two commercially released maintainer lines and a restorer line (CT Hash, ICRISAT, Patancheru, India, personal communication). Thus, if a population progeny has been found to possess excellent combination of high yield potential and agronomic traits, but is moderately susceptible to DM, within-progeny selection for DM resistance may be pursued. However, the likelihood of its effectiveness in improving the resistance to an acceptable level will depend on the genetic variability for DM resistance in the progeny.

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Evaluation of New Grain Pearl Millet Hybrids in Australia

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Introduction

Sorghum *(Sorghum bicolor)* is the predominant dryland summer crop in northern Australia, grown as a feed grain for intensive livestock industries such as poultry, cattle and pigs. However, the dryland cropping environments of central and southwestern Queensland are highly variable and characterized by unpredictable rainfall and summer temperatures (>40°C). Increasingly the feed grain industry is looking for alternative crops to spread production risks and stabilize grain supply.

Pearl millet *(Pennisetum glaucum)* is a potential new crop for the Australian grains industry; it has a short crop duration and is grown widely across the semi-arid tropics of Africa and the Indian subcontinent in environments similar to those of northern Australia. As a high-protein coarse grain, pearl millet will find its key market as an alternative feed grain to sorghum in the intensive production of monogastric animals such as poultry and pigs (Singh and Perez-Maldonado 2003). High-yielding grain pearl millets developed in India and the United States retain the grain quality and' early maturity of traditional pearl millets but are of dwarf stature and well suited to mechanized farming systems. Since these new pearl millets have been successfully produced and marketed in the United States (Andrews et al. 1995), the challenge now is to develop a grain pearl millet industry in Australia.

Materials and Methods

Hybrid seed production. Eighty-six F_1 hybrids of grain pearl millet were produced in February 2002 (32 hybrids) and September 2002 (54 hybrids) in hand-pollinated nurseries at the Queensland Department of Primary Industries and Fisheries (QDPI&F) Biloela Research Station in central Queensland (24°22' S, 150°31' E). Nine male sterile lines in the A_4 cytoplasmic male sterility system (CMS) were crossed in all combinations with nine R_4 restorer lines. Four hybrids were produced from line 59135A4 and a single hybrid (293 A5 x NM-7R 1R5) was available in the A5 CMS.

Evaluation of hybrids. Pearl millet hybrids were evaluated against four check lines; open-pollinated pearl millet breeding lines, NPM-1 (Andrews and Rajewski 1995a) and NPM-3 (Andrews and Rajewski 1995b), and two early-maturing commercial sorghum hybrids (referred to as sorghum #1 and sorghum #2). Trials were planted in September 2002 (spring) and February 2003 (autumn) at Biloela Research Station under high fertility levels (69 kg N ha^{-1} in spring, 92 kg N ha^{-1} in autumn) and with supplementary irrigation. In both trials hybrids were planted in twin-row plots of 7 m length with 1 m row spacing. Trial design was a randomized complete block design with four replications. Established plants were hand-thinned to an effective plant population of 10 plants m^2. Phenology observations were recorded every second day from flag leaf emergence; anthesis was recorded as the day on which stigmas emerged on 50% of the main tiller panicles within each plot. Trial plots were cut to 5 m length and harvested with a small plot mechanical header. Grain mass was measured as the mass of one thousand seeds from a single sample taken from each replication in the autumn trial. No replicated data on grain size was available from the spring trial.

Results and Discussion

Grain yield. Significant differences between yields of pearl millet hybrids in the spring trial (P <0.001) were due to general combining ability of female and male parents (P <0.001) (Table1). Female lines 59041wA4 (mean grain yield 3.3 t ha^{-1}) and 183A4 (mean grain yield 3.1 t ha^{-1}) produced higher yielding hybrids than other female lines (iP<0.001). Hybrids using male line 4AmRm (mean grain yield 3.2 t ha^{-1}) performed significantly better than those of other male parents *(P <0.001)*. Grain yields of some of the elite pearl millet hybrids were comparable to those of sorghum hybrids (sorghum #1 3.9 t ha^{-1} and sorghum #2 3.6 t ha^{-1}); 59041wA4 x 4AmRm was the highest yielding pearl millet and the only hybrid to yield higher than open-pollinated pearl millet checks, NPM-1 (2.91 ha^{-1}) and NPM-3 (3.21 ha^{-1}) (P<0.001).

In the autumn trial significant differences between hybrid grain yields were explained by specific combining ability (P <0.01) and the general combining ability of female and male parents (P <0.001) (Table 2). Lines 183A4 (mean grain yield 4.3 t ha^{-1}) and 59041 wA4 (mean grain yield 3.91 ha^{-1}) were the best performing females (P <0.001); 4Rm (mean grain yield 3.9 t ha^{-1}) and 4AmRm (mean grain yield 3.9 t ha^{1}) were the best performing males. Elite pearl millet hybrids such as 183A4 x 4AmRm (4.8 t ha^{-1}), 183A4 x 1056-58016R4 (4.6 t ha^{-1}), 183A4 x 9Rm4Rm (4.5 t ha^{-1}), 293A5 x NM-7R1R5 (4.3 t ha^{-1}) and 59041wA4 x 4AmRm (4.3 t ha^{-1}) were higher yielding than open-pollinated NPM-3 (3.8 t ha^{-1}), the mean millet hybrid (3.6 t ha^{-1}) and both sorghum hybrids (sorghum #1 1.4 t ha^{-1} and sorghum #2 3.3 t ha^{-1}) (P<0.001). Sorghum treatments suffered a marked yield loss due to sorghum midge *(Stenodiplosis sorghicola)* and ergot *(Claviceps africana).*

Grain size. Significant differences between grain size of pearl millet hybrids (measured as mass of one thousand seeds) was evident in the autumn trial. Differences were due to specific combining ability (P <0.001) and the general combining ability of female and male parents (P <0.001) (Table 3). Hybrids 183A4 x 4Rm (16.4 g), 59041wA4 x 4Rm (15.6 g), 68wA4 x 4Rm (15.5 g) and 68wA4 x 1056-58016R4 (15.2 g) had higher grain mass than the mean hybrid and open-pollinated pearl millets (P<0.001). Sorghum grain was two to three times heavier than pearl millet grain.

Maturity. In the spring trial pearl millet hybrids were marginally quicker to anthesis and physiological maturity

Table 1. Grain yield (t ha^{1}) of 32 hybrids of pearl millet, two open-pollinated pearl millet breeding lines and two commercial sorghum hybrids in spring 2002 yield trial in Queensland, Australia.

	Male parent				
Female parent	4AmRm	59026R4	68wR4	1163wR4	Mean (female)
59041wA4	3.8	3.3	3.4	2.9	3.3
183A4	3.4	3.3	2.9	2.8	3.1
293A4	3.5	2.9	2.4	2.5	2.8
378-2A4	3.0	2.5	2.5	2.7	2.7
59022A4	2.8	2.6	2.6	2.4	2.6
59135A4	3.2	2.4	2.5	2.3	2.6
413A4	3.1	2.5	2.3	2.5	2.6
NM-5A4	3.0	2.1	2.3	2.4	2.5
Mean (male)	3.2	2.7	2.6	2.6	2.8
Checks					
NPM-1	2.9				
NPM-3	3.2				
Sorghum #1	3.9				
Sorghum #2	3.6				
	P	LSD (P <0.05)			
Genotypes	<0.001	0.44			
Female parent	<0.001	0.22			
Male parent	<0.001	0.15			
Female parent x Male parent	0.208				
CV =11.0%					

Table 2. Grain yield (t ha^{-1}) of 86 hybrids of pearl millet, two open-pollinated pearl millet breeding lines and two commercial sorghum hybrids in autumn 2003 yield trial in Queensland, Australia.

	Male parent									Mean (female)
Female parent	4Rm	4AmRm	9Rm4Rm	1056-58016R4	1163wR4	58012R4	68wR4	86R1R4	59026R4	
183A4	4.6	4.8	4.5	4.6	4.2	4.2	3.9	4.0	3.7	4.3
59041 wA4	4.0	4.3	4.1	3.5	4.1	3.8	3.7	3.7	3.5	3.9
59135A4		3.8	-	-	3.8	-	3.6	-	3.5	3.7
293A4	4.2	3.9	3.7	3.8	3.4	3.6	3.5	3.5	3.0	3.6
NM-5A4	4.0	4.0	3.7	3.6	4.1	3.5	3.3	3.1	3.1	3.6
413A4	4.1	3.8	3.7	3.8	3.4	3.3	3.6	3.2	3.2	3.6
68wA4	3.4	3.7	3.7	3.7	3.3	3.7	3.3	3.7	3.6	3.6
378-2 A4	3.7	3.8	3.7	3.8	3.6	3.4	3.3	3.2	3.1	3.5
59022 A4	3.9	3.6	3.7	3.7	3.3	3.2	3.3	3.2	3.5	3.5
95M59668A4	3.3	3.3	3.1	2.9	2.9	2.9	2.9	2.4	3.1	3.0
Mean (male)	3.9	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.3	3.6
293A5 X NM-7R1 R5	4.3									
NPM-1	3.7									
NPM-3	3.8									
Sorghum #1	1.4									
Sorghum #2	3.3									
		P		LSD (P<0.05)						
Genotypes		<0.001		0.44						
Female parent		<0.001		0.15						
Male parent		<0.001		0.15						
Female parent x Male parent		<0.01		0.44						
CV - 8.8%										

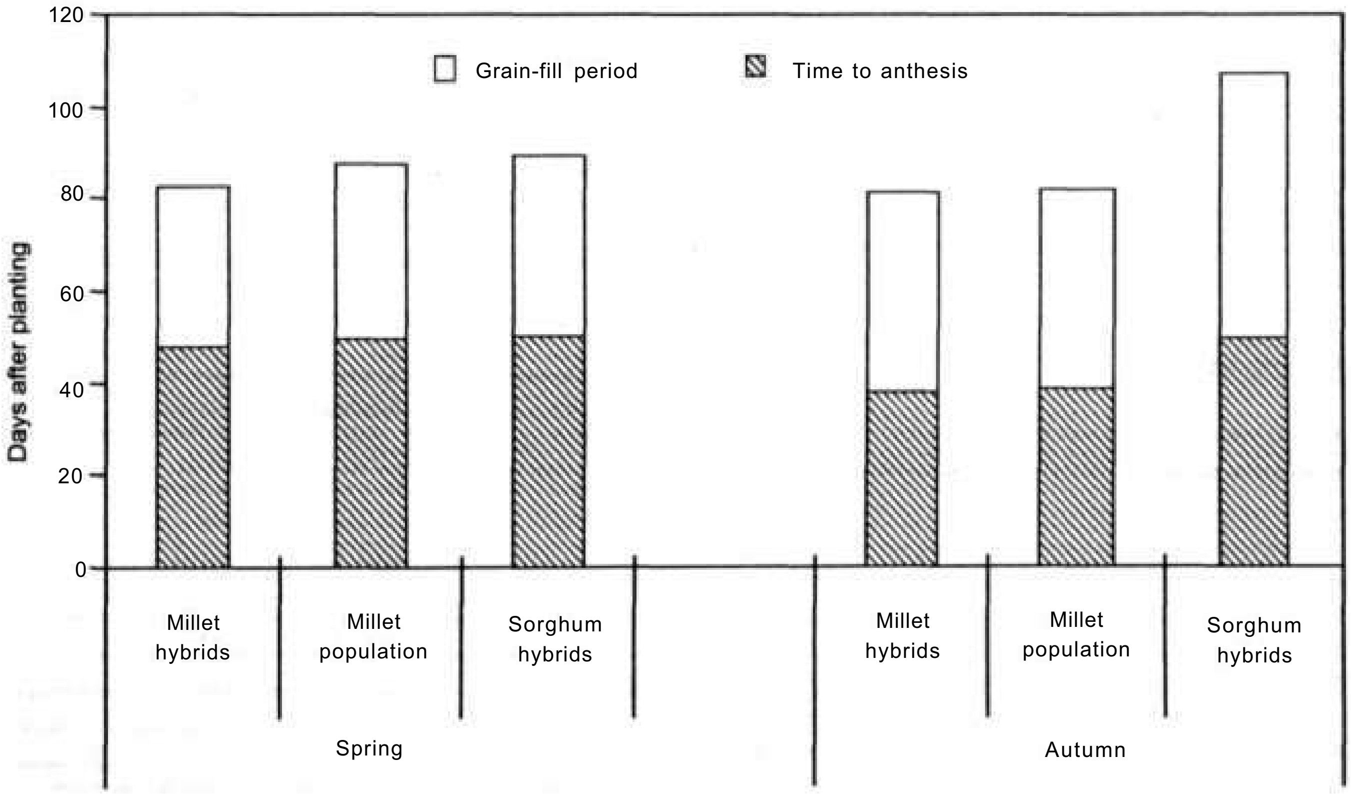

Figure 1. Phenology response of pearl millet and sorghum treatments in spring 2002 and autumn 2003 trials in Queensland, Australia.

Table 3. Mean 1000-seed mass of pearl millet and sorghum in autumn 2003 trial in Queensland, Australia.

Description		1000-seed mass (g)
Pearl millet hybrids		11.5
NPM-1		10.1
NPM-3		11.3
Sorghum #1		34.1
Sorghum #2		35.9
	P	LSD (P<0.05)
Genotypes	<0.001	1.3
Female parent	<0.001	0.4
Male parent	<0.001	0.4
Female parent x Male parent	<0.001	0.4
CV = 7.6%		

than sorghum treatments (83 days vs 87 days) (P<0.001, LSD = 3.3, CV = 2.9%) (Fig. 1). In the autumn trial pearl millet hybrids and open-pollinated lines flowered in less than 40 days and were significantly quicker maturing than sorghum hybrids (P <0.001, LSD = 1.6, CV = 2.9%). Pearl millet hybrids and open-pollinated populations were significantly quicker to physiological maturity than sorghum hybrids (82 days vs 107 days) in the autumn trial (P<0.001, LSD = 3.3, CV = 2.9%).

Accumulated thermal time to anthesis in pearl millet was 568°Cd in spring and 563°Cd in autumn (base temperature of 10°C). Physiological maturity occurred at 1135°Cd in spring and 1071°Cd in autumn. Since both experiments were conducted at daylengths close to or below the critical photoperiod of 12.9 h for pearl millet (van Oosterom et al. 2001), temperature was most likely the predominant factor in determining maturity in pearl millet.

Conclusions

In two yield trials completed in consecutive seasons at a single site, elite pearl millet hybrids produced grain yields **of up to 4.8 t ha^{-1} and took 83 days to reach physiological maturity. Yields were comparable to early-maturing grain sorghum hybrids and from an autumn planting pearl millets matured 25 days earlier than sorghums. Three parents exhibited high general combining ability for grain yield across both seasons. It is envisaged that female** lines **183A4 and 59041wA4 and male line 4AmRm will be** released to seed companies in **2004 and that** their hybrids will form the basis of a new commercial crop in Australia. Male lines such as **4Rm** and **9Rm4Rm** were evaluated in a single trial and also showed high general combining ability for grain yield; these and more recently released germplasm may warrant further research.

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