Indian J. Genet., **60**(1): 45-53 (2000)

COMBINING ABILITY OF PEARL MILLET LANDRACES ORIGINATING FROM ARID AREAS OF RAJASTHAN

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(Received: November 1997; accepted: November, 1999)

ABSTRACT

The combining ability of sixteen landraces of pearl millet (*Pennisetum glaucum* (L.) R. Br.) originating from the arid area of western Rajasthan was determined for four traits by evaluating their crosses in 12 environments grouped into three zones. Three varieties (as pollinator controls) and their hybrids were also included. The results indicated that general combining ability (GCA) effects were more important in the genetic control of grain yield and stover yield, while both GCA and specific combining ability (SCA) effects were important for time to flower and 100-seed weight. The GCA effects were influenced by environments. IP 3333 was identified as best general combiner for grain yield for north dry (ND) zone, IP 3228 for north wet (NW) zone and IP 3188 for terminal stress (TS) zone. GCA effects of most pollinators varied substantially across three production zones. However, a few good combiners across all environments were identified. None of the pollinators exhibited desirable GCA effects for all traits simultaneously. The landraces established their superiority as pollinators over high yielding controls under dry conditions of north India. GCA estimates of pollinators with respect to grain yield for ND zone could not be predicted from evaluation of crosses in NW and TS zones.

Key Words : *Pennisetum glaucum*, landraces, combining ability, stress environments, adaptation.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the major cereal crop and staple food in western Rajasthan and has been cultivated there for approximately 2000 years [1]. The climate of this region is characterised by unpredictable drought and heat stresses during the crop season. The landraces of pearl millet originating from this region have thus been naturally selected over centuries for survival in these harsh environments. These landraces have also been selected for high grain and stover yield by farmers and thus they provide reasonable yields in such environments, even when modern cultivars fail to yield substantially [2, 3]. Thus they provide a potential breeding source material to combine the adaptation to stresses with

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productivity in the cultivars targeted for western Rajasthan or for the areas with similar climatic conditions.

The breeding value of any material is largely determined by its combining ability for important productivity-related traits [4]. One earlier report [5] indicated significant differences in combining ability among pearl millet landraces from the relatively more favourable central and eastern Rajasthan. This study was undertaken to assess the potential of landraces from more arid areas, on the basis of their combining ability for earliness and productivity, as a source for breeding pollinators for hybrids specifically suited for unfavourable growing conditions.

MATERIALS AND METHODS

Sixteen variable landraces from the western districts of Barmer, Jaisalmer and Jodhpur of Rajasthan were selected for this study [6]. Seed samples obtained from the ICRISAT Genetic Resources Division were increased by sibbing by hand pollination taking advantage of protogynous nature of flowering in pearl millet. Atleast 50 plants were used in sibmating to produce the seed of the landraces used in this study.

These landraces were crossed on to two phenotypically diverse male-sterile lines 843A and ICMA 89111, used as testers for this study. There may be some concern about the number of testers used in this study; but considering diversity in them they should provide good preliminary discrimination among the pollinators for their combining ability [4]. 843A is a downy mildew susceptible, very early maturing male-sterile line with bold grains and high harvest index; while ICMA 89111 is downy mildew resistant, medium maturity and high tillering line bred to produce dual-purpose hybrids with high grain yield and reasonable stover yield. Two released high yielding open-pollinated varieties RCB2 and WC-C75; and one newly bred variety 3013, developed at Rajasthan Agricultural University Research Station, Durgapura were used as pollinator checks and their hybrids on 843A and ICMA 89111 were also included.

The 38 topcross hybrids and their 19 pollinator parents were evaluated in a randomised block design with 4-6 replications in the rainy seasons during 1989-91 at the Central Arid Zone Research Institute, Jodhpur; at the Rajasthan Agricultural University Regional Research Station, Fatehpur-Shekhawati and at the Haryana Agricultural University, Hisar. The trials were also grown under managed terminal water stress conditions at ICRISAT, Patancheru in the rainfree dry season (February-April) during 1990-92.

Data were recorded on plot basis for time to flowering as number of days from emergence until stigma emerged on 50% of main panicles in a plot, grain yield

(g/m^2), stover yield (g/m^2) and 100-seed weight (g). The details of the data collection and experimentation have been provided by Bidinger et al. [7]. The data were analysed for combining ability in this study.

The year/location combinations were considered as environments. Effects due to environments and landraces were considered as random and remaining effects as fixed. The environments were subdivided into three zones based on the occurrence of drought stress and mean grain yield of the environment. The environments Fatehpur 1989 and 1990, Jodhpur 1989 and 1991 were placed in north dry (ND) zone with a mean grain yield of 75 g/m^2; while Fatehpur, 1991, Jodhpur, 1990 and Hisar (1989-91) formed the north wet (NW) zone with a mean grain yield of 180 g/m^2. The shorter daylength, offseason managed stress environments (TS) at Patancheru with mean grain yield of 146 g/m^2 were kept separately as they provided very different growing conditions.

Data were analysed using the PROC VARCOMP and PROC GLM procedures of SAS [8]. Variation due to environment was partitioned into variation between zones and locations within zones. The hybrid sums of squares was subdivided into variation due to testers, pollinators and testers × pollinators. The general combining ability (GCA), effects were of primary interest in this study and were computed following Kempthorne [9].

RESULTS AND DISCUSSION

Environment had significant effects on the expression of all four traits (Table 1). The partitioning of the environmental variation into variation due to zones and locations within zones showed that both components were significant. Mean squares due to hybrids were also significant for all characters suggesting that further genetic analysis on combining ability could provide more information on GCA of the pollinators.

The pollinator and tester sources of variation were significant for all traits while the pollinator × tester component was significant only for time to flower and 100-seed weight; but non-significant for grain and stover yields (Table 1). This suggests that GCA effects were important in the genetic control of grain and stover yields, while both GCA and SCA effects were important in the inheritance of time to flower and 100-seed weight. These findings are consistent with earlier results in pearl millet [10]. The zonal interactions of pollinators and testers were significant for all characters, except 100-seed weight, revealing the environmental sensitivity of GCA effects and emphasising the need for appropriately targeting of material for specific zones (Table 1). The significant interactions of genetic effects with locations within zones emphasize

Table 1. Mean squares from different sources of genetic variation and their interaction with environment in combined analysis of variance across 12 environments for four productivity-related traits in pearl millet

Source	d.f.	Time to flower	Grain yield ($x10^{-3}$)	Stover yield ($x10^{-4}$)	100-seed weight
Environment (E)	11(9)!	3584**	681.9**	511.7**	3.72**
Zone (Z)	2	4820**	2636.0**	1572.9**	12.03**
Loc. Within Z	9(7)	3309**	247.7**	208.5**	1.68**
Hybrid (H)	37	539**	14.4**	10.4**	0.45**
Pollinator (P)	18	212**	19.7**	8.4**	0.20**
Tester (T)	1	15367**	118.3**	216.5**	12.02**
P × T	18	42**	3.2	1.1	0.05**
H × E	407(333)	19**	3.5**	1.4**	0.02**
H × Z	74	29**	7.2**	1.7**	0.02**
P × Z	36	39**	6.7**	1.7**	0.02
T × Z	2	92**	106.9**	11.1**	0.02
P × T × Z	36	16**	2.1**	1.1	0.01
H × Loc within Z	333(259)	17**	2.7**	1.4**	0.02**
P × Loc within Z	162(126)	19*	2.8*	1.6**	0.02**
T × Loc within Z	9(7)	30**	12.5**	3.1**	0.08**
P × T × Loc within Z	62(126)	14**	2.0**	1.0	0.01**
Error	2053(171)	6	1.4	0.9	0.006

! figures in parentheses denote d.f. for stover yield and 100- seed weight
*, ** significant at P = 0.05 and 0.01, respectively

the need for testing at more than one site within the target zone for a precise estimate of GCA effects. The SCA effects controlling time to flower and 100-seed weight were also influenced by environment as shown by significant interaction of pollinator × tester with zone. The occurrence of environmental interaction with genotypic effects has been reported in several studies in pearl millet [5, 10-12]. This implied that the estimate obtained in single environment are potentially biased. In our study the sufficiently large number of environments allowed to obtain the unbiased estimate of combining ability effects.

The pollinators IP 3188, IP 3228, IP 3235, IP 3464 and IP 3243 possessed significant negative GCA effects for time to flower in ND zone as well as in NW zone (Table 2) and thus established their utility for producing early maturing hybrids

Table 2. **General combining ability estimates of 19 pearl millet pollinators in three diverse zones (north dry-ND, north wet-NW and terminal stress-TS) for time to flower and grain yield**

Pollinator	Time to flower				Grain yield			
	ND	NW	TS	Pooled	ND	NW	TS	Pooled
IP 3188	−1.5**	−2.5**	−1.2**	−2.0**	1.3	1.6	18.5**	7.5**
IP 3228	−1.0*	−1.5**	−1.8**	−1.5**	9.8	29.2**	9.6	17.0**
IP 3235	−2.0**	−1.1**	−0.2	−1.1**	0.8	3.6	−2.1	2.8
IP 3464	−3.0**	−3.0**	0.2	−2.1**	−1.7	−30.5**	−13.6*	−15.5**
IP3174	0.0	1.1**	−0.3	0.3	8.0	−2.6	−9.2	0.3
IP 3222	0.3	1.3**	−0.6	0.5*	0.1	10.3	12.8*	5.1
IP 3243	−1.1*	−1.9**	1.0**	−1.0**	2.2	10.2	−0.9	5.3
IP 3246	−0.9	−0.3	−2.3**	−1.1**	8.5	6.7	9.1	6.0
IP 3333	−0.8	0.2	−0.1	−0.3	24.7**	0.2	10.6	11.1**
IP 3424	−0.8	−1.8**	−0.1	−1.2**	−1.0	5.0	−13.6*	−1.5
IP 3151	1.7**	1.6**	1.2**	1.5**	−8.4	−29.7**	−16.2**	−19.3**
IP 3201	0.1	0.5	0.1	0.4	−12.4*	−13.3*	−8.5	−13.5**
IP 3296	−0.5	−0.1	2.3**	0.3	4.0	−43.7**	−13.0*	−19.7**
IP 3272	−0.1	1.9**	1.2**	1.1**	−0.1	−34.3**	−1.2	−14.8**
IP 3312	3.5**	3.6**	3.4**	3.7**	−8.5	−28.6**	−22.7**	−18.1**
WRajPop	−1.1*	1.1**	−0.9**	−1.3**	5.6	25.0**	7.5	14.2**
WC-C75	2.9**	1.6**	−1.2**	1.8**	−19.9**	28.6**	18.7**	10.7*
RCB2	2.9**	1.1**	−0.8**	1.4**	−18.7**	25.6**	0.0	3.5
3013	0.3	0.5	0.1	0.5*	5.5	36.8**	14.1*	18.9**
S.E. ±	0.45	0.33	0.33	0.22	5.92	6.18	6.08	3.62

*, ** significant at P = 0.05 and 0.01, respectively

for north Indian conditions. For grain yield, however only IP 3333 possessed statistically significant and positive GCA effects in ND zone, the pollinators IP 3228, IP 3174 and IP 3246 also had positive GCA effects. This suggests their potential in producing high yielding hybrids for dry environments. IP 3333 also proved to be a good combiner for stover yield and 100-seed weight in ND zone (Table 3). The check pollinators WC-C75 and RCB2, with proven high yield potential *per se*, proved to be poor combiners for grain yield in ND conditions but were good combiners for yield in NW zone. This indicates that the hybrids of pollinators selected for high yield potential elsewhere will not necessarily be high yielding under dry conditions but may be in favourable conditions. It was further observed that none of the pollinators showed desirable GCA estimates for all the traits simultaneously (Tables 2 and 3) emphasising the need of ranking traits, and selecting the seed parent to compliment the pollinator parent.

The GCA effects for several pollinators varied considerably across zones. Nonetheless, eight landraces viz., IP 3188, IP 3228, IP 3235, IP 3464, IP 3243, IP 3246, IP 3424 and WRajPop for early time to flower; and four landraces viz., IP 3188, IP 3228, IP 3333 and WRajPop for grain yield were good combiners across all environments (Table 2). Similarly, five landraces for stover yield and eight for 100-seed weight were identified as good combiners over environments (Table 3). This suggested that these landraces can produce hybrids with reasonable performance across environments.

Table 3. General combining ability estimates of 19 pearl millet pollinators in three diverse zones (north dry-ND, north wet-NW and terminal stress-TS) for stover yield and 100-seed weight

Pollinator	Stover yield				100-seed weight			
	ND	NW	TS	Pooled	ND	NW	TS	Pooled
IP 3188	–6.9	3.6	16.8	6.2**	0.042	0.010	0.020	0.020*
IP 3228	–9.0	–62.7**	–36.5**	–38.0**	–0.029	–0.048**	–0.045**	–0.047**
IP 3235	–26.1	–26.9	–18.7	–25.0**	–0.019	–0.031*	–0.016	–0.019*
IP 3464	17.0	9.3	–0.9	9.5**	0.026	0.024	0.011	0.020*
IP 3174	30.0	3.6	–26.4**	1.1	0.029	–0.066**	0.026*	–0.018*
IP 3222	16.7	40.6*	14.2	21.5**	–0.027	0.010	0.027*	0.010
IP 3243	–17.6	–3.1	14.0	–3.5	–0.012	–0.044**	0.000	–0.025**
IP 3246	–2.9	–88.9**	–45.0**	–46.2**	–0.035	–0.051**	–0.001	–0.034**
IP 3333	58.1**	40.9*	–17.4	21.0*	0.128**	0.014	0.041**	0.046**
IP 3424	12.4	–6.4	–17.0	–15.7	0.003	0.017	0.026*	0.015
IP 3151	13.9	–1.5	43.6**	18.5*	0.053	0.041**	0.079**	0.054**
IP 3201	–58.8**	–12.3	17.4	–14.4	0.062	0.030*	0.055**	0.034**
IP 3296	–3.7	7.5	27.8**	11.7	0.113**	0.116**	0.045**	0.092**
IP 3272	6.5	87.3**	25.5**	41.6**	0.037	0.078**	0.005	0.046**
IP 3312	56.9**	100.7**	52.2**	79.3**	0.030	0.088**	0.037**	0.063**
WRAjPop	–9.3	19.1	1.8	8.4	–0.041	–0.053**	–0.051**	–0.041**
WC-C75	14.0	–45.0*	–27.0**	–20.6*	–0.129**	–0.021	–0.078**	–0.061**
RCB2	–30.8	–25.3	–23.8*	–26.5*	–0.160**	–0.108**	–0.110**	–0.115**
3013	–.0*	–40.7*	–0.5	–29.1**	–0.072*	–0.005	–0.076**	–0.039**
S.E. ±	15.96	19.00	9.65	9.24	0.032	0.013	0.012	0.001

*, ** significant at P = 0.05 and 0.01, respectively

On the other hand, IP 3333 produced significantly higher yielding hybrids in ND zone with good stover yield but it produced only average hybrids in NW and TS conditions. Similarly, IP 3228 was a good combiner for grain yield in NW but its GCA effects were non- significant in other two zones. Hybrids with IP 3188 performed significantly better for grain yield under TS zone situations than under ND and NW zones. These results suggest that pollinators IP 3333, IP 3228 and IP 3188 could be utilised to produce zone specific hybrids. Further, IP 3151 and IP 3312 consistently transmitted lateness into hybrids (Table 2) and thus can not be considered desirable for breeding early maturing hybrids. The check pollinators also contributed lateness to their hybrids under north Indian conditions.

The good combiners for grain yield appeared to exhibit, in general, non-significant or highly significant positive GCA effects for either 100-seed weight, stover yield or earliness. For example, IP 3333, a good combiner for grain yield in ND zone (Table 2), had high GCA effects for stover yields and 100-seed weight (Table 3). Similarly, IP 3222 was simultaneously a good combiner for grain yield and seed weight in TS zone. The pollinators producing high yielding hybrids in ND and TS zones were those that contributed earliness in their hybrids (correlation between GCA effects for time to flower and grain yield *per se* = –0.64** in ND and –0.72** in TS zone). This showed that the combining ability of pollinators for grain yield in especially terminal drought environments depended on their combining ability for time to flower in a particular drought environment. This is so because under the drought stress conditions of ND and TS zones, the early maturing genotypes escape the terminal drought.

Correlation coefficients showed, in general, good agreement between *per se* performance and GCA estimates of pollinators for time to flower, grain and stover yields (Table 4). However, the correlation between GCA and *per se* performance was

Table 4. Correlation between performance per se and general combining ability effects of 19 pearl millet pollinators for four productivity-related traits in three diverse zones (north dry ND, north wet- NW and terminal stress-TS)

Zone / Character	ND	NW	TS
Time to flower	0.87**	0.81**	0.75**
Grain yield	0.63**	0.60**	0.63**
Stover yield	0.40	0.61**	0.59**
100-seed weight	–0.10	–0.48*	0.00

*, ** significant at P = 0.05 and 0.01, respectively

high enough only for time to flower (r^2 = 0.56-0.76) to select among pollinators based on their *per se* performance. The seed size of pollinators had no influence on the seed weight of hybrids, perhaps because seed size of testers was markedly larger than that of pollinators. GCA estimates for grain yield of pollinators in ND zone were generally not correlated with those obtained in NW and TS zones for grain yield (Table 5). Thus GCA estimates from that TS and NW zones can not predict the GCA for ND zone. However, there was good agreement between GCA effects for time to flower and stover yield measured in ND and NW zones. The GCA estimates for 100-seed weight across zones were quite similar as shown by significant correlation among the estimates obtained in three zones (Table 5).

Table 5. Correlation between general combining ability estimates obtained in three zones (north dry-ND, north wet-NW, offseason terminal stress-TS) for four productivity related traits in 19 pearl millet pollinators

Character / Zone	Time to flower	grain yield	Stover yield	100-seed weight
ND vs NW	0.82**	0.04	0.54**	0.68**
ND vs TS	0.23	0.23	0.15	0.82**
NW vs TS	0.41	0.72**	0.70**	0.62**

**Significant at P = 0.01

The SCA effects were non-significant for all crosses for time to flower as well as 100-seed weight in ND zone (data not presented). The high value of SCA estimates for a few crosses in NW and TS zones for both of these traits thus led to the significance of overall pollinator × tester interaction. Thus, a rather higher importance of additive than non-additive gene effects in the genetic control of most traits among the landrace material originating from arid areas of Rajasthan is an interesting observation. Ouendeba et al. [13] also observed high additive effects in their study involving pearl millet landraces of African origin. Thus the existence of rather high magnitude of additive genetic effects could be a characteristic feature of pearl millet landraces and this variation can be utilised by placing more emphasis on interpopulation breeding through recurrent selection. Our study, however, could not quantify the nature and magnitude of variation within landraces. Further research is needed to quantify such variation which in turn should be helpful to demonstrate whether further improvements through simple selection capitalising on the additive portion of genetic variance would be rewarding.

The results of the present study showed that GCA effects of landrace pollinators varied considerably across zones; and specific pollinators need to be utilised for a particular zone. The local landraces proved better combiners for grain yield than the control pollinators in ND zone. It was further showed that good combiners for dry zone environments need to be identified, at least for grain yield, by evaluating the crosses in these target environments.

REFERENCES

1. J. M. J. de Wet. 1995. Pearl millet. pp. 156-159. *In*: Evolution of Crop Plants. (eds. J. Smartt and N. W. Simmonds) 2nd edition. Longman Scientific & Technical, Essex, U.K.
2. E. Weltzian and J. R. Witcombe. 1989. Pearl millet improvement for the Thar, Rajasthan, India. Vort. Pflanzenzuchtung., **15**: 23-26.
3. O. P. Yadav and E. Weltzien R. 1998. New Pèarl Millet Populations for Rajasthan, India. Integrated Systems Project Progress Report No. 10. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India. pp 88.
4. A. R. Hallauer and J. H. Miranda. 1988. Quantitative Genetics in Maize Breeding., Iowa State University Press, Ames, Iowa, U.S.A.
5. K. L. Vyas and S. C. Pokhriyal. 1985. Combining ability of landraces of pearl millet from Rajasthan. Indian J. Genet., **45**: 247-254.
6. S. Appa Rao, M. H. Mengesha, K. L. Vyas and C. Rajagopal Reddy. 1986. Evaluation of pearl millet from Rajasthan. Indian J. agril. Sci., **56**: 4-9.
7. F. R. Bidinger, E. Weltzien R., V. Mahalakshmi, S. D. Singh and K. P. Rao. 1994. Evaluation of landrace topcross hybrids of pearl millet for arid zone environments. Euphytica., **76**: 215-226.
8. SAS. 1991. SAS User's Guide. Statistics. Version 6.03. SAS Institute, Cary, NC, U.S.A.
9. O. Kempthorne. 1957. An Introduction to Genetic Statistics. John Wiley & Sons, Inc. New York, U.S.A.
10. O. Parkash, S. Singh and I. S. Khairwal. 1998. Combining ability of some new male sterile and maintainer lines of pearl millet. Crop Improv., **14**: 169-172.
11. D. S. Virk. 1988. Biometrical analysis in pearl millet - a review. Crop Improv., **15**: 1-29.
12. D. R. Satija and S. K. Thukral. 1989. Genetic analysis of grain yield and other quantitative traits in pearl millet lines characterized by disease resistance and phytic acid content. Trop. Agric., **66**: 269-272.
13. B. Ouendeba, G. Ejeta, W. E. Nyquist, W. W. Hanna and A. Kumar. 1993. Heterosis and combining ability among African pearl millet landraces. Crop Sci., **33**: 735-739.