COUNTERMEASURES AGAINST THE OCCURRENCE OF CHALKY GRAIN DURING RICE RIPENING UNDER HIGH TEMPERATURES

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ABSTRACT

Owing to global warming, rice plants are exposed to higher temperatures during ripening. Chalky grain is one of the main types of damage caused by high temperatures (in addition to low solar radiation). Chalky grains are categorized into several types based on the position of the chalky appearance, such as milky-white, basal-white, and white-back. Rice comprising a high proportion of chalky grains when coocked has reduced palatability. Furthermore, farmers are extremely concerned about the occurrence of chalky grains because brown rice containing a high proportion of chalky grains has a low selling price. One of the leading rice varieties in western Japan is 'Hinohikari,' which when coocked has high palatability; however, this variety is particularly susceptible to high temperatures during ripening. The deterioration of the grain quality of 'Hinohikari' has become an important problem. To resolve this problem, a heat-tolerant variety called 'Nikomaru' was developed by NARO in 2005. 'Nikomaru' exhibits reduced occurrence of chalky grain at high temperatures. Recently, in addition to 'Nikomaru', several heat-tolerant varieties, such as 'Sagabiyori,' have been developed, and the area planted with such varieties has gradually been extended to southwestern Japan. However, the area planted with 'Hinohikari' still remains high at approximately 40% of the total rice area planted in southwestern Japan. Therefore, in these areas, the development of cultivation techniques that reduce the frequency of chalky grains is necessary. As a countermeasure against high temperatures, we are now developing a novel weather-adaptive top-dressing technique based on the results of analyzing conditions that result in the occurrence of each type of chalky grain and the weather forecast during ripening. The frequency of basal-white and white-back grains was found to increase when rice plants *with low nitrogen concentrations ripen under high-temperature conditions. When high temperatures are forcast prior to ripening, the amount of top-dressing can be optimized based on the leaf color before heading and an equation to reduce the occurrence of basal-white and white-back grains. In contrast, when high temperatures are not expected prior to ripening, the amount of top-dressing is decided according to conventional farming methods. We further plan to increase the accuracy of the technique by conducting demonstration experiments in farmers' fields. This technique may facilitate consistant rice production under climate changes.*

Keywords: Chalky grain, countermeasure, cultivation technique, global warming, rice, top-dressing variety, rice quality

INTRODUCTION

Rice plants are increasingly being exposed to high temperatures during ripening due to global warming. Chalky grain is one of the main types of visible damage caused by high temperatures (and low solar radiation). Starch granules in the endosperm cells of chalky grains are loosely packed, and numerous air spaces between the starch granules cause random light reflections that create a chalky appearance (Tashiro and Ebata 1975; Tashiro and Wardlaw 1991; Zakaria *et al*. 2002).

Chalky grains are categorized into several types according to the position on the grain with chalky appearance (Fig. 1). The three major types are milky-white, basal-white, and white-back grains. A milky-white grain has a chalky ring in the cross section of the endosperm. A basal-white grain has a chalky appearance near the embryo. A white-back grain has a chalky appearance on the side opposite to the embryo. In addition to these three major types, white-core and white-belly grains are also observed. A white-core grain has a chalky appearance in the center similar to milky-white grains. However, the area of the chalky appearance in white-core grains is smaller than that in milky-white grains. A white-belly grain has a chalky appearance on the same side as the embryo.

Fig. 1. Three major types of chalky grains.

The palatability of cooked rice exhibits a quadraic relationship with temperature during ripening , with a peak at about 25°C in the leading Japanese varieties 'Koshihikari' and 'Hinohikari' (Mastue *et al*. 2012). In addition, the hardness (H)/adhesion (–H) ratio has a quadratic relationship with temperature during ripening, showing a peak at 24 °C in these varieties. Wakamatsu *et al*. (2007) found that the paratability of cooked rice decreases with increasing the proportion of chalky grains. The concentrations of amylose and super-long chains of amylopectin concentrations in rice grains demonstrate positive correlations with the retrodegradation in starch of cooked rice (Yoshii *et al*. 1997; Inouchi 2010). Amylose concentration in rice grain increases with decreasing temperature during ripening (Asaoka *et al*. 1985; Inatsu 1988; Matsue *et al*. 1991). In contrast, the concentrations of super-long chains of amylopectin in rice grains increases with increasing temperature during ripening (Umemoto *et al*. 1999; Okuda *et al*. 2006; Yamakawa *et al* 2007; Igarashi *et al*. 2008). Thus, the concentrations of amylose and super-long chains of amylopectin may cause differences in palatability of cooked rice that is associated with high temperatures during ripening.

In Japan, farmers are extremely concerned regarding the occurrence of chalky grain because brown rice containing a high proportion of chalky grains has a low selling price. Brown rice containing undamaged grains in the proportion of >70%, 60%, or 45% is classified as first, second, or third grade, respectively, whereas a proportion of <45% is considered to be non-standard. The price of brown rice differs by approximately 1,000 yen per 60 kg between the grades.

To reduce the occurrence of chalky grains, the development of heat-tolerant varieties and cultivation techniques are necessary. This paper described some heat-tolerant varieties that are cultivated in southwestern Japan, the conditions under which each type of chalky grain occurs, and countermeasures that can be undertaken to minimize the occurrence of chalky grains during ripening under high temperatures (or low solar radiation).

HEAT-TOLERANT RICE VARIETIES FOR WESTERN JAPAN

The introduction of heat-tolerant varieties is a powerful countermeasure against the occurrence of chalky grain during the ripening of rice under high temperatures. Farmers can select heat-tolerant varieties suitable for their fields before planting in preparation for high temperatures.

Leading variety 'Hinohikari' and heat-tolerant variety 'Nikomaru'

One of the leading varieties in western Japan is 'Hinohikari,' which is planted in 27 prefectures (Fig. 2). The area planted with this variety in 2017 is estimated at approximately 130,000 ha (representing 8.9% of the rice acreage grown in Japan) (Beikokukikiko 2018). The coocked rice of 'Hinohikari' has high palatability ; however, this variety is susceptible to high temperatures during ripening. The deterioration of the grain quality of 'Hinohikari' has become an important problem.

Fig. 2. Leading rice variety 'Hinohikari' and its area planted in Japan.
Green-colored areas indicate prefectures where 'Hinohikari' is planted.

To resolve this problem, a heat-tolerant variety called 'Nikomaru' was developed by NARO and released in 2005 (Fig. 3) (Sakai *et al*. 2007). 'Nikomaru' exhibits a reduced occurrence of chalky grain caused by high temperatures. Since its release, the area in which 'Nikomaru' is planted has been steadily increasing. Morita and Nakano (2011) examined the ripening features of 'Nikomaru' under high temperatures, and revealed that it could accumulate a greater amount of stem non-structural carbohydrates before heading, which could be translocated to the grain to sustain an accelerated grain-growth rate under high temperatures, resulting in the enhancement of ripening performance. In addition, Nagata *et al*. (2013) found that ‘Nikomaru’ has a high resistance to grain cracking. Several heat-tolerant varieties, namely ‘Minoritsukushi’ and ‘Natsuhonoka’ have been developed,using ‘Nikomaru’ as one of the parents (Wada *et al*. 2016; Wakamatsu *et al*. 2016).

Fig. 3. Heat-tolerant rice variety ‘Nikomaru.’
(Provided by Dr. Makoto Sakai, NARO)

Brown rice quality of ‘Nikomaru’ in high temperature year

Morita (2005) investigated the relationship between daily mean temperature during early ripening (i.e., 20 days after heading), which affects the occurrence of chalky grains, and the proportion of chalky grains in ‘Koshihikari’ and found that chalky grains begin to occur at approximately 24℃ with a slope approximately 10% per 1ºC from 28 to 29ºC.

Fig. 3 shows the daily mean temperature during the 2010 rice growing season. The temperature from summer to autumn was much higher than that in normal years. In southwestern Japan, ‘Hinohikari’ seedlings are transplanted in late June, the rice plants head in late August, and are then harvested in early October. The daily mean temperature during early ripening was about 28℃ in

2010, about 2°C higher than that in normal years. Fig. 4 shows the grains harvested at our research center, which is located in Chikugo, Fukuoka, southwestern Japan, in 2010. 'Hinohikari' had a high proportion of chalky grains but 'Nikomaru' had a markedly lower proportion. Therefore, 'Nikomaru' showed greater tolerance to heat than 'Hinohikari' in this year.

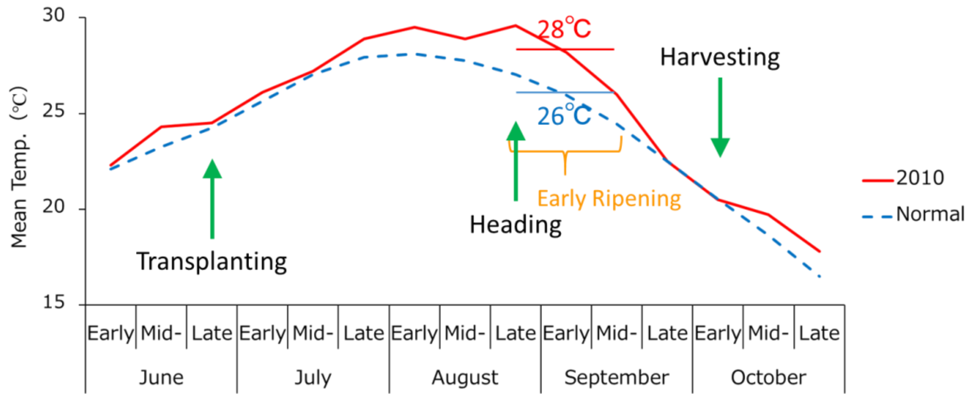

Fig. 4. Daily mean temperature during rice growing season in 2010 in Chikugo, Fukuoka, Japan.

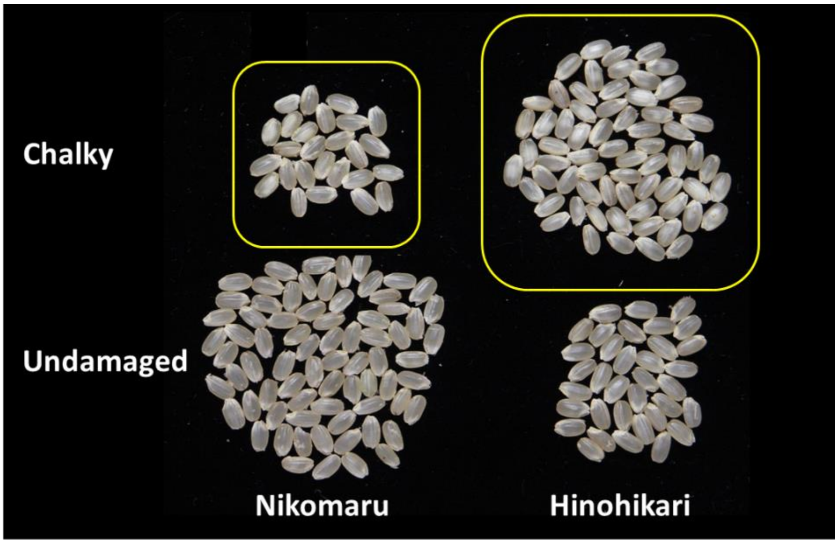

Fig. 5. Rice grains harvested at an experimental field at Chikugo, Fukuoka, Japan in 2010.
One hundred grains of each variety obtained at random were divided into chalky and undamaged grains. (Provided by Dr. Makoto Sakai, NARO)

Fig. 6 shows the proportion of varieties planted in southwestern Japan. Recently, in addition to 'Nikomaru,' several heat-tolerant varieties, such as 'Sagabiyori,' have been developed, and the area planted with these varieties has gradually extended in southwestern Japan. However, the area planted area with 'Hinohikari' still remains high at about 40% of the total rice planted area in southwestern Japan. Therefore, in these area, the development of cultivation techniques to reduce the occurrence of chalky grains has been necessary.

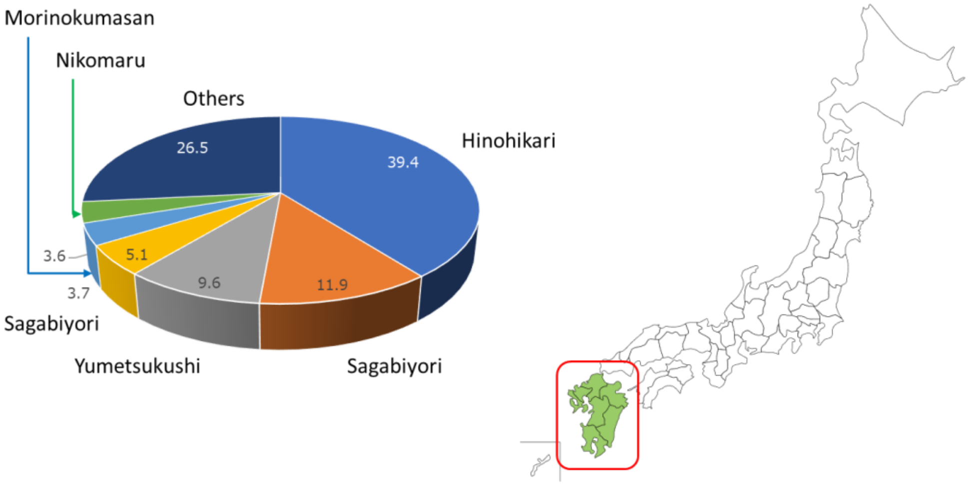

Fig. 6. Proportions of rice varieties planted in southwestern Japan.

CONDITIONS AFFECTING THE FREQUENCY OF EACH TYPE OF CHALKY GRAIN

Chalky grains are categorized into several types, mostly according to the position on the grain of the chalky appearance. To develop cultivation techniques to ameliorate the detrimental effects of high temperatures during grain ripening, it is important to analyze the conditions under which each type of chalky grain occurs.

Solar radiation and daily mean temperature during early ripening

Some research groups have analyzed the relationships between the proportion of each type of chalky grain and the weather or growing conditions. Wakamatsu *et al*. (2009) examined the relationships between solar radiation during early ripening (i.e., 20 days after heading) and revealed that the proportion of milky-white grains increased with decreasing solar radiation.

Kobata *et al*. (2004) reported that milky-white grains occured when the ability of the sources to supply carbohydrate to each developing grain is insufficient. These results mean that the frequency of milky-white grains increaseed when rice plants ripened under high temperatures coupled with low solar radiation. In contrast, basal-white and white-back grains increased when rice plants ripened under high temperatures (Morita *et al.* 2005a; Wakamatsu *et al*. 2008).

Nitrogen status of rice plants

Several research groups have analyzed the relationships between nitrogen status of the rice plant (e.g., the protein concentration in the grain and the leaf chlorophyll content, as measured with a SPAD chlorophyll meter) and the proportion of white-back and basal-white grains. Wakamatsu *et al*. (2008) showed that the proportion of white-back grains had a significant negative correlation with grain protein concentration. Furthermore, the proportion of basal-white grains was significantly negatively correlated with not only grain protein concentration (Morita *et al*. 2005), but also with the SPAD value at full heading (Morita *et al.* 2015). These results mean that white-back and basal-white grains increase in frequency when rice plants with low nitrogen concentrations ripen under high temperatures (Morita *et al*. 2016). Therefore, the frequency of basal-white and white-back grains might be reduced by nitrogen application.

A WEATHER-ADAPTIVE TOP-DRESSING TECHNIQUE

As a countermeasure against the damage caused by high temperatures, a novel weather-adaptive top-dressing technique, based on the results of analysis of the conditions under which each type of chalky grain occurred, and the weather forecast during ripening is being developed (Morita 2011; Morita *et al*. 2015).

In this technique, leaf color is measured before heading (Fig. 7). When high temperatures are forecast prior to ripening, the amount of top-dressing nitrogen applied can be optimized based on the leaf color and an equation to calculate the amount of nitrogen applied, to reduce the occurrence of basal-white and white-back grains. In contrast, when high temperatures are not forecast prior to ripening, the amount of top-dressing applied is decided according to the conventional method used by farmers. We are currently conducting demonstration experiments in farmers' fields. In addition, nitrogen application just before heading has a risk of increasing the protein concentration of the grain. There is a negative correlation between the protein concentration in the grain and the palatability of cooked rice (Ishima *et al*.

1974). A top-dressing technique, which can manage to decrease the proportion of chalky grains while avoiding high protein concentrations in grain leading to low palatavility of cooked rice, will be necessary.

The frequency of milky-white grains increases mainly when rice plants ripen under low levels of solar radiation (Wakamatsu *et al*. 2009). To reduce the occurrence of milky-white grains, it is important to increase the available assimilate supply per grain. Kobata *et al*. (2004) reported that the occurrence of milky-white grains could be reduced by decreasing the number of spikelets per panicle. It was considered that, when low solar radiation is forcast prior to ripening, the amount of top-dressing nitrogen should be reduced (Morita 2011). However, this strategy contains the risk of decreasing grain yield by decreasing the number of spikelets.

It is anticipated that this technique will facilitate consistant rice production under climate changes.

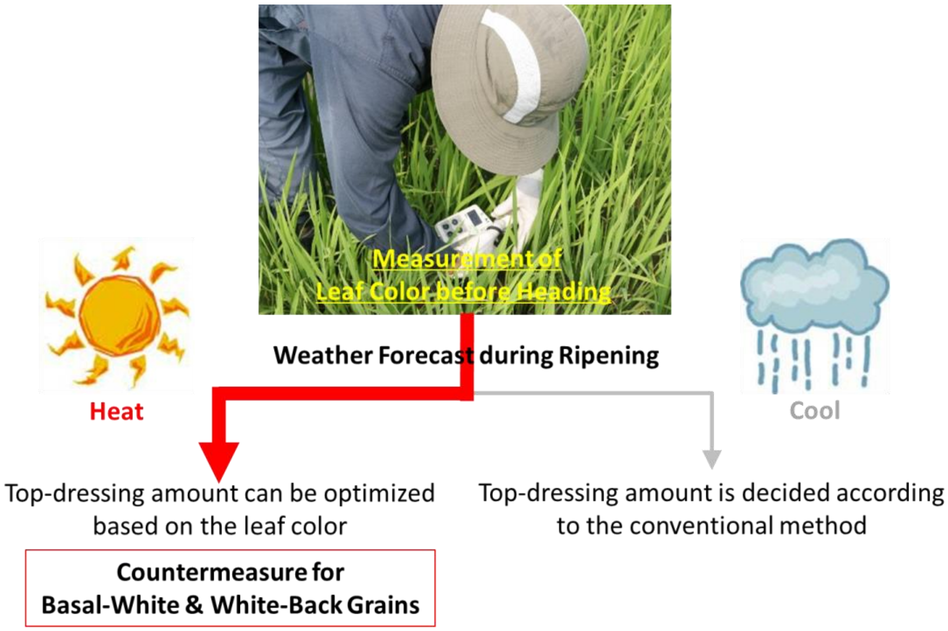

Fig. 7. Weather-adaptive top-dressing technique.
This scheme was modified from that reported by Morita (2011).

CONCLUSION

Heat-tolerant varieties such as 'Nikomaru' have been developed and have demonstrated tolerance in high-temperature years such as 2010. The introduction of heat-tolerant varieties is effective at reducing the frequency of low-quality grain types.

It was found that basal-white and white-back grains increase when rice plants with a low nitrogen concentration ripen under high temperatures. Based on this result, we are developing a novel weather-adaptive top-dressing technique. When high temperatures are expected prior to ripening, the amount of top-dressing can be optimized based on the leaf color and an equation to reduce the occurrence of basal-white and white-back grains. We plan to increase the accuracy of the technique through demonstration experiments in farmers' fields.

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