Japan. Jour. Crop Sci. 60(2) : 312—319 (1991)

Varietal Differences in Geotropic Response of Primary Seminal Root in Japanese Wheat*

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Received October 29, 1990

Abstract : Growth angles of inclination of primary seminal roots for 133 Japanese wheat varieties were examined in an agar medium. Germinated seeds were set on a 0.2% agar medium and the initial emergence directions of the primary seminal roots were adjusted horizontally. Two days after setting, growth angle of inclination, defined as the angle between the root growth direction and the horizontal direction, was measured with a protractor. Root geotropic responses of the varieties were represented by the values of the growth angles of inclination of the roots. Varietal variation was found in the growth angles of primary seminal roots. The inclination angles ranged from the smallest, 4° for Minaminokomugi, to the largest, 64° for Norin 58. Varieties which were bred in the northern part of Japan had large root growth angles and varieties which were bred in the southern part of Japan had small root growth angles. Prostrate-type or high degree of winter habit varieties had large root growth angles. On the other hand, erect-type or low degree of winter habit varieties had small root growth angles. As results of an additional experiment, no significant difference in root elongation rates and in root diameters was found between Minaminokomugi and Norin 58.
Key words : Agar medium, Geotropic responses, Primary seminal root, *Triticum aestivum*, Varietal differences.

コムギ初生種子根の屈地性の品種間差異：小柳敦史・佐藤暁子・和田道宏（農業研究センター）

要　旨：農林登録されているコムギ133品種の種子根の屈地性を寒天培地で調査した．発芽種子を初生種子根の出現角度が寒天面と平行になるような角度で置床し，2日後に初生種子根の伸長角度(伏角)を測定した．その結果，種子根の伸長角度には品種間差異が認められ，伏角はミナミノコムギが最も小さく4°，農林58号が最も大きく64°であった．品種を育成地で分類すると，北日本で育成された品種は伸長角度が大きく，南日本で育成された品種は伸長角度が小さかった．供試品種全体では，直立型の品種に比べほふく型の品種，秋播性程度の低い品種に比べ高い品種の根の伸長角度が大きかった．なお，ミナミノコムギと農林58号の間には，根の伸長速度及び直径に大きな差異は認められなかった．
キーワード：寒天培地，屈地性，コムギ，初生種子根，品種間差．

Development of the root system plays an important role in the growth and yield of crops under stress conditions. However, only a small number of observations have been done on varietal differences in root systems.

Root distribution patterns seem to be closely related to the tolerance to water stress and cold resistance of wheat and barley varieties. In connection with the root distribution pattern, Rufelt[14] found varietal differences in the angles of inclination of seminal roots ranging from 12° to 80° in 200 Swedish wheat varieties. In Japan, Takahashi and Itano[16] reported varietal differences in growth angles of opposite seminal roots and geographical variation of the barley varieties on the root growth angles. In wheat, Sekizuka[15] found that wheat varieties predominant to the southern part of Japan had spreading-type root systems. However, there was no report about differences in geotropic response of the seminal roots in Japanese wheat varieties.

In the present experiments, geotropic responses of primary seminal roots were observed using an agar culture for 133 Japanese wheat varieties released before 1988 by the National Authority of Cultivars Registration.

Materials and Methods

Wheat varieties used in this study included 7 spring-sown varieties bred in Hokkaido and 126 autumn-sown varieties, including 6 varieties bred in Hokkaido, 28 in Tohoku, 13 in Hokuriku-Tosan, 27 in Kanto-Tokai, 28 in Kinki-Chugoku-Shikoku and 24 in Kyushu. The annual mean air temperature and amount of precipitation at a meteorological

* A part of this paper was presented at the 189th (April, 1990) meenting of Crop Science Society of Japan.
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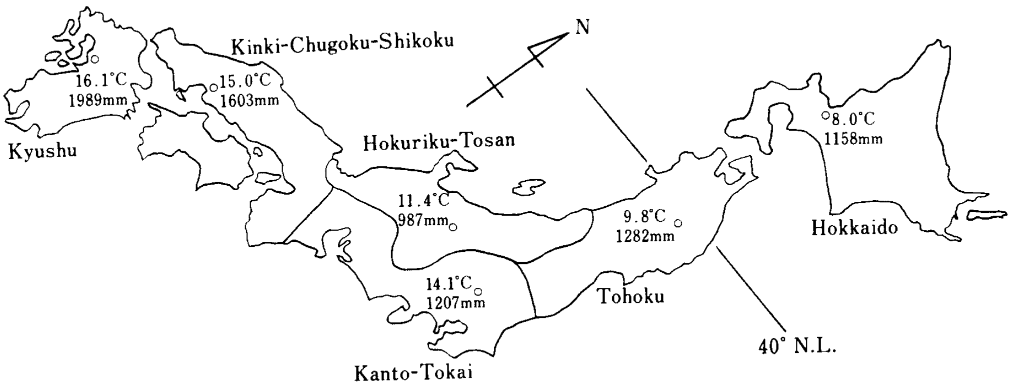

Fig. 1. Annual mean air temperature and amount of precipitation of a meteorological observing site in each region.

observing site in each region were shown in Fig. 1. The autumn-sown varieties predominant to the northern part of Japan tend to be prostrate-type, which is the prostrate plant type before internode elongation stage, and show high degree of winter habit or winter nature[5], *i.e.*, they require long term low temperature for vernalization. On the other hand, the varieties in the southern part of Japan tend to be erect-type or intermediate-type and show low degree of winter habit.

Seeds used in this experiment were harvested at Tsukuba. They were sterilized for one day in a 0.5% benomyl-thiram solution and moved into a plastic petri dish for germination with the embryo side of the seed upward. Germinated seeds, with 3-mm length of primary seminal root, were transplanted to an agar medium of 100 ml beaker. The concentration of agar was 0.2% because of the results of a preliminary experiment which showed that an agar concentration of 0.2% did not affect the root growth angles compared with a water medium.

The agar culture method for measuring root geotropic responses of rice[7] was modified. In order to increase the dissolved oxygen, the agar solution which melted at 70-80°C was bubbled by air until the temperature lowered to 40°C. The dissolved oxygen concentration of the agar medium became 6 mg/l. As a result of preliminary experiment, the root growth angles in the agar medium were not affected significantly by dissolved oxygen concentrations between 6 mg/l bubbled by air and 30 mg/l bubbled by oxygen. The root was put into the agar medium and initial emergence direction of the root was adjusted horizontally in exchange for laying sideways of the culture vessels[7].

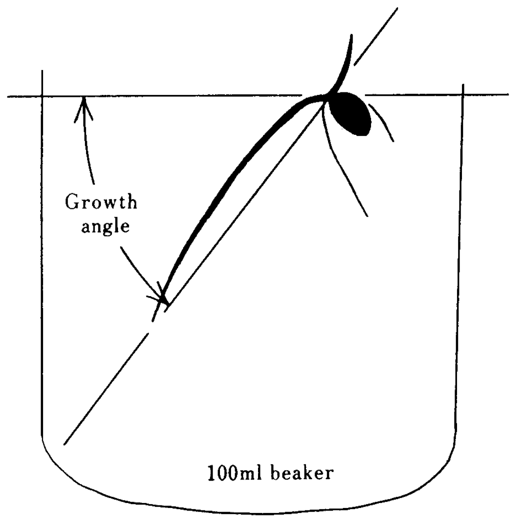

Fig. 2. Measurement of the growth angle of primary seminal root.

The inclination, which is evaluated by the angle between the agar surface and the line connecting the root tip and the root base, was measured with a protractor (Fig. 2). The measurement of the inclination was made after 2 days of cultivation on the agar medium in a growth cabinet, when the root length was 2-4 cm. The culture condition was 20±1°C, 80±10% R.H., and dark. Sixteen varieties consisting of 8 plants of each variety were examined at one time. Two replicated experiments were carried out.

In order to get values for the root elongation rate and root diameter, Minaminokomugi which had the smallest root growth angle and Norin 58 which had the largest root growth angle in the first experiment were examined again. Root length of the primary seminal root

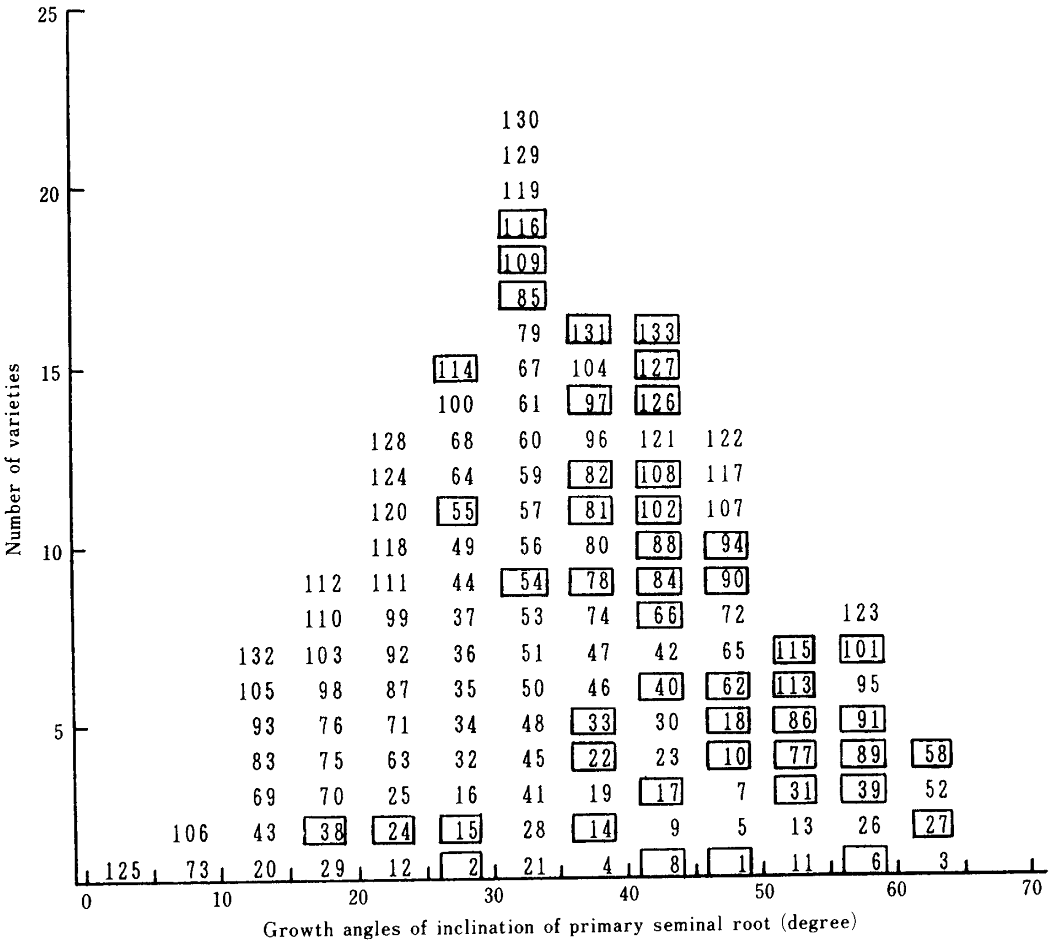

Fig. 3. Growth angles of primary seminal roots in Japanese wheat varieties. Significant varietal differences at the 5% level exist. The least significant difference at 5% is 31°. Numbers in this figure show registered numbers of varieties. Registered names of 1-75 : Norin 1-75, 76 : Yuyakekomugi, 77 : Susonokomugi, 78 : Mutsubenkei, 79 : Iyokomugi, 80 : Hatamasari, 81 : Aobakomugi, 82 : Nanbukomugi, 83 : Akatsukikomugi, 84 : Yukichabo, 85 : Hikarikomugi, 86 : Myokokomugi, 87 : Ebisukomugi, 88 : Hitsumikomugi, 89 : Kokeshikomugi, 90 : Okukomugi, 91 : Sakyukomugi, 92 : Yutakakomugi, 93 : Danchikomugi, 94 : Furutsumasari, 95 : Shirasagikomugi, 96 : Junreikomugi, 97 : Kitakamikomugi, 98 : Fujimikomugi, 99 : Hayatokomugi, 100 : Mikunikomugi, 101 : Shimofusakomugi, 102 : Miyaginokomugi, 103 : Nichirinkomugi, 104 : Haruhikari, 105 : Ushiokomugi, 106 : Omasekomugi, 107 : Hiyokukomugi, 108 : Mukakomugi, 109 : Zenkojikomugi, 110 : Kobushikomugi, 111 : Haruminori, 112 : Sakigakekomugi, 113 : Hachimankomugi, 114 : Horoshirikomugi, 115 : Takunekomugi, 116 : Hanagasakomugi, 117 : Shiroganekomugi, 118 : Gogatsukomugi, 119 : Toyohokomugi, 120 : Setokomugi, 121 : Chikushikomugi, 122 : Shirowasekomugi, 123 : Asakazekomugi, 124 : Fukuhokomugi, 125 : Minaminokomugi, 126 : Chihokukomugi, 127 : Wakamatsukomugi, 128 : Fukuwasekomugi, 129 : Nishikazekomugi, 130 : Haruyutaka, 131 : Shiranekomugi, 132 : Airakomugi, 133 : Koyukikomugi.

[ ] : Autumn-sown varieties bred in the northern part of Japan.

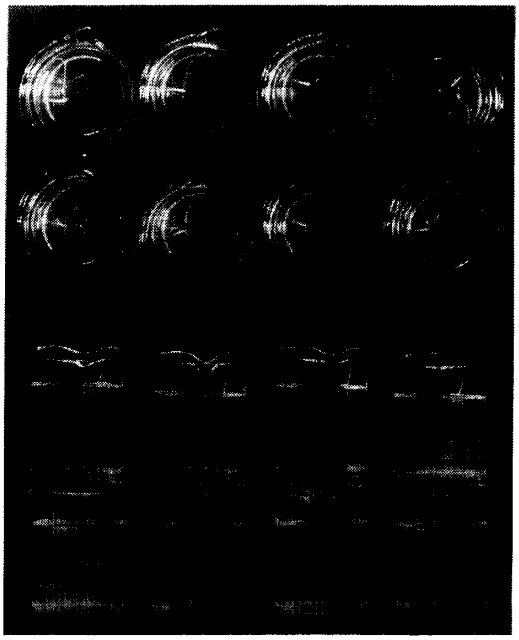

Fig. 4. Root growth of Minaminokomugi.

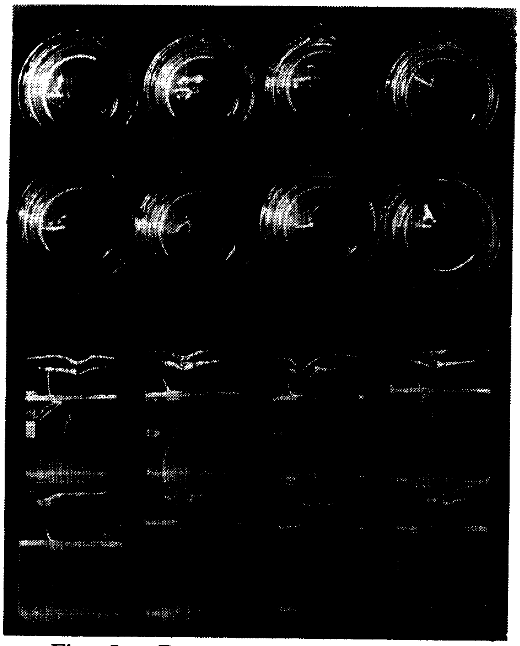

Fig. 5. Root growth of Norin 58.

was measured and the root diameter at 5 mm from the tip was measured under a stereoscopic microscope.

Results

In Fig. 3, the variation of the growth angles among the varieties showed normal distribution with the average 35°. The smallest angle of inclination, 4°, was obtained by Minaminokomugi and the largest angle of inclination, 64°, was obtained by Norin 58. Variance analysis showed significant varietal differences at the 5% level. The least significant difference at the 5% level was 31°. The average standard deviation in 8 plants of each experiment and variety was 18°. Figs. 4 and 5 are the photographs of Minaminokomugi and Norin 58, respectively. Since the photographs taken from the side did not show the root of Minaminokomugi clearly, those from the top were added.

As shown in Table 1, the mean growth angle of 7 spring-sown varieties was 30°. There was no significant difference in the root growth angles between spring-sown and autumn-sown varieties. Autumn-sown varieties could be classified into 6 groups by their breeding site. The growth angles of inclination of seminal roots were the largest in the varieties bred in Tohoku, and the smallest in the varieties in Kanto-Tokai. Variance analysis showed that the differences in the growth angle of autumn-sown varieties among 6 breeding sites were significant at the 1% level. The growth angles of primary seminal roots were large in the northern autumn-sown varieties and small in the southern autumn-sown varieties in Japan.

The varieties were also classified according to their tussock type which is the plant type before the internode elongation stage or winter habit which is the intensity of low temperature requirement for vernalization, and breeding site*. As shown in Table 2, the growth angles were smaller in the erect-type varieties (28°) and larger in the prostrate-type varieties (39°) than in the intermediate-type varieties (34°). Significant differences at the 1% level in the root growth angles were obtained among the types of tussock groups. However, there was no significant difference in the root growth angles among the tussock type groups within each breeding site. As shown in Table 3, the growth angles of inclination of the seminal roots were smaller in the low degree of winter habit varieties (31°) and larger in the high degree of winter habit varieties (44°) than in the intermediate varieties (34°). Significant differences at the 1% level in the growth angles were obtained among the groups of

* Tussock type and winter habit of the varieties were based on the List of wheat and barley varieties[6] and observations in the Wheat Breeding Laboratory and the Wheat & Barley Germplasm Laboratory, Department of Winter Crop Science, National Agriculture Research Center.

Table 1. Mean growth angles of primary seminal roots in the varieties classified by breeding sites.

Sown	Breeding site	Area in Japan	No. of vars.	Growth angle	Analysis of variance
				degree	
Spring	Hokkaido	Northern part	7	30±15	
Autumn	Tohoku	Northern part	28	45±10	
	Hokkaido	Northern part	6	43± 7	
	Hokuriku-Tosan	Northern part	13	37±12	
	Kinki-Chugoku-Shikoku	Southern part	28	33±14	
	Kyushu	Southern part	24	29±14	
	Kanto-Tokai	Southern part	27	28±11	
	Total		126	35	**

Growth angle: degree from the horizontal±S.D.
Analysis of variance: Significant differences at the 1% level (**) exist in the autumn-sown varieties among the 6 breeding sites. The bars show the ranges of no significant differences at the 5% level. Varieties were used as replications.

winter habit. However, there was no significant difference in the root growth angles among winter habit groups within each breeding site.

As shown in Table 4, the root growth angles of Minaminokomugi which had the smallest value and Norin 58 which had the largest value were 7° and 69° in the additional experiment, respectively. Root elongation rates of Minaminokomugi and Norin 58 were 0.44 mm/h and 0.53 mm/h. Root diameters were 0.56 mm for Minaminokomugi and 0.60 mm for Norin 58. No significant difference in root elongation rates and in root diameters between the two varieties was found.

Discussion

Varietal differences of root distribution patterns have been found in wheat[3, 11], rice[8, 18], corn[10] and foxtail millet[10] in Japan. It has been reported that deep root systems increase drought resistance in wheat[4], sorghum[2], upland rice[9] and corn[1], cold resistance in wheat[20], and lodging resistance in paddy rice[17]. It is assumed that root distribution patterns are closely related to the geotropic response of the roots. Varietal differences in geotropic responses of primary seminal roots in Japanese wheat varieties were found in this experiment using the agar culture.

In rice, root growth angles of inclination were large in japonica type varieties and small in indica type varieties[19]. Geographical variation of Japanese wheat and barley varieties in the root distribution patterns has been observed in the experiments by Takahashi and Itano[16], and Sekizuka[15]. It was suggested that autumn-sown wheat and barley varieties predominant to the northern part of Japan tend to form deep root systems in relation to cold resistance of the varieties[15]. On the other hand, the varieties predominant to the southern part of Japan tend to have shallow root systems because injury due to excess soil moisture is one of the most serious problems in winter cropping on drained paddy fields in the southern part of Japan[15, 16].

In this experiment, geographical variation of Japanese wheat varieties in geotropic responses of primary seminal roots was found. The root growth angles for autumn-sown varieties bred in the northern part of Japan were large and the angles for varieties bred in the southern part of Japan were small. Therefore, geographical variation of the root distribution patterns in wheat[15] was due to the difference of the geotropic responses.

It has been reported that erect-type varieties tend to have small root growth angles and prostrate-type varieties tend to have large root growth angles in barley[16]. In this experiment, it was also suggested that root geotropic

Table 2. Mean growth angles of primary seminal roots in the varieties classified by tussock types and breeding sites.

Sown	Breeding site	Tussock type			Analysis of variance
		Erect	Intermediate	Prostrate	
		degree (No. of varieties)			
Spring	Hokkaido	38 (2)	25 (2)	28 (3)	N.S.
Autumn	Northern part of Japan				
	Hokkaido	– (0)	45 (1)	42 (5)	–
	Tohoku	– (0)	45 (6)	45 (22)	N.S.
	Hokuriku-Tosan	30 (3)	30 (2)	42 (8)	N.S.
	Southern part of Japan				
	Kanto-Tokai	24 (4)	29 (12)	29 (11)	N.S.
	Kinki-Chugoku-Shikoku	29 (12)	39 (11)	29 (5)	N.S.
	Kyushu	26 (12)	31 (11)	48 (1)	N.S.
Total		28 (33)	34 (45)	39 (55)	* *

Tussock type is the plant type before internode elongation stage. * * : Significant at the 1% level. N.S. : Not significant. Varieties were used as replications for variance analysis.

Table 3. Mean growth angles of primary seminal roots in the varieties classified by degrees of winter habit and breeding sites.

Sown	Breeding site	Winter habit			Analysis of variance
		Low	Intermediate	High	
		degree (No. of varieties)			
Spring	Hokkaido	30 (7)	– (0)	– (0)	–
Autumn	Northern part of Japan				
	Hokkaido	– (0)	– (0)	43 (6)	–
	Tohoku	– (0)	44 (16)	46 (12)	N.S.
	Hokuriku-Tosan	33 (1)	29 (4)	43 (8)	N.S.
	Southern part of Japan				
	Kanto-Tokai	28 (10)	29 (17)	– (0)	N.S.
	Kinki-Chugoku-Shikoku	34 (16)	32 (12)	– (0)	N.S.
	Kyushu	30 (22)	25 (2)	– (0)	N.S.
Total		31 (56)	34 (51)	44 (26)	* *

Degree of winter habit is the intensity of low temperature requirement for vernalization : Low-I, I～II, II and II～III. Intermediate-III, III～IV, IV and IV～V. High-V, V～VI, VI and VII[5]. * * : Significant at the 1% level. N.S. : Not significant. Varieties were used as replications for variance analysis.

Table 4. Growth angles, elongation rates and diameters of the primary seminal roots in Minaminokomugi and Norin 58.

Variety	Breeding site	Growth angle	Elongation rate	Diameter
		degree	mm/h	mm
Minaminokomugi	Kyushu	7± 9	0.44±0.17	0.56±0.08
Norin 58	Tohoku	69±17	0.53±0.22	0.60±0.10
Analysis of variance		* *	N.S.	N.S.

* * : Significant at the 1% level. N.S. : Not significant.
Eight plants were used as replications for variance analysis.

responses were difference between erect-type and prostrate-type varieties in wheat. Moreover, a close relation between the root geotropic response and degree of winter habit of wheat varieties was found. However, no significant difference in root geotropic responses among tussock types or degree of winter habit groups within each breeding site was found.

It was reported that root growth angles were closely related to the root diameter in rice[21] and corn[22]. However, no significant difference in root diameters between Minaminokomugi which had the smallest root growth angle and Norin 58 which had the largest root growth angle was found in this experiment. Moreover, there was no significant difference in the root elongation rates for Minaminokomugi and Norin 58. According to visual observations for the 133 varieties, no clear relationship between root growth angles and root elongation rates was also found. Therefore, we began to further physiological[12] and genetic[13] studies in order to understand the varietal differences in geotropic responses of the seminal roots in Japanese wheat varieties.

Acknowledgement

The authors wish to thank Dr. Atsushi Yamashita, Director of the Department of Winter Crop Science, National Agriculture Research Center, for his valuable advice.

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* In Japanese with English summary.
** Translated from Japanese by the present authors.