Note

Breeding of new rice cultivar ‘Tohoku 194’ with ‘Sasanishiki’-type good eating quality of cooked rice

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Cooked rice of ‘Sasanishiki’ is soft and not as sticky as those of Japanese leading cultivars ‘Koshihikari’ and ‘Hitomebore’. As a method for efficient selection of a breeding line having a good eating quality like that of ‘Sasanishiki’, the use of physical properties of cooked rice and cooking quality was examined. There were differences of physical properties of the surface layer, starch-iodine blue value per solid substance weight in cooking water and volume expansion of cooked rice between ‘Sasanishiki’ and ‘Hitomebore’, these properties being considered to be usable for the selection of breeding lines. Using these traits as selection targets, one line, named ‘Tohoku 194’, which has eating quality highly similar to that of ‘Sasanishiki’ and cold tolerance derived from ‘Hitomebore’, was selected from progeny of a cross between ‘Sasanishiki’ and ‘Hitomebore’. An application for registration as a new variety has been submitted for ‘Tohoku 194’ under the Japanese Plant Variety Protection Act, and is expected to become a recommended cultivar in Miyagi Prefecture. ‘Tohoku 194’ may fulfill various demands of consumers and companies in the food industry.

Key Words: paddy rice, physical property, cooking quality, cold tolerance.

Introduction

Major rice cultivars in Japan are ‘Koshihikari’ and its progeny, e.g., ‘Hitomebore’ (Sasaki et al. 2002), ‘Hinohikari’ and ‘Akitakomachi’, which are relatively sticky when cooked. ‘Sasanishiki’ (Suena et al. 1963), which is soft but not so sticky, is preferred for box lunches and sushi and is in demand by the food industry and consumers. However, the supply of ‘Sasanishiki’ rice is lower than its demand. Therefore, a new cultivar having ‘Sasanishiki’-type good eating quality should be developed.

‘Sasanishiki’, developed in 1963, was cultivated in five prefectures of the Tohoku region, especially in Miyagi Prefecture and gained status as a high quality rice. In 1990, 207,439 ha were devoted to its cultivation (11.3% of the total paddy field in Japan) and it became the second most popular rice cultivar. However, due to instability of climate, cool-weather damage at the booting stage and high-temperature damage at the grain filling period became prevalent. Since ‘Sasanishiki’ has low cold tolerance at the booting stage, low blast resistance, low lodging resistance and low pre-harvest sprouting resistance, annual fluctuation of yield, taste and rice quality became conspicuous in this cultivar. Since serious cool-weather damage in 1993, ‘Sasanishiki’ has been replaced by ‘Hitomebore’ having high cold tolerance at the booting stage and the production area of ‘Sasanishiki’ has steeply decreased to 8,000 ha (0.5%) in 2010, the 19th among rice cultivars.

A sensory test of rice taste commonly used is suitable for testing relatively sticky rice such as ‘Koshihikari’, but it is difficult to apply cultivars with the ‘Sasanishiki’-type good eating quality. Quantitative analysis of amylose and protein and use of near-infrared spectrometry cannot evaluate the ‘Sasanishiki’-type quality, and a reliable method for evaluation and selection of the ‘Sasanishiki’-type quality has not been established.

In the present study, we applied the method developed by Okadome et al. (1998, 1999, 2003), which enables measurements of multiple physical properties of a single cooked rice grain, to evaluate ‘Sasanishiki’-type quality and found that ‘Sasanishiki’-type quality can be assessed by physical properties of the surface layer, starch-iodine blue value per solid substance weight and volume expansion of cooked rice (Batcher et al. 1956, Chikubu et al. 1970, 1983). Use of these indices enabled selection of a breeding line having the ‘Sasanishiki’-type quality from progeny of a cross between ‘Sasanishiki’ and ‘Hitomebore’ and a new cultivar named ‘Tohoku 194’ was developed. In this paper, the breeding process of ‘Tohoku 194’ and its characteristics, mainly of eating quality, are described.
Materials and Methods

Investigation of traits related to the taste of cooked rice

A total of 18 samples of rice grains produced at the Miyagi Pref. Furukawa Agr. Exp. Stn. from 2003 to 2005 and in 2008 and three samples produced in other prefectures in 2008 were investigated (Table 1). The physical properties of cooked rice, i.e., hardness, stickiness and adhesion distance, were analyzed by a tensipresser (Okadome et al. 1998, 1999, 2003) and cooking quality of rice, i.e., volume expansion and starch-iodine blue value per solid substance weight (Batcher et al. 1956, Chikubu et al. 1970, 1983), were examined at the National Food Research Institute Japan. Analysis of amylose and protein contents and a sensory test of cooked rice were carried out at Miyagi Pref. Furukawa Agr. Exp. Stn.

Selection of breeding lines having of ‘Sasanishiki’-type eating quality

‘Sasanishiki’ was crossed with pollen of ‘Hitomebore’ in June 2001. Plants from F₁ to F₅ were grown in a greenhouse for accelerated generation from July in 2001 to July in 2002. F₅ plants were grown in a paddy field and seeds were harvested from each plant in 2003. In 2004, 179 lines of F₅ were grown in the paddy field and also in a deep-water field for a yield test and a test of specific characteristics, and 13 lines with good agronomic characteristics were selected in 2005. By the sensory test of cooked white rice grains and a test of the gloss of cooked white rice grains, four lines were selected and used for tests of physical properties and cooking quality of white rice grains (Table 3). Agronomic characteristics and taste-related characteristics of the four lines of F₅ were again evaluated and one line having taste-related characteristics most similar to those of ‘Sasanishiki’ was selected in 2006. The selected line was named ‘Tohoku 194’ and distributed to prefectures in Tohoku region for adaptability tests from 2007 to 2010. Investigation of the taste-related characteristics of ‘Tohoku 194’ was repeated in 2007 and 2008.

Results and Discussion

Taste-related characteristics of ‘Sasanishiki’

The physical properties of the surface layer were significantly different between the five cultivars shown in Table 1, while there were no remarkable differences between them in those of all layers analyzed by a high compression test. The hardness of the surface layer of cooked white rice grains in ‘Sasanishiki’ was found to be lower than that in ‘Hitomebore’ (Tables 1, 2). Among the eight cultivars tested, ‘Sasanishiki’ showed the lowest hardness of the surface layer (Table 4). Stickiness and adhesion distance of the surface layer in ‘Sasanishiki’ were found to be lower than those of the four lines of F₅, which were subjected to a yield test and a test of specific characteristics, and 13 lines with good agronomic characteristics were selected in 2005. By the sensory test of cooked white rice grains and a test of the gloss of cooked white rice grains, four lines were selected and used for tests of physical properties and cooking quality of white rice grains (Table 3). Agronomic characteristics and taste-related characteristics of the four lines of F₅ were again evaluated and one line having taste-related characteristics most similar to those of ‘Sasanishiki’ was selected in 2006. The selected line was named ‘Tohoku 194’ and distributed to prefectures in Tohoku region for adaptability tests from 2007 to 2010. Investigation of the taste-related characteristics of ‘Tohoku 194’ was repeated in 2007 and 2008.

Table 1. Rice quality evaluation of cooked rice (major cultivar)

| Crop year | Cultivar   | Physical properties of surface layer (Low compression 25%) | Physical properties of all layers (high compression 90%) | Cooking quality |
|-----------|------------|----------------------------------------------------------|--------------------------------------------------------|----------------|
|           |            | Hardness (H₁₁) (N) | Stickiness (-H₁₁) (N) | Adhesion distance (L₃) (mm) | Degree of balance (H₁₁/H₁₁) | Hardness (H₂₂) (N) | Stickiness (-H₂₂) (N) | Adhesion distance (L₆) (mm) | Degree of balance (H₂₂/H₂₂) | Expanded volume (cm³) | Starch-iodine blue value/solid substance weight |
| 2003–2005 | Sasanishiki | 0.79 a | 0.16 a | 1.21 a | 0.20 ab | 19.5 a | 3.99 a | 1.91 a | 0.20 a | 33.9 ab | 3.28 a |
|           | Sasashigure | 0.89 b | 0.17 ab | 1.26 a | 0.19 bc | 20.5 a | 3.97 a | 1.93 a | 0.19 a | 32.3 bc | 3.19 b |
|           | Koshihikari | 0.86 b | 0.18 b | 1.24 a | 0.21 a | 19.4 a | 3.99 a | 1.90 a | 0.21 a | 32.0 bc | 3.20 b |
|           | Hitomebore  | 0.86 b | 0.18 b | 1.35 b | 0.21 a | 19.3 a | 4.10 a | 1.80 a | 0.22 b | 31.5 c   | 3.00 b |
|           | Toyonishiki | 0.85 b | 0.15 a | 1.11 c | 0.18 c | 19.9 a | 3.41 b | 1.89 a | 0.17 c | 34.9 a   | 3.72 c |

Values with the same letter within a column are not significant different (Tukey, P < 0.05).

Table 2. Analysis of variance for 10 traits in 5 varieties

| Source of variance | df | Mean square |
|--------------------|----|-------------|
|                    |    | Physical properties of surface layer (Low compression 25%) | Physical properties of all layers (high compression 90%) | Cooking quality |
|                    |    | Hardness (H₁₁) (N) | Stickiness (-H₁₁) (N) | Adhesion distance (L₃) (mm) | Degree of balance (H₁₁/H₁₁) | Hardness (H₂₂) (N) | Stickiness (-H₂₂) (N) | Adhesion distance (L₆) (mm) | Degree of balance (H₂₂/H₂₂) | Expanded volume (cm³) | Starch-iodine blue value/solid substance weight |
| Cultivar           | 4  | 8.1E–01 ** | 8.9E–04 ** | 4.6E–02 ** | 9.2E–04 ** | 1.5E–01 | 4.5E–02 * | 1.0E–02 | 1.7E–03 ** | 12.18 ** | 0.42 ** |
| Year               | 2  | 1.4E–04 | 1.1E–02 ** | 4.1E–01 ** | 1.5E–02 ** | 6.6E–01 * | 1.7E–01 ** | 1.5E+00 ** | 7.3E–03 ** | 37.60 ** | 0.17 ** |
| C × Y             | 8  | 4.5E–03 ** | 1.1E–04 | 5.9E–03 * | 4.7E–05 | 7.7E–02 | 7.3E–03 | 3.0E–02 | 1.5E–04 | 6.80 * | 0.02 ** |
| Error             | 15 | 1.1E–03 | 1.3E–04 | 1.9E–03 | 9.1E–05 | 1.4E–01 | 9.9E–03 | 2.0E–02 | 1.2E–04 | 1.70 | 0.01 |

***: Significant at the 5% and 1% levels, respectively.
in ‘Hitomebore’, but higher than those in ‘Toyonishiki’, which is known to be inferior in taste. Although there were annual changes of the values, the order of cultivars did not change, suggesting the physical properties of the surface layer to be useful indices for comparison of taste-related characteristics of cultivars.

There were annual changes in starch-iodine blue value per solid substance weight, while there were clear differences of these characteristics between cultivars. The starch-iodine blue value per solid substance weight of ‘Sasanishiki’ was higher than those of ‘Hitomebore’ but lower than those of ‘Toyonishiki’. Expanded volume of ‘Sasanishiki’ was also higher than that of ‘Hitomebore’ but lower than that of ‘Toyonishiki’. Although ‘Asahi’ in Okayama Prefecture is known to be different from ‘Koshihikari’ and ‘Hitomebore’ in taste, ‘Asahi’ showed the lowest expanded volume and starch-iodine blue value per solid substance weight comparable to that of ‘Koshihikari’ (Table 4). These results suggest that the starch-iodine blue value per solid substance weight is also usable for distinguishing ‘Sasanishiki’-type eating quality from ‘Koshihikari-Hitomebore’-type eating quality.

Selection of a line having ‘Sasanishiki’-type eating quality

Physical properties of cooked white rice grains and cooking quality of the four lines selected in 2005 are shown in Table 3. Although there was no difference in the sensory test between the four lines, physical properties of cooked white rice grains and cooking quality were different between these lines. Physical properties of the surface layer and the starch-iodine blue value per solid substance weight of 5P-317, which later became ‘Tohoku 194’, were the nearest to those of ‘Sasanishiki’. There was no line having physical properties of cooked white rice grains and cooking quality similar to those of ‘Hitomebore’ (Figs. 1, 2).

**Taste-related characteristics of ‘Tohoku 194’**

In the repeated investigations of ‘Tohoku 194’ from 2005 to 2008, except 2006, this line showed physical properties of the surface layer, volume expansion and starch-iodine blue value per solid substance weight comparable to those of ‘Sasanishiki’ (Table 4). Amylose content in white rice grains was lower than those of ‘Sasanishiki’ and ‘Hitomebore’, while protein content was similar to that of ‘Hitomebore’ and slightly lower than that of ‘Sasanishiki’ (Table 5). Selection of lines having ‘Sasanishiki’-type eating quality by the contents of amylose and proteins was considered to be difficult. By sensory tests of hot rice, chilled rice and vinegared rice, the softness and stickiness of ‘Tohoku 194’ were

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**Table 3. Rice quality evaluation of cooked rice (selection lines)**

| Crop year | Cultivar               | Physical properties of surface layer (Low compression 25%) | Cooking quality | Taste evaluation |
|-----------|------------------------|----------------------------------------------------------|----------------|-----------------|
|           |                        | Hardness (H1) (N) | Stickiness (−H1) (N) | Adhesion distance (L3) (mm) | Degree of balance (−H1/1) | Expanded volume (cm³) | Iodine blue value/solid substance weight | Overall  |
| 2005      | 5P−307                 | 0.89            | 0.21            | 1.37           | 6.52             | 32.15                | 3.42                   | 1.2     |
|           | 5P−320                 | 0.82            | 0.19            | 1.37           | 7.21             | 30.53                | 3.57                   | 1.3     |
|           | 5P−321                 | 0.92            | 0.20            | 1.34           | 6.70             | 30.96                | 3.34                   | 1.2     |
|           | 5P−317 (Tohoku194)     | **0.86**        | **0.19**        | **1.29**       | **6.79**         | **31.66**            | **3.47**               | **1.2** |
|           | Sasanishiki            | **0.87**        | **0.19**        | **1.31**       | **6.89**         | **30.90**            | **3.47**               | **1.2** |
|           | Hitomebore             | 0.93            | 0.22            | 1.54           | 7.00             | 30.21                | 3.25                   | —       |

Overall: Good (+5)–Bad (−5)
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assessed to be comparable to those of ‘Sasanishiki’ and stickiness of ‘Tohoku 194’ was evaluated to be lower than that of ‘Hitomebore’ (Table 6). These results suggest ‘Tohoku 194’ to be suitable for sushi, onigiri and box lunch.

General characteristics of ‘Tohoku 194’

Heading date and maturation date of ‘Tohoku 194’ were comparable to those of ‘Sasanishiki’ and ‘Hitomebore’ and culm length of ‘Tohoku 194’ was shorter than those of ‘Sasanishiki’ and ‘Hitomebore’ (Supplemental Table 1). The number of panicles per unit area of ‘Tohoku 194’ was less than that of ‘Sasanishiki’ and larger than that of ‘Hitomebore’.

Lodging resistance of ‘Tohoku 194’ was as strong as that of ‘Hitomebore’ and stronger than that of ‘Sasanishiki’ (Supplemental Table 2). Cold tolerance at the booting stage and high-temperature tolerance at the grain filling stage of ‘Tohoku 194’ were similar to those of ‘Hitomebore’ and higher than those of ‘Sasanishiki’. The pre-harvest sprouting rate of ‘Tohoku 194’ was comparable to that of ‘Hitomebore’ and lower than that of ‘Sasanishiki’. ‘Tohoku 194’ had no true blast-resistance gene and field resistance to panicle blast of ‘Tohoku 194’ was lower than that of ‘Hitomebore’.

The yield of brown rice of ‘Tohoku 194’ was as high as that of ‘Sasanishiki’ (Supplemental Table 3). ‘Tohoku 194’ had a slightly lower grain weight than ‘Hitomebore’. Grain quality evaluated by visual inspection was better in ‘Tohoku 194’ than in ‘Sasanishiki’.

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**Table 4. Rice quality evaluation of cooked rice (Tohoku194)**

| Crop year | Cultivar   | Physical properties of surface layer (Low compression 25%) | Cooking quality |
|-----------|------------|-----------------------------------------------------------|-----------------|
|           |            | Hardness (H1) (N) Stickiness (−H1) (N) Adhesion distance (L3) (mm) Degree of balance (−H1/H1) | Expended volume (cm³) | Iodine blue value/solid substance weight |
| 2005–2008 (except 2006) | Tohoku194  | 0.70 a 0.16 a 1.28 a 0.22 a | 35.2 3.41 |
|           | Sasanishiki | 0.73 ab 0.17 a 1.30 a 0.23 a | 33.7 3.46 |
|           | Hitomebore  | 0.78 b 0.19 b 1.43 b 0.24 a | 32.1 3.13 |
| 2008      | Asahi (OKAYAMA) | 0.61 0.18 1.30 0.30 | 31.5 3.14 |
|           | Hatushima (Gifu) | 0.75 0.23 1.25 0.31 | 38.3 2.96 |
|           | Aichinokaoori-SBL (AICHI) | 0.75 0.17 0.98 0.22 | 34.6 3.10 |
|           | Tohoku 194  | 0.44 0.12 1.30 0.27 | 39.3 3.35 |
|           | Sasanishiki | 0.53 0.14 1.34 0.27 | 35.7 3.45 |
|           | Hitomebore  | 0.54 0.16 1.41 0.29 | 34.8 3.01 |
|           | Sasashigure | 0.55 0.15 1.32 0.27 | 34.5 2.62 |
|           | Toyonishiki | 0.63 0.17 1.17 0.27 | 40.7 3.35 |
|           | Koshikari   | 0.64 0.18 1.22 0.28 | 36.0 3.12 |

Values with the same letter within a column are not significant different (Tukey, P < 0.05).

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**Table 5. Protein and amylose content of new cultivar Tohoku 194**

| Fertilizer condition | Crop year | Cultivar   | White rice grain protein (%) amylase (%) |
|----------------------|-----------|------------|------------------------------------------|
| standard             | 2005–2009 | Tohoku194  | 5.8 a 19.0 a                             |
|                      |           | Sasanishiki | 6.1 b 19.1 b                             |
|                      |           | Hitomebore  | 5.7 a 19.4 c                             |
| heavy                | 2006–2009 | Tohoku194  | 6.3 a 18.7 a                             |
|                      |           | Sasanishiki | 6.5 b 19.3 b                             |
|                      |           | Hitomebore  | 6.1 c 19.6 c                             |

Values with the same letter within a column are not significant different (Tukey, P < 0.05).

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assessed to be comparable to those of ‘Sasanishiki’ and stickiness of ‘Tohoku 194’ was evaluated to be lower than that of ‘Hitomebore’ (Table 6). These results suggest ‘Tohoku 194’ to be suitable for sushi, onigiri and box lunch.

**General characteristics of ‘Tohoku 194’**

Heading date and maturation date of ‘Tohoku 194’ were comparable to those of ‘Sasanishiki’ and ‘Hitomebore’ and

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**Table 6. Result of taste evaluation**

| Condition of cooked rice | Crop year | Cultivar   | Softness | Stickiness | Overall | Standard cultivar |
|--------------------------|-----------|------------|----------|------------|---------|------------------|
| hot rice                 | 2007 (3 times) | Tohoku194  | −0.3     | 0.0 **     | 0.1     | Sasanishiki      |
|                          |           | Hitomebore  | 0.1      | 0.6 **     | 0.6 *   |                  |
| chilled rice             | 2008–2009 (2 times) | Tohoku194  | 0.0      | 0.1        | 0.2     | Sasanishiki      |
|                          |           | Hitomebore  | −0.3     | 0.7        | 0.7 *   |                  |
| vinegared rice           | 2008–2009 (3 times) | Tohoku194  | 0.0      | −0.2 **    | 0.2     | Sasanishiki      |
|                          |           | Hitomebore  | −0.4     | 0.7 **     | −0.4    |                  |

Softness: Hard (+3)–Soft (−3)

Stickiness: Sticky (+5)–Non-sticky (−5)

Overall: Good (+5)–Bad (−5)

* and **: indicate significant differences between standard cultivar ‘Sasanishiki’ and test cultivar at the 5% and 1% levels, respectively.
Investigation of these general characteristics indicated that ‘Tohoku 194’ has higher tolerances to low temperature at the booting stage and high temperature at the grain filling stage than ‘Sasanishiki’, while other traits, including taste-related characteristics, are similar to those of ‘Sasanishiki’. ‘Tohoku 194’ is expected to be usable as a successor to ‘Sasanishiki’. An application for new variety registration under the Japanese Plant Variety Protection Act has been submitted for ‘Tohoku 194’ and ‘Tohoku 194’ is expected to be selected as a recommended cultivar for cultivation in Miyagi Prefecture. Most recently developed cultivars having good taste are similar to ‘Koshihikari’ with high stickiness. ‘Tohoku 194’ with ‘Sasanishiki’-type good eating quality may fulfill various food taste demands of consumers and food companies.

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