Australia: New screening method for cold tolerance during the reproductive stage in rice

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Abstract

Low temperature, particularly during the reproductive stage of the development of rice, limits productivity in the Riverina region of New South Wales (NSW). This study primarily examined genotypic differences in cold damage that are associated with low temperature during reproductive development. Results from experiments in temperature-controlled rooms and the cold water facility were combined with four years of field experiments, which used natural exposure to low temperature to examine the response of over 50 cultivars from diverse origins. Plants were exposed to day/night air temperatures of 27?/13?C in temperature-controlled rooms and to a constant temperature of 19?C in the cold water facility. Low temperature treatments were imposed from panicle initiation (PI) to 50% heading. In field experiments several techniques were used to increase the likelihood of inducing cold damage such as sequential sowing dates (five to eight sowing dates each year), shallow water depths (5cm) and high nitrogen rates (e.g. 300kgN ha^{-1}). Several cultivars were identified that were more cold tolerant than Australia's commercial cultivars.

Media Summary

Three different methods have been examined for their ability to screen rice cultivars for cold tolerance during reproductive development, with exposure to cold water being recommended.

Keywords

low temperature, spikelet sterility

Introduction

Australian rice is produced under irrigated conditions in the temperate area of the Riverina in southeastern New South Wales (NSW). The Australian rice industry has the highest yield in the world (~10t ha^{-1}, IRRI 2002). This high yield reflects well adapted cultivars, mild temperatures, high solar radiation, a long growing season (October-April), absence of major pests and diseases and a rapid adoption of advanced technology. Rice crops are typically sown from early October until mid November, depending on the duration of the cultivar and the availability of irrigation water. An optimum sowing date for each cultivar ensures the young microspore stage occurs during late January to early February when the minimum temperature is historically high (~17?C). However, low night temperatures of 12?C can occur during mid-summer (Boerema 1974) and reduce rice yields. Extended low temperature in the 1995/96 season during reproductive development induced spikelet sterility, reducing industry yields by 25% to 7t ha^{-1}. Yield loss due to low temperature damage at the reproductive stage is estimated to be 1t ha^{-1} every four years and greater than 2t ha^{-1} every 10 years in Australia (Farrell *et al.* 2001).

Rice plants are susceptible to low temperature at different stages of development. Low temperature is a problem in many countries, including Australia, China, Japan, Nepal, Russia and South Korea. Cold damage in rice has been recognised in Japan for hundreds of years, but it was not until 1970 that Satake and Hayase (1970) determined that the young microspore stage is the most sensitive stage. Low temperature at this time disrupts the development of pollen grains, preventing fertilisation and hence causing higher spikelet sterility (Nishiyama 1984) and consequently lower yields (Lee 2001).

Materials and methods

Over 50 cultivars from diverse origins were examined for cold tolerance in three different screening environments at Yanco Agricultural Institute (YAI; 34?37`S, 146?25`E). The first environment was temperature-controlled rooms where cultivars were exposed to three day/night air temperature treatments of 27?/13?C, 25?/15?C and 32?/24?C from after panicle initiation to 50% heading. The second was the cold water facility (~19?C) where plants where exposed to deep cold water for a similar development period. The third environment was in the field where several techniques were used to increase the likelihood of inducing cold damage such as multiple sowing dates (five to eight sowing dates each year), shallow water depths (5cm) and high nitrogen rates (e.g. 300kgN ha^{-1}). The genotypic variation and the consistency of performance among cultivars in the different screening environments were investigated.

Results and discussion

Cold tolerant cultivars had low levels of spikelet sterility at low temperatures in the temperature-controlled rooms, the cold water facility and in the field (e.g. M103 and HSC55). Conversely, cultivars with high spikelet sterility were identified as susceptible to low temperature (e.g. Doongara and Langi). In the temperature-controlled rooms, day/night temperatures of 27/13?C and 25/15?C induced less than 20% spikelet sterility in cultivars such as M103 and HSC55. By comparison, day/night temperatures of 27/13?C and 25/15?C induced 79% and 67% spikelet sterility, in Doongara and 56% and 53% spikelet sterility in Langi, respectively. In the experiments in temperature-controlled rooms the variable and extended exposure period was not related to spikelet sterility among cultivars and hence the levels of spikelet sterility were true genotypic variation for cold tolerance. This genotypic variation for spikelet sterility that was identified in temperature-controlled rooms was confirmed in the field, with 28% spikelet sterility being induced in cultivars M103 and HSC55 when night temperatures were 14?C. By comparison, Doongara had approximately 67% spikelet sterility at 14?C.

The screening methods used in the temperature-controlled rooms, the cold water facility and the field induced sufficient levels of spikelet sterility to identify genotypic differences and consistency in cold tolerance across the different methods. Since many cultivars were common to these different screening environments the genotypic consistency of cold tolerance was also examined. There was a highly significant relationship for spikelet sterility among the common cultivars in temperature-controlled rooms versus cold water facility (r^2=0.63**, n=21), temperature-controlled rooms versus field (r^2=0.52**, n=31) and the cold water facility versus the field (r^2=0.53**, n=21). The genotypic consistency of cold tolerance appears relatively similar across the three screening environments despite the extended exposure period in the temperature-controlled rooms (32 and 24 days in experiments 1 and 2, respectively) and the cold water facility (25 and 28 days in years 3 and 4, respectively), compared to the nine-day mean minimum temperature in the field. Screening for cold tolerance in the temperature-controlled room or the cold water facility was preferred to field screening because of the improved reliability of exposure in both controlled environments. However, while there was a consistent genotypic response to low temperature in these screens, some cultivars varied in their response under the different screens suggesting that it is important to combine a controlled environment screen with field observations.

In each screening environment, several cold tolerant cultivars and susceptible cultivars were identified (Table 1). Cultivars were considered tolerant because they had less than 30% spikelet sterility in low temperature treatment whereas susceptible cultivars had more than 70% spikelet sterility.

Table 1. Origin, growth duration and level of cold tolerance of selected cultivars that were common to all three screening environments

Cultivar	Origin	Growth Duration	Level of cold tolerance
HSC55	Hungary	Short	Resistant

Hayayuki	Japan	Short	Resistant
M103	California	Medium	Resistant
Millin	Australia	Medium	Moderate
Pavlovsky	Russia	Medium	Moderate
Liman	Russia	Medium	Moderate
Sasanishiki	Japan	Medium	Susceptible
Nippon Bare	Japan	Long	Susceptible
Doongara	Australia	Long	Susceptible

The production of cold tolerant cultivars in Australia has been limited by the inability to routinely test genotypes for cold tolerance because of varying maturity. The temperature-controlled rooms and cold water facility were equally as effective in identifying field tolerance but both had several advantages and disadvantages. Given the current facilities at Yanco Agricultural Institute (YAI), the reliability and cost effectiveness of water at the desired screening temperature (19?C), the cold water facility is recommended over the temperature-controlled rooms. In addition, the cold water facility has increased potential to screen large amounts of genetic material compared to temperature-controlled rooms. Notwithstanding the good correlation between cold water and the field, there remains a need to combine screening in the cold water facility with field evaluation. In order to develop a cold water facility that can screen the number of lines required for a breeding program, three large screening tubs (diameter of 3m and depth of 0.8m) were recently developed at YAI (Figure 1). This facility has the potential to screen 400 cultivars or lines with three replications.

Figure 1. The cold water facility established at Yanco in 2003 to screen with cold water (19^{o}C) from a shallow aquifer for cold tolerance during the reproductive stage.

Conclusion

Genotypic variation for cold tolerance was identified in temperature-controlled rooms, a cold water facility and in the field. While consistent performance of cultivars across these environments has been shown, with cold water being the most effective method to induce cold damage. The cold water facility is now being used to screen diverse international cultivars and breeding lines to improve the cold tolerance of Australian commercial cultivars.

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