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RESEARCH PAPER

Heterosis for micronutrients, grain yield and yield components involving diverse male sterile lines in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract: The line tester analysis was used to assess the magnitude of heterosis and combining ability with respect to iron and zinc density,grain yield and its component traits in pearl millet under rainfed conditionsduring *kharif,* 2020 at Regional Agricultural Research Station, Vijayapur using 56 hybrids, fifteen parents (eight lines and seven testers), and four checks including national check GHB-558, local check VPMH 7, commercial checks 86 M 38, and Kaveri super boss.For grain yield per hectare, twenty-seven hybrids exceeded check GHB-558, four hybrids outperformed over local check VPMH 7 and commercial check 86 M 38. One hybrid exceeded over best check Kaveri super boss. Twentyfive and ten hybrids over GHB-558, ten and twenty-eight hybrids over VPMH 7, twenty six and thirty hybrids over 86 M 38 and fifty two and fifty four hybrids over check Kaveri super boss exhibited significant positive standard heterosis for iron and zinc density, respectively. Two hybrids *viz.,* ICMA 15666 × Fe & Zn-1(3,963 kg ha-1 grain yield, 81 and 56 ppm iron and zinc density) and ICMA 15666 × Fe & Zn-9 (3,926 kg ha-1 grain yield, 62 and 41 ppm iron and zinc density) were superior for grain yield, iron and zinc density.

Key words: Grain yield, Heterosis, Pearl millet, Restorers

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] belongs to the family Poaceae (Graminae) and sub family panicoidae, 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 has high 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.

After rice, wheat, and sorghum, pearl millet is India's fourth most important crop. It is cultivated on 6.93 million hectares in India, with an average annual production of 8.61 million tonnes and a national average productivity of 1243 kg/ha in 2018-19. (Anon, 2020). Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, and Haryana are the major Pearl millet producing states, contributing for more than 90% of the country's Pearl millet acreage. 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 (Anon, 2019).

India is growing >70,000 ha of bio-fortified pearl millet, besides more pipeline hybrids and varieties are under various stage of testing at the national (India) and international (west Africa) trials for possible release. Genomic tools will be an integral part of breeding program particularly for nutritional traits to use diagnostic markers and genomic selection. Clinical studies showed that200g grains from biofortified cultivar would provide bioavailable Fe to meet full recommended daily allowance (RDA) in children, adult men and 80% of the RDA in women.

The availability of cytoplasmic genetic male sterile lines in this crop has promoted commercial heterosis and large-scale hybrid seed production. One of the most significant advances in the development of pearl millet production was the commercialization of heterosis. Heterosis breeding is an important component of traditional breeding programmes for identifying the most promising hybrids. The discovery of Tift 23 A1, cytoplasmic-nuclear male sterility (CMS) and its successful utilization in breeding male sterile lines of commercial pearl millet hybrids is a landmark in pearl millet improvement. Keeping these things in view, the work was undertaken to investigate the mid parent heterosis, better parent heterosis and commercial heterosis forquantifying the extent of heterosis for micronutrients, grain yield and its component characters in pearl millet.

Material and methods

The experiment was conducted during *kharif,* 2020 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 fifty six crosses derived from fifteen parental lines (8A and 7R). The crosses were made as per Line × Tester design (Kempthorne, 1957) at Regional Agricultural Research Station, Vijayapur during summer, 2020. Eight cytoplasmic male sterile lines used in the experiment were ICMA 98222 (A1 cytoplasm), ICMA 04999 (A1 cytoplasm), ICMA 06444 (A1 cytoplasm), ICMA 97111 (A1 cytoplasm), ICMA 96666 (A1 cytoplasm), ICMA 15666 (A4 cytoplasm), ICMA 03999 (A4 cytoplasm) and ICMA 05222 (A4 cytoplasm) while, seven biofortified restorer parents include Fe & Zn-1, Fe & Zn-5, Fe & Zn-8, Fe & Zn-9, Fe & Zn-12, Fe & Zn-13 and Fe & Zn-14.

The parental lines (15), F1 hybrids (56) generated and the four checks including national check (GHB558), local check (VPMH 7), private check (86 M 38) and one commercial check (Kaveri super boss) were evaluated in RCBD trial during *kharif,* 2020 to study the heterosis and combining ability status of the lines for yield and yield components.

Results and discussion

Variance analysis for twelve traits is provided 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, except for number of productive tillers per plant, it was significant for the rest of the characters. However, the variation due to parents*vs* crosses was found to be significant for all characters except for Iron density. Parents revealed significant variation for all the remaining traits except for productive tillers per plant, relative chlorophyll content at flowering, panicle girth, grain yield per hectare and dry fodder yield per hectare. Likewise, lines recorded significant variation for eight traits exceptforproductive tillers per plant, panicle girth, grain yield, dry fodder yield whereas testers showed significant variation for all the traits except Plant height, productive tillers per plant, relative chlorophyll content at flowering, panicle girth, grain yield per hectare and dry fodder yield per hectare. Variation due to line × tester showed significant variation for days to 50 percent flowering, relative chlorophyll content at maturity, plant height, panicle girth, Iron density, Zinc density and thousand seed weight.

This indicates the existence of sufficient genetic variability in the experimental material. In the commercial exploitation of hybrid vigour, superiority of F1 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 twelve traits is discussed.

In the present investigation, thirty two hybrids were significant and negative as mid parent heterosis and heterobeltiosis. While, eight crosses registered significant heterosis in negative direction over national check GHB558 and local check VPMH 7. Further, fifty six 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 -98222 × Fe & Zn-14, ICMA -98222 × Fe & Zn-14 and ICMA -15666 × Fe & Zn-1 were the earliest to record 50 per cent flowering (42 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, as many as twenty five and thirteen crosses registered significant relative heterosis and heterobeltiosis, respectively. Twenty five hybrids were found significant and positive over national check GHB-558, three hybrids over VPMH 7, two hybrids over 86 M 38 and neither of hybrids over private check Kaveri super boss, presented in Table 2. The study indicated, that heterosis breeding

Table 1. Analysis of variance (Mean sum of squares) with respect to morpho-physiological characters in pearl millet studied during *kharif,* 2020 at RARS, Vijayapur.

Source	df	Days to 50 % flowering	Plant height (cm)	Number of productive tillers per plant	Relative chlorophyll content at flowering	Relative chlorophyll content at maturity	Panicle length (cm)	Panicle girth (cm)	Grain yield (kg ha^{-1})	Iron (ppm)	Zinc (ppm)	Dry fodder yield (kg ha^{-1})	Thousand seed weight (g)
Replication	2	0.606	430.408	0.078	64.158	16.781	6.267	0.020	214960.407	0.131	1.779	2039737.652	0.287
Treatments	70	23.885**	768.923**	0.306**	101.187**	85.983**	15.754**	0.203**	931029.408**	169.095**	101.770**	7277271.370**	4.249**
Parents	14	18.086**	390.851**	0.057	64.821	53.229**	11.998**	0.100	153133.919	237.184**	118.914**	553242.738	2.052**
Parents *vs.* Cross	1	180.254**	7190.039**	17.544**	1567.848**	866.273**	122.038**	2.034**	40612899.006**	0.562	341.087**	152672323.716**	68.373**
Crosses/ Hybrids	55	22.519**	748.412**	0.055	83.787**	80.134**	14.778**	0.196**	407550.630**	154.828**	93.055**	6345295.888**	3.568**
Line	7	17.089**	544.994**	0.084	85.329*	55.012**	12.507**	0.058	77313.182	293.518**	131.946**	569182.307	1.770*
Tester	6	16.429**	188.540	0.031	49.605	47.553**	12.363**	0.008	194597.590	47.762**	102.714**	385809.700	1.395*
Line × Tester	1	35.003**	525.715**	0.025	12.559	74.810**	6.240	0.949**	435097.044	979.381**	124.889**	1446263.985	3.130**
Error	140	1.006	104.089	0.078	38.024	7.329	2.185	0.100	152576.436	1.612	1.313	988111.943	0.672
Total	212	8.556	326.689	0.153	59.129	33.387	6.704	0.133	410201.322	56.899	34.487	3074642.185	1.848

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

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			Commercial heterosis over VPMH 7			Heterosis over 86 M 38			Commercial heterosis over Kaveri super boss		
	+ve (No's)	-ve (No's)	Range (%)	+ve (No's)	-ve (No's)	Range (%)	+ve (No's)	-ve (No's)	Range (%)	+ve (No's)	-ve (No's)	Range (%)	+ve (No's)	-ve (No's)	Range (%)	+ve (No's)	-ve (No's)	Range (%)
Days to 50 per cent flowering	3	32	-20.75 to 5.05	1	32	-22.22 to 10.42	21	8	-10.64 to 12.77	32	8	-8.7 to 15.22	0	56	-23.64 to -3.64	0	56	-26.32 to -7.02
Plant height (cm)	25	2	-13.47 to 45.91	13	6	-21.6 to 44.22	25	2	-17.84 to 28.89	3	20	-24.83 to 17.93	2	23	-26.85 to 14.77	0	36	-31.01 to 8.23
No. of productive tillers per plant	56	0	13.29 to 51.52	52	0	10.96 to 51.52	55	0	14.08 to 40.85	10	0	1.25 to 25	2	0	-2.41 to 20.48	1	0	-5.81 to 16.28
Relative chlorophyll content at flowering	19	0	-11.67 to 39.47	12	1	-17.75 to 37.02	22	0	-1.44 to 34.02	27	0	0.77 to 37.02	26	0	1.33 to 36.91	12	0	-3.85 to 30.19
Relative chlorophyll content at maturity	32	6	-29.49 to 78.9	23	14	-33.57 to 56.67	39	0	-1.75 to 97.45	41	0	-11.98 to 76.89	51	0	8.25 to 117.54	41	0	1.48 to 103.95
Panicle Length (cm)	28	1	-19.8 to 38.3	17	9	-24.74 to 29.22	11	4	-15 to 28.82	11	4	-15.50 to 28.07	3	17	-23.04 to 16.64	4	17	-21.89 to 18.38
Panicle Girth (cm)	14	0	-9.09 to 24.55	3	0	-10.71 to 20.93	10	0	-11.76 to 24.71	0	2	-20.21 to 12.77	0	2	-26.47 to 3.92	0	2	-21.05 to 11.58
Grain yield (kg ha^{-1})	52	0	10.26 to 90.99	40	0	6.693 to 82.14	27	0	-5.22 to 45.91	4	1	-20.72 to 22.05	4	0	-19.18 to 24.42	1	3	-22.48 to 19.33
Dry fodder yield (kg ha^{-1})	40	0	-9.09 to 98.63	33	0	-15.67 to 91.24	10	1	-22.17 to 59.43	5	7	-29.79 to 43.83	6	9	-30.67 to 42.02	6	9	-32.47 to 38.34
Thousand seed weight (g)	18	19	-37.45 to 44.77	13	22	-38.18 to 32.29	8	15	-31.81 to 20.92	9	34	-37.7 to 10.47	10	35	-36.87 to 8.49	2	35	-36.70 to 12.33
Iron (ppm)	18	27	-30.46 to 42.49	8	40	-33.80 to 28.57	25	14	-23.21 to 44.64	10	30	-29.51 to 32.97	26	12	-23.21 to 44.64	52	1	-6.52 to 76.09
Zinc (ppm)	11	34	-32.58 to 34.18	4	37	-42.77 to 30.23	10	30	-28.57 to 33.33	28	16	-21.05 to 47.37	30	12	-18.92 to 51.35	54	0	0 to 86.67

may be employed for developing dual purpose hybrids (both dry fodder and grain yield). Many researchers have also reported marked heterosis for this trait (Lakshmana, 2008; Kathale *et al.*, 2013 and Salagarkar and Wali, 2016).

The hybrids ICMA 04999 × Fe & Zn-12 and ICMA 06444 × Fe & Zn-1 (3.30) produced highest number of productive tillers among hybrids. Fifty six hybrids exhibited positive relative heterosis and fifty two crosses heterobeltiosis as presented in Table 2. Over the national check GHB-558 and local check VPMH 7 fifty five and ten hybrids were positive and significant. While two and one crosses showed significant heterosis in desired direction over 86 M 38 and Kaveri super boss, presented in Table 2. These outcomes are in line with previous results (Lakshmana, 2008; 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 fifty six cross combinations, ICMA 15666 × Fe & Zn-1 (29.20 cm) produced highest panicle length. Twenty eight hybrids were found to be positively significant as mid parent heterosis is concerned. Similarly, seventeen hybrids were superior when compared with better parent heterosis. Eleven hybrids were noticed to be superior over national check GHB-558 and local check VPMH 7. Further, three crosses registered heterosis in desired direction over commercial check 86 M 38 and four hybrids over private check Kaveri super boss, presented in Table 2. The obtained results are similar to the results noticed by (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).

Fourteen hybrids recorded substantial positive relative heterosis and three hybrids registered heterobeltiosis for panicle girth. On considering heterosis over checks, ten crosses displayed substantial heterosis in desired direction over national check, GHB-558, while none of the crosses were found superior over checks VPMH 7, 86 M 38 and Kaveri super boss for panicle girth (Table 2). Many earlier researchers have also obtained the similar results (Yadav *et al*., 2000; Lakshmana, 2008; Vetriventhan *et al*., 2008a;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).

For the grain yield per hectare ICMB 05222 (2,728.40 kg) and Fe & Zn-12 (2,802.47 kg) were found as the high yielding female and male parent respectively. Further, ICMA 15666 × Fe & Zn-1 (3,962.97 kg) yielded the highest yield among the hybrids, presented in Table 3. out of fifty six hybrids studied, fifty two hybrids recorded significant positive relative heterosis, forty hybrids registered heterobeltiosis and twenty seven hybrids over national check GHB-558, presented in Table 2. While four hybrids registered significant heterosis in desired direction over local check VPMH 7, commercial check 86 M 38 and one crosses over private check Kaveri super boss, presented in Table 2. The first three hybrids mentioned in Table 3 (ICMA 15666 × Fe & Zn-1, ICMA 15666 × Fe & Zn-9 and ICMA 03999 × Fe & Zn-1) were registered to be substantially superior to the best check; Kaveri super boss which was considered superior among all the three checks. These three hybrids were also the only hybrids which were found significantly superior over the next best check *i.e.,* 86 M 38.

Burton (1951) witnessed heterosis for grain yield per plantnoticed heterobeltiosis. They observed that impacts of yield attributes like seed size, panicle girth, panicle length, *etc*. are multiplicative in 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 and nutritional quality in terms of yield determining characters such as panicle length, panicle girth, number of productive tillers per plant, thousand seed weight, iron and zinc density contribute prominently to degree of heterosis. Many investigators have also reported similar outcomes (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; Krishnan *et al*., 2019 and Saxena *et al.* 2021).

The line and tester showing highest dry fodder yield per hectare were ICMB 03999 (7,246.91 kg) and Fe & Zn-14 (6111.11 kg) respectively. In case of hybrids, ICMA 98222 × Fe & Zn-8 (12,518.52 kg) was the superior one. Forty crosses with the significant positive performance with respect to mid parent were observed. Wherein thirty three hybrids recorded significant positive heterobeltiosis. Further ten and five crosses were found substantially superior to national checks GHB-558 and local check VPMH 7, respectively. Meanwhile Six hybrids were significantly superior over commercial check 86 M 38 and private check Kaveri super boss for dry fodder yield (kg/ha) as 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 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 98222 × Fe & Zn-13 (14.10 g) exhibited highest thousand seed weight. The study found that thirteen and one hybrids exhibited positive significant relative heterosis and heterobeltiosis, respectively. Eight crosses recorded substantial heterosis in desired direction over national check GHB-558. While nine, ten and two crosses were substantially superior over local check VPMH 7, commercial check 86 M 38 and private check Kaveri super boss, respectively.

Among fifty six cross combinations, ICMA 15666 × Fe & Zn-1 (81.00 ppm) produced highest iron density. Eighteen hybrids were found to be positively significant as mid parent heterosis is concerned. Similarly, eight hybrids were superior when compared with better parent heterosis. Twenty five and ten hybrids were noticed to be superior over national check GHB-558 and local check VPMH 7. Further, twenty six crosses registered heterosis in desired direction over commercial check 86 M 38 and fifty two hybrids over private check Kaveri super boss. The obtained results are similar to the results noticed byKanatti *et al*. 2014; Rai*et al*. 2012;Govindaraj *et al.* 2013; Kanatti *et al*. 2016; Jeeterwal *et al.* 2018; Kanatti *et al.* 2019; Govindaraj *et al.* 2019.

The hybrid, ICMA 15666 × Fe & Zn-1 (56.00 ppm) produced highest Zinc density. Eleven hybrids were found to be positively significant as relative heterosis is concerned. comparably, four hybrids were superior when compared with better parent heterosis. Ten and twenty eight hybrids were noticed to be superior over national check GHB-558 and local check VPMH 7. Meanwhile, thirty crosses registered heterosis in positive direction over commercial check 86 M 38 and fifty four hybrids over private check Kaveri super boss.

Conclusion

The study on relative heterosis, heterobeltiosis and standard heterosis of 56 hybrids over four checks *viz.,* national check GHB-558, local check VPMH 7, commercial checks Kaveri super boss and 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 -15666 × Fe & Zn-1, ICMA -06444 × Fe & Zn-13 and ICMA -03999 × Fe & Zn-1) were found superior hybrids as they exhibited significant positive heterosis over the popular commercial check; Kaveri super boss for grain yield. In addition, hybrid ICMA -98222 × Fe & Zn-8 was found to be superior with respect to dry fodder yield over check VPMH 7. Hence, these hybrids are to be tested on large scale across the locations to confirm their potentiality and stability. Likewise, the hybrid ICMA -15666 Fe & Zn-1 was found to be superior to the check VPMH 7 in terms of Iron and Zinc densitiesand the consistency of this hybrid to iron and zinc density across the locations and over years need to be tested.

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