VARIETAL RESPONSE TO MID-SEASON COLD DAMAGE IN AUSTRALIAN RICE

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Abstract

The effect of 3 night temperatures during reproductive development on growth, harvest index (HI), percent filled grain and yield was investigated for 4 Australian rice varieties (Amaroo, Millin, Langi and Doongara). Each variety was exposed to three minimum temperatures (12, 15 and 18^{o}C) for the duration of microspore development (panicle initiation to booting), or the duration of flowering (from booting to anthesis), or both stages consecutively. Hereafter the periods during which temperature treatments were applied are referred to as microspore, flowering or the entire reproductive stage (ERS) respectively. The medium grain cultivar Millin was most tolerant to low temperatures at microspore, flowering and the entire reproductive stage, producing the greatest percent filled grains and HI. The long grain cultivar Langi was most sensitive to low temperatures when exposed for the entire reproductive stage. Cv. Doongara, another long grain cultivar, proved most sensitive to low temperatures when exposed to 15 and 18 ^{o}C night temperatures at the microspore stage. The microspore stage is known to be the most sensitive stage to low temperatures and in this experiment proved to be the most sensitive stage for both the 15 and 18^{o}C treatments. However, at 12^{o}C, exposure at the flowering stage produced a greater reduction in filled grains. An understanding of the interaction between the phenological stage when low temperatures occur and the severity of the cold event is crucial to the design of effective selection procedures for improving cold tolerance. Cold damage was not as severe in this experiment as that reported elsewhere. This may have been due to higher maximum temperatures, the buffering effect of the water covering the base of the plant, higher temperatures prior to the low temperature treatments, or water movement. The relative importance of these factors needs to be determined to further refine an effective selection protocol.

Key words: Rice; low temperature; anthesis; flowering; harvest index.

Cold damage during the reproductive phase of rice development limits NSW rice yields in most years (1). Average rice yields in 1996 were 25 % lower than the previous year, due to low temperatures (4^{o}C below normal) during pollen development. Although the current rice breeding and agronomy programs have developed cultivars and strategies that minimise the effect of cold damage, average losses due to low temperature over the last 10 years are estimated to be 2.2 t/ha. This corresponds to an average loss of $44M farm gate income.

Routine screening for cold tolerance is required for the development of cold tolerant genotypes, and novel management options for minimising cold damage. This experiment investigates the interaction of night temperature and stage of exposure on the relative performance of 4 Australian rice varieties.

Materials and methods

The experiment was carried out from Jan 2 1997 to mid April 1997. Eighty pots of 4 varieties (Amaroo, Langi, Doongara and Millin) were established in a day/night temperature regime of 30/20 ^{o}C. Plants were established by watering free draining soil until the 3 leaf stage from when the plants were permanently flooded.? 75 kg N/ha as urea was applied to the soil surface prior to flooding.

Plants were exposed to three night temperature treat-ments (12, 15 and 18^{o}C) during either the microspore development stage (from panicle initiation until boot-ing), the flowering stage (from booting until anthesis), or for the entire reproductive stage (both stages consecutively). All treatments had a day temperature of 30^{o}C, with approximately 12 hr periods of day and night temperature. Eight pots of each cultivar were included in each combination of minimum temperature and stage of exposure. During the low temperature treatment pots were moved daily to minimise positional effects within the controlled

environment rooms. Water from each controlled environment room and each tub within the room was drained to a common sump, and redistributed continuously. Thus plants within each temperature treatment were exposed to a similar water temperature. Following the temperature treatment plants were exposed to 20/30^{o} C until physiological maturity, when plants within each pot were assessed for the percentage of filled grain, above ground biomass, panicle weight and harvest index (HI). Analyses of variance were conducted within each temperature treatment, and across all temperature treatments using weighted means as the low temperature treatment which had a greater variance than the other two treatments.

Results and discussion

Stage of exposure

Table 1. Effect of timing of 12, 15 and 18°C night temperatures on total weight, panicle weight, percent filled grain and harvest index for all varieties combined.

Timing	Night Temperature (°C)	Total weight (g/pot)	Panicle wt (g/pot)	Filled grain (%)	Harvest Index (%)
Microspore	18	35.3	17.5	92.1	52.9 b
Flowering	18	36.8	17.7	91.3	54.5 a
All	18	35.8	17.5	91.3	53.3 b
LSD (p<0.05)		ns	ns	ns	1.2
Microspore	15	36.5	16.6 b	89.3 a	50.3 b
Flowering	15	38.8	18.1 a	86.5 b	51.6 a
All	15	33.4	15.0 c	85.8 b	47.9 c
LSD (p<0.05)		ns	1.4	2.5	1.3
Microspore	12	34.7	15.0 a	89.4 a	46.2 a
Flowering	12	37.6	14.8 a	61.1 b	42.9 b
All	12	32.0	9.3 b	52.3 c	31.1 c
LSD (p<0.05)		ns	1.3	4.3	2.1

Total plant weight per pot was not affected by exposure to low night temperatures. Panicle weight, harvest index and percent filled grain were significantly affected by exposure to low temperatures during reproductive development, generally declining with lower night temperatures (Table 1). Exposure to 18^{o}C night temperatures during the microspore stage or for the entire reproductive stage resulted in a slightly lower harvest index (1.5%) than when exposure was limited to the flowering stage (Table 1). However, there were no significant differences in panicle weight or percentage of filled grain for any stage of exposure.

At 15^{o}C the greatest reduction in HI and panicle weight resulted from exposure during the entire reproductive stage, with significantly greater HI and panicle weights when treatment was limited to the microspore stage. Treatment at the flowering stage resulted in the highest values for each of these characters. Surprisingly, the percentage filled grain was greatest when low minimum temperatures were confined to the microspore stage, while treatment during flowering or for the reproductive stage resulted in a lower proportion of filled grains.

Similarly, exposure to 12^{o}C for the entire reproduct-ive stage affected HI and the percentage of filled grain more than exposure during the microspore and flower-ing stages. Again, contrary to expectations, exposure during flowering had a greater effect on HI and the percentage of filled grain than exposure at the micro-spore stage.

Exposure to 12^{o}C for the flowering or reproductive stages resulted in much lower HI and filled grains than exposure to 15^{o}C. At the microspore stage, the 12^{o}C treatment did not have a greater effect on the percentage of filled grains than the 15^{o}C treatment, however the 12^{o}C minimum did reduce HI by a significant, but relatively minor amount.

Varietal response

Table 2. Maximum harvest index and percent filled grain for 4 rice varieties with an 18ºC night temperature.

	Maximum Harvest Index	Maximum Filled Grain (%)
Amaroo	0.54	98.8
Doongara	0.56	93.4
Langi	0.54	79.5
Millin	0.58	96.9
LSD (P<0.05)	0.015	2.2

Table 3. Reduction of harvest index and percent filled grain for 4 rice varieties at a night temperature of 18ºC.

	Harvest index loss			Percent filled grain loss		
	Flowering	Microspore	Reproductive	Flowering	Microspore	Reproductive
Amaroo	0.000	0.015	0.025	1.0	0.0	1.0
Doongara	0.000	0.038	0.033	2.9	3.0	0.0
Langi	0.000	0.019	0.014	3.9	0.0	9.6
Millin	0.015	0.00	0.027	1.4	0.0	0.4
LSD (P<0.05)		0.026			4.0	

Varieties responded differently to the three temperat-ure treatments and to the stages at which they were exposed to low temperatures. Treatment effects for each variety are expressed as a reduction from the maximum values observed in any 18^{o}C sub treatment. In most cases maximum values occurred in the flowering treat-ment, however for Millin maximum HI occurred in the microspore treatment. Similarly the maximum proport-ion of filled grains occurred in the 18^{o}C microspore treatment for the varieties Amaroo, Langi and Millin, and in the 18^{o}C reproductive stage treatment for Langi. The long grain varieties, Doongara and Langi, had a lower maximum percentage of filled grains than the medium grain varieties Amaroo and Millin. The shorter duration type, Millin, had the greatest HI of all the varieties (Table 2).

At 18^{o}C there were no significant differences in HI between exposure at microspore or the reproductive stage for Amaroo, Doongara and Langi, and no differ-ence between exposure at the flowering or reproductive stage for Millin. There was a significant reduction in the percentage of filled grains of Langi when exposed to 18^{o}C for the entire reproductive stage compared to exposure at flowering or to microspore only (Table 3). The remaining varieties responded similarly to exposure at all stages.

Table 4. Reduction of harvest index and percent filled grain for 4 rice varieties at a night temperature of 15ºC.

	Harvest index loss			Percent filled grain loss		
	Flowering	Microspore	Reproductive	Flowering	Microspore	Reproductive
Amaroo	0.042	0.022	0.039	6.7	6.8	2.0
Doongara	0.027	0.064	0.076	10.9	9.6	8.2
Langi	0.021	0.048	0.082	2.2	4.1	20.3
Millin	0.000	0.070	0.050	7.5	0.0	2.2
LSD (P<0.05)	0.030			5.5		

In the 15^{o}C treatment the HI of Amaroo was affected similarly by exposure at each stage while Millin and Doongara were most affected by exposure at microspore or the whole reproductive stage (Table 4). Exposure at flowering and microspore had a similar effect on Langi, but when exposed at the reproductive stage HI was significantly reduced. Langi had a dramatic reduction in proportion of filled grains when exposed to 15^{o}C for the reproductive stage, while Millin proved most sensitive at flowering, and was less affected when exposed for the entire reproductive stage.

Table 5. Reduction of harvest index and percent filled grain for 4 rice varieties at a night temperature of 12ºC.

	Harvest index loss			Percent filled grain loss		
	Flowering	Microspore	Reproductive	Flowering	Microspore	Reproductive
Amaroo	0.201	0.090	0.244	50.8	0.4	47.0
Doongara	0.124	0.115	0.268	35.6	4.0	52.6
Langi	0.158	0.058	0.360	40.5	1.6	64.0
Millin	0.013	0.104	0.121	5.8	5.5	9.4
LSD (P<0.05)	0.045			9.8		

When exposed to minimum temperatures of 12^{o}C, Amaroo and Langi suffered the greatest reduction in HI when exposed during the whole reproductive stage, and were least affected when exposed at the microspore stage (Table 5). Treatment at flowering produced an intermediate response. Similarly Doongara and Millin had the greatest reduction in HI in the reproductive stage treatment, but for Langi treatment at the microspore and flowering stages had a similar effect on HI. In contrast, 12^{o}C at flowering had little effect on the HI of Millin while treatment at microspore and the reproductive stages reduced HI to a similar degree. A minimum of 12oC at microspore had a smaller effect on the percent-age of filled grains than treatment at flowering or the reproductive stage. Millin had a much smaller reduction in filled grain than the other varieties.

Timing of treatment

Lower HI in the microspore treatment compared to the flowering treatment at 18 and 15oC shows that harvest index is more sensitive at microspore develop-ment compared to flowering. This also confirms that the threshold for damage at the microspore stage (18oC) is higher than at flowering in the sensitive varieties.

Higher HI in the 12oC microspore treatment compar-ed to the flowering treatment are in contrast to the other 2 temperatures and previous research experience where microspore development is more sensitive to low temperatures than flowering. This observation suggests that factors other than night air temperature are affecting cold damage at the microspore development stage, whereas night temperature is likely to be responsible for lower HI at flowering.

Water and air temperature

Water circulation between the three temperature treatments resulted in similar water temperatures across all treatments. Average water night temperature was 20oC in the 18oC treatment, 19oC in the 15oC treatment and 18.5oC in the 12oC treatment. Minimum water temperatures were therefore much higher than could be expected in the absence of water circulation. It is suggested that this contributed to the lower levels of cold damage in the 12oC treatment.

This suggests that the choice of maximum temperat-ure in future low temperature screening is important, not only because of any direct effect that maximum temperatures may have, but also the indirect effect of raising minimum water temperatures. We recommend that water temperatures be routinely measured in future cold damage research.

Extent of damage

This experiment produced much lower levels of damage than expected from previous experimentation. Previous research by L. Lewin (*pers. com.*) showed percent filled grain of Amaroo reduced to 32% when exposed to 25oC day and 14oC night temperature for the full reproductive phase. This was observed in 3 independent experiments. This level of filled grain is much lower than the 97 and 48% filled grain observed in the present trial when exposed to night temperatures of 15 and 12oC, respectively.

The reasons for the low level of damage in this experiment are unclear, but there are a number of poss-ibilities. The current research differed from previous research in maximum temperature, rotation and height of the tubs within the room, pre-treatment temperatures and water circulation.

It is not expected that maximum temperature would have a direct effect on the levels of cold damage on rice as it is the low temperatures that cause the damage. There is a possibility however, that damage to the developing anthers could be repaired or minimised during the higher day temperatures. It is more likely that high day temperatures maintain a higher water temperature during the night, thereby reducing cold damage, if the effect of temperature is mediated by the basal parts of the plant.

Flood water in this experiment was continually flow-ing at all times in contrast to previous experiments. Water movement could be implicated in increasing cold tolerance of rice. In severely cold affected rice crops, the outer 5 m is less affected than the remainder of the crop. This increased tolerance at the edge of the crop could be due to slightly warmer temperatures near the levee, or could be related to the movement of water, which would be greater around the perimeter of the crop. The effect of water movement on cold tolerance requires further investigation.

Variety screening

Table 6. Rank order of the 4 genotypes tested when evaluated at 2 minimum temperatures, 3 durations and for the loss of harvest index (HI) and percent filled grain compared to the maximum observed in this trial (Varieties followed by the same letter are not significantly different).

				Rank Order		
Night temp.	Duration	Character	1	2	3	4
15	Mic	HI	Amaroo (a)	Langi (ab)	Doongara (b)	Millin (b)
15	Mic	Filled Grain (%)	Millin (a)	Langi (ab)	Amaroo (bc)	Doongara (c)
15	Flowering	HI	Millin (a)	Langi (a)	Doongara (a)	Amaroo (a)
15	Flowering	Filled Grain (%)	Langi (a)	Amaroo (ab)	Millin (ab)	Doongara (b)
15	All	HI	Amaroo (a)	Millin (ab)	Doongara (b)	Langi (c)
15	All	Filled Grain (%)	Amaroo (a)	Millin (ab)	Doongara (b)	Langi (c)
12	Mic	HI	Langi (a)	Millin (ab)	Amaroo (ab)	Doongara (b)
12	Mic	Filled Grain (%)	Amaroo (a)	Langi (a)	Doongara (a)	Millin (a)
12	Flowering	HI	Millin (a)	Doongara (b)	Langi (b)	Amaroo (c)
12	Flowering	Filled Grain (%)	Millin (a)	Doongara (b)	Langi (bc)	Amaroo (c)
12	All	HI	Millin (a)	Amaroo (b)	Doongara (b)	Langi (c)
12	All	Filled Grain (%)	Millin (a)	Amaroo (b)	Doongara (b)	Langi (c)

The complexity of screening for cold tolerance is clearly shown in this trial. The rank order of performance on the varieties can change dramatically as the minimum temperature, duration of treatment, and character are varied (Table 6).

Millin generally performed well at all temperatures and stages of exposure. In all but one combination (15oC, during microspore development) Millin ranked the best or equal best for all stages. Millin was the most cold tolerant variety tested in the experiment.

Langi had significantly more damage than any other variety when exposed to 15 or 12oC night temperature for the full duration of reproductive development. However, it performed better than Amaroo at 12oC night temperature during flowering.

Evidence from this trial shows that Millin is more cold tolerant than the industry standard Amaroo, and therefore there is opportunity to improve cold tolerance of future varieties. The poor performance of Langi when exposed to low temperatures for the entire reproductive phase as opposed to exposure at microspore or flower-ing, indicate there are a number of mechanisms influencing cold tolerance. This

raises the possibility of pyramiding the appropriate genes to substantially increase cold tolerance in the Australian rice industry.

The low levels of cold damage experienced in this experiment highlight the lack of understanding of the mechanism leading to mid season cold damage in rice. The superior performance of the short season variety Millin demonstrates the potential for increasing cold tolerance of other varieties. The challenge is to incor-porate this level of tolerance into varieties of all classes and maturity groups of Australian rice.

References

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