Improvement in Pearl Millet Grain and Stover Yields through Hybridization between Indian and African Germplasm under Arid Zone Conditions

OP Yadav

All India Coordinated Pearl Millet Improvement Project, Mandor, Jodhpur-342304, Rajasthan

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Pearl millet (*Pennisetum glaucum*) is valued for both grain and stover in arid and semi-arid regions. This study was designed to measure the magnitude of improvement for grain and stover yields in crosses between Indian landrace-based populations and African composites. Twenty crosses produced from four landrace populations and five elite composites were evaluated for four seasons under rainfed conditions of arid zone. Improvement in crosses was measured as percent increase (referred to as heterosis) in cross performance over landrace parent. There was differential expression of heterosis for different traits. Heterosis in individual crosses was between +32% to -6% for grain yield, +62% to -14% for stover yield and +48% to -10% for biomass. Positive heterosis for biomass resulted into positive heterosis for both grain and stover yields. Contradictory contribution of heterosis for harvest index on grain yield and stover yield heterosis was observed. Only those crosses that had a combination of high heterosis for biomass with no negative heterosis for harvest index resulted into positive heterosis for grain and stover yields.

Key Words: Arid zone, Drought, Heterosis, Landraces, Pearl millet, *Pennisetum glaucum*

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Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] grain forms the staple diet of human and its stover is the basis of ration for large ruminants in crop-livestock farming systems of arid and semi-arid regions of north western India and Sub-Sahara Africa where other cereal crops, such as maize or sorghum are not cultivable. These regions are highly prone to drought of unpredictable intensity and duration and have native soils with low fertility in addition to having high temperatures and greater evaporative demand during the crop season. Such climatic and adaphic conditions result into extremely stressful crop growing environments and render arable cropping a risky preposition especially in northwestern India.

As a strategy to minimize the risk of crop failure under prevalent harsh environmental conditions, drought resilient pearl millet landraces are conventionally grown by farmers. However, this strategy is likely to be at the cost of harvestable yields in more favourable years, as landraces often lack sufficient yield potential to fully exploit improved levels of inputs (Yadav *et al.,* 2004; Yadav and Bidinger, 2007; Yadav 2008). On the other hand, exotic germplasm originating from better-endowed environments, despite having a much higher yield potential, which is better expressed in favourable environment, does not have sufficient adaptation to stress conditions to provide better yields than adapted germplasm under arid zone environments (Kelley *et al.,* 1996; Yadav and Weltzien, 2000; Christinck, 2002; Bidinger *et al.,* 2006). Thus these two groups of material with differential adaptation pattern to contrasting environmental conditions are complimentary to each other. Hence genetic diversification of Indian landraces through introgression of appropriate germplasm from African regions has been suggested as a strategy to diversify the Indian pearl millet germplasm (Yadav and Bidinger, 2007; Yadav *et al.,* 2005; Prestrel and Weltzien, 2003) in order to amalgamate the drought tolerance of landraces and high yield potential of exotic materials. The guiding principal in this approach would be the magnitude of improvement over landraces in crosses between two groups of material. The present study was therefore undertaken to quantify the degree of improvement in crosses between Indian landraces and African composites under arid zone environments with respect to grain and stover productivity and to understand how heterosis in these traits is affected by heterosis in biomass and harvest index under arid zone conditions.

Materials and Methods

This study used four landrace-based populations from northwestern India and five very diverse elite composites developed mainly from African genetic material (Table 1). Landrace populations were chosen to represent

**Author for Correspondence: E-mail:* opyadav21@yahoo.com

Table 1. Origin details of Indian landrace-based populations and elite exotic populations used in the study

Parental populations	Origin
Landraces-based populations	
Jakharana	A dual-purpose landrace from eastern Rajasthan with long, cylindrical and thin panicles with a slight curved panicle
BarPop	Bred by inter-mating five selected, typical landraces from the Barmer district of Rajasthan
ERajPop	Bred from 30 S_1 progenies from four early maturing landraces (IP 3188, IP 3228, IP 3246 and IP 3464) from Rajasthan and improved by several cycles of recurrent selection
WRajPop	Bred from 13 selected, representative landrace accessions from North-western India and subjected to several cycles of improvement through recurrent selection
Exotic composites	
Smut Resistant Composite (SRC)	Composite bred from interpopulation crosses of Smut Resistant Composite (SRC) and intervarietal composite (IVC) which was developed by random mating 79 varietal crosses involving African and Indian germplasm.
Early Smut Resistant Composite (ESRC)	Composite developed by selecting for earliness in the initial bulk of SRC
Medium Composite (MC)	This composite is based on crosses of elite non-Togo material from ICMP 89410 with elite bold seeded early composite. This has African, Indian and Togo germplasm (Iniadi) in its parentage
Early Composite (EC)	Developed by random mating EC II, ICMV 87901, ICMV 87902 and ICMV 87119
Bold Seeded Early Composite	It is a composite mainly based on Iniadi landrace germplasm from Togo and Ghana

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a gradient from elite landrace-based populations to unimproved types. Jakharana, a dual-purpose landrace from eastern Rajasthan, represented the improved type of landrace in terms of productivity and disease resistance. BarPop, on the contrary, represented unimproved typical landrace population from western Rajasthan. ERajPop and WRajPop were made from a small number of carefully selected landrace accessions from Rajasthan, with WRajPop having a geographic focus and ERajPop having a maturity focus. Five exotic elite composites were based on early- to medium-maturing Togo and non-Togo material from Africa (Table 1).

Four landrace populations were crossed using hand pollination with each of five elite populations to produce 20 crosses. In each population, at least 100 plants were used in attempting each cross in order to sample variation from parental populations. These crosses together with nine parental populations were evaluated for their performance at the Central Arid Zone Research Institute, Jodhpur under rainfed conditions of rainy seasons, during 1999-2003 (except 2002 when season was lost due to failure of rains) in Randomized Block Design with three replications. Each entry was grown in four rows at a spacing of 60 cm in 4 m long row. The plots were over sown with a tractor-drawn planter and then thinned to a plant-to-plant spacing of 15 cm within two weeks of sowing. Trials received 20 kg/ha N and 8 Kg/ha P_2O_5 at sowing and an additional 20Kg/ha N was top dressed 3-4 weeks after sowing. Weeds were controlled with two manual weedings.

Flowering was recorded on plot basis as number of days taken from sowing to the emergence of stigma in the main shoot panicle of 50% plants in a plot. All the panicles from entire plot were harvested at maturity and were dried for two weeks before weighing and threshing. Both grain and dry stover weights were recorded on plot basis. To obtain total biomass, dry panicle weight and stover weight were added. The harvest index was calculated as ratio of grain to biomass and was expressed in percentage.

Data of all traits were subjected to both individual environments and across-environment analysis of variance. Heterosis was calculated as percent increase/ decrease in the performance of cross over its landrace populations which is the relevant comparison for the question of increasing grain and stover productivity over currently available farmers' open-pollinated cultivars as it measured the potential exploitable gain in productivity of crosses over traditional landraces. Effect of heterosis for biomass and harvest index on grain yield heterosis and stover yield heterosis was studied through correlation analysis.

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Results and Discussion

Environmental and genotypic effects

The four growing seasons had a considerable variation in grain productivity ranging from 32 g m^{-2} to 216 g m^{-2} covering full range in expected grain yields under rainfed conditions of arid zone. Thus the results obtained in this study would be applicable in a range of environmental conditions of arid zone.

The mean squares due to genotypes were highly significant for all traits. For grain and stover yields and total biomass, genotypes sums of squares (SS) could account for only up to 10% of fraction of total SS. Genotypes, however, accounted for 24% and 43% of variation for days to flower and harvest index, respectively. This observation also explains the historical reason for manipulating crop duration and biomass partitioning rather than grain yield *per se* to enhance the pearl millet productivity in arid zone, though the. higher grain at the cost of stover has little relevance for arid zone (Bidinger *et al.* 2006).

Magnitude of heterosis in crosses

Within genotypes, mean squares due to parental populations and their crosses were significant for all traits suggesting that there occurred adequate genetic differences both within populations and crosses for all the measured traits. These effects were further modified by environments as indicated by significant interaction of each component with environment.

There was differential expression of heterosis for various traits (Table 2). Mean heterosis ranged from 17% for stover yield to 0.3% for harvest index. Heterosis estimates for pearl millet in the literature vary widely, depending upon the type of parental materials used and the type of crosses from which heterosis was estimated (Virk, 1988). Highest heterosis estimates (>100%) are based on single cross hybrids made with highly inbred parents (Virk, 1988) which are often very low yielding due to inbreeding depression. However, estimates of grain yield heterosis (hybrid vs. pollinator) of topcross hybrids made with non-inbred Indian and African population parents are in the order of 20–40% (Mahalakshmi

Table 2. Mean heterosis (%) across four seasons for grain yield, stover yield, biomass, harvest index and days to flower in twenty crosses between four Indian landraces and five African elite populations

	Heterosis (%) over landraces for				
Cross (landrace x elite population)	Grain yield	Stover yield	Biomass	Harvest index	Time to flowering
Jakharana x SRC	32.25 **	51.30 **	41.89 **	–5.01	2.29
Jakharana x ESRC	20.43 *	62.31 **	48.37 **	–8.19	2.99
Jakharana x MC	5.05	37.84 *	22.63 *	–13.15 *	3.35
Jakharana x EC	3.36	24.38	14.58	–3.99	–0.35
Jakharana x BSEC	14.21	22.35	17.84	4.49	–0.53
BarPop x SRC	–6.38	18.29	12.1	–10.3	5.62 *
BarPop x ESRC	–4.15	7.32	5.4	–9.02	4.92 *
BarPop x MC	–12.95	3.35	–1.03	–14.99	6.85 **
BarPop x EC	–3.23	17.38	9.8	–11.49	6.15 *
BarPop x BSEC	17.95	14.94	15.41	8.46	0.35
ERajPop x SRC	36.35 **	20.42	21.94 *	1.82	5.97 *
ERajPop x ESRC	21.64 *	21.13	26.85 *	–0.17	8.58 **
ERajPop x MC	9.36	13.73	10.09	–1.04	7.84 **
ERajPop x EC	–3.61	18.66	11.49	–5.54	6.16 *
ERajPop x BSEC	8.65	–0.71	2.67	11.81	0.19
WRajPop x SRC	13.55	2.31	3.93	14.85	–0.7
WRajPop x ESRC	13.06	17.63	17.79 *	3.63	1.74
WRajPop x MC	2.79	1.45	2.39	13.92	–0.7
WRajPop x EC	4.78	1.16	–0.09	5.85	–2.43
WRajPop x BSEC	11.02	–14.45	–10.2	23.81 *	–2.61
Mean	9.21	17.00	13.69	0.29	2.78

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

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et al., 1992; Yadav et al., 2000; Bidinger *et al.,* 2005). These are comparable to mean grain yield heterosis estimates derived from population crosses Prestrel and Weltzien, 2003; Ouendeba *et al.,* 1993). Level of heterosis observed in the present study thus compared well with those reported in literature in crosses between open-pollinated non-inbred materials; though average level of heterosis was low mainly because of positive and negative heterosis values balanced each other out (Table 2). Individual cross heterosis was positive, though not necessarily significant, in the most of crosses for grain yield, stover yield and biomass. In contrast, heterosis was positive in only half of the crosses for harvest index and in one-fourth of crosses for days to flower.

Mean grain yield heterosis was positive (9%) and there was significant and positive grain yield heterosis in four crosses (Table 2). The best combination was ERajPop x SRC, with an overall yield heterosis of +36%. The other three combinations had a heterosis of +20% to +32%. These data indicated that it is possible to identify crosses of landrace and exotic population with useful levels of positive heterosis for grain yield. All four crosses that had positive and significant heterosis for grain yield also had positive significant heterosis for biomass. However the converse was not true. Out of six crosses that had significant heterosis for biomass, only four had a positive heterosis for grain yield. Of the remaining two, high biomass heterosis in cross Jakharana x MC was accompanied by significant negative heterosis for harvest index. While in other cross *viz.,* WRajPop x ESRC, the moderate level of heterosis for biomass came with no heterosis for harvest index. Thus positive heterosis of grain yield was not exclusive due to biomass heterosis but also depended upon heterosis for harvest index. Only those crosses that had a combination of high heterosis for biomass with no negative heterosis for harvest index only resulted into positive heterosis for grain yield. The role of heterosis for biomass and harvest index was more critically examined by studying the relationship of grain yield heterosis with heterosis for biomass and harvest index. Variation in grain yield heterosis was accounted for by biomass and harvest index heterosis by 36% and 11%, respectively (Fig. 1), both contributing positively to grain yield heterosis.

The overall heterosis for stover yield was positive (17%) ranging from +62% (Jakharana x ESRC) to -14% (WRajPop x BSEC) (Table 2). All but two crosses showed positive heterosis for stover yield, three of them showing significant heterosis over landraces. Positive heterosis for stover yield was strongly associated for positive heterosis for biomass (Fig. 1). The variation for biomass heterosis accounted for 92% of variation in stover yield heterosis. However, higher heterosis for harvest index resulted into negative heterosis for stover yield (r^2 = 33%). These data suggested that improving harvest index might not be a viable strategy in breeding for arid zone areas where pearl millet stover is as important as grain, especially in drought years (Kelly *et al.,* 1996). In contrast, the major gains in grain yield of pearl millet in favourable areas have been achieved through greater partitioning of biomass to grain, rather than increasing the overall biomass (Ouendeba *et al.,* 1993). This is one of main reasons of low adoption of improved cultivars of pearl millet in arid zone of India despite their large scale adoption elsewhere (Kelley *et al.,* 1996; Christinck, 2002) as there is often a trade-off between high grain yield and stover yield in modern cultivars.

Individual cross heterosis for biomass was positive in most of crosses with mean heterosis being 14% (Table 2). Negative heterosis was uncommon occurring only in two crosses. This magnitude of improvement in biomass is very encouraging as previous genetic studies suggest that the improvement of biomass productivity by conventional plant breeding, without extending crop duration, is likely to be slow, especially under marginal conditions. For example, Rattunde and Witcombe (1993) reported average gains in biomass after three to four cycles of recurrent selection for improved grain yield in four populations of only 2.3% per cycle measured under terminal stress conditions. These increases translated to a 2.5% gain in grain yield and 0.5% gain in stover yield per cycle. Such results would be expected physiologically, as growth rate or biomass productivity is a not a simple genetic trait, but the result of the interaction of many underlying, complex factors (canopy development, radiation interception, radiation use efficiency, respiration rate, etc.). The varying effects of stress on the individual components of overall biomass productivity further complicate attempts at genetic improvement of biomass productivity in marginal environments. Growth rate/ biomass productivity in pearl millet appears to be governed mainly by non-additive gene effects (Lynch *et al.,* 1995; Gupta and Phul, 1981) and heritabilities for biomass productivity are modest (Rattunde *et al.,* 1989). Thus exploiting heterosis appeared more effective and rapid way to improve biomass yield in pearl millet under

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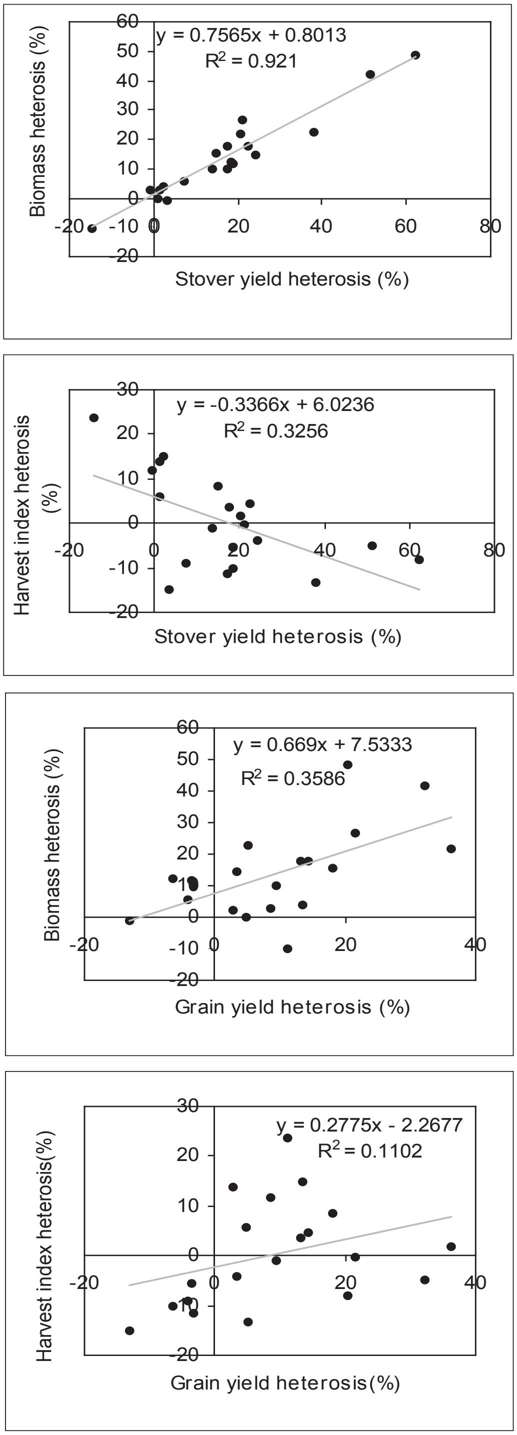

Fig. 1. Heterosis for grain and stover yields of pearl millet as influenced by biomass and harvest index heterosis

marginal conditions of arid zone. Heterosis estimates obtained in the present study are similar to biomass heterosis observed in topcross hybrids produced by crossing male-sterile lines with landrace pollinators (Yadav *et al.,* 2000). The partitioning of this extra biomass of hybrids to either grain or stover was controlled by the harvest index of the seed parent, resulting in differential heterosis for either grain or stover yields, depending upon the seed parent used.

Contradictory contribution of harvest index on grain yield and stover yield as observed in this study raises an important point. Improvement of grain yield in arid regions has to come without any adverse effect on stover yield as pearl millet stover is valued as important feed for ruminants in arid regions. Sale of animals and animal products is often the major source of household cash income in severe drought years (Hall *et al.,* 2004). The practical and more realistic strategy thus would be to enhance biomass yield maintaining the existing levels of harvest index. The data presented here clearly showed that this objective is possible to achieve as one-third of the crosses had positive and significant heterosis for biomass with all but one of them having non-significant heterosis for harvest index (Table 2). However, the biomass improvement has to be made without extending the crop duration to a great extent as increasing duration makes the crop more vulnerable to the end-of-season drought (Sastri *et al.,* 1982; van Oosterom *et al.,* 1995; van Oosterom *et al.,* 1996). Though half of the crosses had significant positive heterosis for days to flower, the magnitude of heterosis in these crosses was in the range of 5-8% which effectively means 2-3 days of additional flowering time in these crosses (with 40-45 days of flowering time) which might be of little practical value considering the magnitude of improvement in biomass and finally in grain and stover yields.

Two crosses (Jakharana x SRC and Jakharana x ESRC) which had a positive grain yield heterosis also exhibited positive heterosis for stover yield (Table 2). This is clearly a reflection of their better adaptation to arid zone conditions and of their ability to provide both enhanced grain and stover yields over landraces. This probably explains the reasons of introgression of modern cultivars into local landraces by some farmers in arid zone of north western India in order to enhance diversity within their landraces (Yadav *et al.,* 2009) and to increase the adaptive range of their seed stocks (Christinck, 2002).

The results of the present study showed that crosses between landraces and elite materials offer good opportunities for exploiting heterosis in arid zone environments. However, not all cross combinations had same benefit. Most importantly, the data clearly demonstrated that it is possible to identify crosses made with adapted landraces and exotic populations that are statistically superior to the landrace populations both for stover and grain yield and expression of heterosis in biomass is most critical to enhance both grain and stover productivity.

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