Analysis of Lodging-Related Traits of Direct Seeded Rice

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ABSTRACT

The objective of this study was to analyze lodging-related traits using different cultivars from Korea, Japan, and the U. S. in direct seeded rice on dry paddy field. Stem diameter and culm wall thickness were highest in 'Caloro' followed by 'Nongan', 'M202', and 'Calrose'. All the U.S. cultivars were higher than the others in stem diameter and culm wall thickness. These two traits were important with regard to lodging. The highest breaking strength (1442g) was observed in Caloro. 'Gancheoek', 'Dongjin', and transplanted 'Hatsuboshi' showed more than 1000g in breaking strength. Lodging index was lowest in Hatsuboshi followed by Nongan and Gancheok. Even though breaking strength of the U.S. cultivars was higher than others, their lodging index values were high. There were no statistically significant differences in starch content. However, Calrose, Caloro, Dongjin, and Koshihikari were relatively higher than others in starch content. Positive correlations were found between culm base weight, lignin and breaking strength. High contents of lignin and cellulose were observed in Nongan, transplanted Hatsuboshi, Calrose, and Caloro.

Traits such as stem diameter, culm wall thickness, bending moment, culm length, breaking strength, cellulose, lignin, and culm base weight were closely related to a lodging index. According to path coefficient analysis, most important traits were culm length, stem diameter, thickness of clum wall, and top plant weight.

Key words : rice, direct seeding, lodging, cultivar, cell wall constituent.

The pattern of rice culture in Korea has been changed from machine transplanting to direct seeding. Recently, agriculture has become unfavorable due to a rapidly decreasing rural population, low labor quality, and the high cost of crop production. In addition, the Korean rice market is less competitive in worldwide markets because of 3 times higher cost of production.

Therefore, it is important to improve international competitiveness and while increasing food supplies. In recent years, direct seeding cultivation has been developed for saving labor and other costs. A lot of studies have been carried out to develop techniques of direct seeding culture appropriate for Korean varieties and soils, but there are still problems of poor emergence, weed control, lodging and so on for direct seeding of rice. Lodging has been a major concern in rice and other production (Hoshikawa & Wang, 1990; Larson & Maranville, 1977; Lee & De Datta, 1990; Weibel & Pendelton, 1964). Lodging causes great losses in grain yield and quality, and creates difficulty in harvest (Dahnous et al., 1982; Kawahara & Nakasatomi, 1996; Oh & Kim, 1992; Weibel & Pendelton, 1964). In rice cultivation, there are more chances of easy lodging due to high nitrogen fertilizer applications for increasing yields.

Comprehensive studies of lodging have been conducted in rice (Larson & Maranville, 1977; Lim et al., 1990; Pinthus, 1973; Terashima et al., 1994). Anatomical, morphological and physiological studies on culm traits of rice have also been conducted with regard to lodging (Kawahara & Nakasatomi, 1996; Kim et al., 1993; Larson & Maranville, 1977; Metsuda et al., 1982; Zuber & Grogan, 1961). In general, lodging easily occurs in direct seeded rice because of overgrowth with more tillers at the low node, fine culms, and shallow root distribution in the soil layer. In addition, lodging resistance is physiologically decreased at ripening.

The objective of this study was to obtain basic information on lodging-related traits in direct seeding cultivation of different cultivars from Korea, Japan, and the U.S.

MATERIALS AND METHODS

This experiment was conducted at National Agriculture Research Center (NARC) in Japan in 1995, using 9 different cultivars; Gancheok, Nongan, and Dongjin from Korea, 'Hitomebore', Hatsuboshi, and Koshihikari from Japan, M202, Calrose, and Caloro from the U.S.. A randomized complete block design with three replications was used.

Sprouted seeds were planted by drill seeding with 25cm-row spacing. Twenty-two-day-old seedlings of Hatsuboshi were transplanted as check for transplanting. Fertilizers, N_2, P_2O_5, and K_2O were applied at 150, 90, 110kg per hectare, respectively. Plots were irrigated 2 or 3cm in depth after 3 leaf stage and 4 or 5cm until the ripening stage. Drainage was imposed 12 days before harvest. Number of seedlings and leaf age were counted. Photosynthetic rate was measured at the 7 main leaf stage 5 times per 2 hills within a replication using a Koito Intelligent Portable Porometer (KIP-8510 version 2.03) during sunny days (10 a.m. to 2 p.m.).

Sampling for measurement of lodging-related traits was done 20 days after heading of each cultivars. Ten tillers were sampled from individual cultivars. Internode length, stem weight, panicle weight, stem diameter, culm length, and breaking strength were measured. Internode length was measured from the tip of panicle to the ground level of the main culm. Breaking strength was measured in two

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Received 20 Dec. 1997.

ways with a digital push pull gauge. One site for this measurement was the third internode from the top and the other at 10cm from the stem base (based on the soil surface). Stem diameter and culm thickness were obtained by measuring the longest and the shortest diameters of 10 samples using a calibrated microscope.

Cross sectional area was calculated by the formula π ab, where, a is a half diameter of the longest axis, and b is the shortest axis. Lodging index (LI) was calibrated by Seko's (1962) method with the formula of moment/breaking strength$\times$100. Cell wall constituents of the culm base, starch, lignin, and cellulose were determined by detergent analytical method (Cramption & Maynard, 1938). Path coefficient using the Wright (1921) analysis were used to analyze data.

RESULTS AND DISCUSSION

All cultivars were well established because of favorable temperature (data not shown). Emergence was faster in Dongjn, Calrose, and Caloro than others. In photosynthetic rate at early growth stage, there was no significant difference among the cultivars except M202 and Nongan. These two cultivars showed higher photosynthetic rates.

Heading started for transplanted Hatsuboshi on 31st July and ended for Caloro on 25th August. Nongan had less panicles than others, because it was a panicle weight type for direct seeding cultivation in Korea (Table 1).

Table 2 shows varietal differences in internode length. Koshihikari was remarkably long in the 5th internode. Calrose and Caloro had quite long culm length. On the other hand, Nongan showed long panicle length and panicle weight proportional to the total weight of the top growth. Panicle weight type is one of the factors to be considered for selecting a suitable variety for direct seeding cultivation. However, in view of the bending moment, panicle weight by itself would be an inadequate factor for predicting lodging (Table 3).

Table 4 shows variations of the lodging-related traits in direct seeded rice of 9 cultivars. In the context of lodging, multiple factors should be considered as well as individual factors. Stem diameter was highest in Caloro followed

Table 1. Varietal differences in seedling stand, photosynthetic rate, heading date, and no. of panicles under the direct seeding cultivation.

Cultivar	Established seedling (%)	Days to emergence	Photosynthetic rate (mg. CO_2/dm^2/hr)	Heading date	Number of panicles per m^2
Gancheok	87	13	22.7de	Aug. 18	393b
Nongan	92	16	26.4ab	Aug. 13	295c
Dongjin	93	13	25.8abc	Aug. 20	395b
Hitomebore	93	15	24.6bcd	Aug. 8	467a
Hatsuboshi	94	15	23.6cd	Aug. 7	467a
Hatsuboshi (T)†	–	–	25.2abc	July 31	381b
Koshihikari	93	17	22.4de	Aug. 13	400b
M202	86	15	27.5a	Aug. 6	393b
Calrose	95	13	20.8c	Aug. 18	440a
Caloro	95	13	25.1abc	Aug. 25	437a

† Transplanted rice (22-day-old seedling)
* Means followed by the same letter within a column are not significantly different at 5% level by DMRT

Table 2. Varietal differences in internode length of direct seeded rice.

Cultivar	Length of internode(cm)					Culm length
	1st	2nd	3rd	4th	5th	(cm)
Gancheok	30.7	15.7	11.4	8.9	3.8	70.5c
Nongan	34.0	13.5	11.3	5.3	1.1	65.2d
Dongjin	32.5	16.1	11.7	10.2	3.8	74.3c
Hitomebore	33.0	16.2	12.0	7.1	3.4	71.7c
Hatsuboshi	31.0	14.7	11.2	7.2	1.3	65.4d
Hatsuboshi (T)†	33.2	14.5	12.4	6.7	1.4	65.2d
Koshihikari	34.0	18.1	14.1	10.1	7.3	83.6ab
M202	36.9	17.0	12.6	5.8	1.4	73.7c
Calrose	42.7	18.6	13.9	11.2	3.7	90.1a
Caloro	38.2	16.0	15.0	12.4	5.5	88.0a

† Transplanted rice (22-day-old seedling)
* Means followed by the same letter within a column are not significantly different at 5% level by DMRT

Table 3. Comparisons of the top growth-related bending moment in direct seeded rice.

Cultivar	Panicle length (cm)	Panicle weight[A)] (g.fw)	Total weight of the top[B)] (g.fw/plant)	Ratio of A/B (%)
Gancheok	18.8bc	2.26cd	9.66bc	23.4c
Nongan	23.9a	3.93a	11.43ab	34.4a
Dongjin	19.2bc	2.54c	10.0b	25.2bc
Hitomebore	18.3bc	2.21cd	7.65cd	28.9b
Hatsuboshi	16.4cd	1.94d	7.15cd	27.1bc
Hatsuboshi (T)†	18.2bc	2.64c	8.17cd	32.4a
Koshihikari	18.1bc	2.55c	9.30bc	27.4bc
M202	18.5ab	3.21b	10.11b	31.8ab
Calrose	21.8ab	3.42ab	11.06ab	30.9ab
Caloro	20.5ab	2.65c	12.71a	20.9d

† Transplanted rice (22-day-old seedling)
* Means followed by the same letter within a column are not significantly different at 5% level by DMRT

by Nongan, M202, and Calrose. All the U.S. cultivars were higher than the others in stem diameter and culm wall thickness. Caloro had the thickest culm wall. These two traits directly influence lodging and are considered as important factors. The center of gravity was lower in Caloro and Calrose than others. The center of gravity is the point to endure load.

Generally, long clum length is susceptible to lodging. However, if the center of gravity is located at the lower part of the stem, this could overcome the disadvantages of a tall culm (Hoshikawa & Wang, 1990; Lim et al., 1992; Metsuda et al., 1982).

The bending moment is one of the factors with close relation to the lodging index, load to stem, and stiffness (Lee & De Datta, 1990; Metsuda et al., 1982). The bending moment was the highest in Caloro whose plant height was tall. The load per unit stem, which was the value of plant weight divided by culm length, was highest in Nongan. Bending moment per unit culm was higher in Nongan than the others. Dry weight of culm base (g/6cm) measured at 10cm from the plant base was higher in Nongan and Caloro. This indicated that stem diameter and thickness of culm might be related to the weight of culm base.

The highest breaking strength, 1442g, was observed in Caloro. Gancheok, Dongjin, and transplanted Hatsuboshi showed more than 1000g. Lodging index was lowest in Hatsuboshi followed by Nongan and Gancheok. Even though breaking strength of the U.S. cultivars was higher than others, their lodging index values were high.

Composition of cell wall components in the culm base was analyzed by detergent analytical method. There were no significant difference in content of starch (Fig. 1). Because starch content is changeable at each growing stages, especially the ripening stage, this component would be accumulated on stem and panicle. The starch content on the lower stem decreases at the heading stage because of translocation to grain sink. On the other hand, starch accumulates on the stem at the ripening stage, 30 days after heading (Kawahara & Nakasatomi, 1996; Terashima

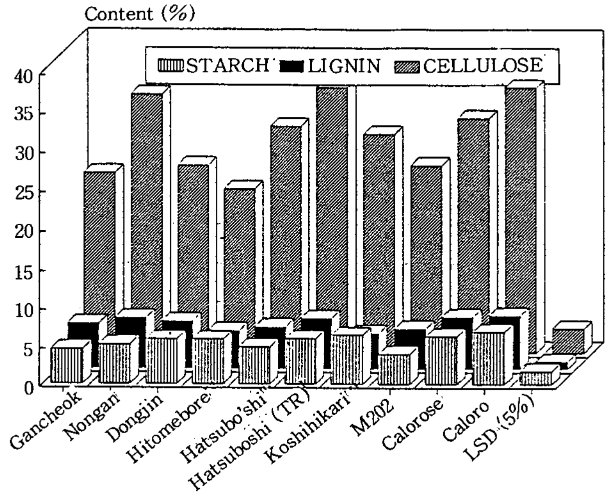

Fig. 1. Contents of cell wall components at culm base of direct seeded rice.

et al., 1994). Nongan, transplanted Hatsuboshi, and Caloro were higher in cellulose content than others. Calrose, Caloro, and transplanted Hatsuboshi were higher in lignin content than others.

High correlation was observed between cellulose content and breaking strength (Table 5). There was also very high correlation between lignin content and breaking strength. The correlations of breaking strength with culm base weight and lignin were positive. Regarding the function of lignin, it is a hydrophobic material, enveloping microfibrils and matrix polysaccharides. They thicken the cell wall and cross linked polymers so that the wall becomes very stiff.

Relationships among the lodging-related traits were analyzed by simple correlation analysis. Table 6 shows that traits of highly positive correlation with breaking strength were stem diameter, cross sectional area, thickness of culm wall, moment, load per unit culm, and culm base weight. There was also a significantly negative correlation between breaking strength and central gravity rate.

Table 4. Variation of lodging-related traits in direct seeded rice.

Cultivar	Stem diameter (mm)	A† (cm^2)	Thickness culm wall (mm)	Central gravity (cm)	Rate of central gravity (%)	Moment‡ 〈W・CL〉 (g・cm)	W/CL (g/cm)
Gancheok	3.04	0.095	0.84	43.5	48.7	681	0.137
Nongan	4.33	0.147	0.93	43.8	49.2	744	0.178
Dongjin	3.23	0.102	0.82	42.0	44.9	750	0.136
Hitomebore	2.80	0.061	0.77	44.1	49.0	625	0.107
Hatsuboshi	2.95	0.071	0.82	39.8	48.6	468	0.109
Hatsuboshi (T)††	3.52	0.098	0.88	40.2	48.2	533	0.125
Koshihikari	3.02	0.070	0.78	51.4	50.5	775	0.111
M202	3.98	0.125	0.87	44.2	47.9	745	0.137
Calrose	3.78	0.112	0.83	46.8	41.8	997	0.123
Caloro	4.38	0.151	1.07	42.4	39.1	1118	0.144

Cultivar	Dry weight W・CL/D§ (g·cm/mm)	W CL/A (g·cm)	Weight of basal node¶ (g/6cm)	Breaking strength(g)		Lodging Index	
				3rd#	Culm base	3rd	Culm base
Gancheok	224	7178	0.27	563	1081	121	63
Nongan	235	5061	0.29	610	1236	122	60
Dongjin	232	7353	0.20	628	1085	119	89
Hitomebore	196	9150	0.18	451	803	139	78
Hatsuboshi	159	6685	0.25	452	926	104	51
Hatsuboshi (T)††	151	5438	0.24	520	1151	103	48
Koshihikari	257	1107	0.20	495	772	157	88
M202	187	5960	0.24	603	925	124	81
Calrose	332	8901	0.26	717	1129	139	88
Caloro	255	7403	0.30	950	1442	117	78

† Cross sectioal area of culm base, ‡ W: Total fresh weight of plant above ground; CL: Culm length, § D: Stem diameter, #3rd: 3rd internode
¶ Node was taken from the 10cm of stem base (based on soil surface), †† Transplanted rice (22-day-old seedling)

Table 5. Correlation coefficients of dry weight and contents of cell wall with breaking strength of culm base of direct seeded rice.

Trait	Culm base[A)] weight (g)	Starch[B)] (%)	Cellulose[C)] (%)	Lignin[D)] (%)	Breaking[E)] strength (g)
(B)	−0.235				
(C)	0.487	0.429			
(D)	0.779*	0.306	0.667*		
(E)	0.684*	0.280	0.689*	0.940**	

*, ** ; Significant at 5% and 1% levels, respectively

However, there was no significant correlation between breaking strength and culm length. On the other hand, significant correlation with lodging index was observed in culm length, central gravity, moment, bending moment per unit stem.

Correlation analysis was conducted for three cultivars, Noangan, Hatsuboshi, and Calrose (Table 7). It revealed a highly significant and positive correlation of lodging index with top plant weight and culm length, respectively. However, there were negative correlations of lodging index with stem diameter, thickness of culm wall and breaking strength.

As discussed above, stem diameter, culm length, thickness of culm wall, and breaking strength were main factors of lodging.

Path coefficient analysis was conducted to identify direct effects between traits (Fig. 2). Fig. 2 indicates that direct effect on lodging index was highest in thickness of

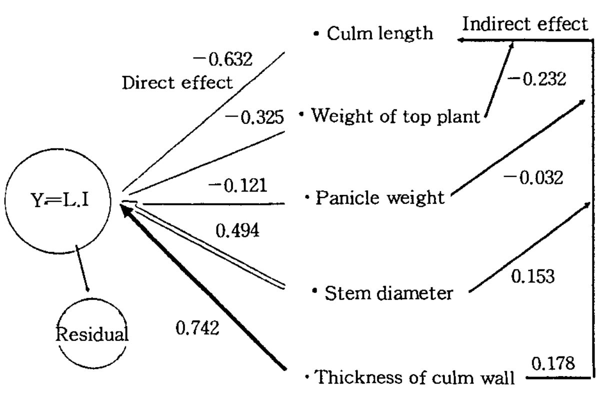

Fig. 2. Path coefficients of lodging-related some traits.

Table 6. Correlation coefficients among lodging-related traits in direct seeded rice.

Character	(A) Culm length (cm)	(B) Stem diameter (mm)	(C) A (cm^2)	(D) Thickness culm wall (mm)	(E) Central gravity (cm)	Rate of (F) central gravity (%)
(B)	0.275					
(C)	0.205	0.966**				
(D)	0.248	0.835**	0.859**			
(E)	0.528	−0.758*	−0.183	−0.318		
(F)	0.694*	−0.537	−0.555	−0.636*	0.209	
(G)	0.851**	0.680*	0.661*	0.647*	0.289	−0.882**
(H)	−0.012	0.770**	0.857**	0.645*	−0.209	−0.151
(I)	0.791**	0.348	0.327	0.160	0.555	−0.554
(J)	0.012	0.009	0.064	0.084	−0.585	0.498
(K)	0.054	0.733*	0.822**	0.801**	−0.414	−0.526
(L)	0.261	0.766**	0.852**	0.881**	−0.374	−0.742**
(M)	0.816**	0.593	0.023	−0.542	0.751**	0.301

Character	(G) Moment 〈W·CL〉 (g·cm)	(H) W/CL (g/cm)	(I) Dry weight W·CL/D (g·cm/mm)	(J) W·CL/A (g·cm)	(K) Weight of basal (g/6cm)	(L) Breaking strength (g)	(M) Lodging index
(B)							
(C)							
(D)							
(E)							
(F)							
(G)							
(H)	0.312						
(I)	0.782**	0.145					
(J)	0.090	−0.070	0.034				
(K)	0.454	0.738*	0.245	0.143			
(L)	0.673*	0.707*	0.396	0.296	0.906**		
(M)	0.678*	−0.275	0.634*	0.109	−0.569	−0.558	

*, ** : Significnt at 5% and 1% levels, respectively

Table 7. Correlations of lodging index with lodging-related traits for three cultivars of direct seeded rice.

Cultivar	Culm length (cm)	Top plant weight (g. fw)	Stem diameter (mm)	Thickness of culm wall (mm)	Rate of central gravity (%)	Breaking strength (g)
Nongan	0.867**	0.728*	−0.760**	−0.717*	0.672*	−0.923**
Hatsuboshi	0.764**	0.672*	−0.587	−0.740*	0.478	−0.894**
Calrose	0.913**	0.780**	−0.832**	−0.773**	0.714*	−0.913**

*, **: Significant at 5% level and 1% levels, respectively

culm wall, positively. Contribution to direct effect on lodging was culm length (negative), stem diameter (positive), weight of top plant and panicle weight (negative) in descending order.

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