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Studies on Physical and Mechanical Properties of Rice Stem for Lodging Tolerance at Reproductive Phase in Rice (*Oryza sativa* L.)

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ABSTRACT

An experiment was conducted to find out "Physical-mechanical basis of lodging nature of rice in rice (Oryza sativa L.)" by studying relevant parameters in three different groups of rice germplasm viz., lodging susceptible varieties (Swarna, BPT-5204, Tellahamsa and RNR-15048); lodging tolerant varieties (MTU-1112, MTU-1121, MTU-1166 and MTU-1001) and stable strong culm mutant lines (SP-351, SP-353, SP-360 and SP-70).The current study showed that lodging tolerant varieties in general have lower plant height and stem lengths along with lower length of basal internode compared to lodging susceptible varieties. Further lodging tolerant varieties have higher outer diameter of basal internode (3rd internode), higher linear density and higher physical strength of culms compared to lodging susceptible varieties. But, the present study also showed that the mutant lines though showed greater plant heights and stem lengths, they were lodging tolerant (higher physical strength values), probably due to the mutagenic reasons. However, numbers of nodes appeared to be having no significant role in lodging nature of rice, which was an evident from the correlation studies between physical parameters and physical strength of culms. It can be concluded that lodging nature of the rice can be measured by taking any or all of the above said parameters except number of nodes. Out of all parameters linear density of the culm, outer diameter of the basal internode appear to be best indices of physical strength of rice culms in other words lodging nature of rice.

Key words: *Plant height, stem length, internodal length, culm diameter, linear density and physical strength.*

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important staple food crops of Asia, Africa, and South America, and serves as a primary source of food for more than half of the world population[1]. It is the main source of the 35-60% dietary calories consumed by more than 3 billion people[2]. It is considered as the world's most diverse crop and is probably the most versatile crop. It is grown below sea level in Kerala, India, at more than 3000 m elevation in the Himalayas, and at sea level in the deltas of the Asian rivers.

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It can be found from 53^0 North in Northeastern China to 35^0 South in New South Wales, Australia[3]. Total world rice production was about 740.9 miilion tonnes with an area of 160.6 million hectares and in India rice production was about 106.65 million tonnes from 44 million hectares with a productivity of 2462 kg/ha (FAO STAT, 2015). Due to the exponential rate of population growth, it is estimated that a 40% increase in rice yield is needed by 2030 to fulfill the growing demand without affecting the resource base[13]. Lodging is usually referred to as that condition in which the stems of crops bend at or near the surface of the ground, which could lead to the collapse of the canopy. It is serious concern which hinders nutrient uptake, raises cost of crop harvesting resulting in lesser farm income increases[4]. Lodging in rice may occur as a result of strong winds, heavy rain, improper water management, higher planting density, or an excessive use of fertilizer and the relative impact of a factor will depend on cultivar being grown[5].

MATERIAL AND METHODS

The present experiment was carried out at experimental field of ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad and the laboratory of the Department of Crop Physiology, College of Agriculture, Rajendranagar, Hyderabad during *kharif*, 2014-2015. 12 varieties or lines of rice were taken for the present study to understand the basis of lodging tendency of rice in three different groups of rice germplasm *viz.*, lodging susceptible varieties (Swarna, BPT-5204, Tellahamsa and RNR-15048); lodging tolerant varieties (MTU-1112, MTU-1121, MTU-1166 and MTU-1001); and stable strong culm mutant lines (SP-351, SP-353, SP-360 and SP-70).In this Physical and mechanical parameters such as plant height, Stem length, number of nodes and internodal length, stem diameter, linear density of culm and Physical strength of the culm were studied. Plant height refers to the longest distance between the plant base and the tip of the highest leaf (or panicle, whichever is longer). Rice leaves, usually bent, are stretched along the culm axis for plant height measurement and these were measured with a meter scale and expressed in cm. Stem length is the distance between the plant base and the panicle neck node.It was also measured by a meter scale and expressed in cm [1]. The number of nodes in the main stem of rice plants was counted after stripping off leaves and leaf sheaths .Since lodging character of rice depends on the internode at the ground level, length of the third internode was considered in this study as the key character, which was measured and expressed in cm. Stem outer diameter was measured at the third internode of the stem after stripping off leaves and leaf sheaths, by using digital vernier caliper and readings were recorded and expressed in mm. The linear density was measured in terms of dry weight per unit length of total stem length. To calculate the linear density, main stems of rice (from the lower node of third internode to the panicle neck node) were dried to constant dry weight in an oven maintained at 70 - 75 °C. Linear density was calculated by using the following equation.

$$Linear\ density\ = \frac{dry\ weight\ of\ stem}{length\ of\ the\ stem},$$

which was expressed in mg dwt cm^{-1}. Pushing resistances of the whole plant (hill) was taken as the indicator of physical strength the culms, which was measured with a 'prostrate tester'[2] (DIK-7401, Daiki Rika Kogyo Co., Tokyo, Japan) as per the method reported by Kashiwagi and Ishimaru[9]. The means of the collected data for different characters were analyzed from each group of varieties / lines i.e., susceptible, tolerant and strong culm mutants and the variety / line with highest means were selected which were compared by using two sample t-test between the varieties and paired t-test within the same variety

between the two stages *viz.*, 50% flowering and full ripening.

RESULTS AND DISCUSSION

Mean values of all the physical parameters measured at 50% flowering stage are presented in the table 1. The results showed that the rice varieties / lines differed in all the measured physical parameters. Mean Plant height and stem lengths were highest in strong culm mutant lines (SP-351, SP-353, SP-360 and SP-70), followed by lodging susceptible varieties (Swarna, BPT-5204, Tellahamsa and RNR-15048) and lowest in lodging tolerant varieties (MTU-1112, MTU-1121, MTU-1166 and MTU-1001). However, RNR-15048 recorded mean plant height value equivalent to strong culm mutants, but with higher mean stem length (84.30 cm), probably due to either lower length of flag leaf or panicle in RNR-15048.

At 50% flowering stage, rice varieties / lines under study also differed in the mean number of nodes as well as in linear density of the culm (Table-1).Except RNR-15048, all the other released varieties either lodging susceptible or tolerant along with SP-351 showed 6 to 7 nodes, while other mutant line and RNR -15048 had 8 nodes. Linear density in general was higher in strong culm mutants, followed by lodging tolerant varieties and lodging susceptible varieties in the order. Mean linear density was highest in SP-360 (76.77 $mg.cm^{-1}$) and lowest in RNR-15048 (30.38 $mg.cm^{-1}$). Mean length and outer diameter of the basal internode (3^{rd} internode), also varied among the rice varieties / lines. Highest mean intermodal length was recorded in RNR-15048 (13.6 cm), while Tellahamsa showed the lowest (5.2 cm). On surface view, mutant lines showed higher mean intermodal length compared to lodging susceptible and tolerant varieties. Same kind of trend was seen even in the mean stem diameter of 3^{rd} internode, in which a lowest value of 3.80 mm was shown by BPT-5204 and a highest value of 8.77 mm was recorded in SP-360. Mean physical strength was in general highest in mutant lines of rice, highest being in SP-360 (30.70 mm), followed by lodging tolerant and lodging susceptible varieties. However, there was an overlap of values of mean physical strength between lodging tolerant and lodging susceptible rice varieties (Table.1). Lowest mean physical strength (23.10 mm) was recorded in BPT-5204. Mean values of physical parameters of rice varieties / lines under study at full ripening stage are presented in the (table1). As at 50% flowering stage, mean plant height and stem lengths were lowest in lodging tolerant varieties, highest in mutant lines of rice and their values in the lodging susceptible varieties are at the mid level, with the exception of RNR-15048, which showed the values comparatively equal to mutant lines of rice. Rice varieties / lines under the present study also differed in mean number of nodes and in mean linear density at full ripening phase. (Table1). Linear density values showed the same kind of groupings as at 50% flowering stage i.e., highest in mutant lines followed by lodging tolerant varieties and lodging susceptible varieties in the order. Highest linear density value was recorded in the mutant line SP-70 (78.26 $mg.cm^{-1}$), while RNR-15048 showed lowest value (32.95 $mg.cm^{-1}$).

Mean internodal length of 3^{rd} basal internode was lowest in Tellahamsa (6.94 cm), while SP-70 recorded the highest value (12.40 cm) at full ripening stage. Mutant lines of rice showed relatively higher values of mean stem diameter at full ripening phase (Table1). Again RNR-15048 differed from other lodging susceptible varieties by showing higher value of mean stem diameter comparable to lodging tolerant varieties.

Table 1: Physical parameters of culm at 50% flowering stage in rice (Mean of 10 samples)

Variety / line	Plant height (cm)	Stem length (cm)	Number of nodes	Inter-nodal length (cm)	Linear density ($mg.cm^{-1}$)	Physical strength (mm deflection)	Culm diameter (mm)
SWARNA	69.20	54.20	6.00	5.75	46.65	23.90	4.00
BPT5204	85.10	59.70	7.00	8.60	37.50	23.10	3.80
TELLAHAMSA	72.40	53.50	6.00	5.20	47.24	24.30	4.40
RNR15048	106.00	84.30	8.00	13.60	30.38	24.00	5.10
MTU1112	60.00	52.60	6.00	6.90	44.39	24.40	4.50
MTU1121	70.00	42.20	7.00	5.50	46.67	23.70	4.70
MTU1166	63.80	44.30	6.00	5.30	57.60	25.50	4.20
MTU1001	69.70	51.70	6.00	4.60	60.05	25.20	4.50
SP-351	105.30	67.60	7.00	10.40	56.46	29.60	6.00
SP-353	97.50	65.30	8.00	10.30	65.80	29.90	6.60
SP-360	104.90	69.40	8.00	10.30	76.77	30.70	8.77
SP-70	110.10	62.30	8.00	8.90	75.93	27.80	8.68

Table 2 Physical parameters of culm at full ripening stage in rice (Mean of 10 samples)

Variety / line	Plant height (cm)	Stem length (cm)	Number of nodes	Inter-nodal length (cm)	Linear density ($mg.cm^{-1}$)	Physical strength (mm deflection)	Culm diameter (mm)
SWARNA	71.8	55.0	6.00	9.20	44.04	23.80	4.20
BPT5204	84.6	61.2	7.00	9.80	39.13	22.90	3.80
TELLAHAMSA	72.2	50.9	6.00	6.94	47.46	24.30	4.50
RNR15048	107.8	84.3	8.00	11.98	32.95	25.00	5.20
MTU1112	64.1	52.6	6.00	7.70	56.93	26.20	4.60
MTU1121	79.1	50.2	7.00	8.41	64.83	26.20	5.20
MTU1166	66.9	44.3	6.00	9.30	63.62	25.60	4.60
MTU1001	69.6	69.6	6.00	9.10	47.48	24.40	4.40
SP-351	106.3	69.3	7.00	11.4	56.46	29.00	6.60
SP-353	106.9	66.1	8.00	9.80	56.54	28.40	7.20
SP-360	107.6	78.4	8.00	10.40	64.09	31.40	8.80
SP-70	115.8	87.5	8.00	12.40	78.26	31.60	8.60

*Significant at 5% level.
NS Non-significant

Intra-varietal changes in physical parameters of rice with maturity between 50% flowering and full ripening, were tested for significance and the results are presented in tables 3, 4 and 5. Plant height increased significantly in the lodging tolerant varieties MTU-1112 and MTU-1121 and in strong culm mutants SP-353, SP-360 and SP-70, between 50% flowering stage and full ripening stage, while it's changes in other varieties / lines are non-significant (Table). There was significant increase in stem length between 50% flowering and full ripening in MTU-1121, MTU-1001, SP-360 and SP-70, while in only variety i.e., Tellahamsa, significant decrease in stem length was recorded. In all others changes in stem length are not significant (Table). Mean inter nodal length of basal node increased significantly in Swarna, BPT-5204, Tellahamsa, MTU-1121, MTU-1166, MTU-1001 and in SP-70 between 50% flowering and full ripening stages. In other varieties / lines changes are not significant (Table). Mean outer diameter of rice culm at 3rd internode significantly increased in all strong culm mutant lines as well as in the lodging susceptible variety Swarna. But in other varieties the changes are non-significant (Table 4.4). Mean number of nodes didn't change significantly between 50% flowering

and full ripening stages (Table). Mean linear density of the culm increased significantly between 50% flowering and full ripening in RNR-15048, MTU-1112, MTU-1121 and MTU-1166, while it decreased significantly in Swarna, MTU-1001, SP-353 and SP-70 (Table). Physical strength of the rice culms which was measured as the pushing resistance of the rice hills, significantly increased between 50% flowering and full ripening stages in MTU-1112, MTU-1121 and SP-70 and significantly decreased only in the mutant line SP-353. In all others changes in physical strength were non-significant (Table 3).

Table 3: Change in the physical parameters of culm with maturity in rice

Sl. No.	Variety / line	Physical parameter	Mean		Student's 't' value
			At 50% flowering stage	At full ripening stage	
1.	**Swarna**	Plant height (cm)	69.20	71.80	1.274^{NS}
		Stem length (cm)	54.20	55.00	1.801^{NS}
2.	**BPT 5204**	Plant height (cm)	85.10	84.60	0.158^{NS}
		Stem length (cm)	59.70	61.20	0.792^{NS}
3.	**Tellahamsa**	Plant height (cm)	72.40	72.20	0.079^{NS}
		Stem length (cm)	53.50	50.90	1.889^{*}
4.	**RNR 15048**	Plant height (cm)	106.00	107.80	0.842^{NS}
		Stem length (cm)	84.30	84.30	0.438^{NS}
5.	**MTU 1112**	Plant height (cm)	60.00	64.10	2.678^{*}
		Stem length (cm)	52.60	52.60	1.245^{NS}
6.	**MTU 1121**	Plant height (cm)	70.00	79.10	2.790^{*}
		Stem length (cm)	42.20	50.20	6.863^{*}
7.	**MTU 1166**	Plant height (cm)	63.80	66.90	1.186^{NS}
		Stem length (cm)	44.30	44.30	0.122^{NS}
8.	**MTU 1001**	Plant height (cm)	69.70	69.60	0.569^{NS}
		Stem length (cm)	51.70	69.60	18.010^{*}
9.	**SP 351**	Plant height (cm)	105.30	106.30	0.353^{NS}
		Stem length (cm)	67.60	69.30	0.696^{NS}
10.	**SP 353**	Plant height (cm)	97.50	106.90	4.763^{*}
		Stem length (cm)	65.30	66.10	0.393^{NS}
11.	**SP 360**	Plant height (cm)	104.90	107.60	1.839^{*}
		Stem length (cm)	69.40	78.40	2.970^{*}
12.	**SP 70**	Plant height (cm)	110.10	115.80	2.595*
		Stem length (cm)	62.30	87.50	12.537^{*}

*Significant at 5% level. NS Non-significant

Table 4: Change in the physical parameters of culm with maturity in rice

Sl. No.	Variety / line	Physical parameter	Mean		Student's 't' value
			At 50% flowering stage	At full ripening stage	
1.	**Swarna**	Number of nodes	6.00	6.00	0.000^{NS}
		Linear density	46.65	44.05	1.851^{*}
		Physical strength	23.90	23.80	0.165^{NS}
2.	**BPT 5204**	Number of nodes	7.00	7.00	0.000^{NS}
		Linear density	37.50	39.13	1.006^{NS}
		Physical strength	23.10	22.90	0.348^{NS}
3.	**Tellahamsa**	Number of nodes	6.00	6.00	0.000^{NS}
		Linear density	47.24	47.46	0.118^{NS}
		Physical strength	24.30	24.30	0.000^{NS}
4.	**RNR 15048**	Number of nodes	8.00	8.00	0.000^{NS}
		Linear density	30.38	32.96	2.773^{*}
		Physical strength	24.00	25.00	1.677^{NS}
5.	**MTU 1112**	Number of nodes	6.00	6.00	0.000^{NS}
		Linear density	44.39	56.94	4.171^{*}
		Physical strength	24.40	26.20	6.194^{*}
6.	**MTU 1121**	Number of nodes	7.00	7.00	0.000^{NS}
		Linear density	46.67	64.84	6.378^{*}
		Physical strength	23.70	26.20	3.478^{*}
7.	**MTU 1166**	Number of nodes	6.00	6.00	0.000^{NS}
		Linear density	57.60	63.63	1.956^{*}
		Physical strength	25.50	25.60	0.160^{NS}
8.	**MTU 1001**	Number of nodes	6.00	6.00	0.000^{NS}
		Linear density	60.05	47.48	2.881^{*}
		Physical strength	25.20	24.40	1.444^{NS}
9.	**SP 351**	Number of nodes	7.00	7.00	0.000^{NS}
		Linear density	56.46	56.46	0.000^{NS}
		Physical strength	29.60	29.00	0.757^{NS}
10.	**SP 353**	Number of nodes	8.00	8.00	0.000^{NS}
		Linear density	65.80	56.54	3.135^{*}
		Physical strength	29.90	28.40	1.963^{*}
11.	**SP 360**	Number of nodes	8.00	8.00	0.000^{NS}
		Linear density	76.77	64.09	3.202^{*}
		Physical strength	30.70	31.40	0.782^{NS}
12.	**SP 70**	Number of nodes	8.00	8.00	0.000^{NS}
		Linear density	75.93	78.27	1.126^{NS}
		Physical strength	27.80	31.60	3.739^{*}

*Significant at 5% level.
NS Non-significant

Correlation between the physical parameters of rice and its physical strength, varietal means of physical parameters of rice were correlated to varietal means of physical strength (Table 5), at both 50% flowering and full ripening stages. At 50% flowering stage, even though all the measured physical parameters viz., plant height, stem length, number of nodes, internodal length and outer diameter of basal (3^{rd}) internode and linear density of culm showed positive correlation with physical strength of culm, only plant height, culm diameter and linear density were significantly positive. Further, culm diameter and linear density showed significantly positive correlation even at 1% level of significance (Table 5). Correlation between physical parameters and physical strength of rice culms at full ripening stage, was similar to that of 50% flowering stage i.e., all parameters showed positive correlation with physical strength; plant height, number of nodes, culm diameter and linear density showed significant correlation. But, at full ripening culm diameter was the only parameter that showed significant correlation at 1% level (Table-5).

Table 5: Correlation between physical parameter of the culm and physical strength of the culm in rice

Sl. No.	Physical Parameter	Correlation coefficient (r) with physical strength	
		50% flowering stage	Full ripening stage
1.	Plant height	0.661*	0.682*
2.	Stem length	0.347NS	0.497NS
3.	Number of nodes	0.558NS	0.649*
4.	Internodal length	0.470NS	0.540NS
5.	Linear density	0.826**	0.570*
6.	Culm diameter	0.960**	0.906**

NS - Not significant
* - Significant at 5% level.
** - Significant at 1% level.

The present study accepts the general statement that reduced plant heights and shorter stalks improves lodging resistance in cereals[2,12,13], since the results show that lodging susceptible varieties showed higher plant heights and stem lengths compared to tolerant varieties (Table-1). But, the present study also showed that the mutant lines though showed greater plant heights and stem lengths, they were lodging tolerant (higher physical strength values), probably due to the mutagenic reasons, not covered by this study.

The study also showed that compared to tolerant varieties, susceptible varieties had longer lower internodes, with lesser culm diameter, which are in line with the findings of Chang and Vergara[1], Rongtian *et al.*[19] and Mahbub *et al.*[15]. Here also the mutant lines are different by having longer basal nodes with higher diameter.

Linear density of the culm was highest in mutant lines followed by lodging tolerant varieties and then by lodging susceptible varieties. These findings agree with the reports of Zuber *et al.* and Islam *et al.*[7], which say that higher the linear density higher the lodging resistance. Out of all parameters linear density of the culm, outer diameter of the basal internode appear to be best indices of physical strength of rice culms in other words lodging nature of rice.

Various physical parameters viz., plant height, stem length, number of nodes, length and outer diameter of basal (3rd) internode, linear density of culm were measured along with physical strength of the culms, to understand the physical basis of lodging nature in rice. Physical data was collected at 50% flowering stage as well as full ripening stage to know the changes in them with maturity in rice. The current study showed that lodging tolerant varieties in general have lower plant height and stem lengths along with lower length of basal internode compared to lodging susceptible varieties. Further lodging tolerant varieties have higher outer diameter of basal internode (3rd internode), higher linear density and higher physical strength of culms compared to lodging susceptible varieties. But, the present study also showed that the mutant lines though showed greater plant heights and stem lengths, they were lodging tolerant (higher physical strength values), probably due to the mutagenic reasons. However, number of nodes appear not to play any significant role in lodging nature of the rice, which was evident from the correlation studies between physical parameters and physical strength of culms. It can be concluded that lodging nature of the rice can be measured by taking any or all of these parameters except number of nodes. However, it should be cautioned that while working with mutants plant height and length of stem couldn't be considered while studying lodging nature. Out of all parameters linear density of the culm, outer diameter of the basal internode appear to be best indices of physical strength of rice culms in other words lodging nature of rice.

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