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Comparison of Growth Characteristics and Yield Components between High-Yielding and Low-Yielding Varieties of Winter Triticale in Hokkaido, Japan

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Abstract

Field experiments were carried out over a period of four years in Hokkaido, the northernmost island of Japan, to determine the differences between growth characteristics of high-yielding and low-yielding winter triticale varieties in a snowy region and to determine the criteria for selecting varieties that can produce high yields and the important points in cultivation in order to obtain high yields. Grain yields, characteristics related to grain yield, winter survival indices, and lodging indices of triticale varieties from Poland, Russia, Ukraine, Canada, France, England and Korea were compared with those of wheat and rye varieties. The grain yields of most of the triticale varieties from Poland were higher than that of Hokushin, one of the main winter wheat cultivars grown in Hokkaido, and those of rye varieties. However, the grain yields of triticale varieties bred in other countries were lower than that of Hokushin. The high grain yields of Polish triticale varieties were thought to be due to greater one-ear weights and plant weights than those of the wheat varieties and due to higher harvest indices than those of the rye varieties. The low grain yields of other triticale varieties were thought to be due to a high incidence of snow mold disease, small number of ears, and low harvest index. Lodging also contributed to the reduction in grain yields of long-culmed triticale varieties. Based on these results, it is thought that high yields of triticale grown in a snowy region of Hokkaido can be obtained by selecting triticale varieties that have a high degree of snow tolerance, a large number of ears and a high harvest index and by taking measures to prevent a reduction in the number of ears due to winter injury.

Key words: winter triticale, winter survival index, grain yield, harvest index, ear number

Triticale is a hybrid produced by crossing wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.). It was first produced in 1876 by A. S. Willson, a Scottish plant breeder [6]. At first, triticale was greatly inferior to wheat in terms of both grain yield and quality[11]. However, the discovery of colchicine in 1938 made the doubling of chromosomes easy, and various improvements to triticale have been made since the 1950s in many countries, including European countries, Canada, United States, Russia and Mexico[33]. Many varieties of triticale produced in recent years are superior to top wheat varieties in yielding ability[27], adaptability to poor-quality soils such as acidic soil[3], soil with a deficiency of manganese or zinc or with an excess of boron[9], and sandy soil[30] resistance to drought[1,4], lodging resistance[23]; and resistance to rust and some pathogens[8]. Many efforts have been made in Poland to improve the properties of triticale, and varieties of triticale are now exported from Poland to many countries[31].

In 1998, the total area of triticale cultivation in

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the world was 2,910,000 ha, with the main countries producing triticale being Poland, Russia, Germany, France, United Sates, Australia, Brazil and China. Most of the triticale is produced for forage such as silage and for concentrated feed, but in some countries it is produced as a food crop, mainly for flour to make bread and cookies[13].

There have been reports of grain yields and plant weights of triticale varieties bred in the 1980s being higher than those of top wheat varieties in many countries, including Mexico[27], Brazil[15], Poland[28], Italy[23], Australia[2], England[17], Germany[14], Spain[24], Canada[16] and Korea[7]. In Japan, most of the reports on triticale have been studied on plant breeding or genetics[19,25,32].

Iwata et al[12]., who carried out experiments on triticale in southern Kyushu, reported that triticale was useful as a companion crop for the prevention of lodging of Italian ryegrass, and Nonaka et al[20]., who carried out tests on rotation cropping of triticale in winter and sorghum in summer in the Kanto district of Japan, reported that triticale, which absorbed excess manure, was useful as a cleaning crop. However, there have been few studies in Japan on techniques for cultivating triticale with a view to future commercial production of triticale.

Mizuochi[18] carried out experiments on winter triticale varieties in Hokkaido, the northernmost island of Japan. He reported that the grain yields of winter triticale varieties that had been bred in Poland after 1985 were more than 30% higher than that of Chihokukomugi, one of the top wheat varieties in Hokkaido. Among the Polish winter triticale varieties, Presto, which had a stable grain yield of 750 g m^{-2}, was reported to be particularly promising as a cultivar for future commercial production. On the other hand, it was reported that grain yields and plant weights of many Polish triticale varieties bred before 1985 and Russian triticale varieties were less than those of Chihokukomugi in years in which there was much winter injury due to heavy snow. However, little is known about the factors that affect the yield of triticale grown in Hokkaido.

Thus, in this study, field experiments were carried out over a period of four years in a heavy snowfall area of Hokkaido to determine the differences between growth characteristics of high-yielding and low-yielding winter triticale varieties in a snowy region and to determine the criteria for selecting varieties that can produce high yields and the important points in cultivation in order to obtain high yields.

Materials and Methods

Field experiments were carried out in the experimental field of the National Agricultural Research Center for Hokkaido region in Sapporo over a period of 4 years, from 1994 to 1998. The soil in the experimental field was Thapto-upland Wet Andosols (Classification of cultivated soils in Japan third approximation, 1995). In 1995, experiments were conducted using three Polish winter triticale varieties, three Japanese winter wheat varieties and three Polish rye varieties. In 1996 and 1997, experiments were conducted using Presto, a winter Polish triticale cultivar; Hokushin, a top winter wheat cultivar in Hokkaido; and Warko Polish rye cultivars (Table 1). In 1998, experiments were conducted using 13 Polish, three Russian and three Ukraine winter triticale varieties and one winter triticale cultivar each from France, Canada, England and Korea (Table 2).

Seeds of winter triticale, wheat and rye cultivars were sown on September 23 in 1994 and 1995, on September 15 in 1996 and on September 13 in 1997. The seeds were sown by hill seeding in 4-meter rows with spacing of 20 cm between rows by the use of seedtape at a seedling rate of 250 seeds m^{-2}. The plot size was 16 m^2. All cultivars were arranged in a randomized complete pattern with three replications in each year. Prior to sowing, compound fertilizer S807 (N8%, P 13.1%, K 14.1%) was applied as a basal dressing by side dressing at a rate of 50 g m^{-2}. Ammonium sulfate was applied as topdressing in the regrowth stage at a rate of 30 g m^{-2}.

Incidences of snow mold disease in the cultivars were investigated one week after the snow had melted using the criteria for prediction of plant diseases in Hokkaido. The mean winter survival index for 50 plants in each plot was calculated using the following visual scale of 0 to 100: 100, no visible injury; 75, survival of the stem and more than 50% of the leaves; 50, survival of the stem and less than 50% of the leaves; 25, survival of the stem but all leaves having died; and 0, death of the entire plant.

The mean lodging index for 30 plants in each plot at the milk ripe stage was also calculated from measurements of the angle between the stem and a line perpendicular to the ground using the following scale of 0 to 4: 0, no lodging; 1, lodging of 0–22.5°; 2, lodging of 22.5–45°; 3, lodging of 45–67.5°; 4, lodging of 67.5–90°.

Plants in the central 1 m² area in each plot were harvested in the yellow ripe stage, and grain yield, plant weight, number of ears, number of grains per head and weight of 1,000 grains were recorded after the plants had been dried naturally over a 2-week period. Grain yield, plant weight and weight of 1,000 grains were corrected to those at 13% water content. The harvest index was calculated as the ratio of water content-corrected grain weight to plant weight, and the weight of one ear was calculated by multiplying the number of grains per head by the weight of 1,000 grains.

Results

1. Growth development

The snow had completely melted on March 28 in 1995, on April 23 in 1996, on April 3 in 1997 and on March 30 in 1998. Regrowth started earlier in years in which the completion of snow melting was early. In 1995, the start of the regrowth stage and the start of the heading stage were earliest for rye, next-earliest for triticale, and latest for wheat (Table 1). There was little difference between first flowering times in the crops. The start of the maturity stage was earliest for wheat, next-earliest for triticale, and latest for rye. Thus, the duration from the start of the regrowth stage until the start of the heading stage for triticale was significantly shorter than that for wheat and significantly longer than that for rye. On the other hand, the duration from the start of the heading stage to first flowering and the duration from first flowering to the start of the maturity stage for triticale were significantly longer than those for wheat and significantly shorter than those for rye. The growth processes in 1996 and 1997 were similar to those in 1995.

In 1998, the start of the regrowth stage for

Table 1 Growth development in 1995, 1996 and 1997.

Year	Crop	Variety	Breeding place	Regrowing (m. d.)	Heading (m. d.)	First flowering (m. d.)	Maturity (m. d.)	Days from regrowing to heading	Days from heading to first flowering	Days from first flowering to maturity
1995	Triticale	Presto	Poland	4.5	5.29	6.13	7.28	54	15	45
		Tewo	Poland	4.6	6.3	6.16	7.30	58	13	44
		Moniko	Poland	4.5	6.2	6.15	7.30	58	13	45
	Wheat	Hokushin	Hokkaido	4.7	6.4	6.12	7.22	58	8	40
		TsukisamuNo. 1	Hokkaido	4.7	6.4	6.12	7.23	58	8	41
		Chihokukomugi	Hokkaido	4.7	6.7	6.15	7.25	61	8	40
	Rye	Warko	Poland	4.2	5.21	6.13	8.3	49	23	51
		Amilo	Poland	4.2	5.20	6.13	8.3	48	24	51
		Mardar	Poland	4.2	5.23	6.14	8.4	51	22	51
		LSD (0.05)						1.6	1.6	2.4
1996	Triticale	Presto	Poland	4.20	6.13	6.20	7.31	54	7	41
	Wheat	Hokushin	Hokkaido	4.21	6.15	6.19	7.25	55	4	36
	Rye	Warko	Poland	4.20	6.9	6.20	8.6	50	11	47
		LSD (0.05)						2.6	2.8	2.0
1997	Triticale	Presto	Poland	4.6	5.31	6.16	7.24	55	16	38
	Wheat	Hokushin	Hokkaido	4.7	6.8	6.14	7.19	62	6	35
	Rye	Warko	Poland	4.5	5.24	6.15	7.29	49	22	44
		LSD (0.05)						1.6	2.6	2.0

m.: month, d.: day

Table 2 Growth development in 1998.

Crop	Variety	Breeding place	Regrowing (m. d.)	Heading (m. d.)	First flowering (m. d.)	Maturity (m. d.)	Days from regrowing to heading	Days from heading to first flowering	Days from first flowering to maturity
Triticale	Pinokio	Poland	4.8	6.4	6.15	7.29	57	11	44
	Presto	Poland	4.8	5.26	6.8	7.22	48	13	44
	Lamberto	Poland	4.8	6.2	6.13	7.25	55	11	42
	Disco	Poland	4.8	5.31	6.15	7.27	53	15	42
	Eldorado	Poland	4.9	6.3	6.15	7.27	55	12	42
	Prego	Poland	4.8	6.2	6.15	7.25	55	13	40
	Moniko	Poland	4.8	5.30	6.13	7.25	52	14	42
	Tewo	Poland	4.11	5.30	6.13	7.25	49	14	42
	Fidelio	Poland	4.11	6.4	6.16	7.29	54	12	43
	Lasko	Poland	4.11	5.29	6.14	7.25	48	16	41
	Moreno	Poland	4.11	5.29	6.15	7.25	48	17	40
	Almo	Poland	4.8	5.29	6.15	7.27	51	17	42
	Prag46/3	Russia	4.8	6.2	6.15	7.27	55	13	42
	Clercal	France	4.11	5.29	6.9	7.23	48	11	44
	Pika	Canada	4.8	6.9	6.21	7.28	62	12	37
	AD3/5	Ukraine	4.8	6.1	6.14	7.27	54	13	43
	AD206	Ukraine	4.8	6.2	6.16	7.27	55	14	41
	Sinkihomil	Korea	4.11	5.24	6.8	7.20	43	15	42
	AD550	Ukraine	4.13	6.2	6.15	7.27	50	13	42
	Prag46/1	Russia	4.8	5.28	6.15	7.29	50	18	44
	Pushkinski I	Russia	4.13	6.14	6.25	8.8	62	11	44
	Newton	England	4.17	5.30	6.14	7.29	43	15	45
Wheat	Hokushin	Hokkaido	4.9	5.30	6.6	7.17	51	7	41
Rye	Motto	Poland	4.6	5.19	6.5	7.28	43	17	53
	Danko	Poland	4.7	5.19	6.4	7.27	42	16	53
	Warko	Poland	4.6	5.18	6.4	7.27	42	17	53
	Paldanghomil	Korea	4.6	5.14	6.2	7.22	38	19	50
	LSD (0.05)						2.0	2.2	2.2

m.: month, d.: day

triticale cultivars that had winter survival indices of more than 60 was 1 or 2 days earlier than that for Hokushin, while the start of the regrowth stage for triticale cultivars that had low winter survival indices was later than that for Hokushin. The start of the heading stage for all triticale varieties was later than that for all rye varieties and Hokushin (Table 2). There were differences between varieties of triticale in the duration from the start of the regrowth stage to the start of the heading stage. The start of the maturity stage for all triticale varieties was later than that for Hokushin. The duration from the start of the heading stage to first flowering for triticale was significantly longer than that for wheat and significantly shorter than that for rye, and the duration from first flowering to the maturity stage for triticale was significantly shorter than that for rye.

2. Grain yield and related characteristics of the cultivars grown in 1995, 1996 and 1997

In 1995, there were no differences between grain yields of triticale varieties or between grain yields of rye varieties, but there were differences between grain yields of wheat varieties; grain yields of Hokushin and Tsukisamu No. 1 were significantly higher than that of Chihokukomugi (Table 3). The grain yields of Presto were more than 20% higher than those of Hokushin and more than 10% higher than those of rye varieties in 1995, 1996 and 1997. The numbers of ears in triticale and wheat varieties were significantly higher than the numbers in rye varieties. In all three years, the numbers of grains per head in triticale varities were significantly higher than those in Hokushin and Chihokukomugi and were significantly lower than those in rye varieties. However, there were no significant differences between numbers of grains per head in triticale varieties and Tsukisamu No. 1. The weights of

Table 3 Grain yield and related characteristics in 1995, 1996 and 1997.

Year	Crop	Variety	Breeding place	Grain yield (g m^{-2})	No. of ears (m^{-2})	No. of grains /ear	1,000 grain weight (g)	Plant weight (g m^{-2})	Harvest index (%)
1995	Triticale	Presto	Poland	733	560	36.3	47.3	1960	37.4
		Tewo	Poland	723	563	34.8	45.7	1974	36.6
		Moniko	Poland	690	573	34.8	47.7	1910	36.1
	Wheat	Hokushin	Hokkaido	606	605	29.8	40.4	1584	38.3
		Chihokukomugi	Hokkaido	502	625	25.7	38.6	1442	34.8
		TsukisamuNo.1	Hokkaido	642	529	34.1	42.6	1622	39.6
	Rye	Warko	Poland	684	479	48.5	34.3	1962	34.9
		Amilo	Poland	679	487	49.0	33.5	2030	33.4
		Mardar	Poland	701	509	47.3	32.5	1960	35.8
		LSD (0.05).		35	84	3.2	2.9	110	1.1
1996	Triticale	Presto	Poland	797	613	36.9	41.5	1884	42.3
	Wheat	Hokushin	Hokkaido	550	595	27.4	39.7	1517	36.2
	Rye	Warko	Poland	623	498	44.4	33.1	2172	28.7
		LSD (0.05).		60	58	2.9	2.8	144	3.9
1997	Triticale	Presto	Poland	846	633	37.0	42.6	1968	43.0
	Wheat	Hokushin	Hokkaido	648	715	26.9	40.1	1522	42.6
	Rye	Warko	Poland	683	491	43.2	35.8	2016	33.9
		LSD (0.05).		81	54	2.2	4.6	183	2.3

1,000 grains in triticale varieties were larger than those in wheat and rye varieties. The plant weights of triticale varieties were significantly greater than those of wheat varieties in all three years. The harvest indices of triticale varieties were similar to or slightly higher than those of wheat varieties but were significantly higher than those of all rye varieties except Mardar.

3. Grain yield and related characteristics of the cultivars grown in 1998

The grain yields of all Polish triticale varieties except Almo were higher than the grain yield of Hokushin in 1998 (605 g m^{-2}). Notably, the grain yields of Pinokio, Presto, Disco and Lamberto were even higher than that of Motto, the variety of rye with the highest grain yield (Table 4). However, the grain yields of Russian, Ukrainian, Canadian, French, Korean and English triticale varieties were lower than that of Hokushin.

The numbers of grains per head in all triticale and rye varieties were significantly higher than that in Hokushin. The weights of 1,000 grains in all triticale varieties were larger than those in rye varieties but were only larger than those in some of the varieties of wheat and similar to those in other varieties of wheat.

The plant weights of all triticale varieties that had higher grain yields than that of Hokushin were significantly greater than that of Hokushin. The plant weights of Prag 46/3 and AD 3/5, Russian triticale varieties, and Pika, a Canadian triticale variety, were significantly greater than that of Hokushin, but the harvest indices of these Russian and Canadian triticale varieties were much lower than that of Hokushin. The plant weights of Presto and Pinokio, triticale varieties that had high yields, were similar to those of Warko and Motto, rye varieties that had high yields, but the plant weights of other triticale varieties were significantly lower than those of Warko and Motto.

The harvest indices of triticale varieties that had higher grain yields than that of Hokushin were similar to or slightly higher than that of Hokushin but significantly higher than those of rye varieties. However, the harvest indices of Russian and Ukrainian triticale varieties were lower than those of rye varieties.

The winter survival indices of all triticale varieties were significantly lower than that of Hokushin and those of all rye varieties except Danko.

Table 4 Grain yield and related characteristics in 1998.

Crop	Variety	Breeding place	Grain yield (g m⁻²)	No. of ears (m⁻²)	No. of grains /ear	1,000 grain weight (g)	Plant yield (g m⁻²)	Harvest index (%)	Winter[a] survival index (0-100)	Lodging[b] index (0-4)	Culm length (cm)
Triticale	Pinokio	Poland	841	553	41.8	46.71	2010	41.8	67.5	0.0	106
	Presto	Poland	826	606	36.5	45.70	2124	38.9	71.5	0.2	119
	Lamberto	Poland	824	445	48.5	39.94	1813	45.5	70.0	0.2	117
	Disco	Poland	795	413	45.6	46.35	1796	44.3	64.1	0.1	105
	Eldorado	Poland	770	546	39.6	39.12	1721	44.7	72.5	0.1	117
	Prego	Poland	767	598	37.1	38.91	1769	43.4	87.0	0.0	107
	Moniko	Poland	754	500	38.8	41.37	1941	38.9	78.8	0.4	115
	Tewo	Poland	743	472	43.1	40.11	1875	39.6	55.3	0.1	110
	Fidelio	Poland	722	513	39.4	45.13	1706	42.3	62.4	0.1	112
	Lasko	Poland	719	525	39.2	37.18	1915	37.6	59.2	0.6	128
	Moreno	Poland	668	490	37.1	38.98	1724	37.6	56.5	0.2	107
	Almo	Poland	584	349	44.7	45.97	1601	36.5	76.3	0.4	101
	Prag 46/3	Russia	557	301	45.8	46.44	1698	32.8	80.1	1.3	125
	Clercal	France	525	365	38.4	46.92	1543	42.2	53.9	0.0	112
	Pika	Canada	525	373	45.6	39.48	1988	26.4	76.3	2.0	141
	AD 3/5	Russia	519	245	44.8	51.45	1838	28.2	83.8	2.0	141
	AD 206	Russia	468	293	42.0	43.67	1550	30.2	87.5	2.1	131
	Singkihomil	Korea	442	311	37.8	40.00	1284	34.4	57.1	0.2	124
	AD 550	Russia	394	201	43.4	48.01	1416	27.9	43.5	2.3	153
	Prag 46/1	Russia	384	213	42.2	45.51	1209	31.8	76.3	2.0	120
	Pushkinski-I	Russia	191	66	56.4	46.17	583	32.7	31.3	0.4	143
	Newton	England	80	50	34.2	49.96	236	33.9	14.1	0.6	120
Wheat	Hokushin	Hokkaido	605	666	26.7	38.66	1508	40.1	92.2	0.1	89
Rye	Motto	Poland	716	560	46.2	34.46	2125	33.7	97.5	0.0	146
	Danko	Poland	697	451	51.2	33.15	1941	35.9	74.0	0.3	145
	Warko	Poland	693	557	44.4	32.24	2106	32.9	93.1	0.2	141
	Paldanghomil	Korea	616	581	40.4	28.91	1850	33.3	98.5	1.2	154
LSD (0.05).			76	58	4.1	1.3	139	3.4	0.3	0.5	5

[a] Winter survival index were visually estimated one week after the snow had melted with a scale of 100–0 where 100, no visible injury; 75, stem alive and more than 50% of leaves alive; 50, stem alive and less than 50% of leaves alive; 25, stem alive without live leaves; 0, death after snow melt 1 week.

[b] Lodging index were visually estimated with a scale of 0–4 where 0, no lodging; 1, stem lodged 0°–22.5°; 2, stem lodged 22.5°–45°; 3, stem lodged 45°–67.5°; 4, stem lodged 67.5°–90° at milk ripe stage

The incidences of snow mold disease in the Ukrainian triticale varieties AD 3/5, AD 206, the Canadian triticale variety Pika, and the Polish triticale varieties Prego and Moniko were lower than those in other triticale varieties.

The culm lengths of the Ukrainian triticale varieties AD 550 and AD 3/5, the Russian triticale variety Pushikinski and the Canadian triticale variety Pika were greater than those of the other triticale varieties and similar to those of the rye varieties. The culm lengths of the Polish triticale varieties Pinokio, Prego and Disco were smaller than those of the other triticale varieties. The lodging indices of triticale varieties that had high yields were very low, but the lodging indices of Russian, Ukrainian and Canadian triticale varieties were high.

Discussion

The relationships of winter survival indices with grain yields and numbers of ears are shown in Figure 1. The winter survival indices of triticale varieties that had lower grain yields than that of Hokushin showed significant positive correlations with grain yields ($r=0.879$) and numbers of ears ($r=0.783$). The grain yields and ear numbers of AD550, Pushikinski and Newton were much lower than those of other triticale varieties, and the low yields of these varieties were thought to be due to decreases in ear numbers caused by winter injury. This speculation is supported by reports of grain yields of winter triticale being affected by the degree of winter injury in cold snowy countries, such as Poland[5] and Switzerland[10]. Thus, snow tolerance seems to be the most important condition for winter triticale to be able to produce a high grain yield in snowy regions.

The relationships between grain yields and plant weights, and the relationships between grain yields and harvest indices of all varieties except for three triticale varieties that had winter survival indices of less than 50 in 1998 are shown in Figure 2. A significant positive correlation was found between grain yields and plant weights of triticale varieties (r = 0.730). Grain yields of the Canadian triticale variety Pika, the Ukrainian triticale variety AD 3/5, and the Russian triticale variety Prg 46/3 were low in despite of high plant weights of these three varieties. A significant positive correlation was also recognized between grain yields and harvest indices of triticale varieties (r = 0.848). The triticale varieties that had higher grain yields than that of Hokushin were all Polish varieties, and the harvest indices of those varieties were all over 37.5%. The harvest indices of triticale and rye varieties that had lower grain yields than that of Hokushin, on the other

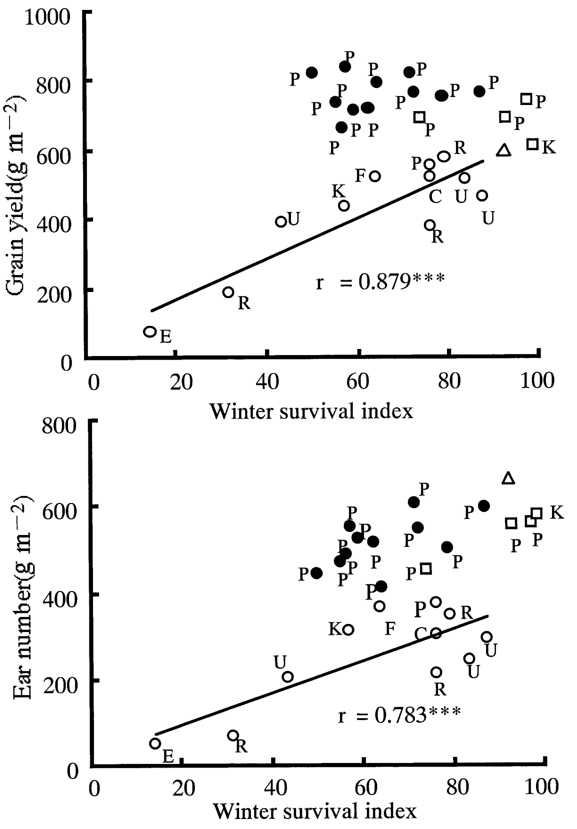

Fig. 1 Relationships of winter survival indices with grain yields and ear numbers (1998).
● Triticale varieties that had higher grain yields than that of Hokushin. △ Wheat. □ Rye.
○ Triticale varieties that had lower grain yields than that of Hokushin.
P, R, U, K, C, F and E denote the countries in which the triticale varieties were bred; Poland, Russia, Ukraine, Korea, Canada, France and England, respectively.
The line represents the regression line for triticale varieties that had lower grain yields than that of Hokushin.
***: significant at 0.1% level of probability.

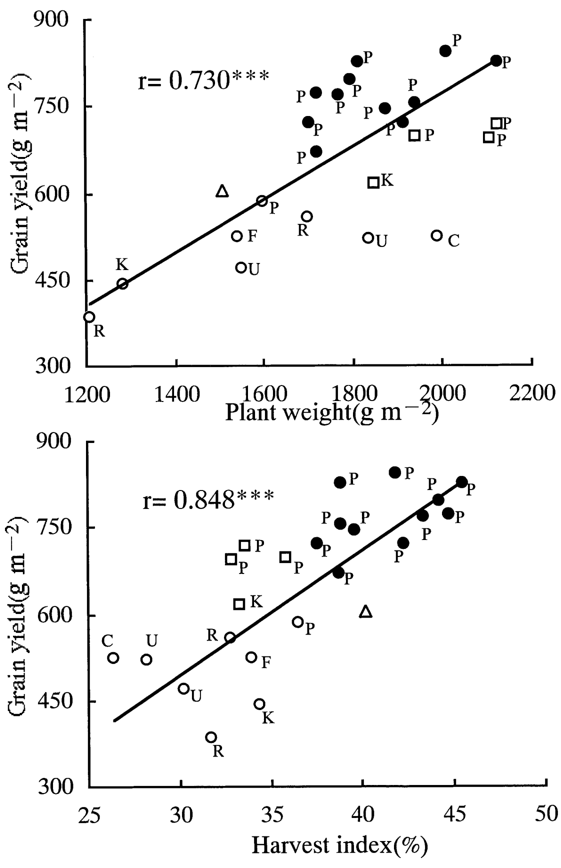

Fig. 2 Relationships of grain yields with plant weights and harvest indices (1998).
● Triticale varieties that had higher grain yields than that of Hokushin. △ Wheat. □ Rye.
○ Triticale varieties that had lower grain yields than that of Hokushin.
P, R, U, K, C, F and E denote the countries in which the triticale varieties were bred; Poland, Russia, Ukraine, Korea, Canada, France and England, respectively.
The line represents the regression line for triticale varieties with a winter survivalindex of more than 50.
***: significant at 0.1% level of probability.

hand, were all less than 37%, and the harvest indices of Russian, Ukrainian and Canadian triticale varieties were less than 33%. These findings suggest that, except for the triticale varieties that had very low winter survival indices, grain yields of triticale varieties were affected more by harvest indices than by plant weights.

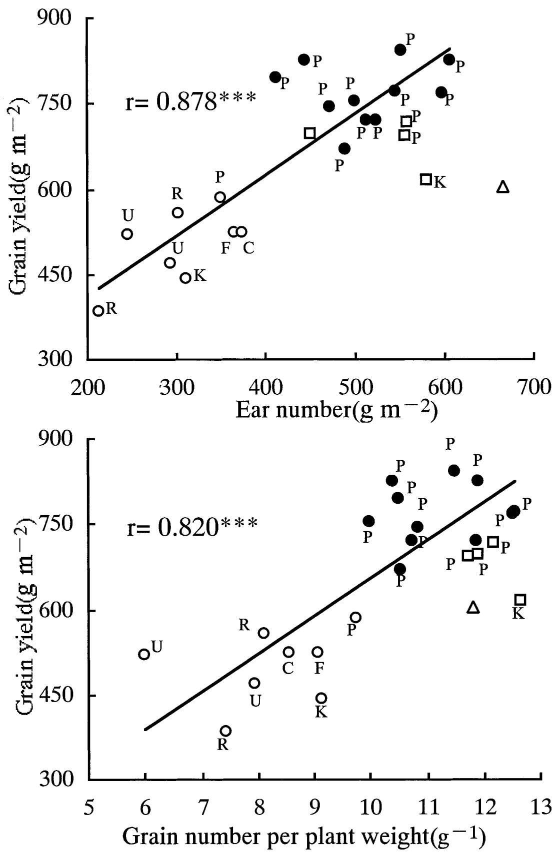

Fig. 3 Relationships of grain yields with ear numbers and grain numbers per plant weight (1998).
● Triticale varieties that had higher grain yields than that of Hokushin. △ Wheat. □ Rye.
○ Triticale varieties that had lower grain yields than that of Hokushin.
P, R, U, K, C, F and E denote the countries in which the triticale varieties were bred; Poland, Russia, Ukraine, Korea, Canada, France and England, respectively.
***: significant at 0.1% level of probability.

The relationships between grain yields and numbers of ears and the relationships between grain yields and numbers of grains per plant weight of all triticale varieties except for the abovementioned three triticale varieties that had winter survival indices of less than 50 in 1998 are shown in Figure 3. A significant positive correlation was found between grain yields and numbers of ears ($r=0.878$). The numbers of ears in triticale varieties that had higher grain yields than that of Hokushin were more than 400 per square meter, while the numbers of ears in triticale varieties that had lower grain yields than that of Hokushin were less than 400 per square meter. A significant positive correlation was found between grain yields and numbers of grains per plant weight ($r=0.820$). Numbers of grains per plant weight of triticale varieties with high yields were more than 10, while those of triticale varieties with low yields were less than 10. These results indicate that the number of grains per unit area is an important factor for obtaining high grain yield in triticale varieties.

The results of multiple regression analysis of grain yields of triticale varieties (except for the three triticale varieties that had low winter survival indices in 1998) and other characteristics of the plants are shown in Table 5. The results suggest that the factors that most strongly affected grain yields of the triticale varieties were ear number, harvest index and plant weight in that order. Lodging index is also thought to have been a factor causing decline in grain yield.

The relationships between plant weights and harvest indices of high-yielding triticale varieties

Table 5 The multiple regression analysis of grain yields and other characteristics of triticale varieties (except for the three triticale varieties that had low winter survival indices in 1998).

Ear number	Grain number per head	1,000 grain weight	Plant weight	Harvest index	Culm length	Lodging index	Days from regrowing to heading	Days from first flowering to heading
0.879***	−0.100	−0.235	0.731**	0.849***	−0.505*	−0.701**	0.155	0.210

***, **, *: significant at 0.1, 1, 5% level of probability respectively.

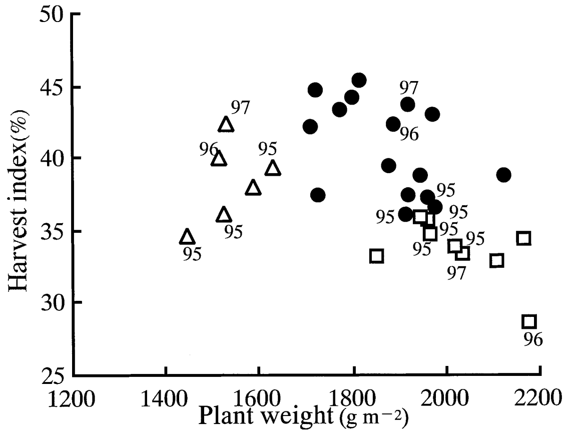

Fig. 4 Relationship between harvest index and plant weight (1995-1998).
● Triticale varieties that had higher grain yields than that of Hokushin.
△ Wheat. □ Rye.
95, 96 and 97 denote 1995, 1996 and 1997 respectively.
Simbols not bearing a number denote 1998.

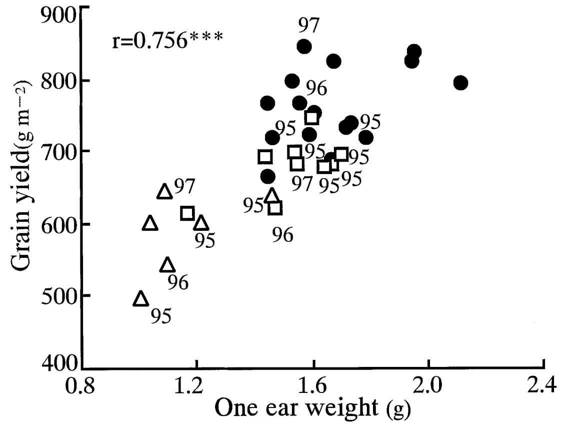

Fig. 5 Relationship between grain yield and one ear weight (1995-1998).
● Triticale varieties that had higher grain yields than that of Hokushin.
△ Wheat. □ Rye.
95, 96 and 97 denote 1995, 1996 and 1997 respectively.
Simbols not bearing a number denote 1998.
***: significant at 0.1% level of probability.

and wheat and rye varieties are shown in Figure 4. The plant weights of the triticale varieties were clearly greater than those of the wheat varieties and similar to or slightly less than those of the rye varieties in all years. The harvest indices of the triticale varieties were higher than those of rye varieties and similar to those of wheat varieties. These results suggest that the difference between grain yields of high-yielding triticale varieties and wheat varieties was mainly due to the difference between plant weights of the triticale and wheat varieties and that the difference between grain yields of high-yielding triticale varieties and rye varieties was mainly due to the difference between harvest indices of the triticale and rye varieties. However, these speculations are not supported by results of previous studies by Sweeney et al[29] and Kochhann[15] et al, suggesting that high yields of spring triticale varieties grown in Australia and Brazil, respectively, were due to high harvest indices.

The relationships between grain yields and one ear weights of high-yielding triticale varieties and wheat and rye varieties are shown in Figure 5. A significant positive correlation was found between grain yields and one ear weights (r= 0.756). The results suggest that large one-ear weight was one factor contributing to the high yields of triticale varieties as has also been suggested in other reports[22,26].

The results of this study suggest that 1) the high yields of Polish triticale varieties were due to greater one ear weights and plant weights than those of the Hokkaido wheat varieties and due to higher harvest indices than those of the rye varieties and 2) the low yields of other triticale varieties were due to a large reduction in the number of ears caused by winter injury, a low harvest index, and a high lodging index. Based on these results, it is thought that high yields of triticale grown in a snowy region of Hokkaido can be obtained by selecting triticale varieties that have a high degree of snow tolerance, a large number of ears and a high harvest index and by taking measures to prevent a reduction in the number of ears due to winter injury.

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要　　約

北海道においてコムギ，ライムギより多収を示す秋播ライコムギ品種と低収にとどまる品種の生育特性の違いを把握し，ライコムギの多収品種育成のための育種目標および多収を実現するための栽培上の注意点を明らかにするために，ライコムギ品種，北海道の秋播コムギ品種，および秋播ライムギ品種の子実収量とその関連形質を 4 ヶ年にわたり比較調査した。ポーランド育成のライコムギ品種に，コムギおよびライムギに比べて子実収量の高いものが多かった。しかし，ロシア，ウクライナ，フランス，カナダ，韓国，イングランド育成のライコムギ品種の子実収量は北海道のコムギ基幹品種に比べて低かった。前者の多収要因は，コムギに比べて一穂重および地上部重が大きいこと，ライムギに比べ収穫指数が高いことにあると考えられた。後者の低収要因には，第一に越冬個体指数が低いこと，第二に越冬個体指数が比較的高い品種においても穂数が少ないこと，第三に収穫指数が低いことがあげられ，長稈のライコムギ品種においては倒伏も低収に関与すると考えられた。北海道においてライコムギの多収を実現するためには，育種目標として冬枯れに対する耐性に優れたもの，穂数が多く収穫指数の高いものを選抜すること，栽培技術としては冬枯れによる穂数の減少を防ぐことが重要であり，これらがある程度満たされた時，穂重型でコムギよりも地上部重の大きいライコムギの特性が多収性に結びつくことが示唆された。