in arid and semi-arid parts of Asia and Africa, pearl millet is one of the main cereal crops grown there (Arya and Yadav, 2009). The utilization of heterosis, or hybrid vigor, has significantly increased pearl millet productivity. The goal of heterosis breeding is to create hybrids that are superior to their parents in terms of quality attributes, stress tolerance, and yield. The genetic divergence between parents, the gene activity involved, and the interactions with the environment all affect the degree and manifestation of heterosis. Large-scale hybrid seed production has been made possible by the advent of cytoplasmic male sterility (CMS) systems, which have aided in the successful creation of hybrids in pearl millet. The evaluation of combining ability, which represents the capability of parental lines to pass on desired features to their offspring, is a crucial step in hybrid breeding. Farmers that produce pearl millet generally expect a higher yield than the native variety in order to increase their revenue. Accordingly, the breeder must use standard tests to assess newly created hybrids or varieties for yield or any other desired characteristics (Sumathi and Revathi, 2017). Specific combining ability (SCA) is connected to non-additive effects including dominance and epistasis, whereas general combining ability (GCA) is mostly tied to additive gene effects. In addition to directing parental selection, the evaluation of GCA and SCA sheds light on the kind of gene action controlling significant agronomic and qualitative characteristics in pearl millet. The most popular technique for figuring out the parent's combining ability as well as the effects and variations of general combining ability (GCA) and specialized combining ability (SCA) for crossings of different characteristics is the line × tester study proposed by Kempthorne (1957). By calculating the average performance of the lines in the crosses, the gca may reflect the breeding values of the lines. Additionally, it could clarify the extent of the gene implicated in the inheritance of grain yield components. To determine the utilization of inbreds and their characteristics, gca and sca are necessary (Navale and Harinarayana, 1992). The assessment of hybrid performance stability in various situations is equally crucial. Finding genotypes with high yield potential and reliable performance is essential because of the extremely changeable climate in areas where pearl millet is grown. Breeders can choose hybrids that continue to perform better across a variety of circumstances by using stability analysis to better understand genotype × environment (G×E) interactions. Understanding the genetic basis of heterosis, enhancing estimates of combining ability, and using stability factors in pearl millet breeding programs have all advanced significantly during the past several decades. Further developments are necessary, nevertheless, given the difficulties brought on by climate change, changing pest and disease pressures, and the demand for higher nutritional quality. With a focus on their implications for sustainable production and resilience in the face of environmental challenges, this study synthesizes current trends and research findings on heterosis breeding in pearl millet by integrating ability analysis and stability investigations. Although it does not appreciate acidic or water-logging soils, it may be cultivated in a variety of soil types. Pearl millet may thrive in a variety of environmental circumstances, including high temperatures and drought stress (Acharya *et al.*, 2017). Selecting attractive parents with good general combiners is necessary to increase the grain production potential of pearl millet types and hybrids (Kumar *et al.*, 2020). The concepts of general combining ability (GCA) and specific combining ability (SCA) were first explained by Sprague and Tatum in 1942. They defined GCA as the relative capacity of a biotype to pass on a desired performance to its offspring. The word "heterosis," which was originally used by Koelreuter in 1766 and was first used by Shull in 1914, describes an increase in F1's fitness and vigor above the parental values. For pearl millet hybrid breeding to be successful, heterosis must be well used. The cytoplasmic male sterile line Tift 23A was initially developed by Burton (1958) and bred at Tifton, Georgia, USA. Characteristics such as early flowering, grain yield per plant, ear head length and girth, Fe and Zn content, and number of tillers/plant require attention in pearl millet improvement. In light of these factors, the current study has been designed with the following goals in mind: to estimate the heterosis for morpho-nutritional characteristics and yield. In India, these hybrids are regarded as dominant cultivars that dominate about 70% of the land, according to findings by Rai *et al.* (2013).

RESULTS AND DISCUSSION

Research on pearl millet shows notable heterosis in stress tolerance, earliness, and grain production, which is mostly caused by non-additive gene activity. Strong GCA in certain parents emphasizes additive effects, but significant SCA effects in some crosses show the importance of dominance and epistasis. Reliable production across a range of climatic circumstances is ensured by hybrids with balanced GCA and SCA, which operate consistently across environments, according to stability assessments.

Combining ability and stability analysis in pearl millet

Combining ability studies in pearl millet reveal that both additive (GCA) and non-additive (SCA) gene actions influence yield and related traits. GCA identifies superior parents, while SCA highlights promising hybrids. Hybrids with balanced GCA and SCA effects retain constant performance across environments, according to stability studies. This ensures dependable production in a range of climatic situations and supports breeding efforts for long-term yield development. Three replications of a randomized block design were used to develop all 50 crosses and the check HHB94. Five competitive plants were measured for total biological yield (g)/plant, harvest index (%), 1000-grain weight (g), protein content (%), plant height (cm), ear length (cm), effective tillers (no.)/plant, ear girth (cm), ear weight (g), grain yield (g)/plant, dry fodder yield (g)/plant, and days to 50% flowering. CSSC46-2 and G73-107 were the two tests that showed the most substantial and favorable gca impacts on grain yield and the majority of its constituents. However, in terms of protein concentration, H77/833-2 and 1307 were the best general combiners. The crosses ICMA95222 x CSSC46-2, ICMA94555 x G73-107, HAMS13A x CSSC46-2, and ICMA94222 x G73-107 were found to have substantially better yields and the majority of the features that contributed to them. These crosses demonstrated strong per se performance for grain production and its component characteristics in addition to significant sca effects (Kumar *et al.*, 2013). Both additive and non-additive genetic factors predominated, according to the combining ability variance analysis. Therefore, a population with high grain Fe and Zn concentrations may be developed by reciprocal recurrent selection. While the Fe and Zn levels separately revealed a negative, if modest, connection with grain yield and a moderately positive relation with grain weight, the Fe and Zn contents in grain showed a very significant and positive link with each other. This suggests that it is possible to increase the mineral and nutritional contents of grains without noticeably lowering yield. These findings might be immediately applied as guiding principles for the genetic increase of Fe and Zn grain content in pearl millet, given the constancy of these trends across the environment (Thribhuvan *et al.*, 2022). The line ICMA 04999 and testers 2325, 2396, 2306, 2337, 2348, and 2394 were the best general combiners for grain production among the parents; their general combining ability might be utilized in a hybridization program. For every trait, the components of variation resulting from gca and sca showed that non-additive gene action predominated. According to Bala Barathi *et al.* (2020), the cross ICMA 04999 × 2309 showed a high significant positive sca impact, mid parent, better parent heterotic effect, and per se performance for grain production. to evaluate heterosis and combining ability in pearl millet using a full 5×5 diallel experiment for grain production and associated parameters. The impacts of general combining ability (gca) were non-significant for panicle girth, number of productive tillers, and days to 50% flowering, but very significant for panicle length, plant height, and days to 50% flowering. The impacts of specific combining ability (sca) were non-significant for the other features but significantly significant for grain production. For the criteria under study, the parent mgp-84 was an excellent general combiner. With the exception of days to blooming, 15rbs-01 was an excellent general combiner for all the characteristics. The crosses that produced the highest grain output included good x good and good x bad general combiners, and they were mgp-84 x 13rbs-09, mgp-304 x 15rbs-01, mgp-84 x 13rbs-10, 13rbs-10 x 15rbs-01, 13rbs-09 x 15rbs-01, and mgp-84 x mgp-304. Grain yield's sca variation was greater than its gca variance, suggesting that non-additive gene activity played a significant part in its inheritance. Gca variations were greater than sca variants for days to flowering, productive tillers, panicle girth, panicle length, and plant height, indicating that additive gene action was crucial to the inheritance of these characteristics (Siddique *et al.*, 2022). The frequency of the good × average combiner was greater in hybrids with favorable and noteworthy SCA implications for grain yield. DHLB -16A x S-21/14, DHLB -23A x S-21/15, DHLB-14A x S-21/13, DHLB -23A x S-21/18, and DHLB -16A x DHLBI -967 were determined to be good specific combiners among the hybrids. S-21/09, S-21/13, and S-21/14 were the best general combiners and produced the highest-yielding hybrid combinations among the three females, and two lines, DHLB-16 A and DHLB-23A, among the males (Barhate *et al.*, 2023). High heritability estimates and high GCA: SCA variance ratios indicated that general combining ability (GCA) was significant across test contexts. Early selection based on parental performance would thus be beneficial. The GCA for GY was significantly negative in the Sudanese parental population (IP8679). In the current germplasm set, additive effects predominate due in part to its lack of adaptability.

Heterosis breeding in pearl millet

In pearl millet, heterosis breeding uses hybrid vigor to increase yield, stress tolerance, and adaptability. Grain yield, earliness, and quality characteristics show significant heterosis, mostly due to non-additive gene activity. Effective hybrid seed production is made possible by the application of cytoplasmic male sterility mechanisms. In a variety of demanding growth conditions, superior hybrids found through heterosis investigations provide reliable performance and support long-term output. Significant heterosis was found in pearl millet's grain production and associated characteristics. In terms of grain yield, four hybrids showed more than 50% standard heterosis over the check HHB94: ICMA95222 × CSSC46-2 (92.05%), ICMA94555 × G73-107 (77.76%), HAMS13A × CSSC46-2 (66.76%), and HAMS9A × CSSC46-2 (55.52%). HMS9A × 1307 and HMS18A × H77/833-2 showed significant standard heterosis for protein content, suggesting room for improvement in nutritional quality (Kumar *et al.*, 2013). Significant heterosis across a range of characteristics in pearl millet hybrids was shown by the experiment. Notably, crosses with high standard heterosis, substantial SCA effects, and higher performance for yield and associated characteristics were shown by ICMA97111 × BIB208, ICMA93333 × BIB186, and ICMA93333 × BIB193. These hybrids can be used in breeding programs that aim to increase both yield potential and stress resilience, and they have the potential to increase production, especially in harsh environmental circumstances (Yadav *et al.*, 2022). Pearl millet's noteworthy heterosis in terms of grain and dry fodder output. In terms of grain production per hectare, 26 hybrids exhibited substantial positive standard heterosis over GHB 558, 12 over Kaveri Super Boss, and 3 over 86 M 38. Thirteen hybrids outperformed GHB 558 in terms of dry fodder output. Dual-purpose potential was shown by the better grain and dry fodder yields of the hybrids ICMA94555 × IP17465 and ICMA94555 × IP14522 (Athoni *et al.* 2022). Grain yield per plant above the hybrid check Aadishakti was the greatest positive standard heterosis in the (4) × (12) line × tester research in DHLB-16A × S-16/08 (36.88%), followed by DHLB-14A × S-16/06 (34.74%) and DHLB-16A × S-16/07 (26.29%). Promising prospects for commercial cultivation, the three hybrids DHLB-16A × S-16/08, DHLB-14A × S-16/06, and DHLB-16A × S-16/07 displayed conventional heterosis, considerable heterobeltiosis, and favorable GCA and SCA effects (Karvar *et al.*, 2017).

Significant heterogeneity was found for all attributes in the 35 hybrids from a line × tester design used in the study, suggesting a large amount of room for heterosis breeding. High per se performance was demonstrated by the hybrids ICMA07777 × 18488R, ICMA06777 × 18805R, and ICMA96222 × 18488R. They also showed conventional heterosis and extremely significant positive heterobeltiosis for grain yield per plant. According to Krishnan *et al.* (2019), these combinations have significant promise for use in pearl millet development initiatives. Non-additive gene action predominated for all yield and yield-contributing variables in the analysis of 60 pearl millet crosses. In terms of grain yield, the line ICMA04999 and tests 2325, 2396, 2306, 2337, 2348, and 2394 proved to be effective general combiners. The cross ICMA04999 × 2309 was a potential hybrid for yield increase because of its noteworthy high significant positive SCA effects, robust mid-parent and better-parent heterosis, and improved per se performance (Barathi *et al.* 2020). While additive effects drove features like days to 50% blooming, productive tillers, panicle girth, panicle length, and plant height, non-additive gene activity dominated the inheritance of grain production in the 5 × 5 diallel research. Superior grain yield performance was demonstrated by the crosses MGP-84 × 13RBS-09, MGP-304 × 15RBS-01, and MGP-84 × 13RBS-10. Pearl millet productivity and growth attributes might be enhanced by these promising hybrids, which involve good × good or good × bad combiners (Siddique *et al.* 2022). In the 3 × 8 line × tester research, DHLB-16A × S-21/14 (103.88% and 18.48%) had the largest positive heterosis over the better parent for grain and fodder yield, followed by DHLB-23A × S-21/09 (116.69% and 4.17%) and DHLB-23A × S-21/18 (113.78% for grain yield). Strong SCA effects and encouraging yield potential were demonstrated by a number of hybrids, such as DHLB-16A × S-21/14 and DHLB-23A × S-21/18, which qualified them for additional breeding and commercial study (Barhate *et al.*, 2023).

Current trends

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] breeding has advanced recently, with a greater emphasis on combining heterosis exploitation, accurate combining ability analysis, and multi-environment stability evaluation to create durable, high-yielding hybrids. To increase the efficiency of hybrid seed production and diversify the genetic foundation, heterosis breeding is increasingly utilizing a variety of cytoplasmic male sterility (CMS) systems, including A1, A4, and new sources. In order to forecast hybrid performance early and shorten breeding cycles, molecular methods like SSR markers, SNP genotyping, and genomic selection are currently being used to identify parental lines with the highest heterotic potential. Finding cross combinations with superior non-additive gene action for yield, stress resilience, and nutritional quality traits like high iron and zinc content is made easier with the help of specific combining ability (SCA), while general combining ability (GCA) directs the selection of parents with strong additive effects for traits like earliness, plant height, and drought tolerance. In order to carefully choose parents and ensure the creation of hybrids with high production and nutritional improvement, there is a move toward the use of line × tester analysis in conjunction with molecular diversity research. Stability studies are also changing, with statistical models such as AMMI (Additive Main Effects and Multiplicative Interaction) and GGE (Genotype and Genotype × Environment) biplot analysis being used in conjunction with multi-environment trials (METs) to analyze genotype × environment interactions. Breeders can find hybrids that consistently perform well in a variety of agro-ecological zones using this method, especially in areas where pearl millet is mostly farmed that are rainfed and subject to stress. A crucial concept that focuses on creating hybrids that can tolerate heat, drought, and unpredictable rainfall patterns without sacrificing grain quality is climate-smart breeding. A growing trend is farmer-led participatory varietal selection (PVS), which aims to guarantee that the hybrids satisfy local adaptation standards and end-user preferences. Also, biofortification is becoming a key breeding goal that supports the objectives of global nutritional security. High production potential, greater nutritional density, resilience to pests and diseases, and higher-quality fodder are all goals of current initiatives. The state-of-the-art in pearl millet enhancement is the combination of traditional breeding techniques with environmental modeling, precision phenotyping, and genomics. Together, these trends seek to produce hybrids that are highly adaptive, nutrient-dense, and climate robust, able to maintain production in the face of shifting market and environmental demands.

Future prospects

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] breeding's future depends on combining precision phenotyping, cutting-edge genetic tools, and sustainable crop improvement techniques to address the twin issues of nutritional security and climate change. Breeding projects will increasingly concentrate on creating hybrids and varieties that are climate-resilient, able to flourish under circumstances of excessive heat, protracted drought, and unpredictable rainfall, given that pearl millet is mostly grown in arid and semi-arid locations. Maintaining production in stressful situations will require incorporating qualities like early maturity, stay-green physiology, and enhanced water-use efficiency. Future work will focus on diversifying the cytoplasmic male sterility (CMS) systems beyond the presently prevalent A1 source, with heterosis breeding continuing to play a crucial role. In addition to increasing the efficiency of hybrid seed production, the introduction of innovative CMS systems and restorative genes will broaden the genetic base and lessen susceptibility to biotic and abiotic stressors. It is anticipated that genome-wide association studies (GWAS), marker-assisted selection (MAS), and genomic selection (GS) may reduce the breeding cycle by accelerating the discovery of superior parental lines and the prediction of hybrid performance. Breeders will be able to precisely target certain adaption zones by combining genetic prediction algorithms with environmental data. Enhancing grain iron, zinc, and protein content without sacrificing yield potential will continue to be a top breeding goal for bio-fortification. This is in line with international efforts to address hidden hunger among rural people that rely on pearl millet as a main diet. The crop's dual-purpose usefulness will be further reinforced by breeding for increased biomass output, digestibility, and fodder quality. In order to maintain yield stability in shifting agro-climatic conditions, resistance breeding for important pests and diseases, such as blast, smut, and downy mildew, will be crucial. In order to precisely capture genotype × environment interactions, future stability research will depend more and more on multi-location, multi-year trials in conjunction with sophisticated statistical models like as GGE biplots and AMMI, as well as high-throughput phenotyping systems and remote sensing techniques. Involving farmers in hybrid evaluation and selection using participatory plant breeding (PPB) techniques can guarantee that new cultivars satisfy regional preferences for grain quality, flavor, and cooking qualities, increasing adoption rates. Precision agriculture, molecular technology, traditional breeding, and farmer-centered participatory methods will all come together to promote pearl millet development in the future. Future breeding projects seek to create hybrids that not only meet food and fodder demands but also support sustainable lifestyles in marginal agricultural settings by emphasizing yield resilience, nutritional improvement, and wide adaptability.

CONCLUSION

Strategic hybrid breeding is still a key method for maximizing pearl millet's output potential, adaptability, and durability by using heterosis. Precision parental selection and effective exploitation of genetic diversity are now possible because to developments in genomic techniques, molecular markers, and bioinformatics that have reinforced the evaluation of general combining ability (GCA) and specialized combining ability (SCA). The issues presented by resource constraints and climate change are addressed by stability analysis, which further guarantees that hybrids operate consistently across conditions. The generation of better hybrids with broad adaption and good nutritional quality will be accelerated by combining heterosis breeding with contemporary genomic selection, doubled haploid technologies, and high-throughput phenotypic. Researchers can optimize the advantages of heterosis and combining ability by fusing traditional breeding knowledge with new developments. This would ensure sustained pearl millet production and promote food security in arid and semi-arid areas.

REFERENCES

Acharya ZR, Khanapara MD, Chaudhari VB, Dobaria JD. 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.

Arya RK, Yadav HP. 2009. Stability of grain yield and its contributing traits in white and grey grain hybrids in bajra. Indian Journal of Agricultural Sciences **79**, 941–944.

Athoni BK, Biradar BD, Patil SS, Patil PV, Guggari AK. 2022. Genetic studies for heterosis for grain yield and yield components using diverse male sterile lines in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Journal of Agricultural Research and Technology **47**(1), 88–95.

Bala Barathi M, Vijaya Lakshmi B, Sanjana Reddy P, Nafeez Umar Sk. 2020. Heterosis and combining ability studies in indigenous collection of pearl millet germplasm [*Pennisetum glaucum* (L.) R. Br.]. International Journal of Current Microbiology and Applied Sciences **9**(10), 2648–2660.

Barhate KK, Pawar VY, Shaniware YA, Karvar SH, Gavali RK. 2023. Heterosis and combining ability studies of newly developed restorers in the pearl millet [*Pennisetum glaucum* (L.) R. Br.]. International Journal of Advanced Biochemistry Research **7**(2), 135–138.

Burton GW. 1958. Quantitative inheritance in pearl millet. Agronomy Journal **43**(9), 409–417.

Karvar SH, Pawar VY, Patil HT. 2017. Heterosis and combining ability in pearl millet. Electronic Journal of Plant Breeding **8**(4), 1197–1215.

Kempthorne O. 1957. An introduction to genetic statistics. John Wiley and Sons Inc., New York, 471 p.

Koelreuter JG. 1766. Vorläufige Nachricht von einigen das Geschlecht der Pflanzen betreffenden Versuchen und Beobachtungen. 266 p. (In German).

Krishnan MRR, Patel MS, Gami RA. 2019. Heterosis analysis in pearl millet hybrids [*Pennisetum glaucum* (L.) R. Br.]. Indian Journal of Agricultural Research **53**(5), 572–577.

Kumar AI, Yadav S, Arya RK. 2013. Combining ability and heterosis for some yield traits and protein content in pearl millet. Forage Research **39**(3), 105–113.

Kumar M, Gupta PC, Pawan K, Heeralal B. 2017. Assessment of combining ability and gene action for grain yield and its component traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Journal of Pharmacognosy and Phytochemistry **6**(3), 431–434.

Navale P, Harinarayana G. 1992. Combining ability in S1 derived lines of pearl millet. Journal of Maharashtra Agricultural Universities **17**, 264–266.

Rai K, Yadav O, Rajpurohit B, Patil H, Govindaraj M, Khairwal I, Rao A. 2013. Breeding pearl millet cultivars for high iron density with zinc density as an associated trait. Journal of SAT Agricultural Research **11**, 1–7.

Shull GH. 1914. The composition of a field of maize. Annual Report of the American Breeder's Association **4**, 296–301.

Siddique M, Khanum S, Kamal N, Khan AH, Hayat S, Raza S, Kohli SA, Bhatti MH, Saleem AGZ, Ahmad R. 2022. Heterosis and combining ability studies in pearl millet. Pakistan Journal of Biotechnology **19**(2), 84–88.

Sprague GF, Tatum LA. 1942. General vs. specific combining ability in single crosses of corn. Agronomy Journal **34**, 923–932.

Sumathi P, Revathi S. 2017. Heterosis and variability studies for yield and yield components traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Electronic Journal of Plant Breeding **8**(2), 528–533.

Thribhuvan R, Singh SP, Sankar MS, Singh AM, Mallik M, Singhal T, Meena JK, Satyavathi CT. 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.

Yadav MK, Gupta PC, Sanadya SK, Chandel D. 2022. Heterosis and combining ability in diverse A and R lines of pearl millet tested in Western Rajasthan. Electronic Journal of Plant Breeding **13**(2), 440–446.