

Pedigree Analysis of Early Maturing Wheat Cultivars in Japan for Breeding Cultivars with Higher Performance

Tomohiko Ushiyama¹, Kazuhiro Nakamura², Anas³ and Tomohiko Yoshida³

¹United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183-8509, Japan;

²Nagano Agricultural Experiment Station, Yaemori, Suzaka, Nagano 382-0051, Japan;

³Faculty of Agriculture, Utsunomiya University, Utsunomiya, Tochigi 321-8505, Japan)

Abstract : Pedigree analysis was conducted for early maturing wheat cultivars developed in Japan. Materials used for this analysis were mainly developed at Nagano Agricultural Experiment Station (Tozan lines). In a recently released Tozan line, the maximum number of generations traced in the pedigree, total number of ancestors in the pedigree and total number of ancestors except common ones was 11, 222 and 94, respectively. Chunaga contributed 24.0% of the genetic background of Tozan lines. Seven ancestors, collectively, contributed 51.5% to the gene pool. Hiyokukomugi had the highest mean coefficient of parentage to Tozan lines and the mean value was 0.216, followed by Kinuiroha (0.213), Norin 61 (0.206), Mikunikomugi (0.205) and Tokai 80 (0.194). The mean coefficient of parentage between Tozan lines and cultivars in the Kanto-Tokai region, Kinki-Chugoku-Shikoku region and Kyushu region was 0.165, 0.155 and 0.157, respectively. Tozan lines more related to cultivars in the Tohoku region tended to be late heading and more cold-tolerant. Tozan lines more related to Ayahikari or Kinuazuma tended to be early maturing. Fukuhokomugi, which was a high yield cultivar and often used as a cross parent, did not contribute to high flour protein. KS831957 showed a positive effect on the crude protein content of flour. In general, Tozan lines had no specific cultivars used extensively as a cross parent having significant influence on yield or flour quality.

Key words : Coefficient of parentage, Maximum number of generations traced in the pedigree, Number of ancestors in the pedigree, Pedigree analysis, Wheat.

Wheat cultivars in Japan are generally early maturing. Especially it is true in Nagano prefecture which is located near Kanto and Tohoku regions. The meteorological characteristic of Nagano is the severe winter and sudden warmth in early spring. The growth of wheat is restrained during the winter season by snow blight, freeze, cold wind and frost column. Nagano has a rainy season. These weather factors cause pre-harvest sprouting (Kuwabara and Maeda 1979). Therefore, the main objectives of wheat breeding at Nagano Agricultural Experimental Station are to breed the cultivars with early maturity with winter habit, high yield, freeze hardiness, snow endurance, heaving resistance and resistance to pre-harvest sprouting. The first cultivar released at this station was Zenkojikomugi (name of breeding line was Tozan 1, 1965), which was mainly used as a gene source for the resistance to pre-harvest sprouting. Although three cultivars (Shiraneikomugi (Tozan 17), Kinuhime (Tozan 30) and Hanamanten (Tozan 40)) were released and grown in many prefectures, new cultivars with higher yield, higher flour quality and wider adaptability are awaited.

Pedigree analysis, which is the study of breeding records of crop cultivars, of the breeding materials

could give valuable information for breeding cultivars with higher performance. However, the pedigree record of recently released cultivars, which are developed after many crossings among promising parents, is very complicated and it is almost impossible to understand the records without proper numerical analysis.

A computer program for the pedigree analysis, i.e., drawing a pedigree tree, calculating the maximum number of generations traced in the pedigree (generations to the furthest last ancestor in the pedigree tree), total number of ancestors in the pedigree, number of ancestors except common ones and coefficients of parentage among any cultivars, has been written in Prolog, a programming language with logical operations for artificial intelligence and data retrieval applications (Mizuta et al., 1996; Yoshida, 2004). Using this program, the genetic background of rice cultivars developed in Fukuoka prefecture (Yoshida and Imabayashi, 1998), in Kanto (Ohta et al., 2006), in Fukushima (Sato and Yoshida, 2007) and in Hokuriku (Shigemune et al., 2006), and of barley cultivars in Fukuoka (Mizuta et al., 1996) were analyzed and the relation to the agronomic and quality characters were studied. For rice cultivars in Fukuoka, Osato and

Yoshida (1996) showed that cultivars more related to Koshihikari had higher eating quality but Sato and Yoshida (2007) found no relationship between them in cultivars in Fukushima. Mizuta et al. (1996) found that malting barley cultivars more related to Harunanijo had higher malting quality. Yoshida and Oosato (1998) showed the relationship between the rate of rice root regeneration from embryo callus and the genetic background. These data show that cross combinations with high performance can be partially estimated in advance by computing the coefficients of parentage, which will lead to the planning of more reasonable and theoretical breeding strategy.

In wheat cultivars developed in Kyushu, the genetic background was narrow, the number of ancestors was relatively small, and Norin 61, the main cultivar in Kyushu, had no contribution to yield and quality (Mizuta and Yoshida, 1996). The genetic background of cultivars in Kyushu and Nagano might be different and pedigree analysis should be conducted at each breeding station. Therefore, pedigree analysis of wheat cultivars developed at Nagano Agricultural Experimental Station (Tozan lines) was attempted with the emphasis of heading data, cold-tolerance and flour characters.

In this paper, to elucidate the general aspect of the pedigree tree, we counted the maximum number of generations traced in the pedigree and the number of ancestors in the pedigree. To determine the genetic background, we also examined the contribution of ancestors to the gene pool of Tozan lines, and the coefficients of parentage between Tozan lines and main cultivars. Finally, we studied the relationship between coefficients of parentage and agronomic or flour quality characters.

Coefficients of parentage show the kinship between two cultivars. It is defined as the probability that a random gene from X is identical by descent with a random gene from Y, considering two individuals, X and Y (Kempthorne, 1969). By using these values, we could numerically characterize recent cultivars with a very complicated pedigree record.

Coefficients of parentage of crop cultivars had been computed using a conventional computer program for soybean (Delannay et al., 1983), rice (Dilday, 1990; Lin, 1991; 1992) and spring bread wheat (Smale et al., 2002). However, these reports did not mention the relationship with agronomic characters.

The coefficients of parentage estimated from pedigree record and the genetic distance estimated from DNA polymorphism had significant correlations in malting barley (Uchimura et al., 2004) and in barley and wheat (Kobayashi and Yoshida, 2006). This shows that the coefficients of parentage, which are calculated assuming that cultivars derived from the crossing have half of the genetic materials of each cross parent, was related to the genetic distance estimated from DNA

Table 1. Maximum number of generations traced in the pedigree, total number of ancestors and number of ancestors except common ones of Tozan lines.

Tozan line	Year of release	Maximum generation in the pedigree	Number of ancestors	
			Total	Except common ones
Tozan 1	1966	2	6	3
Tozan 2	1967	5	26	21
Tozan 3	1975	3	10	4
Tozan 4	1975	5	18	17
Tozan 5	1976	5	20	18
Tozan 6	1976	5	16	15
Tozan 7	1977	5	20	18
Tozan 8	1977	5	16	15
Tozan 9	1978	6	74	45
Tozan 10	1978	3	6	6
Tozan 11	1978	6	44	28
Tozan 12	1979	6	44	28
Tozan 13	1979	7	78	49
Tozan 14	1979	6	74	45
Tozan 15	1980	6	44	28
Tozan 16	1980	7	78	49
Tozan 17	1980	7	78	49
Tozan 18	1981	7	78	49
Tozan 19	1982	9	96	45
Tozan 20	1982	6	62	41
Tozan 21	1983	8	50	34
Tozan 22	1984	6	40	26
Tozan 23	1984	6	32	25
Tozan 24	1985	6	32	25
Tozan 25	1987	6	32	31
Tozan 26	1987	9	138	71
Tozan 27	1988	9	60	31
Tozan 28	1989	10	198	72
Tozan 29	1991	9	138	71
Tozan 30	1994	10	210	82
Tozan 31	1995	7	74	45
Tozan 32	1996	9	106	45
Tozan 33	1997	9	98	41
Tozan 34	1998	9	98	41
Tozan 35	1999	9	98	43
Tozan 36	1999	8	80	51
Tozan 37	2000	9	98	43
Tozan 38	2001	12	196	79
Tozan 39	2001	12	196	79
Tozan 40	2002	12	196	79
Tozan 41	2003	13	192	59
Tozan 42	2004	11	128	75
Tozan 43	2004	9	126	79
Tozan 44	2005	9	94	58
Tozan 45	2006	7	34	27
Tozan 46	2006	11	222	94
Mean		7.5	83.8	43.0

polymorphism.

Materials and Methods

A computer program for the pedigree analysis in Prolog (Mizuta et al., 1996) modified for Windows (AZ-Prolog for Win32, Sofnec co. Ltd., Yoshida, 2004) was used. The 46 Tozan lines shown in Table 1 were studied. Pedigree trees of all cultivars computed were drawn and checked for the accuracy of the record. A cultivar originating from a mutation or pure line selection was considered as an original cultivar. Even if there is some discrepancy in the early crossing record, the values of coefficient of parentage have little difference (Yoshida, 1998).

First, the maximum number of generations traced in the pedigree, the total number of ancestors and the total number of ancestors except common ones in the pedigree tree were counted for each Tozan line. The coefficients of parentage between Tozan lines and main cultivars were computed to find the genetic background of Tozan lines. The main cultivars included 51 main cultivars and 82 cultivars having Norin number (Norin 76 (Yuyakekomugi)–Norin 165 (Hanamanten) except 8 cultivars which were developed in Nagano. The coefficient of parentage to the last ancestor (having no further ancestors) can be considered as the genetical contribution (the value multiplied by 100 to %) of the ancestor to the gene pool (Mizuta and Yoshida, 1996).

To determine the relationship between the genetic background and performance, we computed the correlations between the kinship of a cultivar (coefficient of parentage) and agronomic or flour characters. The characters examined were heading time, date of maturity, milling score, crude ash content, crude protein content, L* value, a* value, and b* value of 60% flour scored as a deviation from Shiranekomugi. These data were collected following the standard method of Nagano agricultural experiment station. Potential yield was calculated as the percentage of weight of whole grains per area to that of a standard cultivar Shiranekomugi). Sprouting resistance was scored as 3 for hardly sprouting, 5 for intermediate and 7 for easily sprouting. Grade of spring habit was scored as 1 for spring habit, 3 for intermediate and 5 for winter habit. Cold tolerance, heaving resistance and snow-mold tolerance were scored as 3 for high, 5 for intermediate, and 7 for low based on the rate of winter killing and the degree of damage after over wintering in Hara village (1080 m above sea), Shiojiri city (760 m), and Iiyama city (300 m).

The means of several replications from 1983 to 2007 were used. Since data was lacking for some Tozan lines, 28 lines (Shiranekomugi (Standard cultivar), Tozan 18, and Tozan 22–46) were used in the correlation studies.

Table 2. Ancestors contributing to the gene pool of Tozan lines.

No.	Ancestors	Mean coefficient of parentage*	Accumulated contribution to gene pool (%)
1	Chunaga	0.240	24.0
2	Igachikugo	0.067	30.8
3	Eshima	0.049	35.7
4	Oregon	0.048	40.5
5	Goshu 13	0.047	45.2
6	Yarl Weizen	0.035	48.7
7	Shirochabo	0.028	51.5
8	Garenet ott 652	0.027	54.2
9	Ridet	0.026	56.8
10	Shirasaya	0.023	59.1

* Average of 46 Tozan lines.

Results and Discussion

1. The maximum number of generations traced in the pedigree and the number of ancestors in the pedigree

Table 1 shows the maximum number of generations traced in the pedigree, the total number of ancestors in the pedigree and the total number of ancestors except common ones, of the Tozan lines. In Tozan 3, the numbers were 3, 10 and 4, respectively, and in Tozan 46, the numbers were 11, 222 and 94, respectively. In Tozan 26 to Tozan 46 lines released recently, the pedigree became more complicated than in Tozan 1 to Tozan 8 lines, and it must be traced to the oldest ancestor up to 13 generations. It had more than or nearly 200 total ancestors in the pedigree, though the number was reduced to about half when common ones were excluded. Half of Tozan 26 to Tozan 46 lines had more than 100 total ancestors in total, though Tozan 1 (Zenkojikomugi) to Tozan 25 lines had less than 100 ancestors.

In rice in Fukuoka, the maximum number of generations traced in the pedigree, the total number of ancestors in the pedigree and the total number of ancestors except common ones were reported to be 17, 1238 and 119, respectively (Oosato and Yoshida, 1996). In barley in Fukuoka, they were 10, 196 and 47, respectively (Mizuta and Yoshida, 1994), and in wheat in Kyushu, they were 9, 138 and 66, respectively (Mizuta and Yoshida, 1996). In wheat of Tozan lines, they were fewer than in rice, showing that the wheat pedigree is simpler than the rice pedigree. It is necessary to introduce many genes into new wheat cultivars that adapt to a large area. Though wheat lines in Kyushu computed were developed earlier than Tozan lines, the pedigree of Tozan lines had more ancestors and was more complicated than Kyushu lines.

Table 3. Top 10 cultivars related to Tozan lines.

No.	Cultivar	Mean of coefficient of parentage*	The region where cultivar was developed
1	Hiyokukomugi	0.216	Kyushu
2	Kinuiroha	0.213	Kyushu
3	Norin 61	0.206	Kyushu
4	Mikunikomugi	0.205	Kanto
5	Tokai 80	0.194	Tokai
6	Iwainodaiti	0.194	Kyushu
7	Gunma w10	0.193	Kanto
8	Junreikomugi	0.192	Shikoku
9	Ayahikari	0.192	Kanto
10	Ushikomugi	0.188	Chugoku

* Average of 46 Tozan lines.

2. Contribution of ancestors to the gene pool

Table 2 shows the contribution of ancestors to the gene pool of Tozan lines. The average value of coefficients of parentage between Chunaga and Tozan lines was as high as 0.240, which showed that Chunaga contributed 24.0% to the genetic background of Tozan lines. It was followed by Igachikugo (0.067), Eshima (0.049), Oregon (0.048), Goshu 13 (0.047), Yarl Weizen (0.035) and Shirochabo (0.028). It shows that only a few ancestors contributed to the gene pool. Seven ancestors, collectively, contributed 51.5% to the gene pool. It also shows the necessity of widening the genetic background to overcome the “genetic vulnerability” (Walsh 1981).

In wheat cultivars in Kyushu, Chunaga contributed 39.3% to the gene pool (Mizuta and Yoshida, 1996), which was higher than that in Tozan lines. Chunaga was often used as a cross parent in early wheat breeding and produced many good cultivars including Norin 61, which has been grown in wide areas. This is the reason for the high contribution of Chunaga to wheat cultivars even at present.

Five ancestors of rice, 3 of malting barley and 5 of wheat, collectively, contributed 62.5, 71.8 and 59.4 % to the gene pool, respectively (Oosato and Yoshida, 1996; Mizuta and Yoshida, 1994; Mizuta and Yoshida, 1996). The value in Tozan lines for the top 5 ancestors was 45.2 (Table 2) and lower than that in cultivars in Kyushu, but it still shows the narrow genetic background of Tozan lines.

3. Cultivars related to Tozan lines

Table 3 shows the top 10 cultivars most closely related to Tozan lines. The table shows the mean values of the coefficients of parentage to Tozan lines. The highest value was 0.216 for Hiyokukomugi, followed by Kinuiroha (0.213), Norin 61 (0.206), Mikunikomugi (0.205) and Tokai 80 (0.194). Among

Table 4. The means and standard deviation of coefficients of parentage between Tozan lines and cultivars having Norin number in each region.

Region	Number of cultivars	Mean of coefficient of parentage*	Standard deviation of coefficient of parentage*
Hokkaido	13	0.022	0.014
Tohoku	19	0.045	0.028
Hokuriku	4	0.046	0.045
Kanto and Tokai	13	0.165	0.024
Kinki, Chugoku and Shikoku	8	0.155	0.042
Kyushu	25	0.157	0.043

* Calculated for 46 Tozan lines.

the cultivars developed in a cold climate, the rank of the highest was 49th in Hokuriku 49 (0.142), followed by Yukichabo (56th, 0.114) and Norin 27 (57th, 0.105) (data not shown).

For 82 cultivars having a Norin number, the coefficients of parentage to Tozan lines were computed. They were divided into five groups depending on the region where they were developed; Hokkaido (region with severely cold in winter), Tohoku (northern cold region), Hokuriku (southern cold region), Kanto-Tokai (eastern mild climate region), Kinki-Chugoku-Shikoku region, (western mild climate region) and Kyushu region (warm region). Table 4 shows the mean values and standard deviations of the coefficients of parentage between the Tozan lines and cultivars having a Norin number in each region. The mean values of the coefficient of parentage in Kanto-Tokai region, Kyushu region and Kinki-Chugoku-Shikoku region were 0.165, 0.157 and 0.155, respectively. The values in the Tohoku, Hokuriku and Hokkaido regions were 0.045, 0.046 and 0.022, respectively. The standard deviation of the values in the Kanto-Tokai region was the lower (0.024) than the standard deviations in Kanto-Tokai region or Kyushu region and Kinki-Chugoku-Shikoku region. Thus, the cultivars developed in the Kanto-Tokai region showed a relatively high kinship to Tozan lines, though the values of coefficient of parentage were not so high.

Among the cultivars developed in Kyushu, the cultivar most related to the Kyushu lines was Asakazekomugi and its mean coefficient of parentage to the Kyushu lines was as high as 0.478, followed by Hiyokukomugi (0.373), Chunaga (0.359) and Shiroganekomugi (0.359) (Mizuta and Yoshida, 1996), showing that a specific cultivar contributed to cultivars developed in Kyushu. It seems that a specific cultivar did not contribute to the Tozan lines in comparison with the cultivars developed in Kyushu.

Table 5. Correlations between agronomic characters and coefficient of parentage to a specific cultivar among Tozan lines.

[Rejion] Cultivar	Mean coefficient of parentage	Heading time	Date of maturity	Potential yield	Cold tolerance ¹⁾	Heaving resistance ¹⁾	Snow mold tolerance ¹⁾	Sprouting resistance ²⁾	Grade of spring habit ³⁾
[Hokkaido]									
Hokushin	0.031	0.39	0.25	0.16	-0.28	-0.20	-0.40*	-0.07	0.27
[Tohoku]									
Norin27	0.105	0.46*	0.32	0.26	-0.39*	-0.05	-0.30	-0.30	0.15
Nanbukomugi	0.081	0.44*	0.28	0.11	-0.38*	-0.21	-0.43*	-0.31	0.29
Sakyukomugi	0.075	0.48*	0.33	0.20	-0.44*	-0.13	-0.41*	-0.27	0.25
Yukitikara	0.051	0.43*	0.29	0.13	-0.45*	-0.17	-0.47*	-0.28	0.31
Furutumasari	0.029	0.46*	0.32	0.23	-0.45*	-0.06	-0.36	-0.32	0.20
[Hokuriku]									
Hokuriku 49	0.142	-0.05	0.04	0.05	0.04	0.03	-0.10	0.68**	0.11
Yukichabo	0.114	-0.04	0.05	0.06	0.03	0.03	-0.11	0.67**	0.11
[Kanto and Tokai]									
Tokai 80	0.194	-0.18	-0.13	0.25	0.17	0.24	0.02	0.54**	0.05
Ayahikari	0.192	-0.21	-0.46*	0.21	0.21	0.19	0.41*	-0.41*	-0.38*
Kanto 107	0.170	-0.18	-0.40	0.30	0.18	0.27	0.41*	-0.37	-0.41*
Fukohokomugi	0.184	-0.17	-0.22	0.52**	0.44*	0.52**	0.24	0.21	-0.07
Tamaizumi	0.151	-0.32	-0.44*	0.42	0.26	0.43*	0.23	-0.16	-0.14
Kinuazuma	0.150	-0.26	-0.49**	0.31	0.24	0.30	0.43*	-0.41*	-0.41*
[Kinki and Chugoku]									
Ushiokomugi	0.188	-0.30	-0.31	0.44*	0.27	0.48**	0.11	0.13	0.01
Fukuhonoka	0.168	-0.25	-0.50**	0.24	0.24	0.22	0.39	-0.40*	-0.35
Fukusayaka	0.166	-0.29	-0.39	0.02	0.12	0.03	0.17	-0.42*	-0.15
[Kyushu]									
Hiyokomugi	0.216	0.03	-0.14	0.47*	0.13	0.32	0.11	-0.15	-0.07
Norin 61	0.206	-0.27	-0.26	0.44*	0.22	0.44	0.08	0.14	0.02
Nishikazekomugi	0.173	-0.37	-0.44*	0.19	0.25	0.31	0.15	-0.15	-0.03
Gogatukomugi	0.166	-0.35	-0.47*	0.49**	0.30	0.50**	0.30	-0.14	-0.21
[other]									
KS831957	0.043	-0.15	-0.06	-0.65**	0.13	-0.36*	0.20	-0.05	-0.35
Odeskaya51	0.022	-0.15	-0.06	-0.65	0.13	-0.36	0.20	-0.05	-0.35
Yarl Weizen	0.035	0.50**	0.39*	0.22	-0.43*	-0.10	-0.37	-0.27	0.23

Original rank was as follows; 1) 3, High; 5, Intermediate; 7, Low. 2) 3, Difficult; 5, Intermediate; 7, Easy. 3) 1, Spring habit; 5, Winter habit.

*, Significant at 5% level. **, Significant at 1% level.

4. The relationship between the performance of cultivars and the kinship to a specific cultivar

Tables 5 and 6 show the correlation of agronomic characters and flour quality, respectively, with the coefficient of parentage to a specific cultivar among Tozan lines, respectively. In the tables, only the main cultivars having statistically significant differences are

shown.

Significant negative correlations (from -0.38 to -0.45) between the coefficient of parentage and cold tolerance were found, showing that Tozan lines more related to cultivars in Tohoku region tended to be more cold-tolerant. However, significant positive correlations (from 0.43 to 0.48) were found between

Table 6. Correlations between flour quality and coefficient of parentage to a specific cultivar among Tozan lines.

[Rejion] Cultivar	Milling score	Crude ash content of 60% flour	Crude protein content of 60% flour	L* value of 60% flour	a* value of 60% flour	b* value of 60% flour
[Hokkaido]						
Hokushin	0.14	0.25	0.05	0.15	0.00	0.33
[Tohoku]						
Norin27	0.24	0.33	-0.02	-0.18	0.33	0.23
Nanbukomugi	0.12	0.34	0.12	-0.04	0.03	0.43*
Sakyukomugi	0.20	0.35	0.06	-0.09	0.23	0.31
Yukitikara	0.14	0.34	0.14	-0.03	0.08	0.41*
Furutumasari	0.21	0.36	0.04	-0.16	0.32	0.24
[Hokuriku]						
Hokuriku 49	0.05	-0.18	-0.05	0.20	0.03	-0.05
Yukichabo	0.05	-0.18	-0.06	0.21	0.03	-0.03
[Kanto and Tokai]						
Tokai 80	0.12	-0.20	-0.33	0.23	0.18	-0.15
Ayahikari	0.24	-0.34	-0.12	-0.10	0.02	0.18
Kanto 107	0.27	-0.34	-0.15	-0.22	0.08	0.26
Fukohokomugi	0.18	0.11	-0.62**	-0.09	0.23	0.02
Tamaizumi	0.22	-0.22	-0.48**	0.13	0.27	-0.12
Kinuazuma	0.27	-0.39	-0.21	-0.12	0.09	0.17
[Kinki and Chugoku]						
Ushiokomugi	0.17	-0.12	-0.56**	0.14	0.29	-0.23
Fukuhonoka	0.24	-0.34	-0.20	-0.01	0.05	0.10
Fukusayaka	-0.00	-0.25	-0.15	0.32	-0.06	-0.14
[Kysyu]						
Hiyokomugi	0.27	0.12	-0.45*	-0.08	0.35	0.09
Norin 61	0.16	-0.10	-0.56**	0.15	0.29	-0.17
Nishikazekomugi	0.12	-0.27	-0.31	0.23	0.17	-0.40*
Gogatukomugi	0.26	-0.29	-0.53**	0.06	0.27	-0.07
[other]						
KS831957	-0.72**	0.18	0.59**	0.08	0.06	-0.24
	-0.75	0.34	0.63	-0.12	0.40	-0.43
Yarl Weizen	0.21	0.41	-0.00	-0.14	0.33	0.19

*, Significant at 5% level. **, Significant at 1% level.

the coefficient of parentage and heading time in cultivars in the Tohoku region, showing that Tozan lines more related to cultivars in Tohoku region tended to be late heading. On the other hand, significant negative correlations (-0.46, -0.49) were found between the coefficient of parentage and date of maturity for cultivars in the Kanto region (Ayahikari, Kinuazuma), showing that Tozan lines more related to Ayahikari or Kinuazuma tended to be early maturing.

In the same cultivars, the grade of spring habit showed a negative correlation (-0.38, -0.41), and snow mold tolerance a significant positive correlation (0.41, 0.43) with the coefficient of parentage. A significant negative correlation (-0.47) with date of maturity and a significant positive correlation (0.50) with heaving resistance were found in Gogatukomugi developed in Kyushu.

A negative correlation (-0.41, -0.41, -0.40 and

-0.42) was found between the coefficient of parentage and sprouting resistance in Ayahikari, Kinuazuma, Fukuhonoka and Fukusayaka. Also in these cultivars, a negative correlation (-0.46, -0.49, -0.50 and -0.39) was found for date of maturity, showing that Tozan lines more related to cultivars in Kanto-Tokai region and Kinki-Chugoku- Shikoku tend to have good combining ability.

In Fukuhokomugi, Tamaizumi, Ushikomugi, Hiyokomugi, Norin 61 and Gogatsukomugi, the crude protein content of the 60% flour showed a significant negative correlation, -0.62, -0.48, -0.56, -0.45, -0.56 and -0.53, respectively, with the coefficient of parentage though potential yield showed a significant positive correlation, 0.52, 0.42, 0.44, 0.47, 0.44 and 0.49, respectively. It shows the difficulty of developing cultivars having both high yield and high quality in Tozan lines. Though Fukuhokomugi was a high yield cultivar and often used as a cross parent (average coefficient of parentage was 0.184), it did not produce a high protein cultivar. KS831957 showed a positive correlation (0.59) for crude protein content of 60% flour. It is used extensively as a cross parent recently for a strong flour wheat, but a significant negative correlation (-0.65) was found for potential yield.

Mizuta and Yoshida (1996) showed that cultivars in Kyushu related to Asakazekomugi had a low value of flour whiteness, showing that Asakazekomugi had a poor combining ability in quality though it was a high-yield cultivar and often used as a cross parent there. Cultivars related to Kanto 107 had high maximum viscosity values. Cultivars related to Siroganekomugi had a high protein content, showing that Kanto 107 and Siroganekomugi might have good combining ability for flour quality. There seems to be no cultivar of Tozan used extensively as a cross parent for high quality. No significant correlation with crude ash content, L* and a* value of 60% flour was found.

Tozan lines related to earlier maturing cultivars had low over-wintering ability and low grade of spring habit. Tozan lines related to high potential yield cultivar had a low protein content of flour protein, and were not related to milling score. However, in comparison with cultivars developed in Kyushu, there seem to be no specific cultivars in the Tozan lines used extensively as a cross parent having significant influence on the yield or flour quality as in the case of Koshihikari in rice or Harunanijo in malting barley.

We have already developed cultivars with early maturity, high winter habit and high yield. Further efforts for developing cultivars with these characters and high over-wintering ability are necessary. It is very difficult to develop cultivars with a high protein content, early maturity and high yield. In this study, KS831957 (0.59) was found to be potentially promising cross parents for high flour quality, which could be

used more extensively as a cross parent.

In comparison with rice, the maximum number of generations traced in the pedigree and the number of ancestors in the pedigree of wheat are far smaller, though total number of ancestors in the pedigree of Tozan lines exceeded 100, showing that more aggressive and shortening of crossing interval might be necessary. In addition to the haploid breeding method (Ushiyama et al., 2006), gathering a lot of major genes with high yield and high quality by conventional cross breeding method is necessary. Pedigree trees of modern cultivars are very complicated and it is almost impossible to evaluate the performance and the combining ability of the cultivar from the pedigree tree. Pedigree analysis conducted in this study could be useful for constructing a more reasonable strategy for developing cultivars with higher yield and higher quality.

The method of this pedigree analysis can be applied to wheat cultivars in other countries and many valuable suggestions could be obtained, if the pedigree records of the materials are completed. Web service for pedigree analysis was constructed by one of the authors (Yoshida, 2008).

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* In Japanese with English abstract.

** In Japanese.