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Adaptation and quality traits of a germplasm-derived commercial seed parent of pearl millet

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Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a major cereal grown on about 25 million hectares, primarily for grain production, in the arid and semi-arid tropical (SAT) regions of Africa and Asia. It is also valued for its stover (dry straw after grain harvest) and green forage. Although pearl millet is a highly drought-tolerant, warm-season cereal, drought remains the major abiotic production constraint of this crop, and breeding for drought tolerance continues to be a major challenge. Conventional approach to genetic enhancement of drought tolerance has had limited success. Thus, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has recently resorted to molecular marker-assisted selection (MAS) to improve this trait. Downy mildew (DM) disease, caused by *Sclerospora graminicola* (Sacc.) Schroet, is a major biotic constraint, especially on single-cross hybrids, as shown by several epidemics of this disease on hybrids in India during the early 1970s to early 1990s (Rai et al. 2006). Besides breeding for high grain yield, breeding for DM resistance is a high priority research area in India, which is the largest producer of this crop with 10 million hectares (more than 90% of the pearl millet area in Asia). DM resistance breeding is also a priority research area in Africa, where pearl millet is cultivated on more than 14 million hectares. Conventional breeding approaches for DM resistance have been highly successful in India, with no widespread epidemic of this disease observed since mid 1990s. MAS as a tool, has enhanced breeding efficiency for this trait. For instance, ICRISAT and CCS Haryana Agricultural University, using MAS techniques, developed “HHB 67-improved”, a DM resistant version of early-maturing hybrid HHB 67 (matures in 65 days and is cultivated on about 600 000 ha in northern India). HHB 67-improved was released in India in 2005 (Khairwal and Hash 2007). Development of HHB 67-improved makes it the first example of a crop cultivar developed with MAS technology in the public domain in India that went into cultivation up to 2006.

In recent years, there has been considerable increase in the fodder requirement for the growing livestock population (Hash et al. 2003). While breeding for high fodder yield is of the highest priority, the role of fodder quality for nutritional security has been recognized as a significant factor. Micronutrient malnutrition has recently been recognized as a widespread problem, especially in areas lacking access to livestock products, fruits and vegetables (Mason and Garcia 1993), which is typical of the SAT environments in Africa and Asia. The HarvestPlus Challenge Program of the Consultative Group on International Agricultural Research (CGIAR) has identified grain iron and zinc as the two principal mineral micronutrients for genetic enhancement in several CGIAR mandate crops, including pearl millet.

ICRISAT is the world centre for genetic resources of this crop, with more than 21 000 accessions from 50 countries in its genebank. It is also a leading world centre for the genetic improvement of this crop, mandated to utilize these genetic resources and generate a wide range of breeding lines and parental lines with high yield, and various adaptation and quality traits as International Public Goods (IPGs). This paper describes the development and morphological, adaptation and quality traits of a maintainer line, 863B, that was selected from an *iniadi* landrace and converted into a male-sterile line, 863A, which is the seed parent of three commercial hybrids bred by the private sector in India.

Origin and development

The *iniadi* landrace is widely distributed in northern Togo and adjoining western Benin, southern Burkina Faso and eastern Ghana regions (Andrews and Anand Kumar 1996). Besides early maturity (75–85 days), this landrace is among the germplasm least sensitive to longer days for flowering, has fewer tillers (1–2 per plant), compact, conical panicles with good exsertion, and typically lustrous, mostly dark grey and globular grains of large size (1000-seed weight in the range of 13 to 20 g). The widespread use of this landrace in pedigree and population breeding in India, southern and eastern Africa, western and central Africa, and the USA, leading to the development and release of several open-pollinated varieties (OPVs) and parental lines of hybrids, has been described by Andrews and Anand Kumar (1996). Development of ICTP 8203 by random mating five S2 progenies selected at ICRISAT from an *iniadi* landrace from northern Togo is a milestone in demonstrating the utility of this landrace. This variety was released in India in 1988 (Rai et al. 1990). It was cultivated on 0.6–0.7 million hectares at the peak of its adoption in Maharashtra State, India (Bantilan et al. 1998). It is still cultivated on 300 000 ha, and retains its initial high level of DM resistance (<2% disease incidence in farmers' fields over the last 18 years).

While the progenies for the development of ICTP 8203 were being identified, one S1 progeny (designated as Togo 13-4) during the inbreeding and selection process was found to be an excellent maintainer of an A_1-system male-sterile line, 81A. It also had a high level of DM resistance in the disease nursery (<5% disease incidence) at ICRISAT, Patancheru. An A/B pair of the male-sterile F_1 (81A × Togo 13-4) and the maintainer (B) line (Togo 13-4) was established in 1981 post-rainy (dry) season. Individual plants selected from the S_1 progeny were further selfed and backcrossed onto individual plants of the sterile hybrid. Selfing and selection in the maintainer progeny with concurrent backcrossing onto individual plants of the sterile backcross progeny was continued for six generations. It led to the identification of a family comprising six male-sterile BC_6 progenies and six maintainer S_8 lines, of which one pair was designated as 863A and 863B. This A/B pair was made available to research programmes in the National Agricultural Research System and the private sector in India in 1987, who made extensive use of it in breeding hybrids. Line 863A or its sub-selections are the seed parents of three commercial hybrids developed and marketed by three private seed companies in India.

Morphological traits

Male-sterile line 863A was bred for its large seed as the principal trait. Based on the mean performance over four environments, 863A had 1000-seed weight of 11.5 g, which was 40% more than that of 841A and 67% more than that of 81A, the two most widely used commercial seed parents in the public sector (**Table 1**). In yield trials conducted in 11 year × location environments, 863A had a mean grain yield of 1.12 t/ha, far below 841A (2.01 t/ha) and took 51 days to 50% flowering (3 days more than 841A). Compared with 841A, 863A had 20 cm less height, 4 cm shorter panicles, and 0.6 less tillers per plant. The panicles of 863A are compact to semi-compact, and cylindrical to lanceolate, with slight tapering towards the tip. It has mostly purple glumes and purple anthers. It is an average pollen producer. Seeds are globular in shape and grey in colour.

Adaptation traits

Tolerance to abiotic stresses, such as drought, soil salinity, low nutrient levels, high temperatures (at seedling and flowering stages); resistance to biotic stresses such as downy mildew, *Striga*, and various insect pests (largely in African regions), and flowering response to day length determine the adaptation range of pearl millet. Drought among the abiotic stresses, and downy mildew among the biotic stresses, are of greater global significance in the arid and semi-arid environments for which 863B has been evaluated.

Downy mildew resistance

Forty-six A-lines, male-sterile counterparts of the B-lines, developed during 1981–1998 were evaluated for resistance to four diverse DM pathotypes from India, including the Patancheru pathotype, under field conditions in disease nurseries and under greenhouse conditions using seedling inoculation. Although the selection during inbreeding and at backcross stages had been made for resistance to the Patancheru pathotype, 863B was found to be DM-free under both conditions for three pathotypes (Patancheru, Durgapura and Jalna) and had 2–8% disease incidence against the fourth pathotype from Mysore (Thakur et al. 2001). Line 841A had low DM incidence (<10%), but it had diseased plants against all the four pathotypes under one or both of the screening conditions. The susceptible control, 7042S, had 70–100% disease incidence in these tests.

A subsequent study involving nine pathotypes, which included the two most virulent pathotypes known so far (one from Banaskantha in Gujarat State, India, and the other from Barmer in Rajasthan State, India), showed that 863B-P2 had 0–6% DM incidence against the eight pathotypes, and 11% DM incidence against the Banaskantha pathotype under high disease pressure in the greenhouse (63–100% disease incidence in the susceptible control, 81B) (Hash et al. 2006). Line 841B-P3 had 5–96% DM incidence, with 30–96% incidence against four pathotypes. Line 863B has been involved in several mapping populations to identify quantitative trait loci (QTLs) for DM resistance. Two major QTLs for resistance effective against a range of DM pathogen populations from eastern Africa and India have been detected on linkage group 4 (LG 4) of this line (**Figure 1**). The first of these (*QRsg.*icp-4.1) maps near RFLP marker *Xpsm*716 and its STS marker counterpart *Xpsmp*716. The second of these (*QRsg.icp-4.2*) maps in the vicinity of RFLP marker *Xpsm*305.

Drought tolerance

Although drought stress can occur at any stage of crop growth, post-flowering (terminal) drought stress has been found to be the most important yield reducer in pearl millet (Bidinger et al. 1987; Fussell et al. 1991). These studies also showed that panicle harvest index (PNHI), expressed as the ratio of grain dry mass/panicle dry mass, provides a direct estimate of grain-setting and grain-filling abilities of the genotypes, and hence is a good measure of drought tolerance. Line 863B has superior general combining ability for grain filling under terminal drought stress (Yadav et al. 2004). Evaluation of a mapping population developed from a cross 863B × ICMB 841 under early- and late-drought stress environments in two tester backgrounds identified two genomic regions (QTLs) in 863B associated with improved PNHI, and hence to terminal drought tolerance (Yadav et al. 2004). Qgydt.icp-2.1 on LG 2 and Qgydt.icp-6.1 on LG 6 (**Figure 1**) account for 23.6% and 14.4% of the total variability for PNHI, respectively. Further evaluation of the mapping population testcrosses across a larger number of screening environments revealed Qgydt.icp-2.1 as the primary QTL for MAS-mediated selection of drought tolerance (Bidinger et al. 2007).

Quality traits

Stover quality

Stover of the testcrosses of the mapping population mentioned above was evaluated for various fodder quality traits, such as *in vitro* organic matter digestibility (IVOMD), metabolizable energy (ME), and sugar content (SUGSDM) on dry matter basis (Nepolean et al. 2006). It was observed that a genomic region on LG2 that was associated with drought tolerance (i.e. PNHI), was also associated with all the above quality traits (**Figure 1**). A second genomic region on LG6 was also associated with all the above fodder quality traits. For stover ME and IVODM, a third QTL mapped nearly at the top of LG1. These QTLs had favourable alleles for all these stover quality traits in 863B.

Grain iron and zinc content

A trial consisting of 40 designated hybrid parents (20 each of seed parents and restorer parents), 30 each of improved populations and population progenies, and 20 germplasm accessions of diverse origin, was evaluated during the 2004 rainy and post-rainy seasons at ICRISAT, Patancheru. Based on the mean performance across the two seasons, 863B had the highest level of Fe (72.7 mg/kg) among the hybrid parents (Velu et al. 2007). A progeny from an open-pollinated variety released in India had 75.7 mg Fe/kg, which was the highest Fe level in the trial. These Fe levels are about twice those reported in wheat germplasm (Graham et al. 1999). It was also observed that 863B had 55.8 mg Zn/kg, ranking among the top five hybrid parents for this trait. The highest Zn level recorded for a hybrid parent in the trial was for seed parent 843B (59.6 mg/kg), while the highest Zn level for any entry in the trial was 63.7–64.8 mg/kg for the two progenies from AIMP 92901. Thus, 863B serves as an excellent source of high Fe and Zn contents in a commercial parental line.

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