J. Agric. Res. Technol., 47 (1) : 088-095 (2022) https://doi.org/10.56228/JART.2022.47117

Gentetic Studies for Heterosis for Grain Yield and Yield Components Using Diverse Male Sterile Lines in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.]

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(Received : 08.07.2021 Accepted : 03.08.2021)

Abstract

The line x tester analysis involving ninety hybrids, thirty three parents (three lines and thirty testers) and three checks including national check GHB558, commercial checks Kaveri super boss and 86 M 38 were used to assess the magnitude of heterosis with respect to grain and dry fodder yield and its component traits in pearl millet under rainfed conditions during *kharif*, 2019 at Regional Agricultural Research Station, Vijayapur. Twentysix hybrids exhibited significant positive standard heterosis over check GHB 558, twelve hybrids over check Kaveri super boss and three hybrids over best check 86 M 38 for grain yield per hectare. Whereas, thirteen hybrids over GHB558, none of hybrids over Kaveri super boss and 86 M 38 exhibited significant positive standard heterosis for dry fodder yield per hectare. Two hybrids *viz*., ICMA 94555 x IP 17465 and ICMA 94555 x IP 14522were superior for both grain and dry fodder yield.

Key words : Line x tester, restorers, heterosis.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] belongs to the family Poaceae (Graminae) and sub family penicedae, having relatively small diploid genome (2n = 2x = 14). It is considered to be originated in Africa from where it was imported to India. Pearl millet is a C4 plant with high photosynthetic efficiency and dry matter production capacity. It is usually grown under the most adverse agro-climatic conditions where other crops like rice, sorghum and maize fail to produce economic yields. Pearl millet has the ability to respond to favourable environments due to its short developmental stages and capacity for high growth rate. It is an excellent crop for short growing seasons under improved crop management. Pearl millet is cultivated in more than 30 countries of five continents *viz*., Asia, Africa, North America, South America and Australia.

In India, pearl millet is the fourth most important crop after Rice, Wheat and Sorghum. In India it is cultivated over an area of 6.93 million hectares with an average production of 8.61 million tonnes with the national average productivity of 1243 kg ha^{-1} during 2018-19 (Anon, 2020). The major Pearl millet growing states are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana which account for more than 90% of Pearl millet acreage in the country. Most of pearl millet in India is grown in kharif season (June-September). It is also cultivated during the summer season (February-May) in parts of Gujarat, Rajasthan and Uttar Pradesh; and during the rabi season (November-February) at a small scale in Maharashtra and Gujarat. In Karnataka, pearl millet is one of the major *kharif* crop, grown on an area of 3.22 lakh hectares with an annual production of 3.67 lakh tonnes with the average productivity of 1140 kg ha^{-1} (Anon, 2019).

The availability of cytoplasmic genetic male sterile lines in this crop is made feasible to exploit heterosis commercially and hybrid seed production on large scale. The exploitation of heterosis on commercial scale in pearl millet is regarded as one of the major breakthroughs in the improvement of its productivity. Heterosis breeding is an important one, among conventional breeding programme to identify the best hybrids which are promising. The improvement in Pearl millet needs attention for the characters like early flowering, plant height, number of tillers plant^{-1}, panicle length and girth, fodder yield ha^{-1}, grain yield ha^{-1} and thousand seed weight. Keeping these things in view, the work was undertaken to investigate the mid parent heterosis, better parent heterosis and commercial heterosis for quantifying the extent of heterosis for grain yield and its component characters in pearl millet.

Material and Methods

The experiment was conducted during *kharif*, 2019 at Regional Agricultural Research Station, Vijayapur. The location is situated at 16° 49' N latitude, 75° 43' E longitude and 593 m above mean sea level, which comes under Northern Dry Zone of Karnataka (Zone 3) with a mean annual rainfall of 590 mm. The soil type and climatic conditions are well suited for pearl millet cultivation.

The material involved in the present study consisted of ninety crosses derived from thirty-three parental lines (3A and 30R). The crosses were made as per Line x Tester design (Kempthorne, 1957) at Regional Agricultural Research Station, Vijayapur during summer, 2019. Three cytoplasmic male sterile lines used in the experiment were ICMA 94555 (A1 cytoplasm), ICMA 04777 (A4 cytoplasm) and ICMA 01777 (A5 cytoplasm) while, thirty mini core collection restorers parents include IP 11546, IP 3706, IP 17465, IP 21452, IP 1917, IP 5711, IP 9645, IP 6340, IP 13991, IP 15119, IP 16863, IP 20576, IP 21283, IP 13261, IP 20274, IP 18657, IP 10665, IP 10925, IP 19448, IP 14522, IP 11010, IP 2704, IP 14537, IP 16863, IP 10437, IP 20611, IP 20409, IP 8863, IP 6057, IP 6482.

The parental lines (30), F_1 hybrids (90) generated and the three checks including national check (GHB558), private check (86 M 38) and one commercial check (Kaveri super boss) were evaluated in RCBD trial during *kharif*, 2019 to study the heterosis and combining ability status of the lines for yield and yield components.

Results and Discussion

The analysis of variance for heterosis worked out for nine characters is presented in Table 1. The table shows that, for all the characters, the variation due to treatments was found to be highly significant. Whereas in the case of crosses, all crosses showed significant for all the characters. However, the variation due to parentsvs crosses was found to be significant for all characters, except for plant height and panicle length, parents revealed significant variation for all the remaining traits. Likewise, lines recorded significant variation for five traits *viz*., days to 50 per cent flowering, Plant height, plant girth, panicle weight, dry fodder yield whereas testers showed significant variation for all the traits except plant height, Number of productive tillers per plant, panicle girth. Variation due to line × tester showed significant variation for days to 50 percent flowering, plant height, panicle girth, panicle weight, grain yield and thousand seed weight.

This indicates the existence of sufficient genetic variability in the experimental material. In the commercial exploitation of hybrid vigour, excess of F_1 over commercial check (commercial heterosis), is of significance. Hence, in the present investigation, the extent of heterosis over commercial check hybrid (Kaveri super boss and 86 M 38) for nine traits is discussed.

In the present investigation, thirty six hybrids were significant and negative as mid parent heterosis is concerned. However, fifty three crosses registered significant negative heterobeltiosis. While, ten crosses registered significant heterosis in negative direction over national check GHB558. Further, eighty one and eighty four hybrids were found to be significant in negative direction over private checks Kaveri super boss and 86 M 38, respectively presented in Table 2. The cross ICMA 94555 x IP 19448 was the earliest to record 50 per cent flowering (45 days). From the results it can be concluded that hybrids flowered three to four days earlier than the parents indicating earliness is dominant.

Positive heterosis is desirable for plant height, as it contribute to fodder yield. Out of twenty two and five crosses registered significant relative heterosis and heterobeltiosis, respectively. Seventeen hybrids were found significant and positive over national check GHB558, none of the hybrids showed positive significant heterosis over private checks Kaveri super boss and only two hybrids showed positive heterosis over commercial check 86 M 38, presented in Table 2. The study also indicated, that heterosis breeding may be employed for developing dual purpose hybrids (both dry fodder and grain yield). Many researchers have also reported marked heterosis for this trait (Harer *et al*., 1990a; Rudranaik *et al*., 1997; Lakshmana, 2008; Kathale *et al*., 2013 and Salagarkar and Wali, 2016).

The hybrid ICMA 94555 x IP 6057 (2.90) produced highest number of productive tillers among hybrids. Fourteen hybrids exhibited positive relative heterosis and six crosses for heterobeltiosis as presented in Table 2. Over the national check GHB558, nineteen hybrids were positive and significant. While eight and three of the crosses were significant in desired direction over Kaveri super boss and 86 M 38, presented in Table 2. These outcomes are in line with previous results (Tyagi *et al*., 1975; Shinde and Desale, 1983; Manga and Dubey, 2004; Pethani *et al*., 2004; Lakshmana, 2008;

Table 1. Analysis of variance (Mean sum of squares) with respect to morpho-physiological characters in pearl millet studied during kharif, 2019 at RARS, Vijayapur

Source	df	Days to 50% flowe-ring	Plant height (cm)	No. of produc-tive tillers plant^{-1}	Relative chloro-phyll content at flowering	Relative chloro-phyll content at maturity	Panicle length (cm)	Panicle girth (cm)	Panicle weight (kg plot^{-1})	Grain yield (kg ha^{-1})	Dry fodder yield (kg ha^{-1})	1000 seed weight (g)
Replication	2	0.323	130.928	0.150	24.288	11.331	0.020	0.008	0.004	129938.054	57683.680	0.287
Treatments	64	25.044**	1488.360**	0.475**	132.924**	37.387**	21.684**	0.163**	0.100**	613879.445**	5769497.935**	4.249**
Parents	14	4.905**	571.698**	0.204**	92.082*	15.414**	5.581**	0.058	0.010	59346.953	550046.950	2.052**
Parents vs. Cross	1	432.154**	3651.775**	23.744**	913.181**	79.369**	633.901**	2.805**	2.020**	15470421.633**	185983440.520**	68.373**
Crosses/Hybrids	49	22.490**	1706.112**	0.078	128.670**	42.809**	13.791**	0.139*	0.086**	469122.561**	3582934.082**	3.568**
Line	4	6.900**	510.100**	0.044	44.058	12.875**	4.536*	0.026	0.022	66019.451	875529.359	1.770*
Tester	9	4.163**	413.707**	0.271**	115.577*	15.693**	4.974**	0.075	0.006	62224.379	399317.181	1.395*
Line × Tester	36	25.106*	1778.362**	0.066	139.772	52.062*	13.901**	0.122	0.073**	309145.947	3271563.943	3.130**
Error	128	0.662	85.058	0.087	46.538	3.561	1.604	0.083	0.016	72932.166	874609.893	0.672
Total	194	8.702	548.476	0.216	74.807	14.801	8.212	0.109	0.043	251976.690	2480996.399	1.848

Note: *Significance at 5% probability, **significance at 1% probabilit

Vetriventhan *et al*., 2008a; Chotoliya*et al*., 2009; Jethva *et al*., 2012; Kathale *et al*., 2013; Chittora and Patel, 2017; Kumar *et al*., 2017; Bhasker *et al*., 2018 and Krishnan *et al*., 2019).

Among ninety cross combinations, ICMA 94555 x IP 1917 (27.80 cm) produced highest panicle length. Eighteen hybrids were found to be positively significant as mid parent heterosis is concerned. Similarly, ten hybrids were superior when compared with better parent heterosis. Six hybrids were noticed to be superior over national check GHB558. Further, neither of crosses registered heterosis in desired direction over private check Kaveri super boss and 86 M 38, presented in Table 2. The obtained results are similar to the results noticed by (Ramamoorthi and Govindarasu, 2000; Manga and Dubey, 2004; Pethani *et al*., 2004; Lakshmana, 2008; Vetriventhan *et al*., 2008a; Chotoliya *et al*., 2009; Jethva *et al*., 2012; Kathale *et al*., 2013; Salagarkar and Wali, 2016; Patel *et al*., 2017; Kumar *et al*., 2017; Bhasker *et al*., 2018 and Krishnan *et al*. 2019).

Twenty one hybrids recorded substantial positive relative heterosis and seven hybrids registered heterobeltiosis. On considering heterosis over checks, five crosses displayed substantial heterosis in desired direction over national check, GHB558. While none of the crosses were found superior over checks Kaveri super boss and 86 M 38, presented in Table 2. Many earlier researchers have also obtained the similar results (Pokhriyal *et al*., 1967; Lakshmana, 2008; Vetriventhan *et al*., 2008a; Jethva *et al*., 2012; Kathale *et al*., 2013; Chittora and Patel, 2017; Kumar *et al*., 2017 and Krishnan *et al*., 2019).

The study showed, as many as twenty eight and nineteen hybrids recorded positive significant relative heterosis and heterobeltiosis, respectively for Panicle weight for plot. Further

Table 2. Number of hybrids showing significant level of heterosis with respective direction and their ranges for morpho-physiological characters in pearl millet

Character	**Mid parent heterosis**			**Heterobeltiosis**			**Heterosis over GHB 558**		
	Positive (No's)	**Negative (No's)**	**Range (%)**	**Positive (No's)**	**Negative (No's)**	**Range (%)**	**Positive (No's)**	**Negative (No's)**	**Range (%)**
Days to 50 per cent flowering	16	36	-17.51 to 15.56	6	53	-28.27 to 13.04	50	10	-10.56 to 28.17
Plant height (cm)	22	0	-11.77 to 41.99	5	6	-20.26 to 23.31	17	0	-7.92 to 29.82
No. of productive tillers plant^{-1}	14	0	-11.76 to 33.33	6	0	-16.67 to 30.30	19	0	-9.09 to 33.3
Panicle Length (cm)	18	7	-19.95 to 25.53	10	11	-23.04 to 25.23	6	0	-14.12 to 20.32
Panicle Girth (cm)	21	2	-18.48 to 30.26	7	4	-19.35 to 28.57	5	0	-13.79 to 17.24
Panicle weight (g plot^{-1})	28	5	-21.76 to 63.82	19	15	-22.02 to 55.24	9	46	-29.23 to 24.28
Grain yield (kg ha^{-1})	58	0	-15.31 to 164.39	48	1	-24.54 to 108.61	26	26	-31.30 to 50.59
Dry fodder yield (kg ha^{-1})	1	56	-46.67 to 19.01	0	68	-49.43 to 3.28	13	12	-28.81 to 27.12
Thousand seed weight (g)	13	12	-30.94 to 23.72	1	15	-34.19 to 22.02	6	7	-28.04 to 14.02

nine crosses registered significant positive heterosis over national check GHB 558, while three hybrids over Kaveri super boss. On the other hand, seven hybrids were found significant over 86 M 38, presented in table 2. Many earlier researchers have also obtained the similar results (Maryam, 2015; Rafiq *et al*., 2016 and Acharya *et al*., 2017).

For the grain yield per hectare ICMB 02555 (2,077 kg) and IP 16863 (2,320 kg) were found as the high yielding female and male parent respectively. Further, ICMA 94555 x IP 17465 (3,771 kg) yielded the highest yield among the hybrids,presented in Table 3. Out of ninety hybrids studied, fifty eight hybrids recorded significant positive relative heterosis, forty eight hybrids registered heterobeltiosis and twenty six hybrids over national check GHB558, presented in Table 2. While twelve and three hybrids registered significant heterosis in desired direction over private check Kaveri super boss and 86 M 38, respectively, presented in Table 2. The three hybrids ICMA 94555 x IP 17465, ICMA 94555 x IP 14522 and ICMA 02555 x IP 8863 were registered to be substantially superior to the best check; 86 M 38 which was considered superior among all the three checks, presented in Table 3. These three hybrids were also the only hybrids which were found significantly superior over the next best check i.e.,Kaveri super boss.

Burton (1951) witnessed heterosis for grain yield per plant. Ahluwalia and Patnaik (1963) noticed heterobeltiosis. They observed that impacts of yield attributes like seed size, panicle girth, panicle length, etc. are multiplicative in

Table 2. Contd.

Character	Heterosis over Kaveri super boss			Commercial heterosis over 86 M 38		
	Positive (No's)	Negative (No's)	Range (%)	Positive (No's)	Negative (No's)	Range (%)
Days to 50 per cent flowering	1	81	-23.49 to 9.64	1	84	-24.85 to 7.69
Plant height (cm)	0	55	-26.99 to 2.93	2	3	-16.71 to 17.42
No. of productive tillers plant^{-1}	8	0	-11.76 to 29.41	3	0	-14.29 to 25.71
Panicle Length (cm)	0	21	-23.39 to 7.33	0	10	-19.89 to 12.23
Panicle Girth (cm)	0	7	-21.88 to 6.25	0	14	-24.24 to 3.03
Panicle weight (g plot^{-1})	3	66	-35.11 to 13.95	7	56	-31.46 to 20.35
Grain yield (kg ha^{-1})	12	53	-44.51 to 21.64	3	54	-46.32 to 17.66
Dry fodder yield (kg ha^{-1})	0	54	-40.85 to 5.63	0	48	-39.13 to 8.70
Thousand seed weight (g)	4	8	-29.79 to 11.25	1	11	-32.06 to 7.65

Table 3. Superior hybrids for grain yield along with their heterosis over mid-parent and 86 M 38

Crosses	Grain yield	SCA effect	Heterosis (%) over mid-parent	Heterosis (%) over 86 M 38
ICMA 94555 x IP 17465	3770.923	1125.73	164.39	17.66
ICMA 94555 x IP 14522	3759.563	265.69	147.54	17.31
ICMA 02555 x IP 8863	3753.637	466.63	103.34	17.12
ICMA 94555 x IP 20576	3666.957	777.11	84.97	14.42
ICMA 94555 x IP 10925	3648.683	473.53	147.38	13.85
ICMA 02555 x IP 2704	3625.963	817.38	128.62	13.14
86 M 38	3204.83			

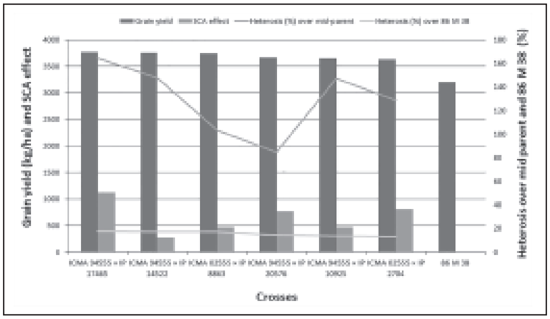

Fig. 1. Mid-parent heterosis and commercial heterosis over 86 M 38 of six superior crosses

nature and thus, established that even a small improvement in few of these yield attributes would reflect in higher grain yield. Here in the present study also the same result has been noticed. Thus it can be concluded that heterotic effects in terms of yield determining characters such as panicle length, panicle girth, number of productive tillers per plant and thousand seed weight contribute prominently to degree of heterosis. Many investigators have also reported similar outcomes (Yadav *et al*., 2000; Blummel and Rai, 2003; Lakshmana, 2008; Vetriventhan *et al*., 2008a; Chotoliya*et al*., 2009; Davda*et al*., 2012; Jethva*et al*., 2012; Kathale *et al*., 2013; Bachkar *et al*., 2014; Athoni*et al*., 2016; Chittora and Patel, 2017; Bhasker *et al*., 2018; Badhe *et al*., 2018; Saini *et al*., 2018; Warrier*et al*. 2020 and Krishnan *et al*., 2019).

The line and tester showing highest dry fodder yield per hectare were ICMB 02555 (9,630 kg) and IP 1917 (10,001 kg) respectively. In case of hybrids, ICMA 02555 x IP 6057 (9260 kg) was the superior one. Only one cross exhibited significant positive performance with respect to mid parent were observed. Whereas none of hybrids recorded significant positive heterobeltiosis. Further thirteen crosses were found substantially superior to national checks GHB558. None of the hybrids were significantly superior over private check, Kaveri super boss and 86 M 38, presented in Table 2. The positive heterotic effect registered in the current study might be mainly due to the parental diversity existed for the character. The obtained result is found similar with the results obtained by Rudranaiket al., 1997; Chittora and Patel, 2017 and Kumar *et al*. 2017.

The thousand seed weight of a genotype functions as a sign of the grain yield as it is a chief component impacting yield. Among hybrids, ICMA 02555 x IP 19448 (12.20 g) exhibited highest thousand seed weight. The study found that thirteen and one hybrids exhibited positive significant relative heterosis and heterobeltiosis, respectively. Six crosses recorded substantial.

Summary and Conclusions

The present study consists of thirty three parents (three lines and thirty testers) and resultant 90 hybrids (developed through line x tester mating design) with three checks evaluated during *kharif*, season of 2019 at Regional Agricultural Research Station, Vijayapur. The five female lines used were ICMA-94555, ICMA-04777 and ICMA-02555 with A1, A4 and A5background and the thirtyMinicore male parents (testers) include IP 11546, IP 3706, IP 17465, IP 21452, IP 1917, IP 5711, IP 9645, IP 6340, IP 13991, IP 15119, IP 16863, IP 20576, IP 21283, IP 13261, IP 20274, IP 18657, IP 10665, IP 10925, IP 19448, IP 14522, IP 11010, IP 2704, IP 14537, IP 6193, IP 10437, IP 20611, IP 20409, IP 8863, IP 6057 and IP 6482.

The study on relative heterosis, heterobeltiosis and standard heterosis over three checks including national check GHB558, commercial check Kaveri super boss and private check 86 M 38 disclosed that, crosses had a heterotic effect for all the characters studied. For every trait, significant positive heterosis over mid and better parent were observed. Three crosses (ICMA 94555 x IP 17465, ICMA 94555 x IP 14522 and ICMA 02555 x IP 8863) were concluded as superior hybrids as they exhibited significant positive heterosis over the popular commercial check; 86 M 38 for grain yield per hectare, presented in Table 3. In addition, hybrid ICMA 94555 x IP 17465 was found to be superior with respect to dry fodder yield over check 86 M 38. Hence, these hybrids are needed to be tested on large scale to confirm their potentiality.The magnitude of average heterosis for grain yield per hectare was 54.59per cent, which is due to positive average heterosis for yield contributing characters like number of productive tillers per plant, thousand seed weight, panicle girth and panicle length.

References

Acharya, Z. R., Khanapara, M. D., Chaudhari, V. B. and Dobaria, J. D. 2017, Exploitation of heterosis in pearl millet [*Pennisetum glaucum* (L.) R. Br.] for yield and its component traits by using male sterile line. Int. J. Curr. Microbiol. App. Sci., 6(12): 750-759.

Ahluwalia, M. K. and Patnaik, M. C. 1963, A study of heterosis in pearl millet. Indian J. Genet., 23: 34-38.

Anonymous. 2019 - 2020. Directorate Of Economics and Statistics.

Anonymous. 2020. Directorate Of Millets Development.

Athoni, B. K., Ishwar, H. B. and Guggari, A. K. 2016. Combining ability and heterosis for grain yield and its components in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Int. J. Sci. Nat., 7(4): 786-794.

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 J. Dryland Agric. Res. Dev., 29 (1): 40-44.

Badhe, P. L., Thakare, S. M., Rasal, P. N. and Borole, D. N. 2018. Identification of heterotic crosses involving cytoplasmic genic male sterile lines in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Int. J. Agric. Sci., 14(1): 133-137.

Bhasker, K., Shashibhushan, K., Krishna, M. and Bhave, M. H. 2018. Studies on heterosis for grain yield and its contributing characters in hybrids of pearl millet (*Pennisetum glaucum* (L.) R. Br.). Int. J.Plant Soil Sci., 18(5): 1-6.

Blummel, M. and Rai, K. N. 2003. Stover quality and grain yield relationship and heterosis in pearl millet. Int. Sorghum Millet News lett., 44: 141-145.

Burton, G. W. 1951. Quantitative inheritance in pearl millet (*Pennisetum americanum* (L.) Leeke). Agron. J., 43: 409-417.

Chittora, K. and Patel, J. A. 2017. Estimation of heterosis for grain yield and yield components in pearl millet (*Pennisetum glaucum* (L.) R. Br.). Int. J. Curr. Microbiol. App. Sci., 6(3): 412- 418.

Chotoliya, J. M., Dangaria, C. J. and Dhedhi, K. K. 2009. Exploitation of heterosis and selection of superior inbreds in pearl millet. Int. J. Agric. Sci., 5(2): 531-535.

Davda, B. K., Dhedhi, K. K. and Dangaria, C. J. 2012. Evaluation of heterosis in pearl millet under rainfed condition. Int. J. Plant Sci., 7(1): 74-78.

Harer, P. N., Navale, P. A. and Harinarayana, G. 1990a. Heterosis and combining ability studies in pearl millet. J. Maharashtra Agric. Univ., 15: 48-51.

Jethva, A. S., Lata, R., Madariya, R. B., Mehta, D. R. and Chetana, M. 2012. Heterosis for grain yield and its related characters in pearl millet. Electronic J. Plant Breed., 3(3): 848-852.

Kathale, M. N., Jadhav, P. A. and Wadekar, P. B. 2013. Heterosis in pearl millet. Bioinfolet., 103(3): 1002-1005.

Krishnan, M. R., Patel, M. S. and Gami, R. A. 2019 Heterosis analysis in pearl millet hybrids [*Pennisetum glaucum* (L.) R. Br.]. Indian J. Agric. Res., 53(5): 572-577.

Kumar, M., Gupta, P. C., Sharma, N. and Sharma, A. K. 2017. Estimation of standard heterosis for grain yield and yield components in Pearl millet (*Pennisetum glaucum* (L.) R. Br.). J. Pharmacogn. Phytochem., 6(4): 785-788.

Lakshmana, D. 2008. Genetic diversity, heterosis and combining ability studies involving diverse sources of cytoplamic genetic male sterility in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Ph. D. Thesis, Univ. Agric. Sci., Dharwad. Karnataka(India).

Manga, V. K. and Dubey, L. K. 2004. Identification of suitable inbreds on combining ability in pearl millet (Pennisetum glaucum). Indian J. Agric. Sci., 74: 98-101.

Maryam, A. H. 2015. Evaluation of heterosis in pearl millet (*Pennisetum glaucum* (L.) R. Br.) for agronomic traits and resistance to downy mildew (*Sclerospora-graminicola*). J. Agric. Crop., 1(1): 1-8.

Patel, S. M., Prajapati, K. N., Parmar, M. B., Patel, B. C. and Joshi, N. R. 2017. Study of heterosis for grain yield and yield attributing characters in pearl millet (*Pennisetum glaucum* (L.) R. Br.). Environ. Ecol., 35(2): 1104-1106.

Pethani, K. V., Atara, S. D. and Monpara, B. A. 2004. Heterosis and combing ability for plant and seed characters in pearl millet. Nat. J. Plant Improv., 6(2): 115-118.

Pokhriyal, S. C., Mangath, K. S. and Rao, S. B. P. 1967. Hybrid vigour in pearl millet (Pennisetum typhoides S. & H.). Indian Agric., 11: 55-61.

Rafiq, S. M., Kumar, B. S. and Rao, U. P. 2016. Heterosis studies in diverse cytoplasmic male sterility sources of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Plant Arch, 16(1): 343-348.

Ramamoorthi, N. and Govindrasu, R. 2000. Heterosis for grain yield and its components in pearl millet. Madras Agric. J., 87: 159-161.

Rudranaik, V., Ravi, K. R. L. and Madhav, R. T. 1997. Heterosis for yield and its components in pearl millet. Karnataka J. Agric. Sci., 10(2): 367-372.

Saini, L. L., Solanki, K. L., Gupta, P. C., Saini, H. and Singh, A. G. 2018 Combining ability studies for grain yield and component traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Int. J.chem. studies, 6(1): 1939-1944.

Salagarkar, S. and Wali, M. C. 2016. Heterosis for yield and yield related components using diverse restorer lines in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. J. Farm Sci., 29(4): 436-438.

Shinde, N. V. and Desale, J. S. 1983. Heterosis in pearl millet. J. Maharashtra Agric. Univ., 8: 231-233.

Tyagi, C. S., Paroda, R. S., Arora, N. D. and Singh, K. P. 1975. Heterosis and combining ability in pearl millet. Indian J. Genet., 35: 403-408.

Vetriventhan, M., Nirmalakumari, A. and Ganapathy, S. 2008a. Heterosis for grain yield components in pearl millet (*Pennisetum glaucum* (L.) R. Br.). World J. Agric. Sci., 4(5): 657-660.

Warrier, S. R., Patel, B. C., Kumar, S. and Sherasiya, S. A. 2020. Combining ability and heterosis for grain minerals, grain weight and yield in pearl millet and SSR markers based diversity of lines and testers. J. King Saud Univ. Sci., 32 (2): 1536-1543.

Yadav, O. P., Weltzien, R. E., Bidinger, F. R. and Mahalakshmi, V. 2000 Heterosis in landrace-based top cross hybrids of pearl millet across arid environments. Euphytica, 112:.285-29.