Japan. J. Breed. 33(3)251～258 (1983)

Application of Ratoon to a Test of Agronomic Characters in Rice Breeding II. The Relationship between Ratoon Ability and Lodging Resistance

Masahiko ICHII and Kunsei HADA
(*Faculty of Agriculture, Kagawa University, Kagawa* 761—07)

The relationship between ratoon ability and lodging resistance was investigated with 21 paddy cultivars grown in a randomized block design with 2 replications. Plant characters concerned with lodging such as internode weight, stem base weight, breaking strength of culm and lodging index were noted at 5 successive 10 days intervals starting on the day of heading. Internode weight, stem base weight and breaking strength increased during the first 10-days period following heading then declined during the next 10- or 20-days period, but reached again the levels at heading or beyond on 40 days following heading. Lodging index increased during the 30-days period following heading, and then declined down. The rice plant was also cut at 5 cm above the ground at 5 different growth stages, i. e. the day of heading, and 10, 20, 30 and 40 days after heading. Some characters of the ratoon crops were surveyed at the ripening stage. Percentage of ratoon tillers showed the same change as internode weight, stem base weight and breaking strength. Changes of the percentage of ratoon tillers and the ratoon height showed a similar tendency in cuttings during the period from 10 days after heading to 40 days. Traits of the ratoon did not show any clear relationship to breaking strength. However, there were significant and negative correlations between traits of the ratoon and lodging index in cuttings on 20, 30 and 40 days following heading. It was suggested from these correlations that ratoon ability might be used as a test indicator of lodging resistance. The contribution rate of leaf sheath to breaking strength ranged approximately from 15% to 40% in the later period of ripening, and it was depended on cultivars and growth stages.
KEY WORDS : *Oryza sativa*, Lodging resistance, Ratoon, Culm strength.

Introduction

Lodging may damage grain yield directly by interfering with dry matter accumulation, and reduce the yield indirectly owing to the difficulties that it imposes on harvest. Lodging may also adversely affect grain quality. Lodging resistance, therefore, has been one of the main breeding objective in rice plants. Lodging resistance of rice plant is dependent on culm length, shape and weight of aerial parts of plant, properties of roots and culm rigidity, especially on culm length and its rigidity. Investigations on culm length have been carried out genetically, and then the short-culmed cultivars were developed. SEKO (1962) found that the high resistance against breaking of culm was associated with the lodging resistance in rice plant. MATSUO (1952) reported on a close correlation between stem base weight and lodging resistance in rice plant. Moreover, it was found by SATO (1957) that rice cultivars which had high starch content in culm seemed to be more resistance to lodging. Considering these investigations, it may be inferred that the stem base weight and the internode weight may play important roles in the lodging resistance.

We have investigated the ratoon following cuttings of the foliage of rice plant during the period later growing stage, and found that ratoon ability was associated with the

Received December 20, 1982

percentage of ripened grains (ICHII and KUWADA 1981). According to ICHII and SUMI (1983), ratoon ability depend largely on stem base weight and food reserves in the stem base. Therefore, the relationship between ratoon ability and lodging resistance as well as culm strength may be worth noting. The purpose of this investigation was to survey this relationship, and to assess whether ratoon ability was worth using as a indicater for lodging resistance.

Materials and Methods

Twenty one rice cultivars (*Oryza sativa* L.), supposed to be different in lodging resistance, listed in Table 1 were used. The experiment was carried out in the farm of the Kagawa University in the 1980 season. Thirty four-days-old seedlings were trans-

Table 1. Rice cultivars used

1	Koganemasari	8	Hokuriku No. 108	15	Minenishiki
2	Kanto No. 116	9	Chubu No. 34	16	Norin No. 22
3	Kanto No. 120	10	Ginmasari	17	Kyoto-asahi
4	Ooseto	11	Chiyohikari	18	Sasanishiki
5	Chubu No. 35	12	Sachiwatari	19	Yaeho
6	Saikai No. 144	13	Nipponbare	20	Koshiji-wase
7	Chugoku No. 68	14	Koshihikari	21	Azusa

planted with a single plant per hill spaced at 30×10 cm on June 17. These cultivars were grown in a randomized block design with 2 replications. Each replication comprised of 150 plants. They were fertilized with 1.0 kg N/a, 0.8 kg P_2O_5/a and 1.0 kg K_2O/a as basal. No fertilizer was applied to the ratoon crop.

The 21 cultivars were cut at 5 cm above the ground at 5 different growth stages, i. e. the day of heading, and 10, 20, 30 and 40 days after heading. To evaluate the ratoon ability, ratoon height and percentage of ratoon tillers were noted on 40 days after cuttings. Ratoon height was measured from the cutting level. The percentage of ratoon tillers was expressed by the number of ratoon-plant tillers times 100 divided by the number of mother-plant tillers. Furthermore, characters associated with lodging such as internode weight, stem base weight, breaking strength of culm and lodging index of non-cut plants were recorded at 5 successive 10 days intervals starting on the day of heading. Internode weight was obtained from the measurement of dry weight per unit length of 3 rd or 4 th internode from the uppermost internode. The materials, the internode weight of which was recorded, were also used for the measurements of the breaking strength by means of the straw fracture tester, Model EO-3 (Kiya Seisakusho Ltd.), with 6 cm spacing between fulcrums. All leaf sheath was removed from the materials tested. The breaking strength of internode with leaf sheath was also measured on 30 and 40 days after heading. Stem base weight was obtained from the measurements of dry weight a stem. The effect of leaf sheath on breaking strength was determined with 4 cultivars, Chugoku No. 68, Minenishiki, Kyoto-asahi and Yaeho, out of 21 cultivars used. The lodging index was taken for evaluating the lodging resistance in the cultivar used. This index was suggested by MATSUO (1952) and SEKO (1962), and was expressed as the ratio of moment (plant height×plant weight) to breaking strength

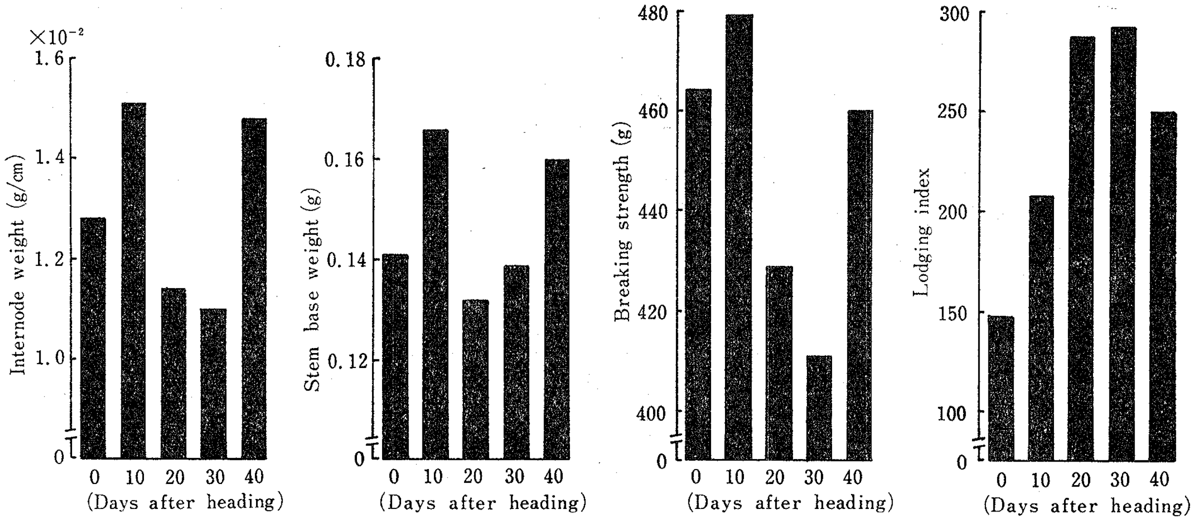

Fig. 1. Characteristics associated with lodging of mother plant during the period following heading.

of internode concerned.

Results

A wide range of intervarietal variation was observed in agronomic characters of mother plant such as heading date, culm length, internode weight, stem base weight, breaking strength and lodging index. The range of heading dates was from August 12 to September 7.

Internode weight, stem base weight, breaking strength and lodging index during the period following heading are shown in Fig. 1. The values in internode weight, stem base weight and breaking strength changed with maturing, increased during the first 10-days period following heading and then declined during the following 10- or 20-days period, finally on 40 days after heading, recovered or exceeded the initial levels. The stage when these values were the largest was on 10 days after heading. Although the change was different in these 3 traits, the lodging index changed with maturing, increased during the 30-days period following heading and then declined down. This showed that rice plants became most susceptible to lodging on about 30 days after heading.

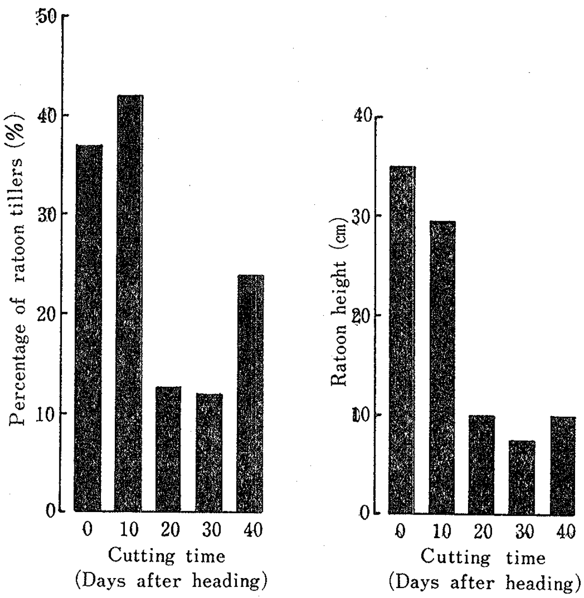

Fig. 2. Percentage of tillers and height in ratoon plant following cuttings at different times.

Fig. 2 shows mean values of percentages of ratoon tillers and ratoon heights of materials at different cutting times. The change in the percentage of ratoon tillers exhibited a similar tendency as the internode weight, the stem base weight and the breaking strength. The percentage of ratoon tillers was highest in cuttings on 10 days after heading and was lowest in cutting on 30 days, though the percentage on 20 days was not different from the lowest one. The ratoon height and the percentage of ratoon tillers were slightly different in their response to delaying of cutting times. The percentage of ratoon tillers reached the maximum in cutting on 10 days after heading, which was higher than that in cutting on heading date. However, from the cutting on 20 days the above 2 traits showed similar tendencies in response to the cutting times. Those tedencies of change agreed with the result of the previous paper (ICHII and KUWADA 1981), though the cultivars used and the year were different.

A wide range of variation among cultivars was observed in the 6 traits (Figs. 1 and 2). The results of analysis of variance for these traits are gived in Table 2. There were significant differences in the variance due to cultivar, growth stage and cultivar×growth stage-interaction of the 4 mother plant's characters concerned with lodging resistance. Significant differences were also observed in the variance due to cultivar, cutting time and cultivar×cutting time-interaction of the 2 ratoon traits. These results suggest that the characters concerned with lodging resistance and the traits of ratoon differ among

Table 2-a. Analysis of variance for plant characters concerned with lodging

Source	d. f.	Mean square			
		Internode weight	Stem base weight	reaking strength	Lodging index
Cultivar (C)	20	0. 671**	0. 0162**	73349. 0**	11470. 1**
Growth stage (G)	4	1. 499**	0. 0391**	32018. 8**	130076. 5**
C×G	80	0. 081**	0. 0014*	5868. 9**	1335. 2**
Error	105	0. 037	0. 0009	2771. 5	675. 0

Table 2-b. Analysis of variance for ratoon traits

Source	d. f.	Mean square	
		Percentage of ratoon tillers	Ratoon height
Cultivar (C)	20	2374. 8**	484. 3**
Cutting time (T)	4	7954. 6**	7036. 5**
C×T	80	251. 1**	66. 8**
Error	105	122. 6	30. 5

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

cultivars. The analysis of variance of ratoon traits also agreed with the results on the previous paper (ICHII and KUWADA 1981).

The fact that the characteristics concerning ratoon are hereditable is of great interest on plant breeding. Relationship between agronomic characters in mother plants and traits of the ratoon is even more important. The phenotypic correlation coefficients between some characters concerned with lodging resistance in mother plants and ratoon traits are given in Table 3. It is noteworthy that there were significant and negative correlations between traits of the ratoon and the lodging index in the cuttings on 20, 30 and 40 days after heading. For cuttings on the 10 and 20 days after heading, traits of the ratoon exhibited significant and positive correlations with stem base weight. The percentage of ratoon tillers showed significant and positive correlations with internode weight in cuttings on 20, 30 and 40 days after heading. Ratoon height, however, were not related to internode

Table 3. Phenotypic correlation coefficients between ratoon traits and characters concerned with lodging in mother plant

	Cutting time (Days after heading)	Internode weight	Stem base weight	Breaking strength	Lodging index
Percentage of ratoon tillers	0	0.03	0.37	0.03	−0.41
	10	0.39	0.67**	0.28	−0.38
	20	0.61**	0.63**	0.44*	−0.76**
	30	0.47*	0.43	0.00	−0.65**
	40	0.44*	0.43	−0.13	−0.61**
Ratoon height	0	0.01	0.34	0.03	−0.33
	10	0.19	0.60**	0.15	−0.10
	20	0.55**	0.64**	0.38	−0.72**
	30	0.28	0.39	−0.16	−0.62**
	40	0.28	0.24	−0.24	−0.57**

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

Table 4. Phenotypic correlation coefficients among some characters concerned with lodging in mother plant

	Days after heading	Stem base weight	Breaking strength
Internode weight	0	0.79**	0.85**
	10	0.81**	0.74**
	20	0.91**	0.85**
	30	0.73**	0.76**
	40	0.87**	0.78**
Stem base weight	0		0.70**
	10		0.54*
	20		0.81**
	30		0.76**
	40		0.74**

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

weight in most cuttings. Furthermore, the percentage of ratoon tillers and the ratoon height did not show any obvious relationships to the breaking strength in most cuttings. Table 4 shows the phenotypic correlation coefficients among some characters concerned with lodging in mother plant. There were significant and positive correlations between internode weight, stem base weight and breaking strength for the period from the day of heading to 40 days after heading.

Breaking strength is also affected with the leaf sheath wrapping the culm. So, the effect of leaf sheath on breaking strength was measured on 4 cultivars. Fig. 3 indicates the contribution rate of leaf sheath to the breaking strength on 30 and 40 days after heading. The contribution rates ranged from 15% to 40% approximately, depending on the cultivars and the growth stages. The contribution rate was larger on 30 days after heading than on 40 days. According to analysis of variance for the contribution rates, there were significant differences among the cultivars and between the 2 growth stages.

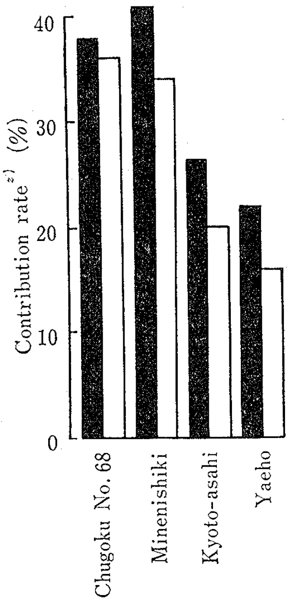

Fig. 3. The contribution rate of leaf sheath to breaking strength.
z) : ((Breaking strength with leaf sheath−Breaking strength without leaf sheath)/Breaking strength with leaf sheath)×100
■ : On 30 days after heading
□ : On 40 days after heading

Discussion

It was very interesting that there were significant and negative correlations between the lodging index during grain development and the ratoon traits: the percentage of ratoon tillers and the ratoon height. These correlations suggest that ratoon traits may be applicable to the test of lodging resistance.

The percentage of ratoon tillers and ratoon height were closely related to the amount of total available carbohydrate (TAC) contained in stem base (ICHII and SUMI 1983). Therefore, it was suggested that loding resistance may also be related to the amount of TAC contained in stem base judging from the finding in this experiment mentioned above. ESECHIE *et al.* (1977) showed in their investigation using sorghum that the correlation between TAC content and lodging degree was negative and significant, indicating an increasing tendency for lodging resistance in the lines with higher TAC content. Similar results had been reported in corn (CAMPBELL 1964). However, according to ESECHIE *et al.* (1977), lodging degree was positively correlated with the content of K indicating that higher K content associated with lodging susceptibility. They inferred that TAC content might be only an indication of the healthiness and of the vigor of plant rather than having a direct relation to lodging. KONO and TAKAHASHI (1961) reported that breaking strength of culm might be secondarily associated with starch content, as breaking strength was related not to content of starch, lignin and silicia, but to K and hemicellulose content. The relationship between breaking strength and starch content, as mentioned above, may have close connection to the fact that breaking strength did not have a significant association with ratoon traits.

According to ICHII and SUMI (1983), stem base weight was closely connected with ratoon traits. In this experiment the stem base weight during the earlier period of grain development was significantly and positively related to the percentage of ratoon tillers and the ratoon height. In the previous paper (ICHII and KUWADA 1981) a significant and positive correlation was reported between the percentage of ripened grains and the ratoon traits in cuttings on 10 and 20 days after heading. It was difficult to make clear the causes of why the stem base weight during the later period of ripening was not correlated to the ratoon traits. However, it was suggested that the main factor controling ratoon traits might be different in early and late ripening stages, and that ratoon traits might not depended on the amount of TAC contained in stem base.

The percentage of ratoon tillers and the ratoon height were closely related to the lodging index. Breaking strength of internode, a component of lodging index, was affected significantly by the existence of leaf sheath. The breaking strength was stronger on internodes with leaf sheath than that without leaf sheath. The contribution rate of leaf sheath to the breaking strength of the stem varied from 15% to 40% approximately. According to MATSUO (1952) and LIM and YAMAMOTO (1978), the contribution rate of leaf sheath were between 30% and 70%. HITAKA (1968) reported that the range of the contribution rate was from 15% to 30%. In the results at IRRI (1963, 1964), 30% to 60% of additional weights was required to buckle a section of internode with persistent leaf sheath than corresponding section of culm without the leaf sheath. It was suggested from these facts that the contribution rate of leaf sheath to the stem strength varied with cultivars and culturing conditions. According to HITAKA (1968), the contribution rate varied with growth stages and showed higher value at the period of heading than at the maturing stage. In this experiment the contribution rate varied depending on the stages of maturing and the cultivars. Similar results have reported by MIYASAKA and TANAKA (1982).

Acknowledgements

The authers would like to thank Dr. Hikaru KUWADA, Emeritus Professor of Kagawa University, Dr. Kiyoshi YAMAMOTO, Professor of Kagawa University for their helpful advice, and Mr. Igal BLUMENREICH of the Hebrew University of Jerusalem for his suggestion.

Literature Cited

CAMPBELL, C. M. 1964. Influence of seed formation of corn on accumulation of vegitative dry matter and strength. Crop Sci. **4** : 31～34.

ESECHIE, H. A., J. W. MARANCILLE and W. M. ROSS 1977. Relationship of stalk morphology and chemical composition to lodging resistance in sorghum. Crop Sci. **17** : 609～612.

HITAKA, N. 1968. Experimental studies on the mechanisms of lodging and its effect on yield in rice plants. Bull. Nat. Inst. Agri. Sci., **A 15** : 1～175.

ICHII, M. and H. KUWADA 1981. Application of ratoon to a test of agronomic characters in rice breeding I. Variation in ratoon ability and its relation to agronomic characters of mother plant. Japan. J. Breed. **31** : 273～278.

———— and Y. SUMI 1983. Effect of food reserves on the ratoon of rice plant. Japan. Jour. Crop Sci. **52** : 15～21.

INTERNATIONAL RICE RESEARCH INSTITUTE 1963. Studies on lodging. Annu. Rep. 22～30.

———— 1964. Studies of lodging. Annu. Rep. 37～48.

KONO, N. and J. TAKAHASHI 1961. Study on the relationships between breaking strength and chemical components of paddy stem. J. Sci. Soil Manure, Japan **32** : 149～152.

LIM, K. T. and R. YAMAMOTO 1978. Studies on the lodging resistance of rice plant growing under submerged condition and its preventive measure. II. Relationship between the lodging resistance and the structural body. Japan. Jour. Crop Sci. **47** : 681～689.

MATSUO, T. 1952. Genecological studies on cultivated rice. Bull. Nat. Inst. Agri. Sci., **D-3** : 1～111.

MIYASAKA, A. and T. TAKAYA 1982. Prevention of lodging of rice plants under direct sowing culture on well-drained paddy field. 1. Varietal differences in lodging resistance under dense sowing. Japan. Jour. Crop Sci. **51** : 360～368.

SEKO, H. 1962. Studies on lodging in rice plants. Bull. Kyushu Natl. Agric. Exp. Stn. **7** : 419～499.

SATO, K. 1957. Studies on the starch contained in the tissues of rice plant. (IV) Starch content in the culm related to lodging. Proc. Crop Sci. Soc., Japan **26** : 19.

水稲における再生の育種的利用に関する研究
II. 再生能と耐倒伏性との関係

一井真比古・羽田　勲誠
（香川大学農学部）

生育後期に稲体の地上部を剪除したときの再生能と耐倒伏性ならびにそれに関連する形質との関係を明らかにしようとした。水稲21品種を供試し，節間重，稈基重，挫折重および倒伏指数を出穂日より出穂後40日まで10日おきに計5回調査した。また倒伏に関連する形質を調査したそれらの日に，地際より5cmで地上部を剪除し，剪除後40日に再生茎率および再生草丈を調査した。再生茎率および再生草丈により再生能を評価した。

節間重，稈基重および挫折重はほぼ同様の推移を示した。それらは出穂後0日より10日にかけて増大し，その後20日または30日まで減少し，40日には再び増大した。倒伏指数は出穂後0日から30日まで増大し，その後減少した。再生茎率は節間重，稈基重および挫折度とほぼ同様に推移し，再生草丈の推移も出穂後10日以降剪除では再生茎率の推移とほぼ同様であった。再生能と倒伏指数ならびにそれに関連する形質との相関関係を調べた結果，出穂後20日以降に地上部を剪除したときの再生茎率および再生草丈と出穂後20日以降の倒伏指数との間に有意な負の相関が認められたことから，耐倒伏性の間接的な検定に再生能を利用しうることが示唆された。なお再生能と挫折重との間には有意な相関がほとんど認められなかった。

再生能と密接に関連する倒伏指数の一構成要素である挫折重に対する葉鞘の寄与率を調べた結果，登熟後期における葉鞘の寄与率は15～40％であったが，品種ならびに生育時期により明らかに異なっていた。