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Breeding dual-purpose pearl millet (*Pennisetum glaucum*) for north-western India: understanding association of biomass and phenotypic traits

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ABSTRACT

A study was conducted during 2006–08 to investigate the relationship between biomass and various phenotypic traits to breed dual-purpose pearl millet for arid regions of north-western India. The study material included 39 pearl millet genotypes evaluated for three seasons under arid zone environments. Plant type had significant role in determining grain yield performance under drought-prone arid environments. Both early flowering and high tillering had a significant advantage over late flowering and low tillering material. Biomass and harvest index had significant influence on both grain and stover yield though nature and degree of association varied considerably. Biomass had positive influence on both grain and stover yield while higher harvest index had positive effect on grain yield but negative effect on stover yield. Longer panicle had adverse impact on grain yield in spite of fact that longer panicles had significantly higher number of grains primarily because genotypes with larger panicles had significantly reduced tillering. Results suggested that producing smaller but many panicles is much more important than producing a few larger panicles. Significant variation existed for tillering, flowering time, grain and stover yields, biomass and harvest index indicating that there existed a good opportunity to select for a combinations of these traits. A balanced selection for improved biomass and harvest index is necessary for improving both grain and stover yields in pearl millet targeted for arid zone of north-western India.

Key words: Arid, Biomass, Drought, Harvest index, Pearl millet, Trait association

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most important cereal crop of arid zone of north-western India which constitutes about 25% of pearl millet acreage in the country. Its grain is the staple food and dry stover forms the basis of ration for livestock during most of the dry period of year. Arid region of western Rajasthan is a unique adaptation zone for pearl millet primarily because of occurrence of drought and higher livestock population which is largely sustained on stover from pearl millet and fodder from grasses like *Cenchrus ciliaris* and *Lasiurus sindicus*.

Previous research established that primary determinants of pearl millet performance under water-limited conditions are drought tolerance and escape, rather than high potential yield (van Oosterom *et al.* 1995, Yadav *et al.* 2003). Consequently, evaluation studies with contrasting genotypes conducted under drought and non-drought conditions suggest a cross-over genotype × environment interaction (Yadav and Weltzien 2000, van Oosterom *et al.* 2003, Yadav 2007) meaning that traits identified useful in drought-free environments may not be so under drought conditions. Hence, it is extremely critical to study the association among traits under arid zone conditions. However, there is very scanty information on this aspect for arid zone pearl millet. The present study was therefore conducted to investigate the relationship between various traits so as to suggest their manipulation in breeding pearl millet for arid regions. The range of variation in yield and yield components was also studied.

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MATERIALS AND METHODS

The material for present study comprised of 39 pearl millet genotypes including landraces, elite composites, crosses between landraces and composites and commercial cultivars with a wide range in their duration and plant type (tillering, panicle size). The genotypes were evaluated for three years (2006–08) at the Central Arid Zone Research Institute, Jodhpur, Rajasthan. Each genotype was grown in three replications arranged in a randomized block design. The plot size was two rows of 4 m length with a spacing of 60 cm between rows. A plant-to-plant distance of 15 cm was maintained by thinning out extra seedlings within 10 days of sowing. The trials were given a fertilizer dose of 40 kg N and 20 Kg P_2O_5/ha each year.

Data on days to flowering data was recorded on plot basis as number of days from sowing till stigma emerged in 50% plants in a plot. Plant height and panicle length was recorded on five competitive plants in each plot. At maturity panicles from entire plot were harvested, counted, dried, weighed, threshed and grain weight was recorded. Dry stover yield was recorded on plot basis. Panicle and stover weights were added to obtain biomass. Harvest index (%) was calculated as ratio of grain to total biomass. Individual grain weight was recorded using 1 000-grain weight of bulk harvest from each plot. The yield and grain number/panicle were derived from recorded traits.

The data for individual environments and across environments were analyzed using analysis of variance (ANOVA) using SPAR 2.0 (SPAR 2004). The relationship between traits was studied through correlation and regression analysis using mean values of genotypes across environments (Gomez and Gomez 1984). The comparison between performance of individual genotypes was performed with LSD.

RESULTS AND DISCUSSION

The total amount of rainfall (197–229 mm) and its distribution during three years of evaluations differed. The rains were 36–49% lesser than long-term average rainfall (360 mm) at Jodhpur. In 2006, only 11 mm of rains fell after average flowering time of trial leading to low grain yield (805 kg/ha). Though the post-flowering rains were higher (62 mm) in 2007 but crop still experienced water stress during reproductive stage resulting in grain yield of 1 001 kg/ha. Only 13 mm of rains occurred during grain-filling and setting during 2008 evaluation and thus crop faced a prolonged spell of drought and virtually ran out of water. Hence, a life-saving irrigation of approx. 25 mm was applied but that didn't fully alleviate drought stress. Thus the test genotypes were exposed to combinations of water stress that are of common occurrence in arid zone.

In spite of occurrence of drought, there was good control over experimental variation as indicated by 10–17% coefficients of variation for biomass, grain yield and stover yield. In the analysis of variance, year was significant source of variation for all traits (Table 1). Performance of genotypes was significantly modified by years. However, there were differences among contribution of different sources in determining variation in traits. Years accounted for 70–75% of variation in biomass, grain and stover yields, grain yield/panicle and plant height. This underlines the high degree of environmental variation in pearl millet growing zone in arid climate and consequent difficulties in breeding new cultivars. A few traits like panicles/m^2 and panicle length were largely stable as genotype accounted for 60–75% of total phenotypic variation. The significant year × genotype variation explained only 15–28% for most of the traits.

Table 1 Mean squares from analysis of variance for 12 traits in 39 genotypes evaluated for thee years at Jodhpur, Rajasthan

Source of variation	d f	Time to flower (no.)	Biomass yield (kg/ha)	Harvest index (%)	Stover yield (kg/ha)	Grain yield (kg/ha)	Panicles/ m^2 (no.)	Grain yield/ panicle(g)	Grain no./ panicle	1 000 - grain weight (g)	Plant height (cm)	Panicle length (cm)	Panicle harvest index (%)
Years	2	6 578.6**	3 746 097**	1 017.3**	1 565 166**	354 662**	137.52**	2 215.18**	31 828 060**	48.13**	142 885.1**	494.3**	13 497.2**
Genotypes	38	69.3**	26 635**	103.1**	20 177**	3 236**	55.94**	31.08**	816 808**	3.62**	1 859.7**	73.3**	145.7**
Year x genotype	76	6.7**	18 158**	29.9**	10 049**	1 833**	5.80**	9.61**	240 929**	1.65**	180.1**	9.5**	84.4**
Error	228	1.6	4 772	8.2	3 186	304.7	1.89	4.91	126 964	0.33	98.5	2.3	48.5

*P=0.05, **P=0.01

Association between grain yield and yield components

Days to flowering had negative association with grain yield (r = - 0.73**) which suggested that later flowering had a significant disadvantage in arid zone and *vice versa* (Table 2). This was expected in view of terminal drought experienced in present study as escaping the drought en route early flowering is an effective mechanism in determining the performance of pearl millet under late-season drought (van Oosterom *et al.* 1995, Yadav and Bhatnagar 2001).

Grain yield had significant positive correlation with panicles/m^2 (r = 0.69**) suggesting a significant benefit to genotypes that have ability to produce greater number of panicles, an observation also made earlier by Bidinger and Raju (2000). In fact, greater number of panicles provides a developmental plasticity under drought. If main panicle is damaged by drought, tillers can compensate by producing panicles when stress in relieved (van Oosterom *et al.* 2003). The panicles/m^2 had negative association with flowering time which showed a good linkage between early maturing genotypes and high tillering. Late flowering genotypes produced taller plants with larger panicles and high yield and grain number per panicle but had significantly reduced seed size. With increase in panicles/m^2, panicle length, grain yield/panicle and grain number/panicle were reduced (Table 2). Number of grains had high positive correlation with yield/ panicle but adversely affected seed size. Indeed, such mechanisms of adjustments in yield components are well-documented in pearl millet (Yadav *et al.* 1994) and are largely governed by source-sink relationship (van Oosterom *et al.* 2003).

Panicle harvest index had significant and positive relationship with grain yield (r = 0.67**) (Table 2). This trait represents ability of genotypes to fill grains under moisture-deficit conditions and thus its positive association with grain yield was expected in view of development of drought stress pattern in present study. In later flowering genotypes, the panicle harvest index was adversely affected resulting in smaller seed and higher number of grains/ panicle.

The negative association between panicle length and grain yield (r = –0.44**) showed that longer panicle had adverse impact on grain yield in spite of fact that longer panicles had significantly higher number of grains (r = 0.46**). This was mainly due to the fact that genotypes with larger panicles had significantly reduced tillering (Table 2). These data suggest that producing smaller but many panicles is much more important than producing a few larger panicles.

The positive relationship of earliness and tillering with grain yield, observed in this study, contrast with reported association of these traits with productivity in drought-free environments (Bidinger and Raju 2000, Yadav and Bhatnagar 2001). Such differential findings in contrasting environments underline the results obtained in this study which have more relevance in developing cultivars suitable for drought-prone environments.

Association between biomass and harvest index with grain and stover yields

Biomass had positive and significant relationship with both grain yield and stover yield. Variation in biomass accounted for as high as 81% stover yield variation and 15% grain yield variation (Fig 1). It has been suggested that biomass, rather than grain yield, should be used as a measure of adaptation to arid conditions (Bidinger *et al.* 2008, Bidinger and Yadav 2009) as harvest index affecting grain yield depends upon history of selection of genetic material. For instance, traditional drought-adapted pearl millet landraces provide higher biomass but have lower harvest index while elite improved cultivars had lower biomass with much higher harvest index (Yadav 2007, Yadav 2008). Harvest index had opposite significant effects on grain and stover yields (Fig 1). Higher harvest index led to greater grain yield (r^2 = 0.70) but to lower stover yield (r^2 = 0.30). This suggested that selection for higher harvest index to improve grain yield may not be appropriate selection strategy in pearl millet for arid zone as stover yield is as important as grain yield in arid regions, especially during severe drought years. Thus, selection exclusively on the basis of either biomass or harvest index may not be able to identify dual-purpose pearl

Table 2 Correlation coefficients among nine traits in 39 genotypes of pearl millet evaluated for three seasons at Jodhpur, Rajasthan

	Days to flower	Plant height	Panicle length	Grain yield	Panicles/ m^2	Grain yield/ panicle	Grain no./ panicle	1 000-seed weight
Plant height	0.47**							
Panicle length	0.63**	0.60**						
Grain yield	–0.73**	–0.12	–0.44**					
Panicles/ m^2	–0.86**	–0.20	–0.49**	0.69**				
Grain yield/ panicle	0.45**	0.16	0.27	0.03	–0.68**			
Grain no./ panicle	0.62**	0.41**	0.46**	–0.1	–0.69**	0.86**		
1 000-seed weight	–0.55**	–0.55**	–0.54**	0.39*	0.27	0.05	–0.44**	
Panicle harvest index	–0.54**	–0.04	–0.36*	0.67**	0.49**	0.04	–0.04	0.21

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

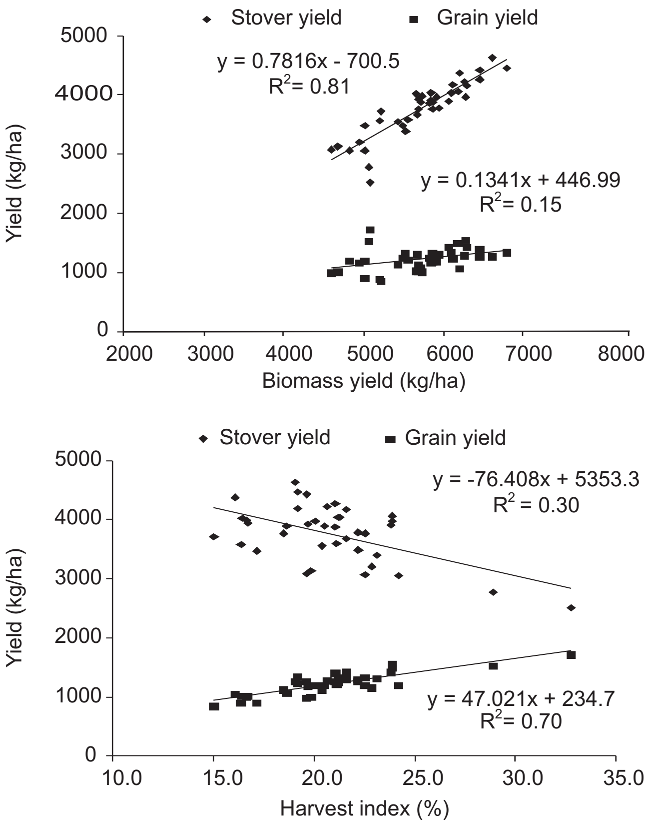

Fig 1 Grain and stover yield of pearl millet genotypes as a function of biomass (*top*) and harvest index (*bottom*)

millet, rather a balanced selection for improved biomass and harvest index needs to be adopted to improve grain yield without adversely affecting stover yield.

Magnitude of variation

The highly significant mean squares in the analysis of variance showed existence of significant genotypic variation for all traits (Table 1). There was a wide range of 14 days in flowering time of genotypes (Table 3). Similarly, there was a three-fold difference among genotypes for panicles/unit area. Such a wide range in flowering time and tillering should provide enough opportunity to select for these two traits that have been demonstrated to be of distinct advantage for arid zone locations. Range in biomass and harvest index was also broad with two-fold differences amongst genotypes which resulted into a good range in grain yield and stover yield *per se* (Table 3). Other phenotypic traits like panicle length, plant height and seed size also exhibited vast range in the test genotypes suggesting that there exists a good opportunity to select for different combinations of these traits in addition to grain and stover yields.

An attempt was made to identify the genotypes with higher stover and grain yields than commercial cultivars by comparing yields of checks and best 10 (equivalent to 25% of test entries) genotypes that produced highest biomass (Table 4). The best test genotypes produced, on an average, 23% higher biomass than commercial checks with four of them producing significantly higher biomass than best check cultivar Raj 171. Most of these genotypes provided significantly higher stover yield, with an average advantage of 35% without any significant penalty in grain yield. This gain in productivity of selected genotypes was achieved without extending the crop duration as their flowering time was similar to that of Raj 171. It was also interesting to note that the check CZP 9802 produced highest grain yield which was expected in view of its earliest flowering (Table 4) that helped to escape the terminal drought experienced in this study. But at the same time, CZP 9802 had the lowest stover yield and the highest harvest index. This reinforces the earlier conclusion that manipulation of harvest index is not the appropriate strategy of improving grain yield in arid zone pearl millet as this is associated with a significant penalty in stover productivity. These results also suggest that earliness

Table 3 Mean and range of 10 traits in 39 genotypes evaluated during 2006-08 at Jodhpur, Rajasthan

Trait	Mean ± SE	Range
Time to flower (days)	51.9 ± 1.49	41.7 – 55.6
Biomass yield (kg/ha)	5712 ± 77.8	4603 – 6790
Harvest index (%)	20.8 ± 3.15	15.1 – 32.8
Stover yield (kg/ha)	3764 ± 57.9	2512 – 4630
Grain yield (kg/ha)	1213 ± 24.7	841 – 1710
Panicles m^{-2} (no.)	10.0 ± 1.39	6.7 – 17.6
1 000-grain weight (g)	6.7 ± 0.74	5.8 – 9.1
Plant height (cm)	205.0 ± 7.74	159.8 – 227.4
Panicle length (cm)	29.0 ± 1.78	20.0 – 33.9
Panicle harvest index (%)	61.3 ± 5.3	53.2 – 69.7

Table 4 Flowering time, grain yield, stover yield and harvest index of pearl millet three commercial cultivars and of 10 genotypes selected for their highest biomass

Genotype/check	Days to flower	Biomass (kg/ha)	Harvest index (%)	Stover yield (kg/ha)	Grain yield (kg/ha)
108×SRC II	51.6	6 790	19.7	4 456	1 335
221×HHVBC	53.8	6 609	19.0	4 630	1 253
235×923	52.0	6 458	21.5	4 271	1 390
221×MCNELC	51.6	6 446	19.5	4 421	1 258
235×MCNELC	51.9	6 291	22.4	4 167	1 412
238×MCSRC II	51.2	6 269	24.6	3 970	1 543
221	51.2	6 266	20.3	4 224	1 273
221×MCSRC II	53.7	6 204	17.0	4 375	1 052
238×HHVBC	51.8	6 184	24.0	4 051	1 487
238×SRC II	53.0	6 122	20.0	4 178	1 225
Checks					
RAJ 171	51.7	5 668	22.7	3 669	1 289
CZP 9802	43.3	5 058	30.1	2 778	1 520
ICTP 8203	51.3	4 818	24.6	3 056	1 187
LSD	1.2	638	2.6	522	161

should not be viewed as a universal trait because it tends to lead to a trade-off in stover yield.

Results showed that higher tillering, early maturity and high panicle harvest index are three major grain yield attributes that significantly affected grain yield under arid zone environments. Biomass had positive affect on grain and stover yields, harvest index had opposite effect on these two traits which suggested that a balanced selection for improved biomass and harvest index needs to be adopted to improve grain yield without adversely affecting stover yield. Vast range of genetic variation for all these traits indicated that there exists a good opportunity to select for a combinations of such traits.

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