Varietal Difference in the Occurrence of Milky White Kernels in Response to Assimilate Supply in Rice Plants (*Oryza sativa* L.)

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Abstract: We examined the association of assimilate supply in the occurrence of milky white kernels in three cultivars with different percentages of milky white kernels in the field condition: ‘Hatsuboshi’, ‘Koshiibuki’ and ‘Koshihikari’. Five days after heading, the plants were placed in four controlled-environment chambers with either a high or low night temperature and elevated or normal [CO₂] supply. Plants in each chamber were either defoliated with only flag leaf remaining, flag leaf and second leaf remaining or left intact (control). The percentage of each type of chalky kernel was examined. The percentage of milky white kernels was increased by defoliation and decreased by elevated [CO₂], associated with assimilate supply. No association was observed between assimilate supply and white back or basal white kernels. The percentage of milky white kernels was negatively correlated with assimilate supply at a high night temperature in all cultivars. At a low night temperature, there was a clear threshold of assimilate supply, over which the percentage of milky white kernels was nearly zero. Cultivar differences were observed in the relation between the percentage of milky white kernels and assimilate supply. In conclusion, we found a varietal difference in the occurrence of milky white kernels in response to assimilate supply. In the cultivars used in this study, ‘Hatsuboshi’ was more sensitive to the low assimilate supply than ‘Koshihikari’.

Key words: Assimilate supply, Chalky kernels, Grain filling, High night temperature, Milky white kernels, Rice, Varietal difference.

The occurrence of chalky kernels lowers the grain quality of rice. Chalky kernels are induced by a high temperature during the grain-filling period. Under the same climate condition, the percentage of chalky kernels differ with the cultivar, which suggests that the susceptibility to high temperature in the grain-filling period is genetically determined (Nishimura et al., 2000; Ishizaki, 2006; Wakamatsu et al., 2007). The varietal differences in the occurrence of basal white or white back kernels observed in the field condition was replicated in the plants exposed to a high temperature during the grain-filling period (Iida et al., 2002; Nagahata and Yamamoto, 2005). However, the reproducibility of the varietal differences in the percentage of milky white kernels at a high temperature was low (Iida et al., 2002).

One of the reasons for the low reproducibility in the percentage of milky white kernels may be the effect of assimilate supply on the occurrence of this type of chalky kernel. Sink-source manipulation significantly affected the percentage of milky white and white belly kernels but hardly affected the percentage of basal white and white back kernels (Morita et al., 2005a; Nakagawa et al., 2006; Tsukaguchi and Iida, 2008). Milky white kernels increased when the number of spikelets was large (Inoue, 2003; Tsukimori, 2003), and when flag leaves were removed or decreased when light environment was improved by thinning at heading (Kobata et al., 2004; Nakagawa et al., 2006). These results indicated that the assimilate supply affected the percentage of milky white kernels.

Therefore, the observed cultivar difference in the percentage of milky white kernels may be influenced by the assimilate supply during the grain-filling period. Nagahata and Yamamoto (2005) observed clear cultivar differences in the occurrence of milky white kernels under a high temperature condition during the grain-filling period, but they pointed out that ‘Hitomebore’ with a higher percentage of milky white kernels bore more spikelets than ‘Tentakaku’ and might be supplied with a...
smaller amount of assimilate. Similarly, the percentage of milky white kernels was much higher in ‘Takanari’ than in ‘Koshihikari’ and this cultivar difference was attributed to the lower assimilate supply in ‘Takanari’ than in ‘Koshihikari’ (Tsukaguchi and Iida, 2008). These studies indicate that the difference in the percentage of milky white kernels might reflect the difference in assimilate supply which is a varietal characteristic and is also influenced by environment. The objective of this study was to clarify whether there is a varietal difference in the occurrence of milky white kernels in response to assimilate supply, by comparing three cultivars contrasting in the occurrence of milky white kernels in the field condition.

Materials and Methods

This research was conducted at the National Institute for Agro-Environmental Sciences, Tsukuba, Japan using the rice cultivars ‘Hatsuboshi’, ‘Koshiibuki’ and ‘Koshihikari’. On 15 May 2006, seeds were sown in the seedling tray. On 5 June, twenty plants were transplanted in plastic pots (16.0 cm diameter and 19.0 cm depth) filled with grey sand soil with a basal dressing of 0.6 g of N as ammonium sulfate, 1.0 g of P₂O₅ as superphosphate and 1.0 g of K₂O as potassium chloride. Each pot was applied with a top dressing of 0.3 g of N as ammonium sulfate on 7 July. Tillers were removed every week until heading. Plants were grown under an outdoor condition until the start of temperature treatment. Plants which headed on 4 August in ‘Hatsuboshi’, 5 August in ‘Koshiibuki’, and 11 August in ‘Koshihikari’ were tagged every week until heading. Plants were grown under an outdoor condition until the start of temperature treatment. Plants which headed on 4 August in ‘Hatsuboshi’, 5 August in ‘Koshiibuki’, and 11 August in ‘Koshihikari’ were tagged and used for the measurement.

Five days after heading, the CO₂ concentration [CO₂] and temperature treatment was conducted using four controlled-environment naturally lit chambers (Shimadzu, Kyoto, Japan). The chambers were glazed with 5 mm-thick tempered glass, whose transmittance of photosynthetically active radiation was >80%, but the rear (north) wall and the floor were made of stainless steel. The amount of solar radiation into the chamber was estimated as the amount of radiation measured outdoors multiplied by 0.8 (Fig. 1). Each chamber was 4 m × 2 m × 2 m (length × width × height) and housed two stainless-steel containers measuring 1.5 m × 1.5 m × 0.3 m (length × width × height) filled with water into which the rice pots were placed. Within each chamber, air temperature and [CO₂] were controlled by using cold-water heat exchangers with proportional-integral-derivative (PID) controllers (DB1000; Chino, Tokyo, Japan) and [CO₂] was maintained at a set-point concentration using a computer-controlled pure-CO₂ injection system with PID controller, which give reliable performance between chamber replicates (Sukai et al., 2006).

The four treatment conditions were as follows: elevated [CO₂] at 680 ppm and high night temperature; ambient [CO₂] at 380 ppm and high night temperature; elevated [CO₂] and low night temperature; ambient [CO₂] and low night temperature. For the high night temperature treatment, day and night air temperatures were maintained at 30°C. For the low night temperature treatment, the air temperature was maintained at 30°C from 0800 to 1600 hr and at 22°C from 2000 to 0400 hr, with a linear temperature transition phase of 2.0°C hr⁻¹ from 0400 to 0800 and 1600 to 2000 hr. The actual average air temperatures in the high and low night temperature treatments were 30.3 and 26.5°C, respectively. The relative humidity was controlled at 80% in all the chambers.

The plants which were transferred into the four chambers were imposed three levels of defoliation treatment; namely, (1) remaining only flag leaves, (2) remaining flag and the second leaves and (3) the control. For each defoliation treatment in each cultivar in each chamber, we prepared ten pots with more than five tagged plants. Five plants with average size from the tagged plants were used for the control or defoliation. We placed half of the pots randomly in each of the two containers and used one pot from each container in each sampling.

At 5, 20 and 40 days after heading, plants were harvested in each treatment. Plants were separated into panicles, leaf blades, and culms plus leaf sheaths (stems), oven dried at 80°C for 72 hr, and dry weight was measured. Dried samples of stems were ground and used for measurement of non-structural-carbohydrate (stem-NSC). The stem-NSC content was determined as the sum of total soluble sugar and starch content as described by Thongbai et al. (1995). Total soluble sugar was extracted with hot ethanol and assayed with anthrone reagent. Starch in the residue was hydrolyzed to glucose by amyloglucosidase and the glucose content was assayed with anthrone reagent. Starch content was determined by multiplying the glucose content by 0.9.

Assimilate supply in the initial half of grain-filling period was calculated as ΔW (20) + ΔNSC (20) / n, where ΔW (20) is dry matter production in the 20 days after heading, ΔNSC (20) is the decrease of stem-NSC in the same period and n is the number of spikelets of a plant.
At 40 days after heading, another ten tagged panicles were harvested. The hulled grains thicker than 1.6 mm were classified into perfect grains, milky white kernels, basal white kernels, white back kernels, and others visually. The simple linear regression analysis was performed between each kind of chalky kernel and the amount of assimilate supply at the initial half of the grain-filling period in each cultivar in each night temperature treatment. The regression coefficients of each cultivar between the percentage of milky white kernels and assimilate supply at high night temperature were tested by Holm’s multiple comparisons procedure.

Analysis of variance of the data was performed in a factorial design by considering two factors in each chamber; cultivar and levels of defoliation with 2 replications. The effects of night temperature and [CO2] were tested using mean values of each chamber. We used the SPSS for Windows 13J statistical software (SPSS, Inc, Chicago, US) for the analysis.

Results

There was a significant varietal difference in the percentage of milky white kernels in each chamber (Table 1). The percentage of milky white kernels in ‘Hatsuboshi’ was higher than those in the other cultivars. ‘Koshihikari’ showed a higher percentage of milky white kernels than ‘Koshiibuki’ at a high night temperature with elevated [CO2] and at a low night temperature with ambient [CO2]. The defoliation treatment significantly increased the percentage of milky white kernels. Although elevated [CO2] had no effect on the percentage of milky white kernels (Table 2), the percentage of milky white kernels was lower at an elevated [CO2] in each cultivar.

The percentage of white back kernels was the highest in ‘Hatsuboshi’. At a high night temperature ‘Koshiibuki’ showed a higher percentage of white back kernels than ‘Koshihikari’. There were significant effects of defoliation on the percentage of white back kernels at a high night temperature but the percentage of white back kernels was

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Table 1. Percentage of milk white kernels, white back kernels and basal white kernels with temperature, [CO2] and defoliation treatments in ‘Hatsuboshi’, ‘Koshiibuki’ and ‘Koshihikari’.

| Cultivar       | Number of leaves | HT  | LT  | HT  | LT  | HT  | LT  | HT  | LT  | HT  | LT  | HT  | LT  | HT  | LT  |
|----------------|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                |                  | A   | E   | A   | E   | A   | E   | A   | E   | A   | E   | A   | E   | A   | E   |
| Hatsuboshi     | 1                | 31.9| 35.1| 19.2| 14.5| 32.3| 44.0| 8.7 | 2.6 | 20.3| 10.2| 8.7 | 4.2 |
|                | 2                | 25.3| 15.7| 2.7 | 5.6 | 24.0| 25.8| 2.9 | 5.0 | 23.9| 16.0| 3.2 | 3.3 |
|                | cont             | 6.5 | 1.3 | 2.0 | 2.0 | 68.5| 39.6| 3.5 | 2.5 | 18.8| 8.9 | 3.0 | 1.0 |
| Koshiibuki     | 1                | 12.2| 12.1| 5.5 | 1.1 | 26.3| 17.5| 0.0 | 0.5 | 4.5 | 4.1 | 0.6 | 0.0 |
|                | 2                | 13.2| 8.2 | 0.9 | 0.8 | 9.7 | 9.2 | 0.0 | 0.4 | 0.9 | 1.7 | 0.0 | 0.0 |
|                | cont             | 10.8| 0.9 | 0.4 | 0.0 | 15.9| 35.1| 0.0 | 0.0 | 0.4 | 2.3 | 0.0 | 0.0 |
| Koshihikari    | 1                | 17.0| 14.8| 13.1| 6.5 | 5.3 | 2.1 | 5.2 | 1.3 | 15.8| 7.9 | 3.0 | 1.6 |
|                | 2                | 19.2| 15.0| 2.6 | 0.0 | 14.6| 6.6 | 0.0 | 0.0 | 8.0 | 5.7 | 1.3 | 0.0 |
|                | cont             | 5.6 | 2.0 | 0.0 | 0.0 | 15.0| 1.9 | 0.0 | 0.0 | 5.8 | 5.1 | 2.2 | 5.1 |

Result of ANOVA test (Factorial effects)

| Cultivar       | HT  | LT  | HT  | LT  | HT  | LT  | HT  | LT  |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Hatsuboshi     | A   | E   | A   | E   | A   | E   | A   | E   |
| Koshiibuki     |     |     |     |     |     |     |     |     |
| Koshihikari    |     |     |     |     |     |     |     |     |

1) mean values in each treatment are shown (n = 2).
2) 1, 2 and cont denote remaining only flag leaves, remaining flag and the second leaves and control, respectively.
3) HT and LT denote high night temperature (30/30, day/night) and low night temperature (30/22, day/night).
4) A and E denote ambient and elevated [CO2], respectively.
5) *, **, *** and ns indicate significant difference at 5%, 1%, 0.1% and no significant difference, respectively and different alphabet within a factor indicate significant difference at 5% level (Tukey’s test).
Table 2. The effects of night temperature and [CO2] on the percentage of milky white kernels, white back kernels, basal white kernels, the amount of dry matter production and assimilate supply

| Treatment | Milky white kernels | White back kernels | Basal white kernels | ΔW\[^2\] (g plant\(^{-1}\)) | assimilate supply\[^3\] (mg spikelet\(^{-1}\)) |
|-----------|---------------------|-------------------|--------------------|-----------------------------|---------------------------------|
| A         | 10.5                | 12.9              | 6.7                | 1.30                        | 13.03                           |
| E         | 7.5                 | 10.8              | 4.3                | 1.41                        | 14.07                           |
| CO2       | ns                  | ns                | ns                 | ns                          | ns                              |
| HT        | 13.7                | 21.9              | 8.9                | 1.35                        | 14.08                           |
| LT        | 11.2                | 19.8              | 8.1                | 1.36                        | 13.02                           |

Night temperature\[^5\] ns * ns ns ns

1) The results of ANOVA test using mean values of each chamber are shown. * and ns indicate significant difference at 5% and no significant difference between the treatments, respectively.
2) The amount of dry matter production per plant was that of the whole grain-filling.
3) The amount of assimilate supply per spikelet was that of the initial half of the grain-filling.
4) A and E denote ambient and elevated [CO2], respectively.
5) HT and LT denote high night temperature (30/30, day/night) and low night temperature (30/22, day/night).

Table 3. The amount\[^1\] of dry matter production and assimilate supply under various temperature, [CO2] and defoliation conditions in ‘Hatsuboshi’, ‘Koshiibuki’ and ‘Koshihikari’.

| Cultivar     | Number of leaves\[^6\] | ΔW\[^2\] (g plant\(^{-1}\)) | assimilate supply\[^3\] (mg spikelet\(^{-1}\)) |
|--------------|------------------------|-----------------------------|---------------------------------|
| Hatsuboshi   | 1                      | 0.55                        | 8.74                            |
|              | 2                      | 1.17                        | 10.70                           |
|              | cont                   | 1.65                        | 19.20                           |
| Koshiibuki   | 1                      | 1.38                        | 12.04                           |
|              | 2                      | 1.71                        | 14.99                           |
|              | cont                   | 2.04                        | 14.51                           |
| Koshihikari  | 1                      | 0.29                        | 6.58                            |
|              | 2                      | 0.44                        | 7.87                            |
|              | cont                   | 2.17                        | 16.78                           |

Result of ANOVA test (Factorial effects)\[^7\]

Cultivar and Treatments

| Cultivar     | HT\[^4\] | HT | LT | HT | LT | HT | LT | LT |
|--------------|----------|----|----|----|----|----|----|----|
| Hatsuboshi   | 1.13     | 1.20 | 1.11 b | 1.17 | 1.11 a | 14.99 a | 14.18 |
| Koshiibuki   | 1.71     | 1.59 | 1.66 a | 1.66 | 13.85 | 17.33 a | 12.60 |
| Koshihikari  | 0.97     | 1.52 | 1.23 b | 1.35 | 10.41 | 12.93 b | 10.19 |

| Cultivar     | ns | ns | ** | ns | ns | ** | ** | ns |
|--------------|----|----|----|----|----|----|----|----|
| Hatsuboshi   | 1  | 0.74 | 0.70 c | 0.74 b | 9.12 | 11.14 b | 9.20 b | 10.05 |
| Koshiibuki   | 2  | 1.11 | 1.34 b | 1.27 b | 11.19 | 15.24 b | 12.63 b | 12.21 |
| Koshihikari  | cont | 1.95 | 2.09 a | 2.03 a | 19.21 a | 14.80 |

Defoliation ns *** *** ns ns ** ** ns

1) mean values in each treatment are shown (n=2).
2) The amount of dry matter production per plant was that of the whole grain-filling.
3) The amount of assimilate supply per spikelet was that of the initial half of the grain-filling.
4) 1, 2 and cont denote remaining only flag leaves, remaining flag and the second leaves and control, respectively.
5) HT and LT denote high night temperature (30/30, day/night) and low night temperature (30/22, day/night).
6) A and E denote ambient and elevated [CO2], respectively.
7) *, **, *** and ns indicate significant difference at 5%, 1%, 0.1% and no significant difference, respectively and different alphabet within a factor indicate significant difference at 5% level (Tukey’s test).
not related with the defoliation level. The plants with flag leaf and second leaf remaining after defoliation showed a lower percentage of white back kernels than the control at a high night temperature.

The percentage of basal white kernels was the highest in ‘Hatsuboshi’ and the lowest in ‘Koshiibuki’. There was no significant effect of defoliation on the percentage of basal white kernels.

Dry matter production during the grain-filling period was decreased by the defoliation treatment (Table 3). The effects of elevated [CO₂] and night temperature were not clear (Table 2). There was a wide variation in the assimilate supply per spikelet in the initial half period of grain filling in each cultivar. ‘Koshihikari’ showed lower assimilate supply per spikelet than ‘Hatsuboshi’ and ‘Koshiibuki’ at a high night temperature with elevated [CO₂] and at a low night temperature with ambient [CO₂].

There was a wide variation with the treatment and cultivar in the amount of assimilate supply per spikelet in the initial half of the grain-filling period and that in ‘Koshiibuki’ was 1.5 times that in ‘Koshihikari’ at high and low night temperatures (Table 3).

At a high night temperature there was a significant negative correlation between the percentage of milky white kernels and assimilate supply in each cultivar (−0.96** in ‘Hatsuboshi’, −0.92** in ‘Koshiibuki’ and −0.96** in ‘Koshihikari’) (Fig. 2a). At a low night temperature, there were thresholds of assimilate supply, over which the percentage of milky white kernels was nearly zero and under which the percentage of milky white kernels negatively correlated with assimilate supply (−0.99** in ‘Koshihikari’ but correlation coefficients were not significant in the other cultivars). At a high night temperature, the percentage of milky white kernels at a given amount of carbohydrate availability was higher than in the low night temperatures in all the cultivars. At a high night temperature, regression coefficients showed a significant difference between ‘Hatsuboshi’ and ‘Koshihikari’ (P<0.05), while there was no significant difference in the regression coefficients between the other pairs. There was no association between assimilate supply and the percentage of basal white kernels or white back kernels at high or low night temperature (Figs. 2b, c).

Discussion

In this study, brown rice thicker than 1.6 mm was investigated, which makes the results less practical since brown rice thicker than 1.8 mm or more is marketed in Japan. However many of the brown rice was less than 1.8 mm thick in the defoliated ‘Koshihikari’. To evaluate the response to a high night temperature or low assimilate supply in the three cultivars, we investigated brown rice thicker than 1.6 mm, which covered most of the brown rice produced in all the environments and cultivars used in
this study.

The percentage of milky white kernels was increased by defoliation and decreased by elevated [CO₂] (Table 1), associated with assimilate supply. The effects of defoliation were not constant among the types of the chalky kernels. Non-defoliated plants at a high night temperature showed the highest percentage of white back kernels, suggesting that assimilate supply is not the major factor causing white back kernels. It is not clear why defoliation treatment (2) reduced the percentage of white back kernels but the shortage of assimilate supply is apparently not the cause of the occurrence of basal white or white back kernels. The chalky appearance of kernels is derived from a change in light reflection resulting from the occurrence of numerous air spaces between loosely packed starch granules and poorly developed small starch granules (Tashiro and Wardlaw, 1991). In the formation of chalky appearance of each type of chalky kernels, different factors seem to be involved. Many studies indicated that a deficit of assimilate supply increased the percentage of milky white kernels (Inoue, 2003; Tsukimori, 2003; Kobata et al., 2004; Nakagawa et al., 2006) whereas the percentage of basal white or white back kernels is hardly affected by assimilate supply during the grain-filling period (Morita et al., 2005 a; Nakagawa et al., 2006; Tsukaguchi and Iida, 2008). The results of this study were in agreement with these previous results.

Poor starch accumulation at the center of the endosperm in milky white kernels suggest that milky white kernels are associated with an assimilate deficit during the initial half of the grain-filling period since starch accumulates in the center of endosperm during this period (Hoshikawa, 1968). The amount of assimilate supply which is available for grain growth in the initial half of the grain-filling period is considered to be the sum of concurrent photosynthetic products and stem-NSC stored prior to heading. Therefore, the amount of assimilate supply can be shown as \( \Delta W (20) + \Delta NSC (20) \) / n, where \( \Delta W (20) \) is dry matter production during the 20 days after heading, \( \Delta NSC (20) \) is the decrease of stem-NSC in the same period and n is the number of spikelets per plant. There was a wide variation with the treatment or cultivar in the amount of assimilate supply per spikelet during the initial half of the grain-filling period and that in ‘Koshihikari’ tended to be larger than that in ‘Koshihikari’ at high and low night temperatures partly due to its smaller number of spikelets. The average number of spikelets per plant was 63, 76 and 91 in ‘Hatsuboshi’, ‘Koshiibuki’ and ‘Koshihikari’, respectively. At high night temperature there was a significant negative correlation between the percentage of milky white kernels and assimilate supply in each cultivar (−0.96** in ‘Hatsuboshi’, −0.92** in ‘Koshiibuki’ and −0.96** in ‘Koshihikari’) (Fig. 2a). At low night temperature, similar trend was observed but there were thresholds of assimilate supply, over which the percentage of milky white kernels was nearly zero. In contrast to milky white kernels, there was no association between assimilate supply and basal white kernels or white back kernels (Figs. 2b, c).

The percentage of milky white kernels was higher at high night temperature than that at a low night temperature with the same assimilate supply. A high temperature accelerated starch accumulation in the grains especially in the inferior spikelets, which resulted in the higher rate of NSC translocation from the stem (Tsukaguchi and Iida, 2008). When stem NSC is depleted, assimilate deficit for grain growth might occur. It is obscure whether a high night temperature has the same effect on the starch accumulation in the grains as a high day temperature. However, Morita et al. (2005b) observed the acceleration of grain growth at a high night temperature, though not as much as at a high day temperature. These results suggest that a high night temperature during the grain-filling period increases the sensitivity to the low assimilate supply causing the occurrence of milky white kernels.

At high and low night temperatures, varietal differences were observed in the percentages of milky white kernels. A clear varietal difference in the percentage of milky white kernels between ‘Koshihikari’ and ‘Takanari’ was well explained by the difference in assimilate supply per spikelets in the initial half period of the grain-filling period (Tsukaguchi and Iida, 2008). In the cultivars used in this study, however, there was a difference in the response to assimilate supply in the occurrence of milky white kernels. The percentage of milky white kernels in ‘Hatsuboshi’ was affected more by the low assimilate supply than that in ‘Koshihikari’. The percentage of milky white kernels tended to be lower in ‘Koshiibuki’ than that in ‘Koshihikari’ at a high night temperature. However, there was no significant difference between these cultivars in the relation between assimilate supply and the percentage of milky white kernels. The amount of assimilate supply in the initial half period of grain-filling in ‘Koshiibuki’ was 1.5 times larger than that in ‘Koshihikari’ (Table 3), which resulted in a little lower percentage of milky white kernels in ‘Koshiibuki’. The higher milky white kernels in ‘Hatsuboshi’ than in ‘Koshihikari’ may reflect its higher sensitivity to a low assimilate supply while the higher milky white kernels in ‘Koshihikari’ than ‘Koshiibuki’ reflect its lower assimilate supply. Since the assimilate supply hardly affects the occurrence of basal white or white back kernels (Figs. 1a, b), the tolerance to the occurrence of those types of chalky kernels can be evaluated by the tolerance to high temperature stress during the grain-filling period. Various ways of imposing high temperature stress on plants during the grain-filling period have been reported (Iida et al., 2002; Omoteno et al., 2003; Ishizaki, 2006). Using these
evaluating system, several qualitative trait loci (QTLs) related to basal white or white back kernels were reported (Kobayashi et al., 2007; Tabata et al., 2007). However, the varietal difference in the percentage of milky white kernels is influenced both by a high temperature and sensitivity to low assimilate supply, which makes the evaluation of the tolerance difficult. Furthermore, the treatment to impose high temperature stress on plants sometimes affects the sink-source ratio, which might have resulted in the low reproducibility of the cultivar difference in the occurrence of milky white kernels by high temperature treatment during the grain-filling period (Iida et al., 2002). Therefore, it is necessary to establish the method to evaluate the tolerance to the occurrence of milky white kernels, which separates the effect of assimilate supply.

In conclusion, there was a close negative relation between the percentage of milky white kernels and assimilate supply, while no association was observed between assimilate supply and the percentage of white back or basal white kernels. There was a varietal difference in the occurrence of milky white kernels in response to assimilate supply. In the cultivars used in this study, ‘Hatsuboshi’ was more sensitive to low assimilate supply than ‘Koshihikari’.

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