Changes in sorghum yield components after chilling

Daniel Tan[1], Alexander Wood[1], Ezaz Mamun[1], Bruce Sutton[1], Paul Castor[2]

[1] Faculty of Agriculture, Food and Natural Resources, The University of Sydney, Sydney, NSW 2006, Australia. www.usyd.edu.au Email d.tan@usyd.edu.au
[2]Michael Castor and Associates Goondiwindi Pty. Ltd., 58 Marshall Street, P.O. Box 1034, Goondiwindi, QLD 4390. Email mcagoondi@bigpond.com

Abstract

Chilling during male gametophyte development in sorghum (*Sorghum bicolor* L. Moench) inhibits development of microspores, causing male sterility. Late planted sorghum in the Liverpool Plains of Northwest New South Wales may suffer from low grain yields because the plant enters the most sensitive reproductive stage during a cooler time of the year. The aim of this study was to assess the effects of night chilling on yield components in sorghum. This study identified and employed collar distance as a morphological marker of anther development following chilling. Two cultivars Buster (Pacific Seeds, Australia) and Bonus (Pioneer Hi-Bred Australia) were subjected to 3 temperature regimes (25?C/20?C, 25?C/12?C and 25?C/8?C) for 5 consecutive nights at the pre-meiotic stage of anther development (at collar distance “0”). Pollen viability and grain number were reduced in both cultivars at 12?C and 8?C night temperatures. Total grain weight of cultivar Bonus was not reduced as much as Buster at 12?C due to Bonus’ ability to increase grain weight per panicle when grain number was low. This work further elucidates the mechanism and genetic potential of chilling-induced yield compensation for developing sorghum cultivars that are better adapted to low night temperatures.

Key Words

Sorghum; male sterility; chilling; yield components; yield compensation

Introduction

Sorghum originated in the semi-arid tropics and is generally heat and drought tolerant. However, sorghum is sensitive to chilling stress just before and during microspore mother cell meiosis. Optimum temperature for sorghum growth is 30?C, however, 13?C is the critical low temperature during reproductive development (Downes and Marshall 1971). Low night temperatures during leptotene in meiosis can adversely affect microspore development, resulting in male sterility and infertile pollen formation (Brooking 1976; 1979). However, female floral organ fertility is not affected at this temperature.

Identification of anther development using morphological markers is important for stress physiology studies in grain crops. Panicle development is related to the emergence and growth of the flag leaf sheath in sorghum. The flag sheath length has been used as a morphological marker to estimate reproductive ontogeny within the anthers (Brooking 1976). Collar distance can be used to identify anther development in the panicle in a similar method to the auricle distance in rice (Mamun *et al.* 2005a,b; Oliver *et al.* 2005). In sorghum, collar distance is the length between ultimate leaf collar and penultimate leaf collar, but there is no report of the relationship between collar distance and anther development in sorghum.

Many regions in Australia experience chilling temperatures (<13?C) during the sorghum growing season (Downes and Marshall 1971). Late planted sorghum in the Liverpool Plains, NSW may suffer from low grain yields because the plant enters the most sensitive reproductive stage during a cooler time of the year (Giblett, G. pers. comm.). The susceptibility of sorghum to chilling stress is thought by growers to be related to genotype (Giblett, G. pers. comm.). The aim of this study was to test the hypothesis that chilling during the meiotic stage reduces pollen viability, grain number and grain weight in two sorghum cultivars (Bonus and Buster). This work reports the changes in sorghum yield components in response to chilling-induced pollen sterility. The relationship of collar distance to anther developmental stage was also explored.

Methods

Morphological marker

Using field grown sorghum plants, florets of the top part of the panicle were collected from plants at different collar distances from the onset of flag leaf emergence. Anthers were dissected under a stereo microscope and stages of microspore development were identified (Orr and Sundberg 1994). The collar distance and corresponding microspore developmental stage was recorded.

Treatments

Plants of two sorghum cultivars, MR Buster (Pacific Seeds, Australia) and MR Bonus (Pioneer Hi-Bred Australia Pty Ltd) were established in a naturally lit glasshouse with the natural photoperiod extended to 16 h with incandescent lamps under an optimal temperature regime of 25?C/20?C (Brooking 1976). Water and nutrients were adequately supplied to ensure non-limiting growing conditions. The experiment had a factorial design with 2 factors. The first factor was cultivar (Buster and Bonus) and the second factor was temperature treatment [25?C/20?C (control), 25?C/12?C and 25?C/8?C (16 h day/ 8 h night) for 5 days]. Plants at the pre-meiotic stage of anther development (at collar distance “0”) were transferred into the growth cabinet at 25?C/12?C and 25?C/8?C. Plants were removed after the chilling treatment and returned to the glasshouse where they continued to develop under optimal growing temperatures of 25?C/20?C until harvest. The experimental layout was a completely randomised design with four replications, and the experiment was repeated three times (referred to as Expts. 1, 2 and 3). Since the results for Expts. 1, 2 and 3 were consistent, the pooled results were presented.

Pollen viability test

The plants progressed to anthesis approximately 2 weeks after the chilling treatment. At this stage, pollen viability of both chilling-induced and control plants was tested using 1% 2,3,5-triphenyl tetrazolium chloride (TTC) solution in 0.15 M Tris-HCl buffer, pH 7.8 (Stanley and Linskins 1974; Tan *et al.* 1999; McDowell *et al.* 2006; Wood *et al.* 2006). To stain pollen, anthers were placed on a microscope slide and apical tips of anthers were excised with a sharp razor blade under a stereo microscope. Pollen was eased out by gentle pressing of the anther and TTC solution was added to the slide. The slides were then kept in the dark for 15-20 min before examination using a compound light microscope. Viable pollen grains were stained red and non-viable pollen remained colourless. The binomial pollen viability data was analysed by binary logistic regression in Genstat[?] v8.

Harvest data

The plants were harvested when the grain had reached maturity (Daynard and Duncan 1969) at 141, 140 and 144 days after sowing for Expts 1, 2 and 3, respectively. Only the primary (main) tiller was harvested since it was not possible to get all tillers at the same stage of panicle development. Grain was removed and the number of grains per panicle was counted. Samples were dried at 78^{o}C for 7 days and then weighed, and harvest index was calculated. The harvest data were subjected to analysis of variance using Genstat[?] v8.

Results and discussion

Morphological marker

The relationship between the stages of microspore development and collar distance was linear and the coefficient of determination (R^2=0.89) suggested this to be a reliable relationship between the collar distance and stage of microspore development (Fig. 1a). Hence, a morphological marker using collar distance provided a good indication of the stage of microspore development.

Pollen viability and grain number

Pollen viability was reduced from 49% to 21% (P<0.001) when the night temperatures were at 12?C and to 16% at 8°C compared to the control in Expts. 1-3 (Table 1). Night chilling reduced pollen viability and grain number, which agrees with other research (Dhopte and Eastin 1988; Tuinstra and Wedel 2000). There was no interaction between the cultivar and chilling treatment in the grain number (P=0.227). Grain number was not further reduced (P>0.05) between the night temperatures 12?C (128 grains per panicle) and 8?C (112 grains per panicle, Table 1). Grain number decreased linearly (R^2 = 0.69) with decreasing pollen viability (data not presented).

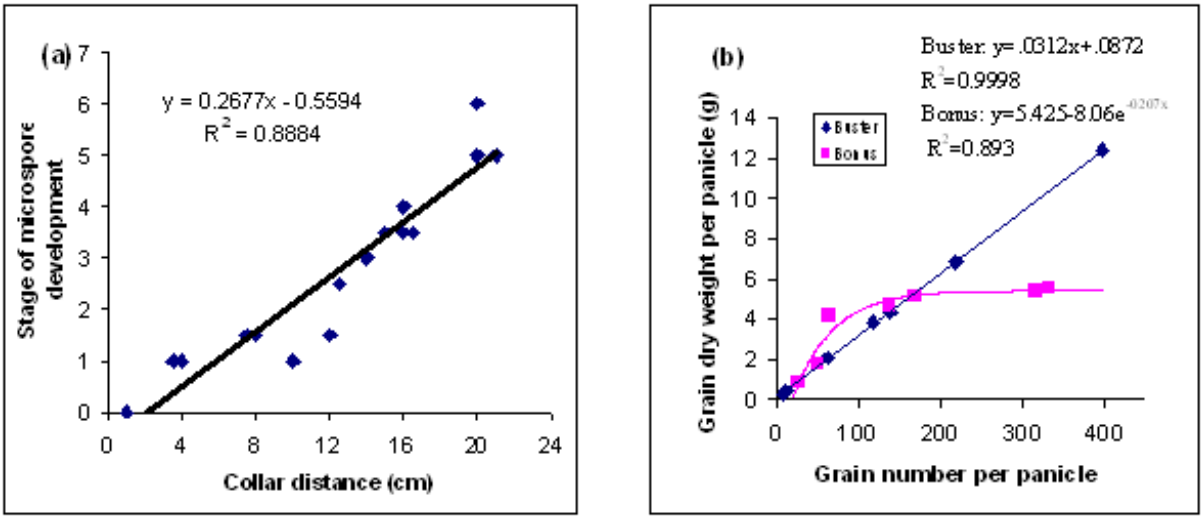

Fig. 1 (a) Relationship between stage of microspore development and collar distance. Stages of microspore development were given a value between 1 and 6 (1 = Pre-meiosis, 2 = Pollen Mother Cell, 3 = Dyad, 4 = Tetrad, 5 = Early Microspore, 6 = Microspore). (b) Relationship between grain number and grain dry weight per panicle for two cultivars (Buster and Bonus).

Table 1. Probability of pollen viability, grain number per panicle, grain weight (g) per panicle, and harvest index for all experiments (Exp 1-3) after exposure to different temperatures (8?C, 12?C & 20?C) for 5 nights.

Night temperature (?C) for 5 nights	Probability of pollen viability (%)	Grain number per panicle	Grain dry weight (g) per panicle		Harvest index	
			Bonus	Buster	Bonus	Buster
8	16	112	2.38	3.11	0.09	0.14
12	21	128	4.63	2.12	0.17	0.12
20	49	228	4.39	7.17	0.12	0.28
LSD (P=0.05)	-	67	2.21		0.06	

F-test probability	Temp *P*<0.001 Interaction n.s.	Temp *P*<0.001 Interaction n.s.	Temp x cultivar *P*<0.01	Temp x cultivar *P*<0.001

Grain dry weight

Mean grain dry weight for Buster (2.12 g per panicle) at 12?C was lower (*P*<0.01) than Bonus (4.63 g per panicle) (Table 1). However, both Bonus (2.38 g per panicle) and Buster (3.11 g per panicle) had low grain weights at the lowest night temperature (8?C). As the grain number for Buster increased, grain weight per panicle increased linearly (Fig. 1b). However, grain weight per panicle in Bonus increased exponentially initially as the grain number increased and then levelled out asymptotically (Fig. 1b). Grain dry weight of Bonus did not increase once the grain number exceeded approximately 150 per panicle. The mean dry weight in Bonus remained high when grain number was reduced below 150 per panicle due to an increase in individual grain weight. Harvest index of Buster (0.28) was higher (*P*<0.001) than Bonus (0.12) in the control. The harvest index of Bonus (0.17) was slightly higher than Buster (0.12) at 12?C showing a similar trend to grain weight per panicle.

Low night temperature is detrimental to certain yield components in sorghum (Downes and Marshall, 1971; Brooking 1979; Dhopte and Eastin 1988). The documented phenomena in most of the commercial cultivars exposed to chilling stress for several days were: decreased number of grains; reduced panicle growth and grain yield (Brooking 1979; Dhopte and Eastin 1988), but no effect on seed size or weight (Dhopte and Eastin 1988). This is similar to our results in Buster. Grain number per panicle was reduced by chilling night temperatures (12?C and 8?C) in both cultivars tested. Buster produced a higher grain weight per panicle than Bonus at 20?C, and gave a higher yield under favourable conditions. As the night temperature decreased to 12?C, there was reduced grain number for both cultivars, but Bonus produced a higher grain weight per panicle than Buster. Hence, Bonus was able to compensate yield by an increase in individual grain weight in response to chilling-induced pollen sterility.

Conclusion

An effective morphological marker using collar distance provided a good indication of microspore development in sorghum. Pollen viability and grain number were reduced in both sorghum cultivars, Bonus and Buster at 12?C and 8?C night temperatures. Total grain weight of Bonus was not reduced as much as Buster at 12?C due to Bonus' ability to increase individual grain weight when grain number was low. Grain weight increased linearly with the increased grain number per panicle in Buster, while Bonus had an exponential increase in total grain weight with increasing grain number until it reached approximately 150 grains per panicle. Above 150 grains per panicle, total grain weight plateaued in Bonus. Hence, in response to chilling-induced sterility, Bonus was able to compensate yield by increasing individual grain weight.

References

Brooking IR (1976). Male sterility in *Sorghum bicolor* (L.) Moench induced by low night temperature. I. Timing of the stage of sensitivity. *Australian Journal of Plant Physiology* **3**, 589-596.

Brooking IR (1979). Male sterility in *Sorghum bicolor* (L.) Moench induced by low night temperature. II. Genotypic differences in sensitivity. *Australian Journal of Plant Physiology* **6**, 143-147.

Daynard TB and Duncan WG (1969). The black layer and grain maturity in corn. *Crop Science* **9**, 473-476.

Dhopte AM and Eastin JD (1988). Response of sorghum to elevated night temperatures imposed during floret differentiation under field conditions. *PKV Research Journal* **12**, 18–25.

Downes RW and Marshall DR (1971). Low temperature induced male sterility in *sorghum bicolor*. *Australian Journal of Experimental Agriculture* **11**, 352-356.

Mamun EA, Cantrill LC, Overall RL, Sutton BG (2005a). Cellular organisation and differentiation of organelles in pre-meiotic rice anthers. *Cell Biology International* **29**, 792-802.

Mamun EA, Cantrill LC, Overall RL, and Sutton BG (2005b). Cellular organisation in meiotic and early post-meiotic rice anthers. *Cell Biology International* **29**, 903-913.

McDowell AJ, Bange MP, and Tan DKY (2006). Cold temperature exposure to 10°C for 10 and 20 nights does not reduce tissue viability in vegetative and early flowering cotton plants. *Australian Journal of Experimental Agriculture* **42** (in press).

Oliver SN, Van Dongen JT, Alfred SC, Mamun EA, Zhao X, Saini HS, Fernandes SF, Blanchard CL, Sutton BG, Geigenberger P, Dennis ES, Dolferus R (2005). Cold-induced repression of the rice anther-specific cell wall invertase gene *osinv4* is correlated with sucrose accumulation and pollen sterility. *Plant, Cell and Environment* **28**, 1534-1551.

Orr AR and Sundberg MD (1994). Inflorescence development in a perennial teosinte: *Zea perennis* (Poaceae). *American Journal of Botany* **81**, 598-608.

Stanley RG and Linskins HF (1974). 'Pollen Biology, Biochemistry, Management.' (Springer and Verlag: Berlin).

Tan DKY, Wearing AH, Rickert KG, Birch CJ and Joyce DC (1999). Freeze-induced reduction of broccoli yield and quality. *Australian Journal of Experimental Agriculture* **39**, 771-780.

Tuinstra MR and Wedel J (2000). Estimation of pollen viability in grain sorghum. *Crop Science* **40**, 968-977.

Wood AW, Tan DKY, Mamun EA and Sutton BG (2006). Sorghum can compensate for chilling-induced grain loss. *Journal of Agronomy and Crop Science* (in press).