Cold tolerance of rice cultivars at the booting stage can be improved by high water temperature during vegetative growth

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Abstract

Cold tolerance as indicated by floral sterility induced by low temperature at the booting stage in rice can be influenced by environment during vegetative growth. In the present study, a pot experiment showed that cold tolerance of a weakly tolerant japonica cultivar ‘Sasanishiki’ grown under high water temperature (Tw) during vegetative growth became stronger than that of a strongly tolerant japonica cultivar ‘Hitomebore’ grown under low Tw. A field experiment using four japonica rice cultivars varying in cold tolerance and maturity group was conducted on two paddy fields screening for cold tolerance at Miyagi and Aomori Prefectural Agricultural Research Stations. Rice cultivars were grown under two levels of Tw during vegetative growth, one warmed (high Tw), and another not warmed (normal Tw), and they were tested their cold tolerance at the booting stage. The field trial also showed that the reproductive cold tolerance of all cultivars under high Tw during vegetative growth was stronger than that under normal Tw. The present study demonstrated that Tw management during vegetative growth, in addition to during reproductive growth can improve cold tolerance at the booting stage of rice.

Key Words

cold tolerance, rice, spikelet sterility, yield

Introduction

Spikelet sterility induced by low temperatures during the reproductive growth phase, especially during the booting stage, has one of the strongest impacts on rice production in areas with a cool climate in the world. Low temperatures during this stage disrupt proper pollen development, leading to a shortage of sound pollen at the flowering stage (Satake 1976; Farrel et al. 2006) and severe yield losses (Shimono et al. 2002).

The level of cold tolerance in rice is under genetic control, with wide varietal differences.. However, the cold tolerance of a cultivar is also strongly affected by management practices, and especially by water management. Recently, we found in pot experiments that the temperatures experienced during vegetative growth, even before panicle initiation, especially for water temperature (Tw), can affect the cold tolerance of rice (Shimono et al. 2007; Shimono and Kanda 2009). However, these studies used a single cultivar, and we obtained no information on genotypic variation in cold tolerance as a function Tw during vegetative growth. In addition, the results were obtained from pot experiments. These conditions differ from those in a field environment, and might have produced different results due to root-zone restriction (Zhang et al. 2001) and differences in root-zone temperature (Gunawardena et al. 2003). To provide the missing information, we examined the genotypic variations in cold tolerance of rice during reproductive growth as a function of Tw during the vegetative growth phase in both pot and field environments.

Methods

Pot experiment

Two japonica medium-maturity rice cultivars differing in cold tolerance were used. These were ‘Hitomebore’ (strong cold tolerance, rank 6, where a higher number from 1 to 6 indicates greater tolarance) and ‘Sasanishiki’ (weak cold tolerance, rank 2). Seedlings were transplanted on 14-May 2009 in a 1/5000a wagner pot (diameter 16 cm, height 20 cm) filled with commercial soil (9 plants per pot) in a sunlit greenhouse at Iwate University, Morioka, Japan. They were grown in tubs placed in the open at two levels of Tw: control (19?C) and high Tw (30?C), maintained until panicle initiation. Tw in the tubs was controlled with a thermostat, coils of cold water and heaters. The pots were randomly placed in each tub and rotated once a week. After panicle initiation of rice cultivars at each level of Tw, the plants were tested for cold tolerance during reproductive growth by immersing the pots in 30 cm-deep water in Tw-controlled tub at 19.1?0.05?C (standard deviation) until mid-grain filling. The method for testing cold tolerance is referred to in a previous study (Shimono et al. 2007). Two pots per each temperature during the vegetative growth (18 plants) for ‘Hitomebore’ and one pot per temperature (9 plants) for ‘Sasanishiki’ were tested.

Date of panicle initiation (defined as the timing when the panicle length reached at 1.0 mm from a destructive sampling for 1~2 plant per each Tw and cultivar) and heading (defined as the timing when more than one spikelet emerged from leaf-sheath) was determined. At the harvest, total spikelet number per panicle and spikelet sterility of a panicle (the percentage of number of sterile spikelets per total spikelets) was measured. Sterile spikelets were carefully identified by backlighting the heads with fluorescent lightbulbs; spikelets that showed no shadowy area (i.e. no developing embryo or grain) were considered to be sterile. Tw at the soil surface and Ta at 1.5m in height with aspirated air were measured by thermo sensor.

Field experiment

Effects of high Tw during vegetative growth on the cold tolerance during reproductive growth were evaluated in cold-tolerance screening fields in two locations: Miyagi Prefecture (Furukawa Agricultural Research Station) and Aomori Prefecture (Fujisaka Agricultural Research Station). The experiment used four cultivars; two early-maturing cultivars with differing cold tolerance ratings: ‘Kakehashi’ (strong tolerance, rank 5) and ‘Mutsuhomare’ (weak tolerance rank, 3) and two medium-mature cultivars with differing cold tolerance: ‘Hitomebore’ (strong tolerance, rank 6, as used for the pot experiment) and ‘Akitakomachi’ (weak tolerance, rank 3). Seedlings of all cultivars, raised in a glasshouse in Iwate University, were transplanted in the paddies in Miyagi Prefecture on 21-May, 2008, and in Aomori Prefecture on 20-May, 2008 at 34.7 plants m^{-2}. In each site, two plots surrounded by plastic board (1 m ? 1 m) were set at the identical distance from the inlet of cold irrigation water to minimize the variations of Tw. One plot (warm-Tw plot) was constantly irrigated with water warmed by water-proofed electric heater from transplanting to 2-July (Miyagi Prefecture) and 6-July (Aomori Prefecture), and the control plot was not warmed. The warm-Tw treatments increased Tw by 3.9?C from 20.5?C for control-Tw in Miyagi Prefecture and 2.2?C from 19.7?C in Aomori Prefecture.

After early July (3-July at Miyagi Prefecture and 7-July at Aomori Prefecture), cool irrigation treatment with deep (30cm) water was conducted for inducing spikelet sterility. In the present study, at the booting stage (15 day before heading to 5 days before heading), the Tw for cultivars was mostly kept at 19.0?C in Miyagi Prefecture and at 19.8?C in Aomori Prefecture for six out of eight cases (2 locations ? 4 cultivars). However, this varied for two cases - the medium maturity cultivars in Aomori Prefecture. where the control- Tw plot suffered 0.5?C lower Tw at the booting stage for ‘Akitakomachi’ than for the high-Tw plot, and 1.6?C lower Tw for ‘Hitomebore’.

Heading date (50% of tillers of all plants were headed) and leaf number on the main stem was measured. At harvest, panicle height, panicle number per plant (excluding late headed panicles), total spikelet number per panicle and spikelet sterility (the percentage of number of sterile spikelets per total spikelets). Measurement was conducted on four of the eight plants per treatment and cultivar to minimize border effects.

Results and discussion

Pot experiment

Spikelet sterility induced by low temperature during reproductive growth was higher for the cultivar 'Sasanishiki' than the cultivar 'Hitomebore' when compared at identical Tw during vegetative growth (Fig. 1), corresponding with the cold tolerance rank. For both cultivars, high Tw during vegetative growth significantly decreased the spikelet sterility. Therefore, the sterility of cultivar 'Sasanishiki' grown under high Tw during vegetative growth (45%) was lower than that of cultivar 'Hitomebore' grown under control Tw during vegetative growth (57%). Note that without low temperature treatment during reproductive growth, spikelet sterility was not induced by any Tw during vegetative growth *per se*, less than 10 % points.

Field experiment

High Tw during vegetative growth decreased the spikelet sterility for all cultivars and for both prefectures (Fig. 2). Between locations, the sterility was higher for Aomori Prefecture, (ranging from 58% to 93%), than Miaygi Prefecture (38% to 87%) even though the Tw at the booting stage was lower for Miyagi Prefecture than Aomori Prefecture. This difference in sterility might be explained by the 0.5?C higher Tw

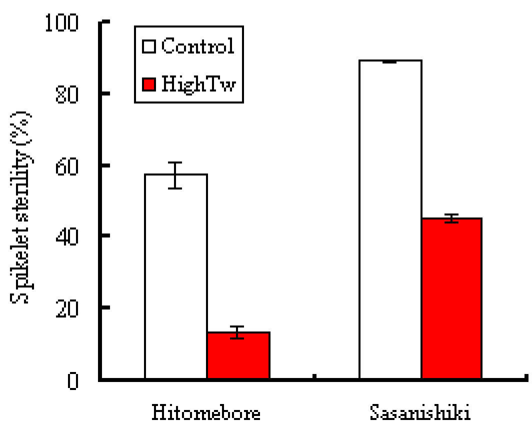

Figure 1. Spikelet sterility of two rice cultivars affected by water temperautre during vegetative growth in the pot experiment. Cold tolerance rank; Hitomebre, 6; Sasanishiki, 2. Vertical bars indicate standard error (n = 16-18 for Hitomebore, n = 5-16 for Sasanishiki).

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vegetative growth.

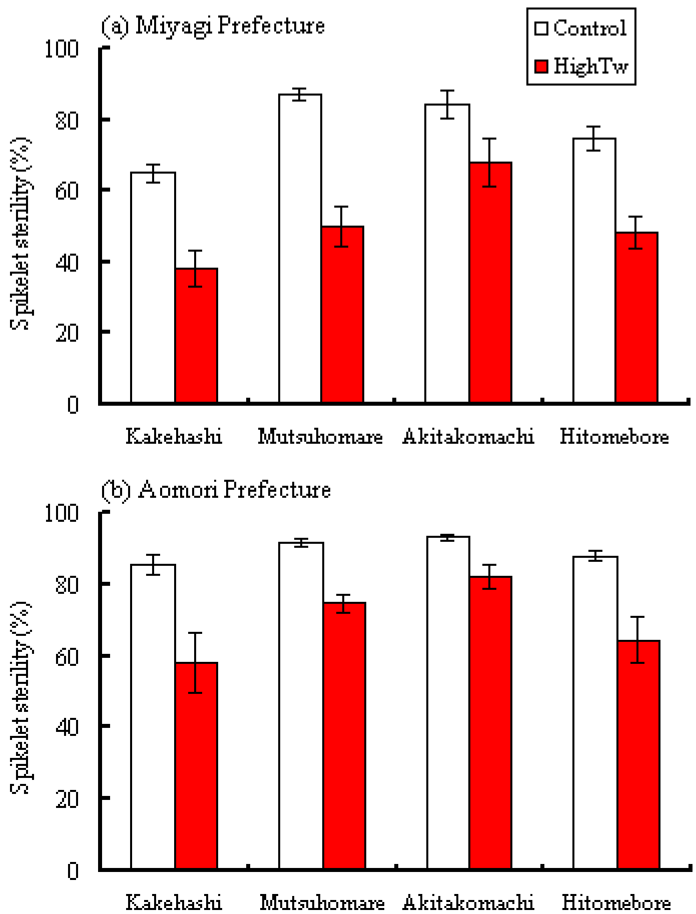

Figure 2. Spikelet sterility of four rice cultivars under different water temperature during vegetative growth at two locations in the field experiment. Cold tolerance rank; Kakehashi, 5, Mutsuhomare, 3; Akitakomachi, 3; Hitomebre, 6). Vertical bars indicate standard error (n = 4).

Conclusion

The present pot and field experiment revealed that high water temperature before panicle initiation (i.e. vegetative growth) significantly decreased spikelet sterility induced by low temperature during reproductive growth over all tested cultivars. Water management during this stage has the potential to improve cold tolerance at the reproductive stage in rice.

References

Farrell TC, Fox KM, Williams RL and, Fukai S (2006). Genotypic variation for cold tolerance during reproductive development in rice: Screening with cold air and cold water. Field Crops Research 98, 178-194.

Gunawardena TA, Fukai S and Blamey FPC (2003). Low temperature induced spikelet sterility in rice. II. Effects of panicle and root temperatures. Australian Journal of Agricultural Research 54, 947-956.

Satake T (1976). Determination of the most sensitive stage to sterile-type cool injury in rice plants. Research. Bulletin of the Hokkaido National Agricultural Experimental Station 113, 1-44.

Shimono H, Hasegawa T and Iwama K (2002) Response of growth and grain yield in paddy rice to cool water at different growth stages. Field Crops Research 73, 67-79.

Shimono H and Kanda E (2008). Does regional temperature difference before the panicle initiation affect the tolerance for low temperature-induced sterility in rice? Plant Production Science 11, 430-433.

Shimono H, Okada M, Kanda E and Arakawa I (2007). Low temperature-induced sterility in rice: Evidence for the effects of temperature before panicle initiation. Field Crops Research 101, 221-231.

Zhang Z, Nakamura T and Nishiyama I (2001) Effects of the amount and activity of roots on the cool-weather resistance in rice plants. Japanese Journal of Crop Science 70, 84-91 (in Japanese with English abstract).