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Hybrid vigour for grain yield components and quality trait in alloplasmic isonuclear lines in pearl millet (*Pennisetum glaucum* (L.) R. Br.)

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Abstract
An experiment was conducted at Pearl Millet Research Station, Jamnagar during Kharif 2018 to studies extent and magnitude of heterosis of hybrids over better parent and standard check The experimental materials was comprised two maintainer lines (females) each have three (A_1, A_4 and A_5) cytoplasmic sources, six inbred testers (males) of pearl millet, their 36 hybrids and two standard checks (GHB 732 for grain yield component and HHB 299 for Fe and Zn content). The experimental results revealed that the crosses based on A_1 and A_4 cytoplasm were $ICMA_1$ 96222 x J-2597, $ICMA_1$ 96222 x J-2598 and $ICMA_4$ 96222 x J-2584 displayed high magnitude of standard heterosis for grain yield and its releted trait while crosses based on A_4 cytoplasm were $ICMA_4$ 95222 x J-2584 and $ICMA_4$ 96222 x J-2603 displayed high magnitude of standard heterosis for Fe and Zn content. These crosses could be exploited further for obtaining desirable types in pearl millet.

Keywords: Heterosis, grain yield, alloplasmic isonuclear lines and pearl millet

Introduction
Pearl millet [*Pennisetum glaucum* (L.) R. Br.] belongs to family Poaceae and genus *Pennisetum*. It is diploid (2n=14) in nature and commonly known as bajra, cat tail millet and bulrush millet in different parts of the world, which is believed to be originated from West-Africa.

Pearl millet is the sixth most important and widely grown potential cereal crop in the world and is the fourth in India, after rice, wheat and maize. Pearl millet is an important coarse grain crop and serves as stable diet for the millions of people thriving under hunger. It is grown on about 6.98 million hectare area with an annual production of 8.06 million tones and productivity 1154 kg/ha. In Gujrat the cultivated area of pearl millet including kharif and summer season is an about 3.97 lakh hectare with production of 9.65 lakh metric tonnes with an average productivity of 2430 kg/ha. (Anon., 2018).

Micronutrient malnutrition has been designated as the most serious world's population is at risk of deficiency in one or more essential mineral elements (White and Broadley, 2009 and Stein, 2010) [28]. The concern is more crucial for developing countries, especially in children, given that the statistics of malnutrition in these countries are high. The widespread deficiencies of Fe and Zn in developing countries are mostly due to monotonous consumption of cereal-based foods with low concentration and reduced bioavailability of Fe and Zn (Graham *et al*., 2001) [14].

The discovery of Tift $23A_1$ and its successful utilization in breeding commercial hybrids is a landmark achievement in pearl millet improvement (Athwal, 1965; Burton, 1965; Burton and Powell, 1968) [5, 9, 8]. Ever since, Tift $23A_1$ constitutes the only male sterility source exploited in developing A-lines of all the commercially grain hybrids in pearl millet. Because of this virtual monoculture, efforts have been made to develop alternative CMS sources in pearl millet, leading to the identification of some distinct CMS systems in pearl millet, namely A_2, A_3, Violaceum (Av), ex-borne (gero), A_4 and A_5 (Burton and Athwal, 1967; Aken'ova, 1985; Marchais and Pernes, 1985; Hanna, 1989; Rai, 1995) [1, 7, 20, 15, 23] . The A_2 and A_3 CMS were found to be not much suitable for hybrid breeding since the expression of male sterility in these sources was less stable as compared to the A_1 CMS (Rai *et al.*, 1996; Chhabra *et al*., 1997) [25, 11]. The more recent among the CMS sources were A_4 and A_5 (Rai, 1995) [23].

Importantly, the A_4 CMS system was shown to have more stable expression of male sterility than the widely used A_1 CMS system and has favorable influence on early maturity. The A_5 CMS was also shown to be better than A_1 CMS being more stable in male sterility expression. It was also shown that almost every inbred line could be a potential maintainer of A_5 CMS (Rai, 1995; Rai *et al*., 2001) [23, 24]. In addition, molecular analysis of mitochondrial genome diversity indicated that A_4 and A_5 CMS were more diverse than other CMS sources implying that these sources might provide the greatest opportunity for both genetic and cytoplasmic diversification. However, available information on the influence of different CMS sources on the agronomic characters in pearl millet are limited (Chandra-Shekara *et al*., 2007) [10].

In heterosis breeding programme, it is essential to study and evaluate available useful promising diverse parental lines in their hybrid combination for yield, its component traits and quality parameter Fe and Zn. To identify a potential hybrid combination, study of the magnitude and direction of heterotic behavior in relation diverse cytoplasm is of paramount importance.

Materials and Methods

The experimental material for present investigation comprised of two maintainer lines (females) each having three sources of cytoplasm (A_1, A_4 and A_5) obtained from ICRISAT *viz.*, $ICMA_1$ 95222, $ICMA_4$ 95222, $ICMA_5$ 95222, $ICMA_1$ 96222, $ICMA_4$ 96222, $ICMA_5$ 96222 and six testers (males) developed at PMRS viz., J-2584, J-2591, J-2596, J-2597, J-2598 and J-2603. The selected 6 lines were crossed with 6 testers in Line × Tester (L x T) mating design to generate 36 crosses. The generated 36 hybrids are divided in two groups based on genetic background of female parent i.e. ICMA 95222 and ICMA 96222 and it is designated group 1 and group 2 hybrids, respectively. The checks included in this experiment were GHB 732 for grain yield component and HHB 299 for Fe and Zn content. Evaluation of single cross hybrids, their parents and checks were done in the *Kharif*, 2018 at J. A. U., Jamnagar. Five competitive plants from each experimental unit for every replication were selected randomly for recording observations on component characters viz., Days to 50% flowering, days to maturity, plant height, number of effective tillers per plant, ear head length, ear head diameter, grain yield per plant, test weight, Fe and Zn content. The analysis of variance for each character was carried out by using the method described by Panse and Sukhatme (1985). The heterosis were calculated according to formula suggested by Fonesca and Patterson (1968) [12].

Result and Discussion

The analysis of variance for the experimental design showed significant differences among the genotypes, parents and hybrids for most of the characters studied. This indicated the presence of variability in the material selected for the present investigation for grain yield and important yield attributes. The estimates of variance due to parents vs hybrids were significant for all the traits except ear head diameter, which indicated the presence of high level of mean heterosis due to selection of female and male lines with diverse genetic origin.

Estimation of heteobeltiosis (Hb) and standard heterosis (SH)

Earliness is desirable character in pearl millet and days to flowering is component which affect on earliness. So, early flowering is desirable for pearl millet. The highest significant and desirable heterobeltiosis for days to 50% was registered by the cross $ICMA_4$ 95222 x J-2597 (-19.89%) in group 1 and $ICMA_5$ 96222 x J-2597 (-19.32) in group 2. The highest significant standard heterosis in group 1 was registered by the cross $ICMA_1$ 95222 x J-2584 and $ICMA_1$ 95222 x J-2598 (-6.45). In group 2, the highest significant and desirable standard heterosis was registered by the cross $ICMA_4$ 96222 x J-2596 (-6.16). The results are in accordance with findings of Yadav (1999) [27], Sheoran *et al.* (2000) [26], Chandra-shekara *et al*. (2007) [10] and Lakshmana *et al*. (2010) [19].

Negative heterosis for days to maturity is desirable. In group 1 the highest significant and desirable heterobeltiosis and standard heterosis was registered by the crosses $ICMA_1$ 95222 x J-2603 (-6.97) and $ICMA_1$ 95222 x J-2584 (-3.42), respectively. While in group 2 the highest significant and desirable heterobeltiosis and standard heterosis was registered by the crosses $ICMA_4$ 96222 x J-2597 (-6.35) and $ICMA_4$ 96222 x J-2596 (-2.99), respectively. These results are in confirmation to the findings of Yadav (1999) [27], Chandra-shekara *et al.* (2007) [10] and Lakshmana *et al*. (2010) [19].

Plant height is regarded as a favorable character due to important role of stem as a source in supplementing assimilates during grain development. The range of heterobeltiosis in group 1
from -2.49% ($ICMA_5$ 95222 x J-2603) to 69.51% ($ICMA_4$ 95222 x J-2584) while for standard heterosis from 30.87 ($ICMA_5$ 95222 x J-2603) to 80.35 ($ICMA_1$ 95222 x J-2596). In case of group 2, the range of heterobeltiosis from 0.12 ($ICMA_1$ 96222 x J-2596) to 77.16 ($ICMA_1$ 96222 x J-2597) while for standard heterosis from 38.20 (ICMA1 96222 x J-2596) to 85.03 ($ICMA_1$ 96222 x J-2597). These results are in confirmation to the findings of Yadav (1999) [27], Chandra-shekara *et al*. (2007) [10], Lakshmana *et al*. (2010) [19] Amiribehzadi *et al.* (2012) [2] and Kumar, *et al.* (2017) [17].

The positive heterosis for number of effective tillers per plant is desirable. The highest significant and positve heterobeltiosis and standard heterosis was registered by the cross $ICMA_5$ 95222 x J-2597 (16.22%) in group 1. In group 2, the highest significant and positive heterobeltiosis (21.92) and standard heterosis (20.27) was registered by the cross $ICMA_4$ 96222 x J-2597. The results are in accordance with findings of Lakshmana *et al*. (2010) [19] Jethva *et al*. (2012) [16], Bachkar *et al*. (2014) [6], Patel *et al.* (2016) [21] and Rafiq *et al*. (2016) [22].

Ear head directly affect on grain yield so, positive heterosis is desirable for this character. In the present investigation, The range of heterobeltiosis in group 1 from -10.41% ($ICMA_5$ 95222 x J-2603) to 48.64% ($ICMA_4$ 95222 x J-2584) while for standard heterosis from 10.49 ($ICMA_5$ 95222 x J-2603) to 48.64 ($ICMA_4$ 95222 x J-2584).

Table 1: Analysis of variance for experimental design for different characters in pearl millet

Source	d. f.	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers per plant	Ear head length (cm)
		1	2	3	4	5
Replications	2	40.50**	47.39**	746.38	0.0488	5.064
Genotypes	47	25.98**	8.732**	4089.90**	0.1431**	23.43**
Parents	11	47.84**	11.53**	1600.97**	0.0420	22.81**
Females	5	0.100	0.100	346.92	0.0490	5.476
Males	5	15.55**	6.588**	981.40*	0.0325	38.81**
Females x males	25	448.02**	93.44**	10969.07**	0.0544	29.52
Hybrids	36	123.074**	4.72**	685.31**	0.1751**	9.80
P. vs H.	1	571.78**	118.23**	150628.82**	0.0390*	507.21**
Error	94	80.98	1.090	335.21	0.03052	8.51

Source	d. f.	Ear head diameter(cm)	Grain yield per plant(g)	Test weight (g)	Fe content (ppm)	Zn content (ppm)
		6	7	8	9	10
Replications	2	0.010	73.182	0.2636	14.312	131.67*
Genotypes	47	0.150**	771.25**	3.674**	247.17**	112.84**
Parents	11	0.129*	563.54**	4.5891**	119.11	40.33
Females	5	0.0108	869.36**	0.3841*	48.40	0.100
Males	5	0.180**	89.43**	8.916**	198.62*	85.43*
Females x males	25	0.462**	1405.0**	3.98**	75.11	16.00
Hybrids	36	0.1014	282.56*	3.47**	221.008**	115.43**
P. vs H.	1	2.090	20160.38**	0.5713*	2571.56**	819.50**
Error	94	0.0656	26.10	19.47	74.29	36.64

*, ** Significant at 5 % and 1 % levels of significance, respectively.

In case of group 2, the range of heterobeltiosis from -2.96 ($ICMA_4$ 96222 x J-2597) to 25.08 ($ICMA_5$ 96222 x J-2591) while for standard heterosis from 17.00 ($ICMA_1$ 96222 x J-2596) to 50.99 ($ICMA_1$ 96222 x J-2597). These results are in confirmation to the findings of Yadav (1999) [27], Lakshmana *et al*. (2010) [19], Rafiq *et al*. (2016) [22] and Ladumor *et al.* (2018) [18].

The range of heterobeltiosis in group 1 for ear head diameter from -12.64% ($ICMA_1$ 95222 x J-2597) to 24.09% ($ICMA_1$ 95222 x J-2584) while for standard heterosis from 9.02 ($ICMA_5$ 95222 x J-2603) to 32.18 ($ICMA_1$ 95222 x J-2584). In case of group 2, the range of heterobeltiosis from -23.62 ($ICMA_5$ 96222 x J-2596) to 24.67 ($ICMA_5$ 96222 x J-2591) while for standard heterosis from -9.85 ($ICMA_5$ 96222 x J-2596) to 30.37 ($ICMA_5$ 96222 x J-2591). These results are in confirmation to the findings of Bachkar *et al*. (2014) [6], Rafiq *et al*. (2016) [22] and Ladumor *et al.* (2018) [18].

The range of heterosis over better parent and over standard check for grain yield per plant in group 1 from -14.06% ($ICMA_1$ 95222 x J-2596) to 22.42% ($ICMA_4$ 95222 x J-2603) In case of group 2, the range of heterobeltiosis from 34.20 ($ICMA_4$ 96222 x J-2597) to 140.59 ($ICMA_4$ 96222 x J-2584) while for standard heterosis from -15.05 ($ICMA_4$ 96222 x J-2597) to 26.16 ($ICMA_1$ 96222 x J-2597). These results are in confirmation to the findings of Lakshmana *et al.* (2010) [19], Amiribehzadi *et al.* (2012) [2], Rafiq *et al*. (2016) [22] and Ladumor *et al.* (2018) [18].

In group 1 the highest significant and positive heterobeltiosis and standard heterosis for test weight was registered by the cross $ICMA_1$ 95222 x J-2596 (12.75) while in group 2 the highest significant and positive heterobeltiosis (11.54) and standard heterosis (27.23) was registered by the cross $ICMA_4$ 96222 x J-2597. Heterotic response for test weight has also been reported by, Bachkar *et al*. (2014) [6], Rafiq *et al*. (2016) [22] and Ladumor *et al.* (2018) [18].

The cross $ICMA_4$ 95222 x J-2584 registered significant and positive heterobeltiosis (22.86) and highest standard heterosis (31.44) in group 1 for Fe content while 30.13 and 34.44 for Zn content, respectively. In group 2 cross $ICMA_4$ 96222 x J-2603 registered highest significant and positive heterobeltiosis (39.61) and standard heterosis (26.20) for Fe content while 26.3 and 25.03 for Zn content, respectively. Heterosis for Fe and Zn content in pearl millet has also been reported by earlier workers like Arulselvi *et al*. (2009) [4] and Govindaraj (2011) [13].

Conclusion

In general, it can be concluded that the magnitude of heterosis was higher in group 1 for days to flowering, days to maturity, plant height and ear head length while moderate for numbers of effective tiller per plants, ear head diameter, test weight, grain yield per plant, Fe and Zn content. In group 2, the magnitude of heterosis was higher for days to 50% flowering, days to maturity, plant height and ear head length, ear head diameter, grain yield per plant while moderate for numbers of effective tillers per plants, test weight, Fe and Zn content. The crosses which showed heterosis for grain yield per plant also showed heterosis for yield attributing components like plant height, ear head diameter and ear head length. The crosses based on A_1 and A_4 cytoplasm were $ICMA_1$ 96222 x J-2597, $ICMA_1$ 96222 x J-2598 and $ICMA_4$ 96222 x J-2584 displayed high magnitude of standard heterosis for grain yield and its releted trait while crosses based on A_4 cytoplasm were $ICMA_4$ 95222 x J-2584 and $ICMA_4$ 96222 x J-2603 displayed high magnitude of standard heterosis for Fe and Zn content. These crosses could be further exploted for obtaining desirable types in pearl millet.

Table 2: Range of heterobeltiosis (H1) and standard heterosis (H2) as well as number of crosses with specific heterotic effects of group 1 for various traits in pearl millet

Sr. No.	Characters	Range of heterosis (%)						Number of crosses with significant heterosis			
		Heterobeltiosis (H1) (%)			Standard heterosis (H2) (%)			H1 (%)		H2 (%)	
								+Ve	-Ve	+Ve	-Ve
1	Days to 50% flowering	-19.89	to	-10.97	-6.85	to	0.68	00	18	00	11
2	Days to maturity	-6.97	to	-2.49	-3.42	to	2.14	00	18	01	06
3	Plant height (cm)	-2.49	to	69.51	30.87	to	80.35	16	00	18	00
4	Number of effective tillers per plant	-17.81	to	16.22	-18.92	to	16.22	01	04	01	04
5	Ear head length (cm)	-10.41	to	48.64	10.49	to	48.64	06	00	13	00
6	Ear head diameter (cm)	-12.64	to	24.09	9.02	to	32.18	01	00	05	00
7	Grain yield per plant (g)	-14.06	to	22.42	-14.06	to	22.42	08	01	08	01
8	Test weight (g)	-16.82	to	12.75	-10.18	to	12.75	04	10	05	04
9	Fe content (ppm)	-17.03	to	27.07	-17.03	to	31.44	03	00	03	00
10	Zn content (ppm)	-24.24	to	30.13	-17.22	to	34.44	02	01	03	00

+ve = Positive and -ve = Negative

Table 3: Range of heterobeltiosis (H1) and standard heterosis (H2) as well as number of crosses with specific heterotic effects of group 2 for various traits in pearl millet

Sr. No.	Characters	Range of heterosis (%)						Number of crosses with significant heterosis			
		Heterobeltiosis (H1) (%)			Standard heterosis (H2) (%)			H1 (%)		H2 (%)	
								+Ve	-Ve	+Ve	-Ve
1	Days to 50% flowering	-19.32	to	-6.45	-6.16	to	0.68	00	18	00	04
2	Days to maturity	-6.35	to	-1.67	-2.99	to	2.14	00	17	01	02
3	Plant height (cm)	0.12	to	77.16	38.20	to	85.03	15	00	18	00
4	Number of effective tillers per plant	-16.22	to	21.92	-16.22	to	20.27	06	01	02	01
5	Ear head length (cm)	-2.96	to	25.08	17.00	to	50.99	02	00	16	00
6	Ear head diameter (cm)	-23.62	to	24.67	-9.85	to	30.37	04	01	09	00
7	Grain yield per plant (g)	34.20	to	140.59	-15.05	to	26.16	18	00	10	02
8	Test weight (g)	-24.65	to	11.54	-19.52	to	27.23	03	10	07	07
9	Fe content (ppm)	-8.57	to	39.61	-8.30	to	26.20	05	00	01	00
10	Zn content (ppm)	-12.73	to	26.67	-8.61	to	28.48	06	01	07	00

+ve = Positive and -ve = Negative

Table 4: Comparative study of five most heterobeltiotic and standard heterotic crosses between groups for grain yield per plant along with *per se* performance and their heterotic effects for component characters in pearl millet

	Crosses	Source of cytoplasm	Grain yield per plant (g)	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers per plant	Ear head length (cm)	Ear head diameter (cm)	Test weight (g)	Per se grain yield per plant (g)
	Heterobeltiosis										
1	$ICMA_4$ 96222 x J-2584	A_4	140.69**	-7.10**	-2.93**	57.28**	17.91**	12.76	11.07	-2.44	81.83
2	$ICMA_4$ 96222 x J-2591	A_4	128.17**	-10.91**	-3.67**	53.96**	0.00	15.63	18.57**	-17.95**	77.61
3	$ICMA_1$ 96222 x J-2591	A_1	122.60**	-15.76**	-5.31**	41.57**	0.00	22.29**	19.23**	-15.97**	75.71
4	$ICMA_5$ 96222 x J-2591	A_5	114.74**	-12.73**	-3.67**	54.05**	2.94	25.08*	24.67**	-20.36**	73.04
5	$ICMA_5$ 96222 x J-2596	A_5	108.14**	-12.57**	-2.90**	13.96	12.86*	9.25	-23.62**	0.55	81.06
	Standard heterosis										
1	$ICMA_1$ 96222 x J-2597	A_1	26.16**	-2.05	1.28	77.16**	18.92**	50.99**	17.34	13.58	82.12
2	$ICMA_1$ 96222 x J-2598	A_1	25.74**	0.00	0.85	33.17**	5.41	47.74**	26.35**	-3.44	81.85
3	$ICMA_4$ 96222 x J-2584	A_4	25.72**	-1.37	-0.85	62.75**	6.76	27.85*	18.31	4.20	81.83
4	$ICMA_5$ 96222 x J-2596	A_5	24.33**	0.00	0.00	57.31**	6.76	23.87	-9.85	7.40*	81.06
5	$ICMA_4$ 95222 x J-2603	A_4	22.42**	-0.68	0.43	67.11**	-10.81	38.52**	28.29**	11.74**	79.69

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