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REVIEW

Selection of New Check Rice Varieties for Evaluating High Cold Tolerance and the Development of Breeding Lines with High Cold Tolerance in the Tohoku Region of Japan

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Abstract

To select new check rice varieties for evaluating cold tolerance at the booting stage higher than 'Very-tolerant', precisely, cold tolerance was investigated using a deep-water irrigation system at 7 breeding stations for 5 years from 2004 to 2008.

Judging from the percentage sterility, new check varieties from pre-existing 'Very-tolerant' to 'Very-tolerant 9' in the very-early heading group ('Yumekogane' class) and from 'Very-tolerant' to 'Very-tolerant 11' in the very-early ('Kakehashi' class), early, early-to-moderate and moderate heading groups were selected. Using the new check varieties, new breeding lines with high cold tolerance and good agronomic traits were developed.

Discipline: Plant breeding

Additional key words: cold weather, deep-water irrigation system, standard variety, sterility

Introduction

Cold weather damage is a serious problem affecting rice production in the northern regions of Hokkaido and Tohoku in Japan. Low temperatures below 19℃ at the booting stage in particular, from panicle formation to flowering, severely impact on male sterility and cause a decline in yield[2]. Boosting the cold tolerance at the booting stage is thus one of the key targets in rice breeding.

In most breeding stations in Japan, screening the breeding lines for cold tolerance is done via a deep-water irrigation system[4]. This is an automated system where cold irrigation water can be maintained at about 19℃ and at a depth of about 25cm from panicle initiation to the heading stages. In this system cold water affects young panicles and induces spikelet sterility artificially (Fig. 1), whereupon the sterility percentages of trial varieties are compared with those of check varieties.

Cold tolerance at the booting stage is divided into 7 levels from 'Very-susceptible' to 'Very-tolerant' (Table 1). The check varieties of Tohoku region are set at each level and heading stage group, followed by the Japanese rice breeding liaison conference in 1986[4].

After the cold weather disaster in 1993, varieties with high cold tolerance at the booting stage were cultivated in the Tohoku region. However, even varieties classed as 'Very-tolerant', such as 'Hitomebore', had numerous sterile spikelets in some Tohoku areas due to cold weather damage in 2003. This suggests that even 'Very-tolerant' varieties are insufficient to withstand cold weather disasters and cold tolerance should be further improved in the Tohoku region[5].

Recently, new breeding lines with cold tolerance seemingly superior to 'Very-tolerant', have been developed in most breeding stations in the Tohoku region. However, levels of cold tolerance superior to 'Very-tolerant' cannot be evaluated by pre-existing check varieties. Accordingly, the development of new check varieties capable of precisely evaluating the level of cold tolerance exceeding 'Very-tolerant' have been requested by breeding stations in the Tohoku region.

The aim of this study is to select new check varieties with cold tolerance superior to 'Very-tolerant' by liaison

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studies among the Tohoku National Agricultural Research Center and breeding stations at 6 prefectures in the Tohoku region for 5 years[1] (Fig. 2) and to introduce new breeding lines with high cold tolerance.

1. Screening of New Check Rice Varieties for Evaluating High Cold Tolerance

Experiments involving cold tolerance at the booting stage were conducted at 7 breeding stations for 5 years from 2004 to 2008 (Fig. 2). Heading stage groups, experimental places and the number of trial varieties are shown in Table 2.

Breeding lines with cold tolerance levels seemingly superior to 'Very-tolerant' and pre-existing varieties with cold tolerance levels superior to 'Tolerant', a total of 47 trial varieties, were used for the cold tolerance experiments.

The cold tolerance of these varieties was evaluated within each heading stage group using a deep-water irrigation system. Cold water was maintained at a constant temperature between from 18.0 to 19.6℃, and at a constant depth between 17 and 30cm from panicle initiation to the heading stage. The heading date was investigated and the percentage sterility and culm length were measured at the maturing stage.

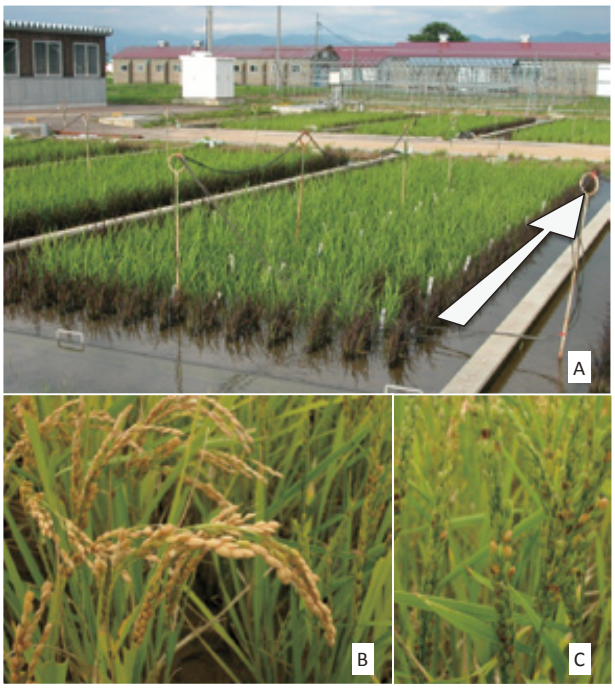

Fig. 1. Cold tolerance experiment by using a deep-water irrigation system at the Tohoku Agricultural Research Center and the panicles after treatment in the ripening stage

A: Cold water is flowing from the near side to the opposite side at a depth of 20cm and preset temperature of 19.0℃. The arrow in figure A indicates the flow of cold water.

B: Tolerant variety, C: Susceptible variety

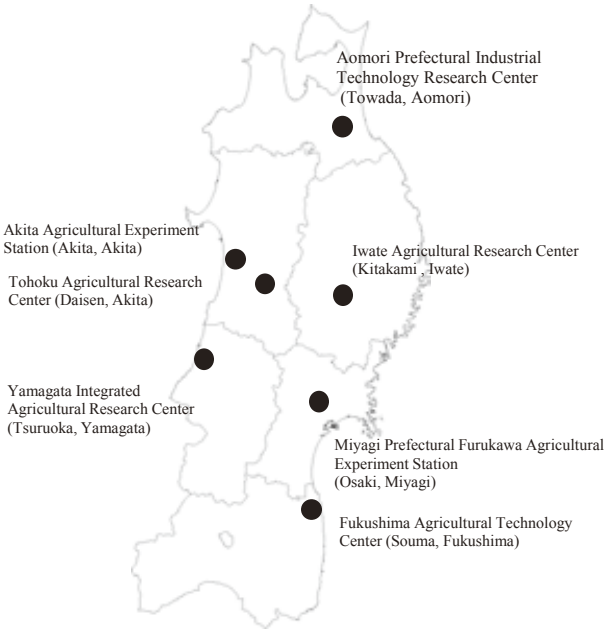

Fig. 2. Location of seven breeding stations in the Tohoku region where cold tolerance experiments were practiced

Table 1. A list of cold tolerance levels at the booting stage

Level	Very-susceptible	Susceptible	Slightly-susceptible	Moderate	Slightly-tolerant	Tolerant	Very-tolerant
UPOV[1)] level	2	3	4	5	6	7	8

[1)] UPOV : The International Union for the Protection of New Varieties of Plants.

Table 2. A list of heading stage groups, experimental places and the number of trial varieties

Heading stage group	Experimental place	Aomori Pref. Ind. Tech. Res. Cent.	Iwate Agric. Res. Cent.	Miyagi Pref. Furukawa Agric. Exp. Sta.	Akita Agric. Exp. Sta.	Yamagata Integrated Agric. Res. Cent.	Fukushima Agric. Tech. Cent.	Tohoku Agric. Res. Cent.	No. of trial varieties
Very-Early	Yumekogane class	*	-	-	-	-	-	*	2
Very-Early	Kakehashi class	*	*	-	-	-	-	*	4
Early	Mutsuhomare class	*	*	*	*	-	*	*	9
Early-to-Moderate	Akitakomachi class	*	*	*	*	*	*	*	12
Moderate	Hitomebore class	-	*	*	*	*	-	*	14
Late	Koshihikari class	-	-	*	-	*	-	*	6
								Total	47

* shows the experimental site of each heading stage group.

Culm length affects the evaluation of cold tolerance since long culm could escape young panicle from cold irrigation water. Trial varieties at 7 breeding stations indicate no extremely long culm (Table 3), suggesting that young panicles were completely treated by cold water.

Evaluations of check varieties arranged in 1986[4] and check varieties for early and very-early maturity groups in the Tohoku region[3] remained unchanged in the liaison studies. In addition, varieties for which the heading stage and percentage sterility were unstable over the years or experimental places were excluded from candidates for new check varieties, and check varieties were selected by choosing a maximum of two varieties in each heading group at each level.

The levels of cold tolerance exceeding 'Very-tolerant' were named 'Very-tolerant 9', 'Very-tolerant 10', and 'Very-tolerant 11' in order, because the levels of cold tolerance were determined as 'Very-susceptible'; 2, 'Medium'; 5, 'Very-tolerant'; 8 in UPOV (The International Union for the Protection of New Varieties of Plants) (Table 1).

Judging from the differences in percentage sterility between the varieties in each heading stage group, check varieties were selected at each level from pre-existing 'Very-tolerant' to 'Very-tolerant 9' in the very-early heading group ('Yumekogane' class), from 'Very-tolerant' to 'Very-tolerant 11' which is 3 levels exceeding 'Very-tolerant' in very-early ('Kakehashi' class), early, early-to-moderate and moderate heading stage groups (Tables 3 and 4), and with a total of 31 varieties selected.

Varietal differences in the sterility percentages between each level exceeding 'Very-tolerant 9' were more obvious under the condition of lower water temperature treatment (Table 3). Severe conditions such as water temperatures from 18.0 to 18.6℃ might be better for screening varieties with cold tolerance exceeding 'Very-tolerant 9'.

After this liaison study, new breeding lines were selected using these new check varieties in the Tohoku region.

2. Development of Breeding Lines with High Cold Tolerance

The development of rice varieties with high cold tolerance is important to reduce cold weather damage. Varieties with the 'Very-tolerant 11' classification, like 'Tohoku PL 3', are estimated to decrease spikelet sterility to 9.0% when cultivated in areas where 'Very-tolerant' varieties like 'Hitomebore' show 65.9% sterile spikelets by cold disaster (Table 3).

However, most new check varieties, derived from native varieties in Japan, China or elsewhere lack good agronomic traits such as high yield, palatability, and grain appearance quality. The next target is thus to develop varieties with not only cold tolerance but also good agronomic traits.

The 'Ouu 415' breeding line developed at the Tohoku Agricultural Research Center had both high cold tolerance and improved agronomic characteristics. 'Ouu 415' was developed with the aim of introducing high cold tolerance from the Chinese variety 'Lijiangxintuanheigu' into the leading variety 'Hitomebore', with good palatability and grain appearance quality. 'Ouu-PL 4', a new check variety of 'Very-tolerant 10', is a breeding line before selecting 'Ouu 415' (Fig. 3).

The grain yield, grain quality, and palatability of 'Ouu-PL 4' are obviously lower than those of 'Hitomebore' (Table 5). However, the grain yield of Ouu 415 is

Table 3. Heading date, percentage sterility and culm length of materials

Heading stage group	Varieties	Start year	Culm length[3] (cm)	Average of all experiments						Average of severe cold-water condions[4]				Evaluation (UPOV level)
				2004-2008		2005-2008		2006-2008		2005-2008		2006-2008		
				Heading date (m/d)	Percentage of sterility (%)	Heading date (m/d)	Percentage of sterility (%)	Heading date (m/d)	Percentage of sterility (%)	Heading date (m/d)	Percentage of sterility (%)	Heading date (m/d)	Percentage of sterility (%)	
Very-Early	Yumekogane[2]	2004	56	7/27	32.5 a	-	-	-	-	7/25	40.9 a	-	-	Very-tolerant (8)
	Fukei-PL 1	2004	61	7/26	20.9 b	-	-	-	-	7/26	23.5 b	-	-	Very-tolerant 9
Very-Early	Kakehashi	2004	58	7/30	66.9 a	-	-	-	-	7/29	75.3 a	-	-	Tolerant (7)
	Hamayutaka[2]	2004	60	8/2	44.3 b	-	-	-	-	8/2	53.4 b	-	-	Very-tolerant (8)
Early	Koihime[1]	2004	58	8/7	67.2 a	8/7	69.4 a	8/8	74.1 a	8/7	87.4 a	8/7	90.2 a	Tolerant (7)
	Komanomai	2004	61	8/7	65.3 a	8/8	67.9 a	8/8	72.4 a	8/8	84.6 ab	8/8	87.4 ab	Tolerant (7)
	Iwatekko	2004	64	8/10	53.6 b	8/10	56.4 b	8/11	59.8 b	8/10	75.9 bc	8/11	76.3 bc	Very-tolerant (8)
	Fukei-PL 2[1]	2004	58	8/6	51.6 b	8/6	53.8 b	8/7	55.9 b	8/6	72.6 c	8/6	72.7 cd	Very-tolerant (8)
	Fukei-PL 3	2004	59	8/10	37.8 c	8/10	41.2 c	8/11	45.5 c	8/10	60.2 d	8/10	61.6 de	Very-tolerant 9
	Akita 60	2005	59	-	-	8/6	40.2 c	8/7	43.3 c	8/7	54.0 d	8/7	55.4 e	Very-tolerant 9
	Fukei-PL 4	2004	62	8/9	28.2 d	8/10	30.3 d	8/10	34.0 d	8/9	38.3 e	8/9	39.8 f	Very-tolerant 10
	Fukei-PL 5	2006	60	-	-	-	-	8/8	23.7 e	-	-	8/7	28.9 f	Very-tolerant 11
Early-to-Moderate	Ibukiwase[1]	2004	63	8/14	62.4 a	8/14	64.1 a	-	-	8/14	82.6 a	-	-	Tolerant (7)
	Kokoromachi	2004	62	8/10	59.8 a	8/11	63.3 a	-	-	8/10	85.8 a	-	-	Tolerant (7)
	Tohoku 182	2004	64	8/11	43.3 b	8/12	46.3 b	-	-	8/11	70.0 b	-	-	Very-tolerant (8)
	Hatajirusi	2004	64	8/12	42.8 b	8/13	46.2 b	-	-	8/12	68.1 b	-	-	Very-tolerant (8)
	Tohoku 155	2004	63	8/10	35.9 c	8/11	39.7 b	-	-	8/10	61.4 b	-	-	Very-tolerant 9
	Ouu-PL 4	2005	68	-	-	8/12	28.9 c	-	-	8/12	37.6 c	-	-	Very-tolerant 10
	Tohoku-PL 1	2005	66	-	-	8/18	16.2 d	-	-	8/16	19.6 d	-	-	Very-tolerant 11
Moderate	Ohtori[1]	2004	62	8/17	66.8 a	8/17	67.4 a	8/17	71.1 a	8/18	87.9 a	8/19	88.6 a	Tolerant (7)
	Okiniiri	2004	68	8/16	62.0 a	8/16	61.6 a	8/17	64.0 a	8/18	83.7 a	8/19	82.3 a	Tolerant (7)
	Haenuki	2004	64	8/20	39.7 b	8/20	39.9 b	8/20	43.3 b	8/22	66.8 b	8/22	68.8 ab	Very-tolerant (8)
	Hitomebore	2004	65	8/18	39.1 b	8/18	38.5 b	8/19	42.4 b	8/20	65.9 b	8/21	65.9 bc	Very-tolerant (8)
	Akita-PL 1	2005	60	-	-	8/20	27.6 c	8/20	31.0 bc	8/22	48.2 c	8/22	49.7 c	Very-tolerant 9
	Tohoku 187	2006	68	-	-	-	-	8/19	30.0 c	-	-	8/20	47.7 c	Very-tolerant 9
	Ouu-PL 5	2004	70	8/16	23.8 c	8/16	23.2 c	8/16	26.9 c	8/17	34.4 c	8/16	37.1 d	Very-tolerant 10
	Tohoku-PL 2	2005	70	-	-	8/14	12.3 d	8/15	13.9 d	8/16	14.7 d	8/17	15.3 d	Very-tolerant 11
	Tohoku-PL 3	2005	74	-	-	8/15	8.2 d	8/16	9.0 d	8/16	9.0 d	8/17	9.5 d	Very-tolerant 11
Late	Mochimusume	2004	62	8/24	61.6 a	-	-	-	-	-	-	-	-	Tolerant (7)
	Hourei[1]	2004	61	8/30	76.1 b	-	-	-	-	-	-	-	-	Tolerant (7)
	Koshihikari[1]	2004	73	8/28	47.3 c	-	-	-	-	-	-	-	-	Very-tolerant (8)

[1] Check varieties selected in 1986.
[2] Check varieties selected at the Aomori Pref. Ind. Tech. Res. Cent. in 1999
[3] Culm length was measured at the maturing stage in the deep-water irrigation system at the Tohoku Agric. Res. Cent. in 2007.
[4] Values were extracted from examinations with preset water temperature from 18.0 to 18.6 ℃ at the Tohoku Agric. Res. Cent., the Aomori Pref. Ind. Tech. Res. Cent. and the Miyagi Pref. Furukawa Agric. Exp. Sta.
[5] Mean values followed by the same letters do not differ significantly at the 0.05 level by t-test in the Very-Early heading stage group and Tukey's test in other groups.

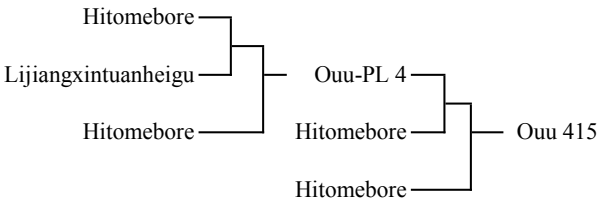

Fig. 3. Genealogy of 'Ouu 415'

only 6% lower than that of 'Hitomebore' and the grain quality and palatability of 'Ouu 415' are equivalent to those of 'Hitomebore'.

The cold tolerance level of 'Ouu 415' was evaluated as 'Very-tolerant 10', because the percentage sterility of 'Ouu 415' was almost equivalent to 'Ouu-PL 5', which is a new check variety of 'Very-tolerant 10' in the moderate heading group, using a deep-water irrigation system at the Tohoku Agricultural Research Center and Iwate Agricultural Research Center in 2010 and 2011 (Table 6).

Table 4. A list of new check varieties with a level exceeding "Very-tolerant (8)" in the Tohoku region

Heading stage group	Level (UPOV level)	Pre-existing level		New level		
		Tolerant (7)	Very-tolerant (8)	Very-tolerant 9 (-)	Very-tolerant 10 (-)	Very-tolerant 11 (-)
Very-Early	Yumekogane class	-	Yumekogane[2)]	Fukei-PL 1	-	-
	Kakehashi class	Kakehashi	Hamayutaka[2)]	-	-	-
Early	Mutsuhomare class	Koihime Komanomai	Fukei-PL 2[1)] Iwatekko	Fukei-PL 3 Akita 60	Fukei-PL 4	Fukei-PL 5
Early-to-Moderate	Akitakomachi class	Kokoromachi Ibukiwase[1)]	Tohoku 182 Hatajirushi	Tohoku 155	Ouu-PL 4	Tohoku-PL 1
Moderate	Hitomebore class	Ohtori[1)] Okiniiri	Hitomebore Haenuki	Akita-PL 1 Tohoku 187	Ouu-PL 5	Tohoku-PL 2 Tohoku-PL 3
Late	Koshihikari class	Mochimusume Hourei[1)]	Koshihikari[1)]	-	-	-

[1)] Check varieties selected in 1986.
[2)] Check varieties selected at the Aomori Pref. Ind. Tech. Res. Cent. in 1999.

Table 5. Agronomic characteristics of 'Ouu 415'

Line	Year	Heading date (m/d)	Maturing date (m/d)	Culm length (cm)	Panicle length (cm)	No. of panicles (No./m^2)	Hulled rice yield (kg/a)	Yield ratio (%)	Lodging degree[1)] (0-5)	1,000-grain weight (g)	Grain quality[2)] (1-9)	Eating quality[3)] (-3~+3)
Tohoku Agricultural Research Center, Daisen, Akita, Japan[4)]												
Ouu 415	2010	8/3	9/10	96	19.9	469	63.1	95	3.0	23.9	3.9	0.20
	2011	8/4	9/23	87	19.1	444	61.9	93	3.5	23.7	4.3	-0.04
	Average	8/4	9/16	92	19.5	457	62.5	94	3.3	23.8	4.1	0.08
Hitomebore	2010	8/3	9/10	93	19.3	470	66.2	100	3.0	23.4	4.3	0.00
	2011	8/4	9/23	83	19.5	464	66.4	100	2.5	23.6	4.7	0.00
	Average	8/4	9/16	88	19.4	467	66.3	100	2.8	23.5	4.5	0.00
Ouu-PL 4	2010	7/28	8/31	95	19.4	458	50.0	76	1.5	21.7	4.9	-1.47**
	2011	7/29	9/10	87	19.0	419	46.6	70	0.0	22.5	4.2	-
	Average	7/29	9/5	91	19.2	439	48.3	73	0.8	22.1	4.6	-1.47**

[1)] Lodging degree was classified into six degrees (0: standing to 5: lodged).
[2)] Grain quality was estimated in comparison with ordinary rice varieties and classified into nine grades (1: excellent to 9: especially bad) based on appearance.
[3)] Palatability shows aggregate evaluation and was classified into seven degrees (3: excellent to -3: especially bad). Hitomebore was used as the standard variety. ** shows significant difference at the 1% level by sign test.
[4)] Sowing date: 22 April, 2010, 21 April, 2011; Transplanting date: 19 May, 2010, 2011, respectively.

Table 6. Percentage sterility of 'Ouu 415' in deep-water irrigation system

Line	Tohoku Agricultural Research Center						Iwate Agricultural Research Center[2)]				Average		Evaluation
	2010a[1)]		2010b[2)]		2011[3)]		2010a[4)]		2010b[5)]				
	Heading date (m/d)	Percentage sterility (%)	Heading date (m/d)	Percentage sterility (%)	Heading date (m/d)	Percentage sterility (%)	Heading date (m/d)	Percentage sterility (%)	Heading date (m/d)	Percentage sterility (%)	Heading date (m/d)	Percentage sterility (%)	
Ouu 415	8/19	18.4	8/18	18.0	8/18	17.5	8/16	15.3	8/14	14.3	8/17	16.7	Very-tolerant 10
Check varieties													
Tohoku-PL 2	8/13	13.0	8/14	10.7	8/15	12.5	8/10	5.4	8/8	11.3	8/12	10.6	(Very-tolerant 11)
Tohoku-PL 3	8/17	7.4	8/18	5.4	8/16	7.5	8/11	4.9	8/9	6.4	8/14	6.3	(Very-tolerant 11)
Ouu-PL 5	8/22	19.1	8/22	14.6	8/21	7.5	8/17	16.0	8/16	21.7	8/19	15.8	(Very-tolerant 10)
Akita-PL 1	8/23	28.5	8/24	21.2	8/20	10.0	8/21	20.3	8/17	18.0	8/21	19.6	(Very-tolerant 9)
Tohoku 187	8/20	29.4	8/19	17.0	8/18	32.5	8/17	13.6	8/14	10.4	8/17	20.6	(Very-tolerant 9)
Hitomebore	8/20	35.3	8/22	33.4	8/20	50.0	8/15	30.6	8/15	31.1	8/18	36.1	(Very-tolerant)

[1)] Sowing date: 12 April; Transplanting date: 27 May; Deep-Water-Treatment period: from 1 July to 26 August at 20cm depth; Setting water temperature: 19.0℃.
[2)] Sowing date: 12 April; Transplanting date: 27 May; Deep-Water-Treatment period: from 1 July to 8 September at 20cm depth; Setting water temperature: 18.4℃.
[3)] Sowing date: 16 April; Transplanting date: 26 May; Deep-Water-Treatment period: from 1 July to 24 August at 20cm depth; Average water temperature: 18.8℃.
[4)] Sowing date: 13 April; Transplanting date: 11 May; Deep-Water-Treatment period: from 2 July to 14 July at 20cm depth, 15 July to 31 August at 30cm depth; Average water temperature: 18.4℃.
[5)] Sowing date: 13 April; Transplanting date: 11 May; Deep-Water-Treatment period: from 8 July to 14 July at 20cm depth, 15 July to 31 August at 30cm depth; Average water temperature: 18.4℃.

'Ouu415' is now used as a parent of crosses to improve the cold tolerance of other varieties, and as a material to further boost the cold tolerance of rice.

In other breeding stations in the Tohoku region, breeding lines with high cold tolerance and improved agronomic characteristics, such as 'Iwate 100' ('Very-tolerant 9'), 'Tohoku 207' ('Very-tolerant 11'), have been developed.

However, it is not obvious how these varieties with high cold tolerance can decrease actual cold weather damage. Cold tolerance of these varieties should be confirmed in farmers' fields prone to cold weather damage. More cultivation data and further improvement of agronomic characteristics are expected to see these breeding lines emerge as commercial varieties.

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