The Effect of High-Temperature Stress Applied to the Root on Grain Quality of Rice

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Abstract: We verified the effect of high-temperature stress applied to the root on the occurrence of white immature kernels (WIKs) in order to breed rice (Oryza sativa L.) cultivars tolerant to the high temperature during the ripening period. The plants were grown in control and warmed pools after the heading date. The WIK percentages in the warmed pool were higher than those in the control pool. This suggests that high-temperature stress applied to the root increases the occurrence of WIKs. On the other hand, the WIK percentages correlated positively and significantly with the 1000 kernel weight and kernel width, suggesting that rice cultivars with high-temperature tolerance might have a smaller and/or thinner grain.

Key words: Grain quality, High-temperature tolerance, 1000 kernel weight, Kernel width, Rice, Root, White immature kernel.

The rise in summer temperatures in Japan in recent years appears to be increasing the occurrence of injury to rice (Oryza sativa L.) grain. A high temperature during the rice ripening period reduces the accumulation of starch in the grain, thus increasing the occurrence of white immature kernels (WIKs) and decreasing grain quality (Nagato and Ebata, 1960; Tashiro and Wardlaw, 1991). WIK occurrence is greatly influenced by temperature during the 20 days after heading; it increases drastically when the average air temperature during this period is above 26 to 27°C (Terashima et al., 2001; Wakamatsu et al., 2007). The decrease in grain quality lowers the commercial value of rice, resulting in an economic loss to rice producers all over Japan. Therefore, it is important to breed rice cultivars having high tolerance to high temperature. The degree of the occurrence of WIK varies widely with the cultivar (Nagato and Ebata, 1965; Iida et al., 2002) and is genetically determined (Tabata et al., 2005). Therefore, it is possible to breed rice cultivars with high-temperature tolerance.

In the breeding of such cultivars, grain quality under high-temperature stress should be an index of selection. Generally, air temperature around the panicles is increased to examine the high temperature effect. For example, “Tentakaku” (Yamaguchi et al., 2006), “Akisakari” (Tomita et al., 2009) and “Nikomaru” (Sakai et al., 2010) have been bred by using a vinyl coating and climate chamber, a greenhouse, and a shield tunnel, respectively. In these examples, however, the necessary equipment is large and the care and maintenance require much labor, and the load becomes larger as the size of the equipment increases. Moreover, if the temperature during the ripening period is low, the occurrence of WIK may be rare making it difficult to evaluate high-temperature tolerance.

On the other hand, there are few reports about the effect of high-temperature stress applied to plant parts, other than the panicle, on grain quality. Morita et al. (2004) reported that the occurrence of WIK could not be influenced by high-temperature stress applied to leaves and stems. Hoshi et al. (2002) and Wada et al. (2010) have bred a cultivar with high-temperature tolerance, “Koshiibuki” and “Genkitsukushi”, through selection by hot water irrigation and warm water treatment, respectively. However, the decrease in grain quality due to these treatments is attributable to the rise in air temperature around the panicle (Kasaneyama et al., 1999; Tsubone et al., 2008), so the effect of the warming of root is unknown. Therefore, the effect of high-temperature stress applied only to the root on grain quality is obscure at the moment.

In the present study, we examined the effect of high-temperature stress applied to the root on grain quality of rice. The plants were grown in control and warmed pools after the heading date. The WIK percentages in the warmed pool were higher than those in the control pool. This suggests that high-temperature stress applied to the root increases the occurrence of WIKs. On the other hand, the WIK percentages correlated positively and significantly with the 1000 kernel weight and kernel width, suggesting that rice cultivars with high-temperature tolerance might have a smaller and/or thinner grain.

Abbreviations: HWG, high white immature kernel percentage group; LWG, low white immature kernel percentage group; WIK, white immature kernel.
temperature stress applied only to the root by using a warmed pool, and investigated the relationship between the occurrence of WIK and several kernel traits.

Materials and Methods

Twenty-one lines bred at the National Agricultural Research Center and seven cultivars were used in the present study. Seeds were sown on April 21, and the seedlings were transplanted to a paddy field at the National Agricultural Research Center, Joetsu, Niigata, Japan (37°6′59″N, 138°16′14″E) on May 19, 2010. Compound fertilizer was incorporated into the soil at the rates of 4 g m⁻² each of N, P₂O₅, and K₂O, respectively, just before transplanting. The plants were then transplanted to 50⁻¹ m⁰² Wagner pots on June 18, and cultivated hydroponically. All plants grew well until heading. After the heading date, the plants were transplanted to a control pool (26 to 27°C) or a warmed pool (32 to 33°C). The temperature was controlled by water-flowing and electric heater, respectively. Air and water temperatures were measured with an Ondotori Jr. thermometer (model RTR-52A; T&D Corporation, Nagano, Japan), every 10 minutes. Air temperature was measured at a height of 75 cm above the ground to estimate temperatures around the panicles. The panicles were harvested 40 days after heading and the grain was investigated.

The percentage of WIK, 1000 kernel weight, kernel length, kernel width and kernel thickness were measured with a grain quality inspector (model RGQI20A; Satake Corporation, Hiroshima, Japan). The percentage of WIK was defined as the sum of the percentages of milky-white, basal-white, white-back and white-belly immature kernels, which were calculated based on the number. The data on the percentage of WIK was transformed by \( p' = \arcsin(\sqrt{p}) \), where \( p \) is the incidence in each individual, to normalize the variance.

Results and Discussion

1. The effect of high-temperature stress applied to the root on the occurrence of WIK

Fig. 1 shows the simple moving average temperatures during 20 days. The air temperature around the panicles in the two pools was similar.

The percentages of WIK of all lines and cultivars in both pools are shown in Fig. 2. The lines and cultivars were divided into two groups from the percentages of WIK in the control pool; the low WIK percentage group (LWG) with 30.5% or fewer, and high WIK percentage group (HWG) was over 30.5%, respectively. The percentage of WIK in both pools showed a significant positive correlation. In HWG, the percentage of WIK increased in many lines and varieties in the warmed pool (Fig. 3). Several
representative lines and cultivars were shown in Fig. 2.

The averages and variances of the percentages of WIK and result of ANOVA are shown in Table 1. There was no significant interaction between lines or cultivars and water temperature, suggesting that the order of the lines and cultivars in their WIK percentage could not be changed by high-temperature stress applied to the root. The variance of WIK percentage in the warmed pool was significantly greater than that in the control pool, while there were no significant differences in the average WIK percentages among all lines or varieties and LWG. However, in HWG, the average WIK percentage in the warmed pool was significantly higher than that in the control pool.

The above results suggest that high-temperature stress applied only to the root could increase the occurrence of WIK; high-temperature stress applied to the root causes WIK to more frequently in lines and cultivars, which show a higher WIK percentage in unwarmed water. Under high-temperature conditions during the ripening period, the shortage of carbohydrates due to the rapid growth of kernels causes a deficiency in starch accumulation and an increase in WIK (Kobata et al., 2004). The occurrence of WIK has been reported to be related to the ability to synthesize starch and to transport sugar (Hirano and Sano, 2000; Umemoto and Terashima, 2002; Jiang et al., 2003; Yamakawa et al., 2007). On the other hand, in the experiment in the open air, it is difficult to correlate the occurrence of WIK to climatic change (Ishizaki, 2006). Thus, although more data is needed, the application of high-temperature stress to the root may be effective in evaluating high-temperature tolerance because it is easy to perform. Further studies are needed to determine the most suitable water temperature.

2. Relationship between the percentages of WIK and several kernel traits

The relationship between the percentages of WIK and several kernel traits is shown in Fig. 4. The percentages of WIK correlated with the 1000 kernel weight and kernel width positively and significantly in both pools. These correlation coefficients were higher in the warmed pool than in the control pool. Large-kernel rice needs so much carbohydrate per kernel that the shortage of starch accumulation occurs easily, resulting in decreased grain.

|                | The number of lines and cultivars | Control pool | Warmed pool | Significance according to t-test (average) or F-test (variance) |
|----------------|----------------------------------|--------------|-------------|---------------------------------------------------------------|
| All Average (%) | 28                               | 30.5         | 31.3        | ns                                                            |
| Variance       | 28                               | 8.10         | 31.42       | ***                                                          |
| ANOVA Lines and cultivars (A) | ***                           |              |             |                                                               |
| Water temperature (B) | ns                              |              |             |                                                               |
| A×B            |                                  |              |             | ns                                                            |
| LWG Average (%) | 14                               | 28.3         | 27.5        | ns                                                            |
| Variance       | 14                               | 2.57         | 20.19       | ***                                                          |
| ANOVA Lines and cultivars (A) | *                           |              |             |                                                               |
| Water temperature (B) | ns                              |              |             |                                                               |
| A×B            |                                  |              |             | ns                                                            |
| HWG Average (%) | 14                               | 32.7         | 35.1        | *                                                            |
| Variance       | 14                               | 3.92         | 13.95       | *                                                            |
| ANOVA Lines and cultivars (A) | ns                           |              |             |                                                               |
| Water temperature (B) | *                              |              |             |                                                               |
| A×B            |                                  |              |             | ns                                                            |

Data for all lines and cultivars, and for LWG and HWG.

*** and *: significant at 0.1% and 5% levels, respectively. ns: not significant.
quality (Takita, 1985). The heavier final grain weight is, the higher the percentage of grain filling becomes (Kato, 1989). Moreover, the grain filling percentage increases, and milky-white grains increase under a high-temperature condition (Kobata et al., 2011). Therefore, we suppose that more WIKs occur in large-kernel rice under a high-temperature condition, and it may be effective to reduce the 1000 kernel weight and/or thin the grain in the process of breeding of rice cultivars with high-temperature tolerance.

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References

Hirano, H. and Sano, Y. 2000. *Genes Genet. Syst.* 75: 245-249.

Hoshi, T. et al. 2002. *J. Niigata Agric. Res. Inst.* 5: 21-33***.

Iida, Y. et al. 2002. *Jpn. J. Crop Sci.* 71: 174-177**.

Ishizaki, K. 2006. *Jpn. J. Crop Sci.* 75: 502-506**.

Jiang, H. et al. 2003. *Phytochemistry.* 63: 53-59.

Kasaneyama, H. et al. 1999. *Hokkaido Crop Sci.* 34: 21-23*.

Kato, T. 1989. *Japan. J. Breed.* 39: 431-438.

Kobata, T. et al. 2004. *Jpn. J. Crop Sci.* 73: 315-322**.

Kobata, T. et al. 2011. *Plant Prod. Sci.* 14: 359-364.

Morita, S. et al. 2004. *Jpn. J. Crop Sci.* 73: 77-83**.

Nagahata, H. and Yamamoto, K. 2005. *Breed. Res.* 7: 95-101**.

Nagato, K. and Ebata, M. 1960. *Proc. Crop Sci. Soc. Jpn.* 28: 275-278***.

Nagato, K. and Ebata, M. 1965. *Proc. Crop Sci. Soc. Jpn.* 34: 5946***.

Sakai, M. et al. 2010. *Bull. Natl. Agric. Res. Cent. Kyushu Okinawa Reg.* 54: 43-61***.

Tabata, M. et al. 2005. *Breed. Res.* 7: 9-15**.

Takita, T. 1985. *Breed. Res. Cent.* 3: 55-71***.

Tashiro, T. and Wardlaw, I.F. 1991. *Aust. J. Agric. Res.* 42: 485-496.

Terashima, K. et al. 2001. *Jpn. J. Crop Sci.* 70: 449-458**.

Tomita, K. et al. 2009. *Bull. Fukuoka Agric. Exp. Sta.* 46: 1-21***.

Tsubone, M. et al. 2008. *Rep. Kyushu Br. Crop Sci. Soc. Japan.* 74: 21-23*.

Umemoto, T. and Terashima, K. 2002. *Funct. Plant Biol.* 29: 1121-1124.

Wada, T. et al. 2010. *Bull. Fukuoka Agric. Res. Cent.* 29: 1-4***.

Wakamatsu, K. et al. 2007. *Jpn. J. Crop Sci.* 76: 71-78**.

Yamaguchi, T. et al. 2006. *Bull. Toyama Agric. Res. Ctr.* 23: 29-43***.

Yamakawa, H. et al. 2007. *Plant Physiol.* 144: 258-277.

* In Japanese.

** In Japanese with English abstract.

*** In Japanese with English summary.