Low Grain Ripening in the New Plant Type Rice due to Shortage of Assimilate Supply

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Abstract

Grain ripening in the new plant type rice (NPT) is sometimes poor; our objective was to clarify why. NPT and two rice cultivars with high grain ripening were grown in a paddy field. Panicles cut five days after heading were transported to the laboratory and incubated in a liquid cultural solution under artificial environmental conditions for about one week. The spikelet weight increased as sucrose concentration in the solution increased to a maximum of 40 ~ 60 g/L, which was the optimal concentration of sucrose for all three cultivars. However, the spikelet dry weight of the NPT under the incubated condition was significantly higher than that under the field condition, while the other cultivars showed similar weights or only slight increases. The ratio of panicle dry weight increase/absorbed sucrose was 0.7 and similar among the three cultivars. Thus, spikelet dry weight in the NPT would increase if there was an abundant supply of assimilates. When the plant density of field-grown NPT was halved after heading to increase assimilate supply to the grain, the grain filling improved. It was concluded that the low grain ripening in NPT results from a shortage of assimilate supply to grain. Likewise, neither the inadequacy of assimilate transport system to the grains or a low efficiency of assimilate partition in the grain can be assumed to limit the grain ripening in NPT.

Media summary

Low grain ripening of the new plant type rice results from shortage of assimilate supply to grain during the grain filling period.

Key Words

Assimilate, Conversion efficiency, Ear culture, Grain, New plant type, Rice

Introduction

In recent decades, new rice genotypes have been bred to increase grain yield potential. The new plant type (NPT) line of the International Rice Research Institute (IRRI) is one of these genotypes (Kush and Peng 1996). The NPT lines are characterized by fewer tillers and a greater density of spikelets. Although the NPT lines clearly suggest a higher potential yield (Peng et al 1999), their actual yields have been similar to or lower than those of the standard improved cultivars (Horie 2001). The lower yield results from low grain ripening. There are several hypotheses for the poor grain filling of NPT lines, including inferior assimilate accumulation capacity in the panicle or spikelet (Yamagishi et al. 1996, Kush and Peng 1996). It has been suggested that morphological impediments such as arrangement of spikelets or vascular bundle connections for assimilate transport restrict grain ripening in NPT lines, although assimilate supply to grain is one of the dominant factors determining grain ripening in rice (Kobata et al. 2000). Our objective was to test the hypothesis that shortage of assimilate supply to grain is the dominant reason for low grain ripening in NPT cultivars. To test this hypothesis, we observed whether grain ripening improved if assimilate supply to grains during grain filling period was improved by a panicle solution culture or field thinning treatment.

Methods

Plant materials

The improved lowland cultivars, Nipponbare, Koshihikari and IR65564-44-2-2(NPT), were grown in the clay soil of the paddy fields at the experimental farm of Shimane University, Matsue, Japan. Nipponbare was transplanted on 26 June 2002, Koshihikari on 29 May 2002 and IR65564-44-2-2 on 22 May 2002. IR65564-44-2-2 occupied an area 11 m in length and 8 m in width while other cultivars occupied an area of 5.0 m in length and 2.8 m in width. All rows were 0.3 m in width with a row spacing of 0.15 m. Fertilizers for Nipponbare, Koshihikari and IR65564-44-2-2 were applied at a rate of 4-8-4 g/m^2 in the form of ammonium sulphate, super phosphate and potassium chloride,respectively, before transplanting. Nitrogen was top-dressed at the early tillering stage (Nipponbare and IR65564-44-2-2) and nitrogen was top-dressed close to the panicle initiation stage at a rate of 4.0 g/m^2 (all cultivars). Panicles on the main stems or primary tillers headed within the late morning of the same day were tagged.

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Thinning treatment

Plant density in part of the IR65564-44-2-2 field was halved from the full heading stage to increase assimilation during the grain filling period.

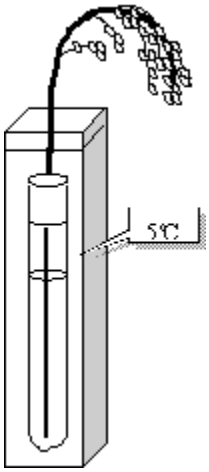

Figure 1. Rice panicle solution culture method. Cut edge of panicle is immersed in a test tube containing sucrose and MS solutions. The test tube is housed in a refrigerator at 5 ?C while the upper parts of the panicle are in 30 ?C air and 24 h illuminated conditions (Kobata et al. 2001). The base of the panicles were immersed in a series of sucrose concentrations of 0, 20, 40, 60, and 80 g/L.

Culture method of detached panicles

Culture methods and procedure were derived from Kobata et al. (2001) (Figure 1). At five days after heading, when the flowering in the panicles was almost finished, shoots were cut from the stem base in the early evening. The stem base was immediately immersed in shallow water, and the detached shoots were enclosed in a plastic bag. After the shoots were carried to the laboratory, each stem just below the node of the flag leaf was cut off in fresh water to protect against capillary discontinuity, and the flag leaf was removed. The stem below the neck node of the panicle was sterilized with 25 g/L of Antiformin solution for 10 minutes and then washed with water. Through a small hole in a plastic cap, the neck of the panicle was placed into a test tube with an inside diameter/height of 0.018/0.200 m containing 45 ?10^{-3} L of culture solution. Each test tube was filled with a half –strength Murashige & Skoog Plant Salt Mixture (MS) (Nippon Seiyaku Co., Tokyo) containing sucrose at 0, 20, 40, 60, and 80 g/L. The experiment was conducted in a random design with four replications. The test tubes were housed in a refrigerator at 5 ?C

(Engel, Sawafuji Elec. Co., Tokyo) to prevent microbial contamination of the solution, and the upper parts of the panicles were exposed to air in an incubator at 30 ?C (NK Systems Biotron, Nippon Ika Co., Tokyo). Styrofoam plates were used to form partitions between the test tubes and the upper parts of the panicles. The panicles were continuously exposed to fluorescent light at 84 μmol m^{-2} s^{-1}. At 0 and 7 or 8 days after the start of culture, four panicles from each treatment were harvested, dried in an oven at 80 ˚C for 48 h, divided into spikelets and other parts, and weighed. At day 0 and day 7 or 8, the spikelet dry matter of field-grown plants was measured. The sugar concentrations in the culture solutions were monitored with a refractometer (N-1E, Atago Co., Tokyo) before and after the culture. The average spikelet dry matter per panicle was calculated to eliminate the effect of the spikelet number on the response of spikelet dry matter increase to the concentration of sucrose in the culture solution. Spikelet number per panicle of incubated panicles differed among cultivars, with Nipponbare at 103?6, Koshihikari at 107?3 and IR65564-44-2-2 at 274?12 (mean?se for all samples).

Results and Discussion

Response of spikelet dry weight to different sucrose concentrations

The relationship between the average spikelet dry weight (SDW) and the sucrose concentration suggested that a sucrose concentration from 40 to 60 g/L was optimal for SDW in all three cultivars (Figure 2). The sucrose concentration in the sieve tube of the panicle neck in rice during the grain filling period has been suggested to be 200 g/L (Hayashi and Chino, 1990); hence, the optimal concentration of sucrose in our culture tubes was lower than that in the sieve tube. The critical sucrose concentration in liquid culture for SDW in rice was slightly higher than that in wheat (40 g/L) (Sing and Jenner, 1983) and soybean (35～40 g/L) (Egli et al., 1989).

SDW in the field-grown plants at the end-day of panicle incubation was similar or a little lower than that of incubated panicles in Nipponbare and Koshihikari. However, the incubated SDW in IR65564-44-2-2 was significantly higher than that in the field grown plants (Figure 2). This suggested that the spikelets in IR65564-44-2-2 suffered from a shortage of assimilate under field conditions, and that SDW should increase if abundant assimilate is supplied to the spikelets.

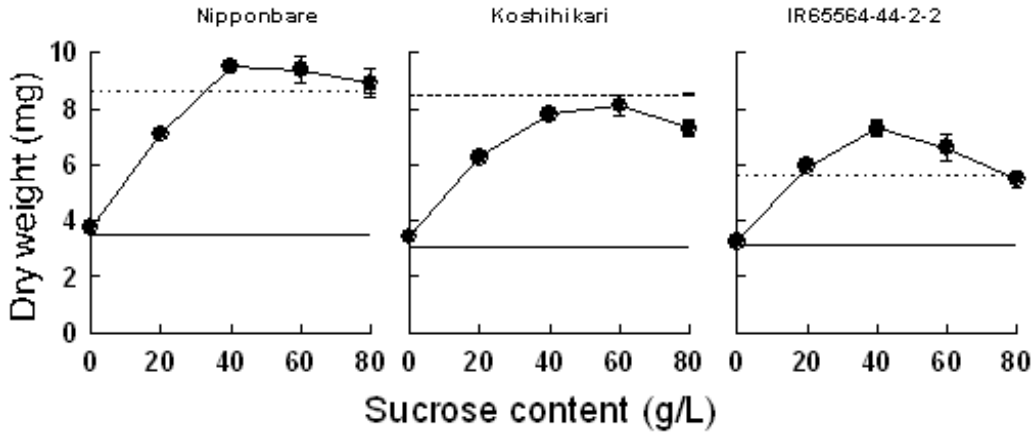

Figure 2 Spikelet dry weight at the start (—) and the end (●) of panicle incubation for 7 – 8 days under different sucrose concentrations of culture solution for three rice cultivars. The values are means ? one standard error of the mean (n = 4) (mg per spikelet). Dotted line indicates spikelet dry weight at the last day of the incubation in field grown plants. The panicle incubation was done under 30 C? and 48 h illuminated conditions.

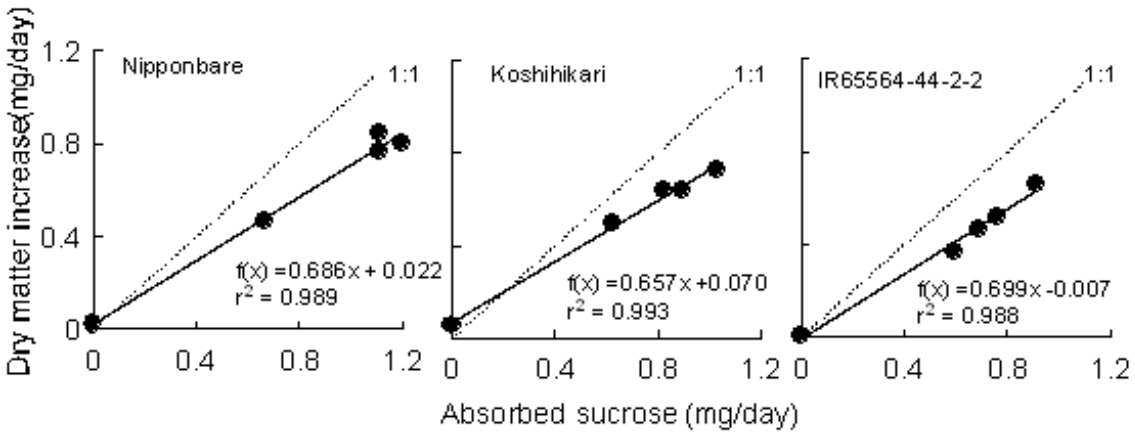

Figure 3 Relationship between panicle dry matter increase and absorbed sucrose during the incubation term in three rice cultivars. Each point is a mean of four replications. Data are indicated by mg/day/spikelet number.

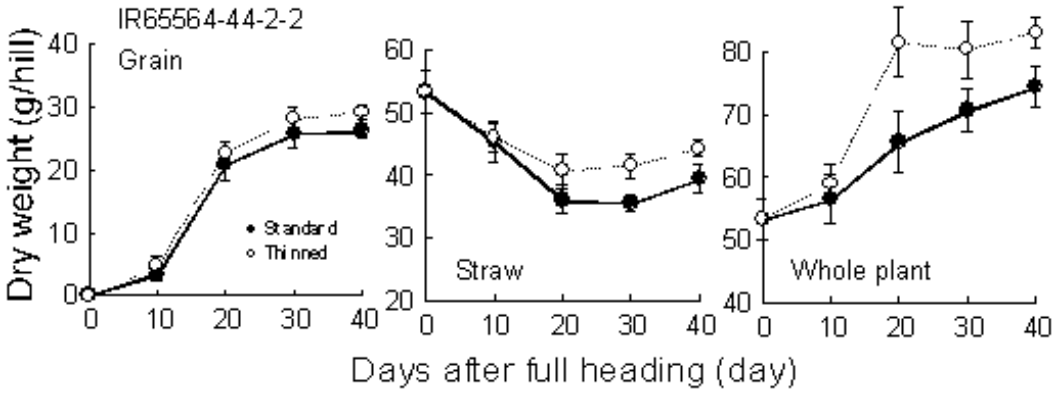

Figure 4 Dry matter increase of grain, straw, and whole plant of standard density and thinned plants in IR65564-44-2-2 under a filed condition. Plant density was halved at the full heading date. The values are means ? one standard error of the mean (n = 2).

Relationship between absorbed sucrose and spikelet dry matter increase

Panicle organs other than spikelets during the incubation showed much less increase than the SDW. Thus, most of the panicle dry matter increase must be due to increase of spikelets. The amount of absorbed sucrose could be estimated from the amount of solution culture absorbed because sucrose concentration in the solution scarcely changed during panicle incubation (Data are not shown) (Kobata et al. 2001). The relationships between increase of SDW and absorbed sucrose for three cultivars indicated that the slope between them was similar (from 0.66 to 0.70); generally, about 70% of absorbed sucrose turns into panicle dry matter increase while the remaining 30% is used for respiration (Figure 3). This suggests that the conversion efficiency of assimilate from supplied assimilate to panicle dry matter scarcely differed among the three cultivars.

Response of spikelet filling to thinning in filed condition

When plant densities of IR65564-44-2-2 in the field plot were halved at the full heading stage, dry matter production increased from the non-thinned control, and it resulted in the increase of the grain dry matter while decreases of the straw dry weight were less than that of the control (Figure 4). Thus, under field

conditions, spikelets of IR65564-44-2-2 would increase if each plant's total assimilation was increased by thinning.

Conclusion

Our results suggested that low grain ripening in the NPT rice, IR65564-44-2-2, results from a shortage of assimilate supply to spikelets, because the SDW increased when abundant assimilate was supplied by a culture solution and by a thinning treatment of field-grown rice. Hence, inadequacy of assimilate transport system to the grains or a low efficiency of assimilate partition into the grain is not what limits the grain ripening in NPT. Leaf area and/or photosynthetic activity in the NPT rice might not match the number of spikelets.

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