Yielding Performance of “Kita-aoba”, High-yielding Rice Variety for Hokkaido Region, Northern Japan

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Abstract: The yielding performance of the first high-yielding rice variety for Hokkaido, Kita-aoba, after application of various amounts of nitrogen (9.0 to 23.7 g m⁻² in 2008 and 10.5 to 16.5 g m⁻² in 2010) and under various planting densities (13.2 to 33.2 hills m⁻² in 2008 and 17.5 to 36.8 hills m⁻² in 2010) was examined in comparison with that of the common variety, Kirara397. Kita-aoba had higher grain yield than Kirara397 owing to its large sink capacity through larger sink capacity per unit biomass at heading. Kita-aoba had a high yield potential (the maximum grain yield of 1081 g m⁻²), and achieved a high grain yield even in Hokkaido where the rice-growing season is short. Kita-aoba had a large sink size, but, judging from the relationship between sink capacity and percentage of sink filled, further increase of sink size might not result in increase of grain yield. Kita-aoba showed a great increase in shoot dry matter from heading to maturity, but it was not enough to fill its large sink.

Key words: High-yielding rice, Sink capacity, Yield potential.

Breeding of high-yielding rice is a means of improving the food (forage) and energy self-sufficiency in Japan. Although high-yielding varieties suitable for Honshu, Shikoku and Kyushu areas have been released (Higashi et al., 1994; Imbe et al., 2004; Nakagomi et al., 2006; Goto et al., 2009), no high-yielding variety was available in Hokkaido region until 2007. In 2008, Kita-aoba (formerly called Hokkaishi308) was released as the first high-yielding variety for Hokkaido (Shimizu et al., 2008).

However, the yield potential of this high-yielding variety has not been clarified. Since grain yield is the product of shoot dry matter at maturity and harvest index, it is important to increase shoot dry matter for high grain yield. Although a long growth duration is an effective way to increase shoot dry matter (Nakano et al., 2008; Nakano and Morita, 2009), it is difficult to extend the growth duration of rice in Hokkaido due to the lower temperature compared with other regions in Japan. To find another means of increasing the grain yield in Hokkaido, we examined the biomass productivity of Kita-aoba in comparison with that of a common variety.

Grain yield can also be increased by increasing the high harvest index. In the Tohoku region, located south of Hokkaido, high-yielding varieties, Fukuhibiki, Takanari and Bekoaoba, showed a similar shoot dry matter but achieved higher grain yield than the common varieties, Akitakomachi and Hitomebore, owing to their high harvest index (Fukushima et al., 2011a). These high-yielding varieties in Tohoku also showed a large sink capacity. However, it is not clear whether Kita-aoba has a similar yield performance in Hokkaido.

The objectives of this study were to clarify the yield potential of Kita-aoba, compared with the common variety in Hokkaido, Kirara397, and to clarify the factors contributing to its high grain yield by evaluating the growth under various planting densities and amounts of nitrogen.

Materials and Method

1. Cultivation management

The field experiment was conducted using Kita-aoba in 2008 and 2010 in the paddy fields (Andosol) at the NARO Hokkaido Agricultural Research Center (Sapporo city, Japan: 43°0’N, 141°25’E). The number of replications was two in 2008 and three in 2010. Kirara397 was also used for comparison. In 2008, young seedlings were transplanted, and both young and mature seedlings were used in 2010 (only mature seedlings for Kirara397). Sowing date in 2008 was 15 April, and that in 2010 was 14 April for matured seedlings and 20 April for young seedlings. Seedlings were transplanted on 19 May in 2008 and on 20 May in 2010, using transplanting machine. Planting density of Kita-aoba
Table 1. Cultivation of Kita-aoba in 2008 and 2010.

|          | 2008                                      | 2010                                      |
|----------|-------------------------------------------|-------------------------------------------|
| Type of seedlings | Young                                     | Matured                                   |
| Planting densities (hills m$^{-2}$) | 13.2, 21.0 and 33.2 | 17.5, 26.5 and 34.9                      |
| Nitrogen application (g N m$^{-2}$) | 8.3-0-0-3-0, 8.3-0-0-3-0-1.7-0, 12.4-0-0-3-0, 12.4-0-3-0-1.7-0, 16.6-0-0-0-0, 16.6-0-0-0-3-0-1.7-0, 20.7-0-0-0-0-0-1.7-0 and 20.7-0-0-0-0-3-0-1.7-0 | 0-0-0-0-0 and 10.5-0-3-0-3, 10.5-0-0-0-0, 10.5-0-0-3-0-0, 10.5-0-0-0-3, 10.5-0-3-0-0 and 16.5-0-0-0-0 |

Nitrogen application indicates basal-panicle initiation stage-panicle formation stage-flag leaf stage-heading stage.
*Nitrogen application of 0-0-0-0-0 and 10.5-0-3-0-3 was examined in the planting density of 36.8 m$^{-2}$ in matured seedlings in 2010.

Fig. 1. Time course of mean air temperature in 2008 (a) and 2010 (b) and solar radiation in 2008 (c) and 2010 (d). Average value of 20 years from 1981 to 2000 is shown by solid line.
in 2008 ranged from 13.2 to 33.2 hills m\(^2\), and that in 2010 was from 17.5 to 36.8 hills m\(^2\) (Table 1). Total nitrogen application during growth of Kita-aoba was from 9.0 to 23.7 g m\(^2\) in 2008 and 10.5 to 16.5 g m\(^2\) in 2010. Planting density of Kirara397 was 21.0 hills m\(^2\), and the nitrogen application pattern was 8.3-0.4-0.9-1.7-0 in 2008. In 2010, planting density of Kirara397 was 18.4 hills m\(^2\) and nitrogen application was 10.5 g m\(^2\) at basal. No topdressing was applied for Kirara397 in 2010. In 2010, plot with no nitrogen application was also examined for both Kita-aoba and Kirara397. The amount of P\(_2\)O\(_5\) and K\(_2\)O applied each year was 8.0 g m\(^2\).

2. Measurements

The air temperature and solar radiation were measured at the meteorological station in NARO Hokkaido Agricultural Research Center. In both 2008 and 2010, ten hills of rice shoot were taken out from the field to determine shoot dry matter and nitrogen uptake at the panicle formation stage and heading stage (50% of panicles emerged). Tiller number was also counted at the panicle formation and heading stages. At maturity (90% of spikelets turned into yellow), 1.7 to 3.6 m\(^2\) was harvested at ground level in 2008 (area varied depending on available plot size). Sampled area at maturity in 2010 was 3.0 m\(^2\). From the sample at maturity, shoot dry weight, gross hulled grain yield (at moisture content of 15% g g\(^{-1}\)) (hereafter referred to as grain yield), yield components (panicle number per area, spikelet number per panicle, percentage of ripened grains, and ripened grain weight) and nitrogen content were determined. Hullled grains thicker than 1.8 mm were regarded as ripened grains (Kita-aoba and Kirara397 have similar grain size). From shoot dry matter and the amount of nitrogen fertilizer, fertilizer-N use efficiency for biomass production was defined as follows.
(Fertilizer-N use efficiency for biomass production) = 
((Shoot dry matter with nitrogen fertilizer)−(Shoot dry weight without nitrogen fertilizer))/(Amount of nitrogen fertilizer)

From grain yield and yield components, sink capacity (at moisture content of 15% g g⁻¹) and percentage of sink filled was determined by following equations.

(Sink capacity) = (Panicle number per area) × (Spikelet number per panicle) × (Ripened grain weight)
(Percentage of sink filled) = (Grain yield) / (Sink capacity) × 100

Results

1. Climate conditions during experiment

Mean air temperature in 2008 was generally higher than the average of 20 years, although sharp decrease was recorded in the end of May (soon after transplanting) and latter half of August (Fig. 1). Solar radiation in 2008 was also higher than the average except in the mid July. Although low temperature was observed in May and end of September, mean air temperature in 2010 was higher than the average. Solar radiation in 2010 also tended to be higher than the average, but that in July and early August was low.

2. Comparison between Kita-aoba and Kirara397

Nitrogen uptake by Kita-aoba tended to be higher than that by Kirara397 (Fig. 2). Kita-aoba also showed heavier shoot dry weight than Kirara397, although the difference in 2008 was not significant due to large error in Kita-aoba. Kita-aoba produced more shoot dry matter from heading to maturity than Kirara397. Grain yield of Kita-aoba was higher than that of Kirara397, owing to its larger sink capacity. Grain yield in 2010 was lower than in 2008, due to smaller number of panicles (data not shown). Kita-aoba tended to have more shoot dry matter without nitrogen fertilizer, and shoot dry matter tended to be increased more greatly by nitrogen fertilizer (Fig. 3). The ratio of sink capacity to shoot dry matter at heading was also higher in Kita-aoba than in Kirara397, although the difference in 2008 was relatively small and not significant (Fig. 4).
3. Yielding performance of Kita-aoba

Grain yield of Kita-aoba increased with increased nitrogen uptake at maturity, and the rate of yield increase decreased with increasing nitrogen uptake (Fig. 5). Grain yield had a strong positive correlation with the amount of shoot dry matter at maturity, but not with harvest index (Table 2). Grain yield also showed a strong positive correlation with sink capacity, and negative correlation with percentage of sink filled. These results indicated that biomass production and sink capacity must be sufficient to obtain a high grain yield in Kita-aoba supplied with nitrogen. Although a negative correlation was observed between sink capacity and percentage of sink filled, grain yield increased with the increase of sink capacity (Fig. 6). The grain size (i.e., grain weight) did not affect sink size, and sink capacity was determined by the number of spikelet per area (Table 2). Spikelet number per area was increased by both panicle number per area and spikelet number per panicle, but the contribution of the former was greater than that of the latter, judging from correlation coefficients. Rice with a larger sink capacity showed a greater shoot dry matter accumulation during the grain-filling period (Fig. 7). Shoot dry matter accumulation was almost equal to sink capacity if sink capacity was small, but it was less than sink capacity if sink capacity was large. Grain yield increased with increasing shoot dry matter accumulation during the grain-filling stage (Fig. 8).

The highest grain yield, 1081 g m$^{-2}$, was achieved in 2008, with the planting density of 21.0 hills m$^{-2}$ and nitrogen application of 19.6 g m$^{-2}$ (16.6-0.4-0.9-1.7-0) (Table 3). A large sink capacity owing to large number of panicles or spikelets per area resulted in a high grain yield, even though the percentage of ripened grains or sink filled was low. A high planting density over 30 hills m$^{-2}$ could not achieve a large panicle number (maximum was 639 panicles m$^{-2}$ in 2008) or sink capacity (maximum was 1238 g m$^{-2}$ in 2008), resulting in reduced grain yield (maximum was 875 g m$^{-2}$ in 2008).

**Table 2.** Correlation coefficient between grain yield and yield-related factors in Kita-aoba.

| Factor 1       | Factor 2              | Correlation coefficient |
|----------------|-----------------------|-------------------------|
| Grain yield    | Shoot dry matter      | 0.929**                 |
|                | Harvest index         | −0.184                  |
| Grain yield    | Sink capacity         | 0.860**                 |
| Percentage of sink filled | Spikelet number per area | 0.960**     |
| Spikelet number per area | Panicle number per area | 0.937**     |
| Spikelet number per panicle | Spikelet number per panicle | 0.570**     |

** indicates significant correlation at P=0.01 level. n=54 (including the data in 2008 and 2010).

**Fig. 6.** Relationship between sink capacity and percentage of sink filled of Kita-aoba in 2008 and 2010. Linear regression is drawn, and ** indicates significant at P=0.01 level. The broken lines indicate the relationship for grain yield of 400, 600, 800, 1000 and 1200 g m$^{-2}$.

**Fig. 7.** Relationship between sink capacity and shoot dry matter accumulation from heading to maturity of Kita-aoba in 2008 and 2010. Linear regression is shown, and ** indicates significant at P=0.01 level.

**Discussion**

Kita-aoba showed the maximum grain yield of 1081 g m$^{-2}$, indicating its high yield potential. This also indicated that high grain yield can be achieved in Hokkaido with the limitation by lower temperature compared with other regions in Japan. Relationship between nitrogen uptake and grain yield (Fig. 5) indicated that Kita-aoba in this study exhibited almost its potential grain yield. The regression line suggested that grain yield was increased by increasing the nitrogen uptake up to around 25 g m$^{-2}$, but
the increment was not large.

One of the high-yielding factors in Kita-aoba, compared with Kirara397, was the larger sink per unit biomass at heading. A larger number of spikelets per panicle of Kita-aoba (107 vs. 75 spikelets per panicle) resulted in a larger sink capacity. Achieving a large spikelet number per area and sink capacity through large number of spikelet per panicle was common to other high-yielding varieties such as Bekoaoba, Fukuhibiki, Hokuriku193 and Takanari (Nagata et al., 2001; Goto et al., 2009; Taylaran et al., 2009; Fukushima et al., 2011a). Grain weight of Kita-aoba was lighter than that of Kirara397 (22.4 vs. 23.3 g per 1000 grains), and Kita-aoba had a larger sink capacity through a large number of spikelets per area than Kirara397 (51.3 vs. 30.6×10³ spikelets m⁻²), which was larger than that in other high-yielding varieties mentioned above. Kita-aoba had both a large panicle number and spikelet number per panicle, resulting in larger spikelet number per area than other high-yielding varieties. Nitrogen uptake and fertilizer-N use efficiency for biomass production also tended to be higher than Kirara397 (Fig. 2b and Fig. 3). High fertilizer-N use efficiency for biomass production was also reported for Takanari (Taylaran et al., 2009).

The contribution of shoot dry matter to grain yield was larger than that of harvest index in Kita-aoba (Table 2). Large sink capacity also contributed to high grain yield, as discussed above. However, a further increase in sink capacity may not result in the increase in grain yield, judging from the relationship between sink capacity and percentage of sink filled (Fig. 6). Enhancing source ability is required for further increase in grain yield. Another character of Kita-aoba was large increment of shoot dry matter from heading to maturity (the maximum was 1364 g m⁻²). The increment of Kita-aoba was larger than in other high-yielding varieties reported in other studies (Nagata et al., 2001; Fukushima et al., 2011a, 2011b), which suggests that Kita-aoba had both large sink capacity and source ability (shoot dry matter production in grain-filling stage). This large biomass production in the later growth stage could be essential for a high-yielding variety in Hokkaido with a lower temperature, since early growth is suppressed by lower temperature. Although Kita-aoba increased the biomass during the grain-filling stage, it was not enough to fill its large sink (Fig. 8). Carbohydrates stored at heading such as non-structural carbohydrate might be another source for filling the sink (Song et al., 1990; Nagata et al., 2001), but the contribution of such carbohydrates to the grain yield might not be large in Kita-aoba since shoot dry matter at heading was not so large. Enhancing source ability may further increase the grain yield of Kita-aoba, by improving the balance between sink and source (Takami et al., 1990).

Conclusions

Kita-aoba had a maximum grain yield of 1081 g m⁻², showing its high yield potential. The high grain yield can be achieved even in Hokkaido, owing to the large sink capacity and high sink production efficiency. Nitrogen uptake and biomass production efficiency also tended to be higher in Kita-aoba than in Kirara397. Another factor of high yield in Kita-aoba was shoot dry matter production at the grain-filling stage.

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