Int.J.Curr.Microbiol.App.Sci (2020) *9*(2): 486-499

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 2 (2020)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2020.902.060

Genetic Analysis of Grain Yield and Its Attributes Using Diverse Systems of Male Sterile Lines and Pollinators in Direct Sown and Ratooned Pearl Millet

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Keywords

Combing ability, Cytoplasm, Male sterility, gca effects, sca effects, Environment, Rationing, Pearl millet

Article Info

Accepted:
05 January 2020
Available Online:
10 February 2020

A B S T R A C T

The genetics of grain yield and its attributes were studied using diverse cytoplasmic male sterile lines in 144 hybrids developed by crossing six A- and their six B-lines with 12 R-lines of pearl millet in a line x tester mating design. The six A- lines 81A_1 and 8A_1 (A_1), Pb 313A (A_2), Pb 402A (A_3), 81A_4 and 81A_5 and their corresponding B- lines represented five different systems of male sterility were very diverse. The 24 parents and the 144 hybrids were grown separately in contiguous blocks in 2r x 2.5 m × 0.45 m in randomized block design with two replications in six environments under natural condition viz., early sown non-cut crop (E_1, E_4), ratoon crop (E_2, E_5) and late sown non-cut crop (E_3, E_6) at Research Farm, CCSHAU, Hisar. The analysis of variance for combining ability revealed that the mean squares due to lines, testers and lines × testers were highly significant when tested against the error mean sum of squares for all the characters in all the environments during both years. The higher magnitude of fixed effect sca variances to that of fixed effect gca variances for all the characters indicated that non-additive gene effects governed the inheritance. The perusal of data with respect to gca effects of lines revealed that 3 (313A) and 9 (313B) representing A_2 system of male sterile cytoplasm and fertile cytoplasm combined favourably for grain yield and growth rate, exhibited significant positive gca effects in most of environment including ratoon crop. Lines 4 (402A) and 10 (402B) of A_3 system proved good general combiners for 500 grain weight. Lines 5 (81A_4 and 81B_4)of A_4 system showed significant positive gca effects for harvest index, turned to be good general combiner. Tester 17 (77/245) emerged to be good general combiner for grain yield, harvest index and growth rate, exhibited significant positive gca effects in most of environments for these characters. Other testers showed significant positive gca effects for grain yield in most of the environments were 20 (ICR 161), 16 (CSSC46-2) and 23 (77/180). Tester 20 (ICR 161) was also good general combiner for 500 grain weight. The hybrids 1 x 13 (81A_1 x H90/4-5), 1 x 14 (81A_1 x H77/833-2), 4 x 21 (Pb 402A_3 x ISK 48), 9 x 18 (Pb 313B_2 x 78/711), 3 x 18 (Pb 313A_2 x 78/711), 11 x 18 (81B_4 x 78/711), 12 x 16 (81B_5 x CSSC 46-2), 7 x 21 (81B_1 x ISK 48) showed significant positive sca effects for grain yield and one or more characters in most of the entrainments. The hybrids 1 x 13 (81A_1 x H90/4-5), 1 x 14 (81A_1 x H77/833-2), 9 x 13 (313B_2 x H90/4-5) and 12 x 16 (81B^5 x CSSC46-2) performed better on the basis of *per se*, sca effects including ratoon crop indicating their hope for sustainable dual purpose pearl millet production in harsh environments and can be recombined to develop base population for improvement for ratoonability by cyclic breeding.

Introduction

Pearl millet *(Pennisetum glaucum* (L) R. Br.), an important food, feed and dual purpose crop, is life line of human and cattle population inhabiting under most trying conditions in India and Africa. The crop is cultivated mainly under poor fertility, low inputs, severe heat and rainfed conditions where drought in one to four years is not uncommon. It assumes greater significance as no other crop competes with its biomass production potential and per day productivity. Green fodder of pearl millet is preferred over that of sorghum because its HCN content is low and can be fed to cattle without harm at any stage of growth Unavailability of green fodder in pre-monsoon periods is frequent therefore, identification of lines for regeneration potential and with ability to give good grain yield holds significance. The appreciable higher grain yield of pearl millet in crop cut after 35 days of sowing in comparison to non-cut reported by Tomer and Saini (1979) is encouraging. Day *et al.*, (1968) and Skorda (1977) also reported increase in grain yield in cereal crops after cut. Kumar *et al.*, (2005) observed that regeneration and ratooning ability under genetic control and regeneration potential could be incorporated in genotype with high grain yield in pearl millet. Thus, the practice of sowing the crop early sometimes in June to reduce the risk of non-receipt of rains in time and regenerating the crop for grain yield is advantageous. The ratoonability of pearl millet adds a degree of versatility that could be useful in a period of unfavourable or dry monsoon. The ratoonability saves the cost for establishing new crop and offers an opportunity of availability of green fodder at scarcity time.

Pearl millet is endowed with a rich reservior of genetic variability for various traits of yield, adaptation and quality. Exploitation of immense genetic variability in the available germplasm holds the promise of producing high yielding hybrids and open pollinated varieties adapted to a wide range of both traditional and non-traditional agro-ecological environments. The more diverse are the parents, the greater are the chances of obtaining new combinations of genes and thus more are the chances of improvement. The efficiency of a breeding method for improving a trait depends largely on its inheritance pattern (Sagar and Kapoor, 1988). Though, there are several mating designs available for evaluation of lines, the line × tester design suggested by Sprague and Tatum (1942) and statistical analysis given by Kempthorne (1957) is simple and extensively used mating design for studying the combining ability of lines and genetic variances for characters.

Several other sources of male sterility inducing cytoplasms besides A_1 (A_2, A_3 A_4 and A_5) have been reported to diversify the cytoplasm and nuclear genetic base of pearl millet hybrids. However, commercial utilization of different CMS systems depends on several factors including their effect on agronomic traits. The iso-nuclear 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. Studies have indicated that cytoplasm exhibits pronounced effect on combining ability (Young and Virmani, 1990, Kumar 2002, Kumar and Sagar, 2010 and Kumar and Sagar 2015). Moreover, there are diverse opinions about combining ability effects as influenced by type of sterile cytoplasm (Yadav, 1999). Studies on combing ability involving diverse cytopasmic male sterlity system in direct sown and ratoon pearl millet crop is very scanty. Thus, a systematic and comprehensive study was carried out on combining ability for grain yield and its three component characters viz., 500-grain weight (g), harvest index (%) and growth rate (g/plant/day) involving diverse CMS sources lines in direct sown and ratooned (cut regenerated) pearl millet crop.

Materials and Methods

The material for the present study consisted of six male sterile lines from five systems of male sterility namely two male sterile lines from system A_l (MS 8lA_l, HMS 8A_1) and one each from A_2 (Pb.313A_2), A_3 (Pb.402A_3), A_4 (MS 8lA_4) and A_5 (MS 8lA_5), their corresponding maintainer (B) lines B_l (MS 81B, HMS 8B), B_2 (Pb.313B), B_3 (Pb.402B), B_4 (MS81B_4) and B_5 (MS81B_5) and twelve restorer lines viz. H90/4-5, H77/833-2, G73-107, 77/245, 77/273, CSSC 46-2, ISK 48, ICR I61, 77/180, 78/711 and Raj. 42. The six male sterile lines and their corresponding maintainer lines were crossed with twelve restorer lines in line x tester design. The 24 parents and 144 crosses were grown separately in contiguous blocks in randomized block design with two replications in six environments (treatments) three each viz., early sown non-cut crop (E_1, E_4), ratoon crop (E_2, E_5) and late sown non-ratooned (E_3, E_6) at Research Farm, Bajra Section, CCS HAU, Hisar. To assess ratoon effect planting was done in four environments E_1, E_2 and E_4, E_5 earlier than normal time and crop was cut in E_2 and E_5 after 40 days and regenerated / ratooned. The crop in E_3 and E_6 was sown at time on date of cutting in E_2 and E_5, respectively. The plot size was 2r x 2.5 m x 0.45 m with 10 cm intra-row spacing. All the recommended agronomic practices were followed to raise a good crop. The data were recorded for grain yield and three other yield related characters viz. 500-grain weight (g), harvest index (%) and growth rate (g /plant/day).The harvest index was calculated in percentage by formula given by Donald (1962).The growth rate was calculated as suggested by Bramel Cox *et al*., (1984). The analysis of variance was carried out in each of the environments according to Federer (1977). Combining ability analysis was carried out following Kempthorne (1957).

Results and Discussion

The analysis of variance for combining ability (Table 1) revealed that the mean squares due to lines, testers and lines x testers were highly significant when tested against the error mean sum of squares for all the characters in all the environments during both years However, the mean sum of squares due to lines and testers when tested against the interaction (lines×testes), the mean sum of squares due to lines exhibited non-significance in some environments for the traits viz. grain yield, harvest index in E_5; growth rate (E_2, E_4, E_5), This revealed that lines did not show much variation in these environments.

The mean squares due to testers were highly significant for all the traits in all the environments except for some characters in some environments viz. grain yield and growth rate in E_4 and harvest index (E_6). This revealed that testers differed more for general combining ability. Further highly significant mean squares due to lines × testers suggested the hybrids differed significantly for specific combining ability for all the traits in all the environments during both the years. Further, the magnitude of mean square due to testers was invariably higher as compared to those of lines for most of the traits. This indicated that a large portion of the genetic variability in crosses was accounted by the differences in testers.

The fixed effect variances due to general combining ability (gca) and specific combining ability (sca) presented in Table 1 revealed that the magnitude of sca variances exceeded to that of gca variances for all the characters and also the estimates of gca and sca variances and the ratio between gca and sca variances was less than unity for all characters under study that supported for non-additive gene action. Preponderance of non-additive genetic control of all characters has been reported in a compendium of biometrical analysis in pearl millet by Yadav *et al.*, (2000), Bhadalia *et al*., (2014), Mungra *et al*., (2015), Rafiq *et al*., (2016), Kumar *et al*., (2017) and Sharma *et al.,* (2019).

The estimates of general combining ability effects of lines are important in a crop like pearl millet where large number of hybrids are developed and tested every and therefore, would help in selecting the parents for using them in hydridization. None of the lines (sterile as well as maintainer) and testers proved to be good general combiners for all the characters (Table 2) in all the environments, the crosses in general also did not express significant high sca effects in all the environments for all the characters studied. Kumar (2002), Sharma *et al.,* (2005) and Sharma *et al.,* (2019) also reported similar observation.

A critical examination of gca effects of lines revealed that 3 (313A) and 9 (313B) representing A^2 system of male sterile cytoplasm and fertile cytoplasm combined favourably for grain yield, and growth rate. Lines 4 (402A) and 10 (402B) of A^3 system proved good general combiners for 500 grain weight. The combining ability of A^1 system lines 1/7 (81A/81B) and 2/8 (8A/8B) was not similar at system level. But 1 (81A) and 7 (81B) combined better for harvest index and line 1 (81A) also combined better for grain yield. Lines 2 (8A) and 8 (8B) for 500-grain weight and 8 (8B) also combined favourably for grain yield. The lines 5 ($81A^4$) and 11 ($81B^4$) gave high gca effects for harvest index. The line 6 ($81A^5$) combined better for grain yield, and harvest index. Virk and Brar (1993) reported that the A^3 system (Pb $406A^3$ and Pb $402A^3$) cytoplasm was better general combiner than A^2 cytoplasm (Pb$310A^2$ and Pb $311A^2$) for grain yield and the superiority of A^3 cytoplasm for gca for plant height and ear characters. This observation is in contrast to ours. We have found high gca effects for grain yield for Pb $313A^2$ (A^2). This is in agreement with Mangat *et al.*, (1998) for grain yield. This is probably due to differences in maintainer nuclear background and use of different resource.

The male sterile lines and maintainers representing, different sources of cytoplasm showed substantial differences for combining ability for one or more characters (Kumar, 2002, Kumar and Sagar, 2010, Kumar and Sagar, 2015). Kumar *et al.,* (1996) reported that none of the male sterile cytoplasmic sources in general was good combiner for all the traits studied by them. The sterile cytoplasm (A-) lines and the fertile (B-, maintainer) line expressing significant gca effects in almost similar number of environments, suggests that the cytoplasm had not the pronouncing effect on gca of a line. The effect of environment on cytoplasm was implicit from the same and differential behaviour of lines (A-line and B-line) for gca in different environments which could be due to micro climatic influences accumulated over different phenophases of plant development (Kumar, 2002).

The gca effects of near–isonuclear polycytoplasmic male sterile lines (81, $81A^4$, $81A^5$) carrying the same nucleus of 81B revealed that for grain yield significant positive effects in a number of environments though varied for the three A lines viz. 81A (3 environments), $81A^4$ (2 environment), $81A^5$ (4 environments), their B lines expressed significant gca effects in two environments each, but different ones. More or less similar behaviour of these lines was noted for other characters shows that maternal cytoplasm provided an unstable and differential substrate for the paternal genes as hypothesized by Renner and Kupper (1921) in plasmone sensitivity, this shows that same nucleus showed differential behaviour in different cytoplasm as a result of cytoplasm and nuclear (genic) interaction. Thus the expression of the phenotype is under the influence of nuclear genes, cytoplasmic factors and the interaction of two, and also certain nuclear-genotypic combinations perform better than others (Virk and Brar, 1993).

Tester 17 (77/245) emerged to be good general combiner for grain yield, harvest index and growth rate, exhibited significant positive gca effects in most of environments for these characters. Other testers showed significant positive gca effects for grain yield in most of the environments were 20 (ICR 161), 16 (CSSC46-2) and 23 (77/180). Tester 20 (ICR 161) was also good general combiner for 500 grain weight including ratoon crop. Testers 17(77/245), 13(90/4-5), 14 (H77/833-2) and16 (CSSC 46-2) proved to be good general combiners for harvest index as indicated by their significant positive gca effects in three of six environments. Among testers, 23 (77/180) and 17 (77/245) were noted to be good combiner for growth rate in four of six environments.

A list of few crosses selected on the basis of sca for various characters and *per se* is given in Table 3. The estimates of sca effects for all the characters studied were inconsistent across the environments. Kumar (2002) and Sharma (2005) also reported similar observations. The cross 1x14 combined significantly higher for grain yield in all the six environments. The F1 hybrids 11 x 18 and 12 x 16 showed significant positive sca effects in most of the environments except former in $E^2$and E^6; and latter in E^3 and E^6. The crosses 1x17, 3 x 24, 4 x 17, 4 x 21, 7 x 14, 9 x 19, 10 x 15 and 11 x 20 expressed significant positive effects in Non-ratoon early crop (E^1, E^4). The F_1 hybrids 2 x 24, 3 x 18 and 10 x 23 showed their desirability in non-ratoon late crop (E^3, E^6). The crosses 1 x 13 (E^2, E^4, E^5), 6 x 13 (E^2, E^5) and 9 x 13 (E^2, E^3, E^5) were found to be good specific combinations in ratoon crop (E^2, E^5). The other crosses proved to be good combinations were 7 x 21 (E^1, E^2,E^3), 8 x 16 (E^1, E^5, E^6), 10 x 16 (E^1, E^5, E^6), 5 x 17 (E^2, E^3, E^4) and 5 x 24 (E^1, E^3, E^5).

An appraisal of sca effects for 500-seed weight revealed that crosses 6 x 24 and 9 x 15 exhibited significant sca effects in five of six environments except former in E^5 and latter in E_1, respectively. The other good combinations 1 x 16 (E^2, E^3, E^5, E^6), 1 x 21(E^1, E^3, E^4, E^6), 6 x 18 (E^2, E^3, E^5, E^6), 6 x 23 (E^2, E^4, E^5, E^6), 7 x 21(E^1, E^3, E^4, E^6) and 9 x 16 (E^1, E^3, E^4, E^6) showed significant positive sca effects in four of the six environments. The F1 crosses 3 x 24, 4 x 21, 4 x 22, 5 x 20, 8 x 18, 8 x 23, 12 x 14 in E^1 and E^4; 3 x 15, 9 x 24, 11 x 14, 11 x18, 12 x 18,12 x 21 in E^2 and E^5; and 1 x 13, 2 x 24, 5 x 19, 7 x 16, 8 x 14, 10 x 15, 10 x 17, 11 x 19 E^3 and E^6 were desirable combination in non-ratoon early, ratoon and non-ratoon late sown crop, respectively.

The F1 hybrid 11 x 20 exhibited its promise with regard to sca behavior for harvest index in all environments except E^5 (ratoon crop). The crosses 4 x 23, 8 x 15, 9 x 18, 10 x 16, 10 x 23, 11 x 17 and 11 x 18 showed significant positive sca effects in four of the six environments. In both non-ratoon early sown environments (E^1 and E^4) desirable specific combinations were noted to be 3 x 24, 4 x 21, 7 x 20, 9 x 14, 10 x 13 and 12 x 16. The F1 crosses 1 x 24 and 4 x 20 in E^2 and E^5 and crosses 2 x 14, 3 x 20, 10 x 21 and 10 x 23 in E^3 and E^6 showed promise for their high specific combining ability.

Hybrids 1 x 14 (E^1, E^4, E^5, E^6), 4 x 17 (E^1, E^3, E^4), 10 x 15 (E^1, E^3, E^4) and 11 x 18 (E^1, E^4, E^5) exhibited significant positive sca effects for growth rate at least in three of the six environments. Crosses 1 x 13, 6 x 20, 9 x 13 and 10 x 24 showed significant positive sca effects in ratoon crop (E^2 and E^5). Crosses 4 x 15 (E^1, E^4, E^5, E^6) and 7 x 15 (E^1, E^2, E^3) were found to be good combinations in different environments.

Table.1 Combining ability analysis, gca and sca variances for some quantitative characters in different environments

Source of variation	d.f.	Mean sum of squares					
Grain yield (g/plant)							
		E1	E2	E3	E4	E5	E6
Lines	11	494.60**	321.70**	349.93**	373.08**	118.90**+	248.46**
Testers	11	206.56**	176.44**	99.91**	113.17**+	373.43**	182.15**
Lines ×testers	121	60.70**	60.06**	41.60**	72.25**	87.34**	69.62**
Error	143	6.23	`8.34	7.23	9.28	6.30	7.72
gca variances		12.08	7.88	7.64	7.11	6.62	6.07
sca variances		27.24	25.84	17.19	31.50	40.52	30.95
gca variances/sca variances		0.44	0.30	0.44	0.23	0.16	0.20
500-grain weight (g)							
Lines	11	1.90**	2.69**	1.05**	1.70**	4.47**	2.02**
Testers	11	1.45**	2.88**	3.37**	1.35**	1.62**	2.86**
Lines ×testers	121	0.30**	0.62**	0.58**	0.27**	0.40**	0.50**
Error	143	0.05	0.03	0.01	0.03	0.03	0.04
gca variances		0.06	0.09	0.07	0.05	0.11	0.08
sca variances		0.13	0.29	0.28	0.12	0.19	0.23
gca variances/sca variances		0.46	0.31	0.25	0.42	0.58	0.35
Harvest Index (%)							
Lines	11	98.01**	124.68**	60.84**	74.73**	25.54**+	125.88**
Testers	11	64.00**	43.13**	39.44**	44.97**	41.34**	29.29**+
Lines ×testers	121	13.51**	17.22**	17.75**	17.47**	18.32**	23.07**
Error	143	1.06	2.76	1.52	1.75	1.52	2.17
gca variances		2.81	2.78	1.34	1.77	0.63	2.27
sca variances		6.23	7.24	8.13	7.85	8.40	10.45
Ratio		0.45	0.38	0.16	0.23	0.08	0.22
Growth rate(g/plant/day)							
Lines	11	0.12**	0.02**+	0.26**	0.08**+	0.07**+	0.13**
Testers	11	0.13**	0.10**	0.15**	0.11**+	0.26**	0.16**
Lines ×testers	121	0.06	0.03**	0.07**	0.06**	0.040**	0.07**
Error	143	0.01	0.007	0.01	0.01	0.04	0.01
gca variances		0.003	0.001	0.01	0.002	0.004	0.003
sca variances		0.03	0.013	0.03	0.024	0.02	0.03
gca variances/sca variances		0.10	0.08	0.33	0.08	0.20	0.10

*, **Significant at P=0.05 and P=0.01 levels, respectively.
+ Non-significant when tested against line x tester mean sum of squares at P=0.05.
E_1 and E_1–Non-ratoon early sown crop, E_2 and E_5–Ratoon crop, E_3 and E_6–Non-ratoon late sown crop

Table.2 The estimates of general combining ability effects of parents (lines and testers) for different traits in six environments

Sr.No.	Genotype	Grain yield(g/plant)						500-grain weight (g)					
		E_1	E_2	E_3	E_4	E_5	E_6	E_1	E_2	E_3	E_4	E_5	E_6
	Lines												
1	$81A_1$	-0.71	1.72*	0.37	0.01	2.97*	2.29*	-0.19*	-0.25*	-0.12*	-0.25*	-0.54*	-0.33*
2	$8A_1$	1.55*	1.01	1.65*	0.77	-0.05	-3.10*	0.40*	0.51*	0.48*	0.32*	0.46*	0.16*
3	$Pb313A_2$	3.01*	2.37*	5.46*	1.73*	1.71*	-4.47*	0.06	-0.10*	0.12*	0.13*	0.16*	0.05
4	$Pb402A_3$	-8.29*	-5.63*	-6.11*	-8.72*	-3.59*	-4.08*	0.36*	0.37*	0.17*	0.30*	0.36*	0.44*
5	$81A_4$	3.93*	1.37	0.38	1.41	-1.26	3.62*	-0.21*	-0.33*	-0.21*	-0.15*	-0.34*	-0.03
6	$81A_5$	5.72*	1.45	0.81	3.14*	1.48*	2.16*	-0.27*	-0.33*	-0.22*	-0.36*	-0.48*	-0.01
7	$81B_1$	0.97	0.61	-0.43	2.02*	1.56*	0.85	-0.18*	-0.28*	-0.36*	-0.27*	-0.23*	-0.37*
8	$8B_1$	1.63*	2.79*	0.78	3.81*	0.07	1.18	0.31*	0.50*	0.17*	0.34*	0.41*	0.13*
9	$Pb313B_2$	-0.94	1.81*	2.46*	0.56	1.74*	4.24*	0.11	0.13*	0.21*	0.11*	0.54*	0.10
10	$Pb402B_3$	-9.43*	-9.41*	-8.77*	-7.51*	-4.15*	-4.17*	0.26*	0.28*	0.14*	0.21*	0.43*	0.46*
11	$81B_4$	1.98*	1.31	1.45	1.80*	-1.51*	-1.02	-0.28*	-0.25*	-0.04	-0.05	-0.24*	-0.17*
12	$81B_5$	0.59	0.60	1.94*	0.97	1.04	2.48*	-0.36*	-0.25*	-0.35*	-0.32*	-0.53*	-0.44*
	S.E.(d)	0.72	0.83	0.78	0.88	0.72	0.80	0.06	0.05	0.03	0.05	0.05	0.06
	Testers												
13	H90/4-5	-1.16	1.93*	-1.34	-0.79	-4.54*	-1.05	-0.04	-0.19*	-0.22*	0.04	-0.01	-0.22*
14	H77/833-2	-2.29*	3.05*	-0.11	-1.67	-3.80*	-1.93*	-0.21*	-0.46*	-0.29*	-0.18*	-0.20*	-0.34*
15	G73-107	-0.48	0.94	-1.67*	1.07	-2.97*	-3.15*	-0.24*	0.12*	-0.06*	-0.17*	0.02	-0.34*
16	CSSC46-2	-3.62*	3.77*	-1.63*	-1.76*	4.41*	4.74*	0.33*	0.17*	-0.29*	0.14*	0.14*	-0.06
17	77/245	5.29*	-4.45*	5.00*	2.55*	2.30*	1.85*	-0.27*	-0.42*	-0.10*	-0.31*	-0.34*	0.05
18	78/711	0.66	1.23	-0.81	0.41	0.28	1.80*	0.39*	0.41*	0.11*	0.37*	0.20*	0.42*
19	77/273	-0.45	1.20	-0.53	-0.04	3.47*	0.13	-0.15*	-0.28*	0.07*	-0.10*	-0.19*	-0.03
20	ICR·161	3.67*	-4.25*	0.86	2.26*	5.10*	2.28*	0.07	0.29*	0.60*	0.09	0.51*	0.63*
21	ISK-48	0.02	-0.35	1.80*	-0.40	3.55*	-2.24*	0.40*	0.32*	0.73*	0.49*	0.32*	0.45*
22	77/28-2	-0.17	-0.98	-2.60*	0.31	1.80*	-0.02	-0.12*	0.40*	0.28*	-0.03	-0.11*	-0.03
23	77/180	3.23*	1.03	-0.47	2.93*	-3.76*	2.43*	-0.18*	-0.48*	-0.41*	-0.19*	-0.34*	-0.50*
24	Raj-42	-4.71*	-3.13*	1.28	-4.86*	-5.85*	-4.84*	0.02	0.13*	-0.40*	-0.14*	0.01	-0.03
	SE.(d)	0.72	0.83	0.78	0.88	0.72	0.80	0.06	0.05	0.03	0.05	0.05	0.06

*Significant at P=0.05 level.

E_1 and E_1–Non-ratoon early sown crop, E_2 and E_5–Ratoon crop, E_3 and E_6–Non-ratoon late sown crop

Table.2 Continued

Sr. No.	Genotype	Harvest Index (%)						Growth rate (g/plant/day)					
		E_1	E_2	E_3	E_4	E_5	E_6	E_1	E_2	E_3	E_4	E_5	E_6
	Lines												
1	$81A_1$	0.70*	1.77*	1.65*	0.57	0.26	1.44*	-0.05	-0.03	-0.07*	-0.01	0.08*	0.02
2	$8A_1$	1.40*	0.52	0.03	0.93*	·0.32	-1.04*	-0.02	0.02	0.07*	-0.01	0.02	-0.09*
3	$Pb313A_2$	0.27	0.66	1.64*	-0.23	1.10*	-1.22*	012*	0.12*	0.15*	0.08*	0.02	-0.13*
4	$Pb402A_3$	-3.83*	-2.76*	-3.35*	-3.92*	-0.37	-3.60*	-0.09*	-0.04*	0.05	-0.11*	-0.10*	0.08*
5	$81A_4$	1.37*	0.95*	0.55	0.91*	0.03	2.97*	0.08*	0.02	-0.01	0.00	-0.04*	-0.02
6	$81A_5$	2.59*	1.36*	1.4B*	1.B2*	0.70	2.01*	0.03	-0.02	-0.06*	0.00	0.03	-0.02
7	$81B_1$	0.49	1.14 *	0.39	1.45*	-0.12	-0.60	0.01	-0.02	-0.05	0.01	0.06*	0.05
8	$8B_1$	0.99*	1.21*	0.25	1.11*	0.64	-0.60	0.00	0.03	0.04	0.05	-0.02	0.06*
9	$Pb313B_2$	-1.26*	-0.12	0.17	-0.45	-0.64	1.87*	0.07*	0.04*	0.12-	0.04	0.07*	0.09*
10	$Pb402B_3$	-3.93*	·6.24*	-2.94*	-304"	-2.23*	-4.15*	-0.13*	-0.02	-0.24*	-0.11*	-0.05*	0.09*
11	$81B_4$	0.54*	0.89*	0.04	0.14	-0.80*	0.61	0.01	0.02	4.00	0.04	-0.03	-0.08*
12	$81B_5$	0.55	0.61	0.10	0.70	1.81*	2.30*	-0.01	-0.01	0.05*	0.02	-0.04*	-0.05
	S.E.(d)	0.30	0.48	0.36	0.38	0.36	0.43	0.03	0.02	0.03	0.03	0.02	0.03
	Testers												
13	H90/4-5	1.03*	0.88	-0.23	1.14*	-1.63*	1.30*	-0.11*	0.04*	-0.07*	-0.07*	-0.08*	-0.06*
14	H77/833-2	0.74*	1.04*	-0.87*	0.96*	0.06	0.03	-0.07*	0.10*	0. 13*	-0.05	-0.10*	0.04
15	G73-107	-0.31	1.21*	-0.95*	1.00*	0.45	-1 16*	0.00	-0.04*	-0.03	-0.03	-0.09*	-0.09*
16	CSSC46-2	-1.45*	1.89*	1.27*	-0.50	0.75*	0.65	-0.10*	0.01	-0.16*	-0.07*	0.09*	0.13*
17	77/245	1.81*	-0.40	2.10*	0.99*	0.70	0.28	0.14*	-0.09*	0.13*	0.05	0.06*	0.08*
18	78/711	-0.48	0.36	0.19	-0.25	-1 39*	-1.06*	0. 03	0.01	-0.03	0.05	0.04*	0.06*
19	77/273	0.10	-0.36	-1.02*	0.19	1. 38*	-1.10*	-0.02	0.06*	0.02	-0.06*	0.05*	0.01
20	ICR·161	0.74*	-1.77*	0.51	-0.21	0.72*	0.54	0.02	-0.10*	-0.01	0.05	0.12*	-0.02
21	ISK-48	1.62*	0.93	1.62*	0.71	0.95*	0.55	-0.04	-0.05*	0.04	-0.04	0.08*	-0.09*
22	77/28-2	-0.67*	-0.52	-2.52*	-0.38	-0.01	1.56*	0.00	-0.04*	-0.03	0.02	0.04*	-0.09*
23	77/180	1.04*	-0.41	0.06	0.26	0.98*	0.49	0.07*	0.07*	0.00	0.15*	-0.14*	0.11*
24	Raj-42	-4.18*	-2.86*	-0.16	-3.91*	-2.97*	2.08*	0.06*	0.03	0.04	0.00	-0.09*	-0.09*
S.E.(d)		0.3	0.48	0.36	0.38	0.36	0.43	0.03	0.02	0.03	0.03	0.02	0.03

*Significant at P=0.05 level.

E_1 and E_1–Non-ratoon early sown crop, E_2 and E_5–Ratoon crop, E_3 and E_6–Non-ratoon late sown crop

Table.3 Specific combining ability effects and per se performance (in parentheses) for top fourteen F_1 hybrids for some quantitative characters in different environments

F_1 Hybrids	Grain yield (g/plant)							F_1 Hybrids	500-grain weight (g)						
	E_1	E_2	E_3	E_4	E_5	E_6	Environ-mental mean		E_1	E_2	E_3	E_4	E_5	E_6	Environ-mental mean
1×14	5.70*	5.90*	7.90*	9.72*	7.45*	6.14*		9x15	0.36	1.40*	0.35*	0.38*	0.90*	0.44*	
	(35.8)	(38.8)	(33.6)	(39.9)	(32.8)	(33.1)	(35.7)		(4.7)	(5.8)	(5.1)	(4.7)	(5.6)	(4.6)	(5.1)
11×18	13.06*	-0.57	5.84*	11.06*	9.65*	-5.88*		6x24	0.47*	0.34*	0.85*	0.39*	-0.62*	0.86*	
	(48.8)	(30.1)	(31.7)	(45.1)	(34.6)	(21.5)	(35.3)		(4.7)	(4.3)	(4.8)	(4.3)	(3.0)	(5.2)	(4.4)
12×16	7.53*	5.91*	5.18	6.05*	9.47*	-13.83*		lx16	0.05	0.51 *	0.55*	-0.23	0.73*	0.48*	
	(37.6)	(38.4)	(30.7)	(37.1)	(41.1)	(20.0)	(34.2)		(4.6)	(4.6)	(4.7)	(4.1)	(4.4)	(4.5)	(4.5)
3×18	9.23*	0.27	6.53*	5.53	-5.27*	15.57*		2x20	-0.36	0.35*	0.38*	-0.25	0.55*	0.72*	
	(46.0)	(32.0)	(36.4)	(39.5)	(22.9)	(39.5)	(36.1)		(4.6)	(5.3)	(6.1)	(4.6)	(5.6)	(5.9)	(5.3)
1×13	3.27	7.72*	2.85	6.04*	8.59*	2.26		6x18	0.05	0.47*	0.78*	-0.27	0.37*	0.92*	
	(34.5)	(39.5)	(27.1)	(37.1)	(33.2)	(30.1)	(33.6)		(4.6)	(4.7)	(5.3)	(4.1)	(4.2)	(5.7)	(4 8)
2×24	12.56*	-1.31	9.45*	3.85	1.53	6.34*		6x23	0.15	1.03*	-0.14	0.52*	0.63	0.41 *	
	(42.5)	(24.7)	(37.6)	(31.6)	(21.8)	(25.0)	(35.5)		(4.1)	(4.4)	(3.8)	(4.4)	(3.9)	(4.3)	(4.1)
4×21	6.07*	4.45	1.29	7.39*	(5.35*	3.58		7x21	0.84*	0.17	0.56*	1.05*	0.06	0.59*	
	(30.9)	(26.6)	(22.2)	(30.1)	(31.5)	(16.7)	(26.3)		(5.5)	(4.4)	(5.5)	(5.7)	(4.2)	(5. 1)	(5. 1)
5×17	2.18	8.45*	9.40*	6.81*	1.38	-3.97		1x13	0.21	-0.18	0.23*	0.05	0.70*	0.40*	
	(44.5)	(33.5)	(40.0)	(42.6)	(28.6)	(28.1)	(36.2)		(4.4)	(3.5)	(4.5)	(4.2)	(4.2)	(4.2)	(4 2)
7×21	7.71*	6.11*	8.22*	0.24	3.50	2.79		3x15	0.17	1.42*	1.16*	0.20	0.52*	0.19	
	(41.8)	(34.5)	(34.8)	(33.7)	(34.8)	(28.0)	(34.6)		(4.4)	(5.6)	(5.8)	(4.6)	(4.8)	(4.3)	(4.9)
8×16	6.88*	-2.48	0.83	3.71	6.44*	5.48*		4x22	0.70*	-0.21	0.22*	0.53*	0.16	0.35	
	(38.0)	(32.2)	(25.2)	(37.6)	(37.1)	(38.0)	(34.7)		(5.4)	(4.7)	(5.3)	(5.2)	(4.5)	(5.2)	(5.0)
9×13	1.00	7.93*	6.97*	-1.11	7.62*	2.21		4x21	0.63*	-0.81*	-0.15	0.45*	0.50*	-0.34	
	(32.0)	(39.8)	(33.3)	(30.5)	(31.0)	(32.0)	(33.1)		(5.8)	(4.0)	(5.3)	(5.6)	(5.3)	(4.9)	(5.2)
10×16	5.75*	0.42	-0.12	2.74	11.86*	7.32*		9x19	0.66*	1.69*	0.20*	-0.08	0.12	-0.15	
	(25.8)	(22.9)	(14.7)	(25.3)	(38.3)	(34.5)	(26.9)		(5.I)	(5.7)	(5.1)	(4.3)	(4.6)	(4.3)	(4.8)
11×20	5.34*	2.42	4.58	10.11*	-3.27	8.93*		10x 17	0.30	0.58*	0.34*	0.20	-0.11	0.72*	
	(44.1)	(27.6)	(32.1)	(46.0)	(26.5)	(36.8)	(35.5)		(4.7)	(4.6)	(5.0)	(4.5)	(4.10)	(5.6)	(4.7)
9×15	5.32*	7.63*	-1.71	7.63*	-9.45*	0.31		11 x 19	-0.29	-0.57*	1.37*	0.85*	-0.08	1.68 *	
	(37.0)	(38.5)	(24.3)	(41.1)	(15.5)	(28.0)	(30.7)		(3.7)	(3.1)	(6.0)	(5. 1)	(3.6)	(5.9)	(4.6)
S.E.(Sij)	2.50	2.89	2.69	3.05	2.51	2.78		S.E.(Sij)	0.22	0.17	0.10	0.17	0.17	0.2	

*Significant at P=0.05 level.

E_1 and E_4–Non-ratoon early sown crop, E_2 and E_5–Ratoon crop, E_3 and E_6–Non-ratoon late sown crop

Table.3 Continued

F1 Hybrids	Growth rate (g/plant/day							F1 Hybrids	Harvest index (%)						
	E_1	E_2	E_3	E_4	E_5	E_6	Environ-mental mean		E_1	E_2	E_3	E_4	E_5	E_6	Environ-mental mean
1×14	0.20*	0.08	0.18	0.34*	0.14*	0.30*		11×20	2.19*	4.41*	2.49*	5.15*	1.94	3.00*	
	(1.4)	(1.1)	(1.4)	(1.4)	(0.9	-(1.5)	(1.3)		(32.3)	(30)	(30.7)	(33.7)	(30.9)	(31.9)	(31.6)
4×15	0.32*	-0.07	0.13	0.36*	0.19*	0.33*		4×23	5.39*	0.05	6.58*	7.03*	1.17	7.78*	
	(1.6)	(0.8)	(1.2)	(1.4)	(0.7)	(1.5)	(1.2)		(31.3)	(23.3)	(31)	(32.4)	(30.9)	(32.4)	(30.1)
1×13	0.27*	0.17*	0.09	0.19	0.22*	0.18		8×15	3.53*	-1.73	5.33*	2.83*	-0.11	4.47*	
	(1.4)	(1.1)	(1.1)	(1.2)	(1.0)	(1.3)	(1.1)		(32.9)	(27.2)	(32.3)	(33.6)	(30.1)	(30.4)	(31.1)
7×15	0.23*	0.17*	0.25*	0.14	0.00	-0.16		9×18	2.10*	3.78*	-0.15	2.97*	3.21*	0.62	
	(1.6)	(1.0)	(1.3)	(1.3)	(0.7)	(1.0)	(1.1)		(29.1)	(30.5)	(27.9)	(30.9)	(30.3)	(29.2)	(29.6)
9×22	0.14	0.14	0.34*	0.20*	0.23*	0.11		10×16	3.80*	1.70	0.88	4.89*	5.76*	3.05*	
	(1.6)	(1.1)	(1.6)	(1.4)	(1.1)	(1.3)	(1.3)		(27.1)	(23.8)	(26.9)	(30)	(33.4)	(27.3)	(28.1)
10×15	0.40*	0.03	0.21*	0.26*	-0.03	0.03		10×23	2.46*	1.85	4.38*	2.43	4.23*	6.27*	
	(1.6)	(0.9)	(1.1)	(1.3)	(0.6)	(1.2)	(1.1)		(28.3)	(21.7)	(29.2)	(28.3)	(32.1)	(30.3)	(28.3)
11×18	0.31*	0.15	0.07	0.22*	0.16*	-0.23		11×17	2.26*	-1.89	-0.21	3.15*	3.64*	3.59*	
	(1.7)	(1.1)	(1.3	(1.5	(0.9)	(0.9)	(1.2		(33.4)	(25.1)	(29.6)	(32.9)	(32.6)	(32.2)	(31.0)
4×17	0.25*	-0.01	0.37*	0.30*	-0.12*	0.07		11×18	2.81*	-3.28*	2.72*	2.89*	4.14*	0.13	
	(1.6)	(0.8)	(1.6)	(1.4)	(0.6)	(1.4)	(1.2)		(31.7	(24.4)	(30.7	(31.4	(31.0	(27.4)	(29.4)

									)		)	)	)		
2×24	0.09	0.08	0.08	0.20*	0.18*	0.2		1×24	-1.03	3.50*	-1.67	3.30*	5.81*	-0.18	
	(1.5)	(1.1)	(1.4)	(1.3)	(0.9)	(1.2)	(1.2)		(24.2)	(28.9)	(27.5)	(28.6)	(32.6)	(26.9)	(28.0)
3×18	0.17	0.01	0.45*	0.04	0.10	0.35*		2×14	2.04*	-0.64	3.56*	-0.06	-1.25	3.99*	
	(1.7)	(1.0)	(1.7)	(1.3)	(0.9)	(1.4)	(1.3)		(32.9)	(27.4)	(30.4)	(30.5)	(27.6)	(30.7)	(29.9)
6×20	0.04	0.21*	0.17	0.1	0.13*	0.16		4×21	3.08*	0.04	-1.13	5.00*	4.81*	1.56	
	(1.4)	(1.0)	(1.3)	(1.3)	(1.0)	(1.3)	(1.2)		(29.6)	(24.7)	(24.8)	(30.4)	(34.5)	(26.2)	(28.4)
4×19	0.30*	0.06	0.1	0.19	-0.01	0.24*		11×19	2.09*	3.25*	3.56*	-0.70	-2.13	1.07	
	(1.5)	(1.0)	(1.2)	(1.2)	(0.7)	(1.5)	(1.2)		(31.5)	(30.2)	(30.3)	(28.3)	(27.5)	(28.3)	(29.4)
5×24	0.24*	0.05	0.23*	0.07	0.06	-0.14		12×16	5.46*	0.63	3.41*	3.95*	0.81	-2.66	
	(1.7)	(1.0)	(1.4)	(1.2)	(0.7)	(0.9)	(1.2)		(33.3)	(29.6)	(32.5)	(32.8)	(32.5)	(28.0)	(31.4)
7×14	0.07	-0.14	0.23*	0.33*	-0.05	0.13		3×24	5.03*	5.85*	2.29	7.57*	0.78	-4.42*	
	(1.3)	(0.9)	(1.5)	(1.4)	(0.7)	(1.4)	(1.2)		(29.8)	(30.1)	(31.5)	(32.0)	(28.0)	(20.0)	(28.6)
S.E. (Sij)	0.10	0.08	0.10	0.10	0.06	0.12		S.E. (Sij)	1.03	1.66	1.23	1.32	1.23	1.47	

*Significant at P=0.05 level.

E_1 and E_4–Non-ratoon early sown crop, E_2 and E_5–Ratoon crop, E_3 and E_6–Non-ratoon late sown crop

The hybrid 1 x 14 (M x L) expressed significant positive sca effects for all four characters in most the environments. The hybrid 1 x 14 (M x L) involving both poor combinations for grain yield expressed significant positive sca effects in all the environments and also gave high *per se*. In general, most of the crosses showed no relationship between sca and *per se*. Inability of a single cross to rank uniformly in all the environments on the basis of *per se* performance as well as sca in different environmental situations has been reported by Sagar and Kapoor (1988). The hybrid 1 x 13 (81A x H90/4-5=HHB50, a released hybrid) involving M x L combining parents gave positive sca effects in three environments involving environments (E_2, E_4, E_5) during both the years for grain yield. Interestingly the parents 81A and H90/4-5 of HHB-50 also possessed regeneration potential. Besides grain yield it also gave high sca and *per se* for 500-grain weight. This confirms the superiority /good performance across the environments of this released (HHB-50 hybrid).

The hybrids 1 x 13 ($81A_1$ x H90/4-5), 1 x 14 ($81A_1$ x H77/833-2), 9 x 18 (Pb $313B_2$ x 78/711), 3 x 18 (Pb $313A_2$ x 78/711), 11 x 18 ($81B_4$ x 78/711), 12 x 16 ($81B_5$ x CSSC 46-2), 7 x 21 ($81B_1$ x ISK 48) showed significant positive sca effects for grain yield and one or more characters in most of the environments. The hybrids based on diverse male sterility systems A1, A_2, A3, and A4 has significant sca effects for grain yield and some others characters indicating the a distinct advantage of these cytoplasm sources. Rai *et al., (*1996) reported that A2 and A3 source is highly unstable and is commercially in viable. However, A4 and A_5 sources have been shown to be highly stable. Therefore, the results of this study on combining ability suggest that other than A1 source, A4 and A5 systems should provide a good opportunity to diversify the cytoplasmic base of pearl millet.

Based on the results obtained in the present study it can also be concluded that the hybrids based on A_1, A_2 and A_5 cytoplasms were superior to other cytoplasmic sources. The parents involved in these crosses were allowed to intermate among them for few generations to get desirable recombinants. The hybrids 1 x 13 ($81A_1$ x H90/4-5), 1 x 14 ($81A_1$ x H77/833-2), 9 x 13 ($313B_2$ x H90/4-5) and 12 x 16 ($81B^5$ x CSSC46-2) performed better on the basis of *per se*, sca effects including ratoon crop indicating their hope for sustainable dual purpose pearl millet production in harsh environments and can be recombined to develop base population for improvement for ratoonability by cyclic breeding.

Acknowledgement

Authors acknowledge the CCS Haryana Agricultural University to carry out this research work

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How to cite this article:

Ramesh Kumar, Sudhir Sharma, Prem Sagar and Ashok Kumar. 2020. Genetic Analysis of Grain Yield and Its Attributes Using Diverse Systems of Male Sterile Lines and Pollinators in Direct Sown and Ratooned Pearl Millet. *Int.J.Curr.Microbiol.App.Sci.* 9(02): 486-499.
doi: https://doi.org/10.20546/ijcmas.2020.902.060