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Studies on heterosis involving diverse cytoplasmic male sterility systems in pearl millet

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Abstract
Investigation was undertaken to quantify the magnitude of heterosis of alloplasmic- isonuclear lines of pearl millet in two environments (normal and late sown crop). Three alloplasmic isonuclear pearl millet lines ($81A_1$, $81A_4$, $81A_5$ and their corresponding maintainer lines) were crossed with eight diverse pollinators in a line x tester design to study the nature and magnitude of heterosis for grain yield and its eight component traits. The extent of heterosis varied in each cross for all the characters studied. The high magnitude of heterosis was not observed for any of the trait; medium level of heterosis was exhibited for grain yield per plant, dry fodder yield per plant, harvest index and effective tillers per plant. While, low amount of heterosis was recorded for days to 50 % flowering, 1000-grain weight, plant height, panicle length and panicle girth. Among 48 crosses, eight (Environment 1) and seven (Environment 2) hybrids exhibited significant and positive heterosis over standard check (HHB-197) for grain yield. The direction and magnitude of heterosis varied from cross to cross in two different environments. This indicates environmental influence on the expression of hybrid vigour. The hybrid combination 3×11 ($81A_5$×ERC) expressed significant positive heterosis for grain yield, effective tillers, panicle girth, harvest index in one or both the environments. The hybrids namely 1×13 ($81A_1$×99HS141) for days to 50% flowering, 1000-grain weight, panicle girth and 4×12 ($81B_1$×H77/833-2) for dry fodder yield, effective tillers, panicle length expressed high heterosis for these productivity traits. The other crosses namely 1×10 ($81A_1$×MRC) exhibited desirable heterosis for grain yield, effective tillers, panicle girth, panicle length and harvest index; 3×14 ($81A_5$×HTP 92/80) for grain yield, 1000- grain weight and harvest index. These crosses involved the $81A_1$ and $81A_5$ cytoplasmic sources. This indicated the superiority of these two cytoplasmic sources to produce heterotic hybrids.

Keywords: Pearl millet, heterosis, diverse cytoplasmic sources

Introduction

Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] is an important cereal crop grown in tropical semi-arid regions of the world primarily in Africa and Asia. It is a highly nutritious cereal crop with wide agroecological adaptation primarily grown for grain production, but also valued for its fodder (both stover and green forage). It is nutritionally very rich, supplying highest number of calories than all other cereals, having high protein, fibre and fat content (NIN, 2003) [13].

It is a highly cross pollinated crop, and single-cross hybrids generally give 20–30% more yield than open pollinated varieties (Rai *et al.* 2006) [16]. Hybrid cultivar development in pearl millet became possible with the discovery of cytoplasmic- genic male-sterility (Burton, 1958) [4]. The use of CMS (cytoplasmic-genic male sterility) in pearl millet paved the way for grain yield augmentation with the development and release of first grain hybrid HB-I (Tift 23 A x BIL-3B) by Athwal (1965) [3].

Several other sources of male-sterility inducing cytoplasms besides A_1 (Burton, 1965) [5] such as A_2, A_3 (Burton and Athwal, 1967) [6], PT732A (Appadurai *et al.*, 1982) [2], ex-Bornu (Gero) (Aken'ova, 1985) [1], *violaceum* (Marchais and Pernes, 1985) [12], A_4 (Hanna, 1989) [8] and A_5 (Rai, 1995) [14] have been reported in pearl millet. Since then, large number of hybrids have been developed and commercialized in India, largely based on the A_1 CMS system except two (GHB 316 on A_3, HHB 216 on A_4 CMS system) hybrids. It has been shown that the A_4 and A_5 CMS systems are good alternative to the A_1 system in terms of the agronomic performance of pearl millet hybrids (Rai *et al.*, 2001; Rai *et al.*, 2009) [17, 15].

The isonuclear lines have also been established in the background of several diverse CMS sources, which provides an opportunity for studying cytoplasmic effects on the expression of different characters. In any hybrid breeding programme based on several CMS sources, the information on relative magnitude of heterosis in cytoplasmically diverse hybrids helpful in determining relative chance and quantifying the magnitude and direction of heterosis in hybrids carrying different cytoplasm in pearl millet.

Studies have indicated that cytoplasm exhibits pronounced effect on heterosis and combining ability (Young and Virmani, 1990; Yadav, 1994) [24-25, 22]. Heterosis breeding was ideal for increasing yield in pearl millet (Ramamoorthi and Nadarajan, 2001) [18]. Commercial exploitation of hybrid vigour in pearl millet has resulted in a substantial improvement in the productivity in the country as a whole and in a few states in particular but there is still a need to improve the grain yield to make this crop more economically viable. Therefore, the present investigation was conducted to study the extent of hybrid vigour in F_1 for grain yield and its components involving alloplasmic isonuclear lines of pearl millet.

Materials and Methods

The material for present study consisted of three CMS lines (A-lines), their corresponding maintainers (B-lines) and eight restorers and the details are presented in **Table 1**. Three male sterile lines and their corresponding three maintainer lines were crossed with eight restorers in line x tester fashion at ICRISAT, Hyderabad, during off season crop (January- April 2013). The forty eight pearl millet hybrids, thus, produced and their parents along with the standard check HHB-197 were grown in two environments (two dates of sowing) E_1 - Planting 15th July (Normal sowing) and E_2 Planting 24th July (Late sowing) during *kharif* 2013. The experiment was raised in a Randomized Block Design with three replications in each of the environments at CCSHAU, Hisar with a plot size of 2row x 4 m x 0.5 m with 10-12 cm intra- row spacing. All the recommended agronomic practices were followed to raise a good crop.

During *kharif* 2013, total rainfall of 594.3 mm was recorded with a total of 24 rainy days. The total rainfall was below normal and distribution was also abnormal. The highest rainfall (154.2 mm) in a single week was recorded on 33rd week. The weekly mean minimum temperature (June to November) varied from 16.3^{0}C to 27.5^{0}C, whereas, the maximum temperature was between 31.3^{0}C to 38.7^{0}C and both were normal. The mean weekly morning relative humidity ranged between 78 to 96%.

Table 1: Male sterile lines, their corresponding maintainers and restorers lines used in the study:

Sr. No.	Lines	Source
1.	81A_1	ICRISAT
2.	81A_4	ICRISAT
3.	81A_5	ICRISAT
4.	81B_1	ICRISAT
5.	81B_4	ICRISAT
6.	81B_5	ICRISAT
Testers		
7.	H77/29-2	HAU
8.	TCH 26-1	HAU
9.	G 73- 107	HAU
10.	MRC/10/61 (MRC)	ICRISAT
11.	ERC/99/35 (ERC)	ICRISAT
12.	H77/833-2	HAU
13.	99HS141	HAU
14.	HTP 92/80	HAU

Results and Discussion

In the commercial exploitation of hybrid vigour, excess of F_1 over standard check (standard heterosis), is of significance. Hence, in the present investigation, the extent of heterosis over standard check hybrid (HHB 197) for grain yield and eight yield component traits is discussed. The magnitude of heterosis in terms of per cent increase or decrease in the performance of the hybrids over the standard check HHB-197 was studied and the results are presented. The analysis of variance of the data performed (including check values) for the various characters studied in two environments are presented in **Table 2**. The mean squares due to treatments (hybrids and standard check) were highly significant for all the characters studied.

Grain yield is of economic importance for which considerable degree of heterosis was registered in a number of crosses. Among the 48 crosses studied in two environments, 8 in E_1 and 7 in E_2 exhibited significant positive heterosis manifested significant positive standard heterosis. Environment wise percent standard heterosis ranged from -31.11 to 24.07 and -31.98 to 22.67 with mean values -8.91 and -6.57 in E_1 and E_2, respectively (**Table- 4**). The crosses namely, 1×8 (E_1, E_2), 3×11 (E_2), 3×14 (E_2), 6×10 (E_1) and 1×10 (E_2) expressed significant heterosis over the check HHB-197 (**Table- 3**). This result indicated that the favorable combination of yield contributing characters resulted in a higher proportion of cross combinations showing significant positive standard heterosis. Vetriventhan *et al*. (2008) [21] also observed high magnitude of heterosis for grain yield.

Low of heterosis has been observed in fodder yield, which is an important component of pearl millet being a dual-purpose crop. The cross 1×14 (14.61 %) recorded the maximum standard heterosis for higher dry fodder yield in E_2 environment followed by 4×12 (12.33 %). The results on per cent heterosis for dry fodder yield revealed that most of the crosses were poor combinations with negative significant values. Environment wise percent standard heterosis ranged from -41.49 to 10.73 and -49.03 to 14.61 with mean values -10.29 and -7.98 in E_1 and E_2, respectively.

Early flowering was treated as desirable attribute and accordingly negative estimates of heterosis were considered to be desirable. The results on per cent heterosis for days to 50 per cent flowering revealed that out of 48 crosses as many as 7 in E_1 and 4 in E_2 showed significant negative values of heterosis. The hybrid 4×13 was noted for negative and significant heterosis in both the environments. The crosses 1×9, 3×8, 6×8 in E_1 and 1×13 exhibited significant negative values of heterosis in E_2. Environment wise percent standard heterosis ranged from -8.62 to 25.86 and -12.23 to 11.87 with mean values 9.65 and 2.47 in E_1 and E_2, respectively. Chotaliya *et al.*, (2009) [7] and Vaghasiya *et al.*, (2009) [20] also observed heterosis to some extent for this trait.

None of the hybrids were found to be exhibit significant positive heterosis for plant height in both of the environments over the standard check. The most of the crosses exhibited negative values for heterosis. Environment wise percent standard heterosis ranged from -31.20 to 11.30 and -27.63 to 12.73 with mean values -4.11 and -9.09 in E_1 and E_2, respectively.

The effective tillers considered an important yield component trait. The cross combinations 1×9, 2×13, 3×11 and 4×12 proved to be favorable combinations in both the environments and 1×10 in E_2. The results on percent heterosis revealed that out of 48 crosses as many as 17 in E_1 and 11 in E_2 showed significant positive values of heterosis. Environment wise percent standard heterosis ranged from -44.58 to 39.76 and -34.21 to 36.84 with mean values -4.99 and -7.81 in E_1 and E_2, respectively.

Test weight being an important yield attributing character, use of parents with high test weight in breeding programme may be most desirable. The results on per cent heterosis for 1000-

grain weight revealed that out of 48 crosses as many as 4 in each of E_1 and E_2 showed significant positive heterosis. Environment wise percent standard heterosis ranged from -36.59 to 10.71 and -30.41 to 13.41 with mean values -18.80 and -16.52 in E_1 and E_2, respectively. The highest standard heterosis for 1000-grain weight was observed in cross 5×7 (22.89 %) in E_1 and 15.79% in E_2. The crosses 1×13, 2×10, 3×14 and 5×12 exhibited significant positive heterosis in both the environments and 1×11 in E_2. Heterosis for test weight in pearl millet was also reported by Chotaliya *et al.* (2009) [7] and Vaghasiya *et al.* (2009) [20].

The estimates of heterosis for panicle girth revealed that crosses 1×10, 1×13, 3×11and 5×8 exhibited significant positive values of heterosis in both of the environments and 6×10 in E_2. Environment wise percent standard heterosis ranged from -49.68 to 11.86 and -36.36 to 15.49 with mean values -16.06 and -17.21 in E_1 and E_2, respectively.

The results on percent heterosis for panicle length revealed that out of 48 crosses as many as 5 in E_1 and E_2 exhibited significant positive heterosis. The cross 1×10 exhibited significant positive values in both of the environments. The other desirable crosses in one of the two environments were 2×7 (E_2), 2×13 (E_2), 4×12 (E_2) and 6×13 (E_1). Environment wise percent standard heterosis ranged from -19.76 to 25.21 and -35.03 to 21.97 with mean values -6.86 and -11.81 in E_1 and E_2, respectively.

The estimates of heterosis for harvest index revealed that crosses 1×7 and 3×11 exhibited significant positive values for heterosis in both the environments and 1×10 (E_2), 6×10 (E_2) and 3×14 (E_2). Environment wise percent standard heterosis ranged from -11.49 to 18.84 and -14.00 to 28.33 with mean values 0.85 and 0.99 in E_1 and E_2, respectively. Hybrids displayed desirable heterosis for almost all the characters except plant height. The desirable heterosis has also been reported by Dangaria *et al.* (2009a) [7-15-20]; Vagadiya *et al.* (2010) [19] and Jethva *et al.* (2012) [9] in pearl millet. Low heterosis may also be obtained for some characters and some crosses as also reported by Lakshmana *et al.* (2010) [11]. Heterosis in cross pollinated crops such as in pearl millet is an important phenomenon and also reported by Yadav (1999) [23]; Vagadiya *et al.* (2010) [19] and Kathale *et al.* (2013) [10] for grain yield and its components characters.

The direction and magnitude of heterosis varied from cross to cross in two different environments. This indicates environmental influence on the expression of hybrid vigour. The hybrid combination 3×11 ($81A_5$×ERC) expressed significant positive heterosis for grain yield, effective tillers, panicle girth and harvest index. The hybrids namely 1×13 ($81A_1$×99HS141) for days to 50% flowering, 1000-grain weight, panicle girth and 4×12 ($81B_1$×H77/833-2) for dry fodder yield, effective tillers, panicle length expressed high heterosis for these productivity traits. The other crosses namely 1×10 ($81A_1$×MRC) exhibited desirable heterosis for grain yield, effective tillers, panicle girth, panicle length and harvest index; 3×14 ($81A_5$×HTP 92/80) for grain yield, 1000-grain weight and harvest index; 6×10 ($81B_5$×MRC) for grain yield, panicle girth and harvest index. These crosses involved the $81A_1$ and $81A_5$ cytoplasmic sources. This clearly revealed superiority of these two cytoplasmic sources to produce heterotic hybrids.

Table 2: Analysis of variance for Randomized Block Design for some quantitative traits in two environments

Source of variation	d.f.	Grain yield (g/plant)		Dry fodder yield (g/plant)		Days to 50% flowering	
		E_1	E_2	E_1	E_2	E_1	E_2
Replication	2	7.70	0.37	19.85	219.50	13.35	12.21
Treatment	48	35.51**	29.03**	388.90**	407.40**	64.51**	14.39**
Error	96	9.75	9.57	51.80	42.68	5.10	91.40

Source of variation	d.f.	Plant height (cm)		Effective tillers (No./plant)		1000-grain weight (g)	
		E_1	E_2	E_1	E_2	E_1	E_2
Replication	2	577.09	90.27	0.01	0.05	0.43	0.02
Treatment	48	744.93**	677.85**	0.73**	0.50**	2.60**	1.95**
Error	96	91.40	76.68	0.10	0.06	0.39	0.17

		Mean squares					
Source of variation	d.f.	Panicle girth (cm)		Panicle length (cm)		Harvest Index (%)	
		E_1	E_2	E_1	E_2	E_1	E_2
Replication	2	0.004	0.03	15.17	1.33	4.30	6.12
Treatment	48	0.38**	0.38**	13.12**	14.82**	9.20**	21.50**
Error	96	0.05	0.05	1.79	1.81	3.97	3.67

** significant at P= 0.01

E_1 and E_2 = Normal and late sown crops, respectively

Table 3: Estimates of heterosis (%) of top five hybrids and their *per se* performance (in parentheses) for different characters in two environments

Character	Hybrids	Pedigree	Mean		Heterosis over standard check		Env. mean	Number of crosses showing significant desirable heterosis	
			E_1	E_2	E_1	E_2		E_1	E_2
Grain yield (g/plant)	1×8	$81A_1$× TCH 26-1	30.65	28.53	6.44* (30.65)	8.30* (28.53)	(29.59)	8	7
	3×11	$81A_5$ × ERC 99/35 (ERC)	28.91	28.05	0.37 (28.91)	6.48* (28.05)	(28.48)		
	3×14	$81A_5$× HTP 92/80	23.89	30.07	-17.04* (23.89)	14.12* (30.07)	(26.98)		
	6×10	$81B_5$× MRC/10/61 (MRC)	30.51	26.03	5.93* (30.51)	-1.21 (26.03)	(28.27)		

	1×10	81A$_1$× MRC /10/61 (MRC)	24.96	32.32	-13.33* (24.96)	22.67* (32.32)	(28.64)		
Dry fodder yield (g/plant)	4×12	81B$_1$× H77/833-2	76.87	96.90	-6.94 (76.87)	12.33* (96.90)	(86.88)	0	2
	1×14	81A$_1$× HTP 92/80	62.63	98.87	-24.17* (62.63)	14.61* (98.87)	(80.75)		
	3 x 13	81A$_5$× 99HS141	90.97	88.53	10.13	2.63	(6.38)		
	4 x 10	81B$_1$× MRC /10/61 (MRC)	91.27	90.53	10.49	4.95	(7.72)		
	5 x 7	81B$_4$× H77/29-2	91.47	90.20	10.73	4.56	(7.64)		
Days to 50 % flowering	4×13	81B$_1$× 99HS141	44.17	40.67	-8.62* (44.17)	-12.23* (40.67)	(42.42)	7	4
	6×8	81B$_5$× TCH 26-1	46.20	46.00	-4.41* (46.20)	-0.72 (46.00)	(46.10)		
	1×9	81A$_1$× G 73- 107	44.47	45.50	-8.00* (44.47)	-1.80 (45.50)	(44.98)		
	1×13	81A$_1$× 99HS141	47.17	42.93	-2.41 (47.17)	-7.34* (42.93)	(45.05)		
	3×8	81A$_5$× TCH 26-1	45.33	45.17	-6.21* (45.33)	-2.52 (45.17)	(45.22)		
Plant height (cm)	1x 9	81A$_1$× G 73- 107	166.23	146.40	4.68	5.78	(5.23)	0	0
	2x 7	81A$_4$× H77/29-2	184.73	181.20	7.28	7.58	(7.43)		
	4 x 12	81B$_1$× H77/833-2	177.93	189.87	3.33	12.73	(8.03)		
Effective tillers (No./plant)	1×9	81A$_1$× G 73- 107	3.00	3.47	8.43* (3.00)	36.84* (3.47)	(22.63)	17	11
	1×10	81A$_1$× MRC/10/61 (MRC)	2.13	3.20	-22.89* (2.13)	26.32* (3.20)	(2.66)		
	2×13	81A$_4$× 99HS141	3.73	3.13	34.94* (3.73)	23.68* (3.13)	(3.43)		
	3×11	81A$_5$× ERC/99/35 (ERC)	3.07	2.80	10.84* (3.07)	10.53* (2.80)	(2.93)		
	4×12	81B$_1$× H77/833-2	3.87	2.73	39.76* (3.87)	7.89* (2.73)	(3.30)		
1000- grain weight (g)	1×13	81A$_1$× 99HS141	8.67	8.33	3.17* (8.67)	1.63* (8.33)	(8.50)	4	4
	2×10	81A$_4$× MRC/10/61 (MRC)	8.70	8.40	3.57* (8.70)	2.44* (8.40)	(8.55)		
	3×14	81A$_5$× HTP 92/80	8.67	8.27	3.17* (8.67)	0.81* (8.27)	(8.47)		
	5×12	81B$_4$× H77/833-2	8.70	8.23	3.57* (8.70)	0.41 (8.23)	(8.46)		
	1×11	81A$_1$× ERC/99/35 (ERC)	8.33	9.30	-0.79 (8.33)	13.41* (9.30)	(8.81)		

Table contd…………

Character	Hybrids	Pedigree	Mean		Heterosis over standard check		Env. mean	Number of crosses showing significant desirable heterosis	
			E$_1$	**E$_2$**	**E$_1$**	**E$_2$**		**E$_1$**	**E$_2$**
Panicle girth (cm)	1×10	81A$_1$× MRC/10/61 (MRC)	2.80	2.56	8.01* (2.80)	8.26* (2.56)	(2.68)	8	8
	1×13	81A$_1$× 99HS141	2.73	2.54	5.44* (2.73)	7.30* (2.54)	(2.63)		
	6×10	81B$_5$× MRC/10/61 (MRC)	2.50	2.73	-3.45* (2.50)	15.49* (2.73)	(2.61)		
	3×11	81A$_5$× ERC/99/35 (ERC)	2.77	2.53	6.72* (2.77)	7.04* (2.53)	(2.65)		
	5×8	81B$_4$× TCH 26-1	2.90	2.67	11.86* (2.90)	12.68* (2.67)	(2.78)		
Panicle length (cm)	1×10	81A$_1$× MRC/10/61 (MRC)	24.27	22.33	8.98* (24.27)	6.69* (22.33)	(23.30)	5	5
	2×7	81A$_4$× H77/29-2	22.46	21.43	0.87 (22.46)	2.39* (21.43)	(21.94)		
	2×13	81A$_4$× 99HS141	22.67	22.13	1.80 (22.67)	5.73* (22.13)	(22.40)		
	4×12	81B$_1$× H77/833-2	22.50	23.33	1.05 (22.50)	11.46* (23.33)	(22.91)		
	6×13	81B$_5$× 99HS141	23.99	21.27	7.72* (23.99)	1.59 (21.27)	(22.63)		
Harvest index (%)	1×7	81A$_1$× H77/29-2	29.64 (32.96)	36.46 (37.12)	7.86* (29.64) (32.96)	28.33* (36.46) (37.12)	(33.05)	15	16

	6×10	81B5× MRC/10/61 (MRC)	26.35 (30.86)	25.58 (30.31)	0.97 (26.35) (30.86)	4.79* (25.58) (30.31)	(25.96)		
	1×10	81A1× MRC/10/61 (MRC)	24.84 (29.87)	33.71 (35.46)	-2.28 (24.84) (29.87)	22.61* (33.71) (35.46)	(29.27)		
	3×14	81A5× HTP 92/80	25.52 (30.30)	32.20 (34.55)	-0.87 (25.52) (30.30)	19.44* (32.20) (34.55)	(28.86)		
	3×11	81A5× ERC/99/35 (ERC)	31.85 (34.30)	30.90 (33.76)	12.21* (31.85) (34.30)	16.70* (30.90) (33.76)	(31.37)		

*significant at P= 0.05
Bold figures in parentheses are angular transformed values
E_1 and E_2 = Normal and late sown crops, respectively

Table 4: Mean and range of heterosis (%)

	Grain yield (g/plant)				**Dry fodder yield (g/plant)**				**Days to 50% flowering**			
	E1	**HC (%)**	**E2**	**HC (%)**	**E1**	**HC (%)**	**E2**	**HC (%)**	**E1**	**HC (%)**	**E2**	**HC (%)**
Mean	26.23	-8.91	24.62	-6.57	74.10	-10.29	79.38	-7.98	53.00	9.65	47.48	2.47
Minimum	19.84	-31.11	17.92	-31.98	48.33	-41.49	43.97	-49.03	44.17	-8.62	40.67	-12.23
Maximum	35.73	24.07	32.32	22.67	91.47	10.73	98.87	14.61	60.83	25.86	51.83	11.87

	Plant height (cm)				**Effective tillers (No./plant)**				**1000- grain weight (g)**			
	E1	**HC (%)**	**E2**	**HC (%)**	**E1**	**HC (%)**	**E2**	**HC (%)**	**E1**	**HC (%)**	**E2**	**HC (%)**
Mean	165.12	-4.11	153.12	-9.09	2.63	-4.99	2.34	-7.81	6.82	-18.80	6.85	-16.52
Minimum	118.47	-31.20	121.90	-27.63	1.53	-44.58	1.67	-34.21	5.33	-36.59	5.71	-30.41
Maximum	191.67	11.30	189.87	12.73	3.87	39.76	3.47	36.84	9.30	10.71	9.30	13.41

	Panicle girth (cm)				**Panicle length (cm)**				**Harvest index (%)**			
	E1	**HC (%)**	**E2**	**HC (%)**	**E1**	**HC (%)**	**E2**	**HC (%)**	**E1**	**HC (%)**	**E2**	**HC (%)**
Mean	2.18	-16.06	1.96	-17.21	20.74	-6.86	18.46	-11.81	30.82	0.85	29.21	0.99
Minimum	1.30	-49.68	1.51	-36.36	17.87	-19.76	13.60	-35.03	27.05	-11.49	24.87	-14.00
Maximum	2.90	11.86	2.73	15.49	27.88	25.21	25.53	21.97	36.32	18.84	37.12	28.33

HC-heterosis over check
E_1 and E_2 = Normal and late sown crops, respectively

References

1. Aken'ova ME. Confirmation of a new source of cytoplasmic-genic male sterility in bullrush millet [*Pennisetum typhoides* (L.) Leeke.]. Euphytica. 1985; 34:34-38.
2. Appadurai R, Raveendran TS, Nagarajan C. A new male sterility system in pearl millet. Indian J. of agri. Sci. 1982; 52:832-834.
3. Athwal DS. Hybrid bajra-1 marks a new era. Indian Farming. 1965; 15(5):6-7.
4. Burton GW. Cytoplasmic male-sterility in pearl millet (*Pennisetum glaucum* (L.) R. Br.). Agro. J. 1958; 50:230-231.
5. Burton GW. Pearl millet Tift 23A released. Crops and soils. 1965; 17:19.
6. Burton GW, Athwal DS. Two additional sources of cytoplasmic male-sterility in pearl millet and their relationship to Tift 23A. Crop Sci. 1967; 7:209-211.
7. Dangaria CJ, Chotalia JM, Savaliya JJ, Davda BK, Pansuriya AG. Hybrid vigour studies in ten newly developed restorer lines of pearl millet (P*ennisetum glaucum* (l.) r. br). Agri. Sci. Digest. 2009; 29(4):275-278.
8. Hanna WW. Characteristics and stability of a new cytoplasmic-nuclear male-sterile source in pearl millet. Crop Sci. 1989; 29:1457-1459.
9. Jethva AS, Raval L, Madariya RB, Mehta DR, Mandavia C. Heterosis for grain yield and its related characters in pearl millet. Electronic J. of Plant Breed. 2012; 3(3):848-852.
10. Kathale MN, Jadhav PA, Wadekar PB. Heterosis in pearl millet. Bioinfolet. 2013; 10(3B):1002-1005.
11. Lakshmana D, Biradar BD, Deshpande SK, Madaiah D. Studies on combining ability and heterosis involving diverse cytoplasmic male sterility system in pearl millet. Indian J. of Genet. and plant breed. 2010; 70(1):29-33.
12. Marchais L, Pernes J. Genetic divergence between wild and cultivated pearl millet (*Pennisetum typhoides*). 1. Male sterility. Z. Pflanzenziichtung. 1985; 95:103-112.
13. NIN. Nutritive value of Indian Foods. Ed Gopalan and Deosthale, National Institute of Nutrition, Hyderabad, 2003.
14. Rai KN. A new cytoplasmic-nuclear male sterility system in pearl millet. Plant Breed. 1995; 114:445-447.
15. Rai KN, Khairwal IS, Dangaria CJ, Singh AK, Rao AS. Seed parent breeding efficiency of three diverse cytoplasmic-nuclear male-sterility systems in pearl millet. Euphytica. 2009; 165:495-507.
16. Rai KN, Kulkarni VN, Thakur RP, Haussmann BIG, Mgonja MA. Pearl millet hybrid parents research: approaches and achievements. Pages 11–73 *in* Hybrid parents research at ICRISAT (CLL Gowda, KN Rai, BVS Reddy and KB Saxena eds.). International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India, 2006, 11-73.
17. Rai KN, Kumar KA, Andrews DJ, Rao AS. Commercial viability of alternative cytoplasmic-nuclear male-sterility systems in pearl millet. Euphytica. 2001; 121:107-114.
18. Ramamoorthi N, Nadarajan N. Genetic analysis for yield attributes in pearl millet (*Pennisetum glaucum* (L.) R.

Br.). Madras Agri. J. 2001; 87(4/6):316-317.
19. Vagadiya KJ, Dhedhi KK, Joshi HJ, Bhadelia AS, Vekariya HB. Studies on heterosis in pearl millet [*Pennisetum glaucum* (L.) R. BR.]. Agri. Sci. Digest. 2010; 30(3):197-201.
20. Vaghasiya VD, Dangaria CJ, Dhedhi KK. Heterosis studies in B x R crosses for selection of superior females for A-line development in pearl millet. Agri. Sci. Digest. 2009; 29(2):6-10.
21. Vetriventhan M, Nirmalakumari A, Ganapathy S. Heterosis for grain yield components in pearl millet (*Pennisetum glaucum* (L.) R. Br.). World J. of Agri. Sci. 2008; 4:657-660.
22. Yadav OP. Genetic divergence in pearl millet accessions of Indian and exotic origin. Indian J. of Genet. and plant breed. 1994; 54:89-93.
23. Yadav OP. Heterosis and combining ability in relation to cytoplasmic diversity in pearl millet. Indian J. of Genet. and plant breed. 1999; 59:445-450.
24. Young JB, Virmani SS. Heterosis in rice over environment. Euphytica. 1990; 51:87-93.
25. Young JB, Virmani SS. Effects of cytoplasm on heterosis and combining ability for agronomic traits in rice (*Oryza sativa* L.). Euphytica. 1990; 48:177-188.