Amalgamation of drought adaptation and high productivity in arid zone pearl millet (*Pennisetum glaucum*)

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Abstract

New pearl millet (*Pennisetum glaucum*) cultivars for arid zone environments need to combine adaptation to drought with increased yield potential. We describe here results of three approaches viz., utilization of existing variation in landraces, genetic diversification of landraces and exploitation of heterosis in landrace-based hybrids, used to achieve this objective. Results demonstrate good exploitable differences among landraces for their response to both drought stressed and higher productivity environments. In the diversification study, the relative mean performance of landraces and elite composites showed a distinct crossover between drought and favourable crop seasons. Crosses between these two groups of material showed significant and positive heterosis for grain yield with magnitude of up to 33% over landrace parents. A few crosses showed consistent improvement over both landraces and elite parents. Exploitation of heterosis in landrace-based hybrids also proved to be a rapid and effective way to improve the production, while retaining critical adaptation of landraces to the arid zone environments. Development and performance of a commercial pearl millet variety CZP 9802, through selection within the landraces, are described.

Media summary

We explored several possible approaches to combining improved yield potential with tolerance to drought stress in pearl millet breeding materials and developed a commercial variety CZP 9802 having these features.

Key Words

Pearl millet, landrace, drought adaptation, heterosis

Introduction

Pearl millet (*Pennisetum glaucum*) is an important coarse-grain cereal of the arid and drier semi-arid regions of southern Asia and sub-Saharan Africa. It is also of importance as a high quality forage crop in the USA, Australia, South America and southern Africa. Because of its exceptional ability to tolerate drought, pearl millet may in near future extend into regions that are too dry for sorghum.

Pearl millet in south Asia and sub-Saharan Africa is grown as a rainfed crop in areas where rainfall is too limited for higher yielding cereals such as sorghum or maize. Erratic distribution of low rainfall in millet growing regions, combined with high evaporation rates and high soil and air temperatures frequently expose the crop to varying degrees of intensity of drought. Adaptation to drought stress is the primary requirements for new pearl millet cultivars. At the same time, however, increased grain and stover yield potential in these cultivars is necessary to support ever-growing populations in this region. This accentuates the need to integrate adaptation to drought stress conditions of landraces and high yield and disease resistance of elite breeding material, so that new cultivars do not trade increased productivity with reduced yield stability and increased risk of crop failure. This paper briefly discusses the results of three strategies, which are being successfully employed to achieve this objective. These strategies are exploitation of existing variation for grain yield in adapted pearl millet landraces, genetic diversification of landraces through introgression of suitable elite genetic material and exploitation of heterosis for improving yield in landrace-based hybrids.

Materials and methods

Genetic material

The material consisted of pearl millet landraces, elite breeding material with no known records of arid zone landraces in their parentage, crosses between landraces and elite genetic material and landrace-based top cross hybrids (TCHs). For assessing the existing genetic variation for drought tolerance 105 landraces from northwestern India were used. The genetic diversification study included four landraces (Jakharana, BarPop, ERajPop and WRajPop), five elite composites (ESRC, SRC, MC, EC, BSEC) and 20 population crosses between them. The magnitude of heterosis was assessed in a set of TCHs between 16 unimproved landraces from western Rajasthan and two phenotypically diverse male-sterile lines.

Evaluation

The evaluations were conducted during the past decade or so (1990-2003) as a part of breeding programme with the aim of producing the most suitable cultivars for arid regions using different approaches. All the evaluations were done in replicated field trials under rainfed conditions at research stations located in the states of Rajasthan, Gujarat and Haryana that cover most of the Indian arid zone. The landraces were evaluated in three locations during 1990-1991; the population crosses and parents at one location during 1999-2003, and the topcross hybrids at three locations in 1990-91. The evaluation of a commercial variety developed through the research reported here was undertaken during 1999-2001 through Indian national testing system.

Percent heterosis was calculated as superiority of individual TCH over landrace pollinator. Drought response index (DRI) was calculated using the regression model developed by Bidinger et al. (1987) to assess the drought response of landraces. Individual landrace x test environment means were regressed on overall environment means (6) for grain yield to compare the landraces for their response to changing environmental productivity (measured by regression coefficient).

Results

Exploiting existing variation among landraces

There were large differences among landraces for their response to drought as evidenced by a wide range in their DRI values (-8.52 to 13.9). As many as 37 landraces possessed drought tolerance (positive DRI) that was independent of their yield potential and flowering time. Also, the landraces differed significantly in their response to improved environmental productivity (regression coefficient b=0.40-1.55). It was interesting to note that more than 10% landraces (Table 1) had good adaptation to drought and simultaneously responded very well to favourable environments.

Table 1: Drought tolerance index (DRI), responsiveness to productive environments (b), and grain yield in stress (Ys) and non-stress (Yns) conditions of selected landraces

Landrace (IP no.)	DRI	b	Ys (g m^{-2})	Yns (g m^{-2})
3123	3.67	1.02	68	178
3228	9.48	1.08	92	196
3243	13.88	0.93	98	189

3258	4.64	1.00	71	172
3303	5.49	1.01	68	172
3333	1.71	1.22	58	187
3341	2.08	1.28	64	206
3424	8.20	1.03	91	182
3429	2.33	1.15	71	191
3430	2.29	1.23	71	202
3437	2.03	1.20	66	192
11087	2.19	1.16	62	186
11141	4.29	1.29	72	209

Diversification of genetic base of landraces

The comparative performance of parental populations across environments showed a distinct crossover between two types of material (Table 2). The landraces were significantly superior in severe drought environment and elite composites in favourable seasons, demonstrating that adaptation to drought is at the cost of higher grain yield and vice-versa. The population crosses performed better than elite composites in severe drought year and better than landraces in one of the two good rainfall years.

Table 2: Mean grain yield (g m^{-2}) of four landraces populations, five elite composites and their 20 crosses in four contrasting seasons at Jodhpur, India

Group	1999 (severe drought)	2000 (moderate drought)	2001 (no drought)	2003 (no drought)
Landrace	42.4a*	57.6a	156.0a	205.6a
Elite composite	24.6b	69.4a	237.1b	257.5b
Crosses	31.9c	65.8a	202.1c	207.7a

* values within a column having different alphabet differ significantly at P=0.05

There were differences among the individual population crosses both across and within years in both grain yield and heterosis (data not shown). Nine out of 20 crosses exhibited significant and positive mean yield heterosis over their landrace parent; with as high as 30% heterosis in a few crosses (data not shown). More importantly, four crosses had a positive heterosis over their landrace parent in optimum growth seasons, and over their elite parent in drought seasons (Table 3). In addition, three crosses (WRajPop with SRC, MC and EC) exhibited significant and positive heterosis over the elite parent in both drought years and over landrace parent in one of the two optimum growth years. Thus, these crosses had an enhanced adaptation range, beyond that of their parents as they were better able than their landrace parent to capitalize on the additional resources of good growing seasons, and simultaneously had a better capacity than their elite parent to tolerate drought.

Table 3: Grain yield heterosis (%) in four population crosses over elite parent in drought seasons (1999 and 2000) and over adapted landrace parent in optimum seasons (2001and 2003)

Cross	1999 (severe drought)	2000 (mild drought)	2001 (no drought)	2003 (no drought)
Jakhrana x SRC	118*	42*	61*	18
Jakhrana x MC	37*	2	19	15
Jakhrana x EC	75*	1	24*	15
Jakhrana x ESRC	-2	42*	57*	42*

* significant at P=0.05

Exploitation of heterosis in landrace-based hybrids

Average improvement in grain yield of landrace-based topcross hybrids over their landrace pollinators was 20-40% (Table 4). Choice of male-sterile line had considerable effect on the manifestation of heterosis for grain and stover yields. Hybrids on early maturing and grain type male-sterile line 843A showed greater heterosis for grain yield while the later maturing and dual-purpose ICMA 89111 male-sterile line produced longer duration hybrids resulting into greater gains in stover yield. The gain in productivity through heterosis was also higher under drought than optimum conditions (Table 4). Thus, the most effective and rapid way to improve the grain and stover production, while retaining critical adaptation to arid zone environments, is by exploiting heterosis in hybrids based on locally adapted landraces.

Table 4. Magnitude and range (in parentheses) of heterosis (%) over landrace pollinator (n = 19) in topcross hybrids of pearl millet on two male sterile lines 843A (grain type) and ICMA 89111 (dual purpose type) under four drought and five near-optimum growing environments (from Yadav et al., 2000)

Trait	Environment	843A hybrids	ICMA 89111 hybrids
Grain yield	Drought	40 (-10 to 87)	20 (-11 to 68)
	Near optimum	29 (2 to 67)	35 (3-78)
Stover yield	Drought	0 (-41 to 20)	16 (-20 to 42)

	Near optimum	-9 (-30 to 10)	8 (-14 to 32)
Time to flowering	Drought	-6 (-14 to 0)	2 (-5 to 7)
	Near optimum	-9 (-14 to -2)	1 (-6 to 9)

Release of variety with combined yield potential and adaptation

We synthesized a pearl millet composite variety CZP 9802 from a landrace-based population ERajPop (Yadav and Weltzien, 2000). In Indian national testing system for new cultivars, its grain yield performance was 25-58% superior to two national checks (ICTP 8203 and Pusa 266) in drought environments and it also maintained its superiority under near-optimum growth conditions by a margin of 16-47% for stover yield and 4-6% for grain yield (Table 5). Thus, CZP 9802 enjoys a unique feature of having adaptation to drought stress in addition to being responsiveness to improved conditions. As a result millet variety CZP 9802 has been recently (2003) released by the Government of India for cultivation in drought-affected millet growing areas in the states of Rajasthan, Gujarat and Haryana.

Table 5. Summary performance of pearl millet variety CZP 9802 and two national checks under 13 drought- and five near optimum-growth environments of arid zone of India in the All India Coordinated Pearl Millet Improvement Project trials (1999-2001)

Variety/ Check	Drought environments (13)*		Optimum growth environments (5)	
	Grain yield (g m^{-2})	Stover yield (g m^{-2})	Grain yield (g m^{-2})	Stover yield (g m^{-2})
CZP 9802	105	300	211	500
ICTP 8203	67	190	199	340
Pusa 266	84	250	202	430

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