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Studies on the Histological and Biochemical Basis of Rice Culm for Lodging Tolerance in Rice (*Oryza sativa* L.)

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ABSTRACT

An experiment was conducted to find out "studies on the histological and biochemical basis of rice culm for lodging tolerance at reproductive phase in rice (Oryza sativa.L) by studying relevant parameters in three different groups of rice germplasm viz., stable strong culm mutant lines (SP-351, SP-353, SP-360 and SP-70) ; lodging tolerant varieties (MTU-1112, MTU-1121, MTU-1166 and MTU-1001) and lodging susceptible varieties (Swarna, BPT-5204, Tellahamsa and RNR-15048) . Histological studies revealed that in rice physical strength of the culm was highly correlated to the number of vascular bundles of cross sectional area of the basal culm (3rd internode) as well as the thickness of dermal sclerenchyma. It should be noted that pattern of distribution of vascular bundles didn't differ in the varieties / lines under the present study. Therefore, if time and facilities permits, these two histological parameters should be considered while measuring lodging nature of rice culms. Biochemical analysis showed that mineral components are strongly correlated to the physical strength of rice culms in other words, lodging nature. It should be noted that N and Si content of culms decreased between 50% flowering and full ripening stages of rice, while K increased. At 50% flowering stage, N content of culms significantly correlated to physical strength of culms, while at full ripening stage showed non-significant correlation. However, K and Si contents of culms showed highly significant correlation with physical strength of culms i.e., lodging tolerance.

Key words: *Thickness of Epi Hypo Dermal Sclerenchyma, Number of Vascular Bundles, Total Content of N, P and K.*

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[9]. It is the main source of the 35-60% dietary calories consumed by more than 3 billion people[3]. 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[10,14]. 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[9]. The agricultural land for crop production is decreasing annually due to urban growth and land degradation, hence, rice production needs to be increased from the same or even smaller amount of land. Novel high yielding rice cultivars, ultra-modern rice production practices and technologies need to be developed to meet the increasing rice demand to feed the entire world. But in a high-yielding environment, lodging is the most important constraint on yield for most cereals crops, including rice (Setter *et al.,* 1997). Lodging resistance is a complex trait, determined by plant height, root thickness, culm diameter, strength and elasticity of culm, and the weight of the upper part of the plant[6]. Plant height has been the main target for improvement of lodging resistance. It is observed that genotypes having higher solid pith area have higher lodging resistance capability which possess thicker sclerenchyma layer with, sclerenchyma cell layers. Number of vascular bundles is positively correlated with lodging resistance lines because vascular bundles contribute to mechanical strength. To improve lodging resistance a more practical approach is selection for shorter and solid stems[4]. 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[16]. 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[1]. Yield reduction due to lodging was reported to be dependent on the season weak culmed varieties in from 50% in dry season to 80% in wet season. Jennings and Sornchai[8]; whereas in semi-dwarf varieties recorded a loss of 35% yield. (IRRI, 1986) .Weather conditions, especially wind and rain near heading and harvest time, appear to be a major factors influencing lodging[12]. So improving lodging resistance is an important challenge in rice breeding programs. With this background and considering the importance of lodging in rice the present research was taken up for histological and biochemical characterization of lodging tolerance in rice (*Oryza sativa* L.).

MATERIAL AND METHODS

The present study was carried out in the experimental field of ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad and the laboratory of the Department of Crop Physiology, College of Agriculture, Rajendranagar, and 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); stable strong culm mutant lines (SP-351, SP-353, SP-360 and SP-70) ; lodging tolerant varieties (MTU-1112, MTU-1121, MTU-1166 and MTU-1001) and lodging susceptible varieties (Swarna, BPT-5204, Tellahamsa and RNR-15048). In this histological and biochemical parameters were studied i.e thickness of epi / hypo dermal sclerenchyma, number of vascular bundles, N, P and K. Histological studies on rice culms made by transverse sections of third internode of rice culm were made, at 12 µm thickness, with rotary microtome with steel blades using the paraffin embedding procedure as described by Johansen (1940). Reagents as well as detailed procedure used were given i.e i) Formalin-Aceto-Alcohol (FAA): 50% ethyl alcohol, glacial acetic acid and formaldehyde were

mixed in the volumetric ratio of 18: 1: 1, to prepare FAA, which was used for killing and fixing the tissue samples. ii) **Alcohol series**: Dehydration of tissue samples was done by the following series of solutions of water, ethyl alcohol and tertiary butyl alcohol. iii) Toluidine Blue stain: 0.05 % (w/v) solution of the polychromatic stain 'toluidine blue'in ethanol was prepared, which was used to stain the sections. iv) Mayer's adhesive: To mount the paraffin sections on to the slides, Mayer's adhesive was used which was prepared by thoroughly mixing the white of one fresh egg to about equal quantity of glycerol and 1 g sodium salicylate. The mixture was filtered through sterile cheese cloth. Internodal samples (third internode from base) of length of 0.5 to 0.75 cm length were cut with a sharp blade (Fig. 3.3), which were immediately killed and fixed in FAA solution for a minimum period of 24 hours or till the samples get cleared. Then the samples were dehydrated by immersing in alcohol series solutions of increasing strength in the order of 50%, 70%, 85%, 95%, 100% alcohol, with at least 1 hour duration at each step, followed by immersion in 2 changes of tertiary butyl alcohol again for at least one hour at each step. Then, these dehydrated tissue samples were infiltrated with paraffin in an oven maintained at 60-80 ^{0}C temperature. Infiltration with paraffin again was done gradually to prevent damage to the tissue by following changes of infiltrating solution viz., 1:1 mixture of Tertiary butyl alcohol and light paraffin oil, paraffin topped with 1:1 mixture of tertiary butyl alcohol and light paraffin oil followed by at least two changes of pure paraffin. Then the samples were infiltrated with and embedded in an embedding mixture of paraffin and bee wax (3:1 w/w) in paper boats. Infiltrated samples were then neatly trimmed to cuboid shape, attached to the sample holder of rotary microtome with sufficient paraffin wax at the base and were microtomed at 12 micro meter thickness, to get the ribbon of serial sections of the sample. These ribbons were then cut into small pieces, which were then mounted on to the slides smeared with a thin layer of Mayer's adhesive. These mounted slides were flooded with water and the paraffin ribbons were straightened on a warming plate maintained at 45 ^{0}C. After straightening, excess water was drained from the slides, which were then observed under microscope to select the slides with better sections. The selected slides were then left overnight on the warming plate maintained at 45 ^{0}C to make the sections adhere to the slides. Slides with adhered paraffin sections were deparaffinised by immersing in xylene, till all the paraffin dissolved leaving only the sections on the slide. Later the slides along with adhered sections were immersed in 1:1 mixture of xylene and absolute ethyl alcohol for about one hour. Slides with sections were flooded for about 5 minutes with 0.05% Toluidine blue solution to stain the sections. After staining sections were mounted using DPX mountant, duly covered with a cover slip. Later the slides were dried in an oven at 70^{0}C for 2-3 days, additional mountant was scraped off the slide, and slides were wiped clean to remove smudges of mountant over the cover slip aswellas slide with a lint free cloth wetted with xylene.

Microphotography:

Mounted sections on the slides were used for micro-photography, at 100x magnification with a digital camera mounted, binocular, compound microscope (OLYMPUS - CX41).

Measurement of tissue thickness in microscopic sections: Calibration of the 'ocular micro-meter: A 'stage micrometer' (with 10 µM spaced equidistant lines) was kept on the stage, at the required magnification level (100 x) and an 'ocular micro meter' was placed into the micrometer mounting frame of a NCWHK 10X eye piece in such a way that the micrometer lines are facing downwards. Then the micrometer fitted eye piece was rotated till the lines of the ocular micrometer are parallel with those of the stage micrometer. Lines on the left edges of the two micrometers were matched by moving the stage micrometer so that the lines of the ocular micrometer are superimposed over those of the stage micrometer. Then the number of ocular

micrometer divisions that fall within a given number of stage micrometer divisions was checked at three different scale locations, and the average size of a division of the 'ocular micrometer' was calculated at that specific magnification. Measurement: Mounted rice culm sections, were observed at 100 x magnification, with a calibrated ocular micrometer fitted eye piece, to measure the thickness of the epi / hypo dermal lignified tissue. To measure the thickness, ocular fitted eyepiece was rotated in such a way that a line of the scale was just touching stem surface like a tangent. No. of divisions encompassing the peripheral lignified tissue were counted at five different locations of the section, and the averagethickness of the lignified tissue was computed. Number and distribution pattern of vascular bundles in the stems: Mounted rice culm sections were observed under low power magnification (40x magnification), to know the number and distribution pattern of vascular bundles in basal part of rice culm. **Scanning electron micrography**: The basal third internode of rice culms were cut into 5 mm pieces and fixed in 2.5% glutaraldehyde in phosphate buffer for 2 hours at 40 ^{0}C.At the end of the incubation, the samples were washed with phosphate buffer post fixed with2% osmium tetroxide for 4 hours and dehydrated using a graded series of ethanol .The dehydrated samples were dried with critical-point liquid carbon dioxide as a transition fluid. The dried materials were adhered on to aluminium specimen mounts with double-stick adhesive tape .The samples were later coated gold-palladium in an automated sputter coater (JEOL IFC-1600) and examined with a scanning electron microscope (JEOL-JSM 5600) as per the standardized protocols at RUSKA lab, college of veterinary Science, Rajendranagar, Hyderabad. Due to paucity of funds only the mutant lines under the present study, were taken up for scanning electron micrography. Rice culm samples (third basal internode) collected from all the varieties / lines under study were dried in hot air oven at about 60^{0}C till they attained complete dryness. Samples were then powdered with the help of a mechanical grinder, and passed through 2mm stainless steel sieve.

Total nitrogen was estimated by the micro Kjeldahl method as per AOAC (1995) using KEL-PLUS™ Automatic Nitrogen Estimation System. 0.5 g of sample was transferred to digestion tube, to which 10 ml of concentrated sulphuric acid and 5 g of catalyst mixture (potassium sulphate, cupric sulphate and metallic selenium powder in the ratio of 50:10:1) were added in sequence. Then the digestion tubes were loaded into the digester (Model KES 06R) and digested initially at a temperature of 100 ^{0c}till the frothing is over, and then at 410 ^{0c} till the samples turn into light green color. After digestion, tubes were allowed to cool and then loaded into distillation unit (Model Classic DX). Liberated ammonia was captured in a 250 ml conical flask with 20 ml of 4%boric acid duly added with mixed indicator (0.006g methyl red and0.099 g bromocresol green dissolved in 100 ml of 95% alcohol) kept at the hose end of the distillation unit. Simultaneously a blank sample (without plant sample) was also kept to run Distillate of both sample and blank were titrated with 0.02 N sulphuric acid till the end point (change from green to original pinkish colour) , to get the respective titres. Total nitrogen content of the sample was calculated by using the formula

$$Nitrogen\ content\ in\ plant\ sample\ (\%) = \frac{(Sample\ titre - Blank\ titre)x\ 14\ x\ 100}{Sample\ weight\ (g)x\ 1000}$$

Nitrogen content finally was expressed in mg. g^{-1} dwt.

Potassium content in the sample was estimated by flame photometric method, as given by Jackson (1967). 0.5 g of sample was digested in 10 mL di-acid mixture (5: 2 ratio of nitric acid (HNO_3) and per chloric acid ($HClO_4$)) to obtain the extract, which was

made up to 50 mL with double distilled water and suitable aliquots were used for estimation of potassium by direct feeding of the extract to the flame photometer after adjusting the instrument with standards. A standard curve was prepared for 0, 20, 40, 60, 80 ppm of potassium solution by using potassium chloride salt, which were fed to flame photometer and readings were noted. Standard curve was prepared by taking concentrations of K on x-axis and flame photometer readings on Y-axis. Potassium concentration in pant extract (ppm) was obtained from the flame photometer readings of the plant extract by using the standard curve. Potassium concentration was finally expressed as mg.g-[1]dwt of tissue. Si content in rice culms was estimated using the method of Saito *et al.*[14], where Si of plant samples was extracted with dilute hydrofluoric acid and estimated by spectrophotometric molybdenum yellow method. During the entire procedure only plastic vessels are used to prevent contamination of Si from glass containers. 0.5 g of the sample was extracted by using a 10 mL solution containing 1.5 M Hydroflouric acid and 0.6M hydrochloric acid for overnight. Supernatant from this extraction was taken for si estimation by molybdenum yellow method. 0.1 mL of si extract was taken, to which 2mL of 0.1 M boric acid, 0.5M sodium molybdate, 4mL of 0.1 M citric acid were added and the volume was made to 10 mL by addition of distilled water after thorough mixing. This reaction mixture turned to yellow colour after 5 minutes, whose absorbance was read at 400 nm wave lengths by using a spectrophotometer. Standard Si solutions were prepared in the range of 3 to 30 µg Si. These standards were used in the place of plant extract in the above procedure and a standard curve was prepared by taking Si content on x-axis and absorbance at 400 nm on y-axis. Silicon content in the plant sample was estimated by using the standard curve, and was expressed in mg.g^{-1} dwt.

RESULTS AND DISCUSSION

Mean values of all the histological and biochemical parameters measured at 50% flowering stage are presented in the (table 1).

Table 1: Histological-biochemical parameters of rice culm (Mean of 5 samples) at 50 % flowering stage

Variety / line	50 % flowering stage				
	Number of vascular Bundles (No.)	Thickness of epi/hypodermal lignified tissues (mm)	Total nitrogen content (mg.g^{-1} dwt)	Total potassium content (mg.g^{-1} dwt)	Total silicon content (mg.g^{-1} dwt)
SWARNA	20.0	10.0	12.56	4.60	1.04
BPT5204	18.0	8.0	11.95	7.46	1.00
TELLAHAMSA	20.0	12.0	12.45	7.54	1.48
RNR15048	23.0	9.0	12.24	7.15	1.24
MTU1112	22.0	11.0	12.07	6.81	1.28
MTU1121	21.0	18.0	11.13	7.32	1.56
MTU1166	21.0	10.0	11.50	6.73	2.00
MTU1001	20.0	10.0	12.16	7.02	1.44
SP351	25.0	21.0	13.21	8.3	2.00
SP353	26.0	23.0	13.12	8.04	1.84
SP360	27.0	28.0	12.82	8.29	2.16
SP70	26.0	26.0	13.35	8.03	2.24

The results showed that the rice varieties / lines differed in all the measured histological parameters mean thickness of epi hypo dermal sclerenchyma, number of vascular bundles and also chemical parameters total potassium content and silicon content were highest in strong culm mutant lines (SP-351, SP-353, SP-360 and SP-70), followed by lodging tolerant varieties (MTU-1112, MTU-1121, MTU-1166 and MTU-1001) and lowest in lodging

susceptible varieties (Swarna, BPT-5204, Tellahamsa and RNR-15048). Total number of vascular bundles present in the cross sectional area of the rice culms were presented in the (table 1). These results show that the rice varieties / lines under the present study differed in the number of vascular bundles of the culm. Lowest number of vascular bundles per cross sectional area was observed in BPT-5204 (18), whereas the mutant line SP-360 showed the highest i.e, 27 vascular bundles. It is also evident that except BPT-5204 (18) and RNR-15048 (23) all the other released varieties of rice showed not much difference in vascular bundle number in culm. Thickness of the epi/hypodermal sclerenchyma tissue layer in rice culms of all the rice varieties / lines of the current study are also presented in the table .1, which showed that the varieties / lines of rice differed in this character as well. Out of all the rice varieties / lines BPT-5204 showed lowest sclerenchyma thickness both at 50% flowering and full ripening stages, while the mutant line SP-360 showed highest sclerenchyma thickness both at 50% flowering and full ripening stages. From these results (table 3.). It was also evident that lignified layer thickness in rice culms increased with time between 50% flowering stage and full ripening stages. Total potassium content of rice culms in the mutant line SP-351 (8.34 $mg.g^{-1}$) showed the highest total potassium content at 50% flowering stage, while Swarna (4.60 $mg.g^{-1}$) recorded the lowest. At full ripening stage, a highest total potassium content of 10.59 mg. $g^{-1}$was seen in SP-70, while a lowest content of 6.09 mg. g^{-1} was observed in the lodging susceptible variety BPT-5204 (Table 2.). A highest content of 2.24 $mg.g^{-1}$ and a lowest content of 1.00 $mg.g^{-1}$ of total silicon were found in the mutant line SP-70 and the lodging susceptible BPT-5204, respectively, at 50% flowering stage among the rice varieties / lines studied table 1. At full ripening stage, MTU-1166 (2.00 $mg.g^{-1}$) and RNR-15048 (1.04 $mg.g^{-1}$) showed the highest and lowest contents of silicon in culms, respectively (Table 2.). From the above said parameters revealed that histological studies in rice physical strength of the culm was highly correlated to the number of vascular bundles of cross sectional area of the basal culm (3^{rd} internode) as well as the thickness of dermal sclerenchyma. It should be noted that pattern of distribution of vascular bundles didn't differ in the varieties / lines under the present study table 3.

Table 2: Histological-biochemical parameters of rice culm (Mean of 5 samples) at full ripening stage

Variety / line	At full ripening stage				
	Number of vascular Bundles (No.)	**Thickness of epi/hypodermal lignified tissues (mm)**	**Total nitrogen content ($mg.g^{-1}$ dwt)**	**Total potassium content ($mg.g^{-1}$ dwt)**	**Total silicon content ($mg.g^{-1}$ dwt)**
SWARNA	20	14.0	4.42	6.50	1.13
BPT5204	18.0	10.0	3.92	6.09	1.08
TELLAHAMSA	20.0	15.0	4.52	7.33	1.16
RNR15048	23.0	12.0	4.50	6.91	1.04
MTU1112	22.0	14.0	3.71	10.41	1.28
MTU1121	21.0	20.0	4.53	9.11	1.56
MTU1166	21.0	15.0	3.62	9.49	2.00
MTU1001	20.0	13.0	3.79	9.26	1.44
SP351	25.0	25.0	4.34	8.99	1.60
SP353	26.0	26.0	4.52	9.52	1.68
SP360	27.0	32.0	4.42	10.17	1.60
SP70	26.0	28.0	4.55	10.59	1.76

Therefore, if time and facilities permits, these two histological parameters should be considered while measuring lodging nature of rice culms and also biochemical analysis showed that mineral components are strongly correlated to the physical strength of rice culms in other words, lodging nature. It should be noted that N and Si content of culms decreased between 50% flowering and full ripening stages of rice, while K increased. At 50% flowering stage, N content of culms significantly correlated to physical strength of culms, while at full ripening stage showed non-significant correlation. However, K and Si contents of culms showed highly significant correlation with physical strength of culms i.e., lodging tolerance. Total nitrogen, total potassium and total silicon contents of rice culms at 50% flowering and full ripening stages were compared to know significance of change between these two growth stages and the results were presented in table 3. This analysis of data showed that the total nitrogen content of rice culms decreased significantly in all varieties between 50% flowering and full ripening stages (Table 3.). The total potassium content of the rice culms increased significantly in all lodging tolerant varieties and strong culm mutant lines of rice. In lodging susceptible rice varieties potassium content of culm significantly increased in the variety Swarna (from 4.60 to 6.50 $mg.g^{-1}$), significantly decreased in the variety BPT-5204 (from 7.46 to 6.09 $mg.g^{-1}$), while it decreased but non-significantly in the varieties Tellahamsa and RNR-15048 (Table 3).

Table 3: Histological parameters of rice culm (Mean of 5 samples)

S.N	Variety / line	At 50% Flowering stage		At full ripening stage	
		Number of vascular bundles (No.)	Thickness of epi / hypo dermal sclerenchyma (mm)	Number of vascular bundles	Thickness of epi / hypo dermal sclerenchyma (mm)
1.	**SWARNA**	20.0	10.0	20	14.0
2.	**BPT5204**	18.0	8.0	18.0	10.0
3.	**TELLAHAMSA**	20.0	12.0	20.0	15.0
4.	**RNR15048**	23.0	9.0	23.0	12.0
5.	**MTU1112**	22.0	11.0	22.0	14.0
6.	**MTU1121**	21.0	18.0	21.0	20.0
7.	**MTU1166**	21.0	10.0	21.0	15.0
8.	**MTU1001**	20.0	10.0	20.0	13.0
9.	**SP351**	25.0	21.0	25.0	25.0
10.	**SP353**	26.0	23.0	26.0	26.0
11.	**SP360**	27.0	28.0	27.0	32.0
12.	**SP70**	26.0	26.0	26.0	28.0

Total silicon content of rice culms didn't change between 50% flowering and full ripening stages in all the lodging tolerant rice varieties. There were non-significant increase in Si content in lodging susceptible Swarna and BPT-5204, but significant decrease in Tellahamsa and RNR-15048 with maturity. In the rice mutant lines, with maturity Si content of culms decreased significantly in all, except in SP-353 in which there was non-significant decrease. Dependence of physical strength of the rice culms on the number of vascular bundles[2,11] and on the fusion of outer vascular bundles with dermal sclerenchyma[2] which can be equated to the thickness of epi/hypodermal lignified tissue, were reported earlier and the present findings either in terms of differences in histological parameters in varieties differing in lodging nature or in terms of physical strength dependence on histological parameters support them. It should be pointed out that the distribution pattern of vascular

bundles in rice culms was similar in all the three groups of rice varieties / lines studied, implying that this parameter didn't play a role in the lodging nature of rice in these varieties. However, it was reported by Chaturvedi *et al.*[2] that fusion of outer vascular bundles with epidermal sclerenchyma was observed in lodging tolerant rice varieties, which was not observed in any rice variety / line studied in the present work. Lower contents of nitrogen and higher contents of potassium in rice internodes decreased lodging tendency[11]. The results from the current study show clearly that strong culm mutant line had higher potassium contents followed by lodging tolerant varieties in the culms, both at 50% flowering and full ripening stages (Table 4).

Table 4: Change in the biochemical components of culm with maturity in rice

Sl. No.	Variety / line	Name of the component	Mean Content (mg.g^{-1} dwt)		Student's 't' value
			50% flowering stage	Full ripening stage	
	Swarna	Potassium	4.60	6.50	7.361*
		Silicon	1.04	1.13	0.673^{NS}
	BPT 5204	Potassium	7.46	6.09	5.655*
		Silicon	1.00	1.08	1.000^{NS}
	Tellahamsa	Potassium	7.54	7.33	0.679^{NS}
		Silicon	1.48	1.16	1.809*
	RNR 15048	Potassium	7.15	6.91	1.359^{NS}
		Silicon	1.24	1.04	2.236*
	MTU 1112	Potassium	6.81	10.41	12.170*
		Silicon	1.28	1.28	0.000^{NS}
	MTU 1121	Potassium	7.32	9.11	5.352*
		Silicon	1.56	1.56	0.000^{NS}
	MTU 1166	Potassium	6.73	9.49	8.418*
		Silicon	2.00	2.00	0.000^{NS}
	MTU 1001	Potassium	7.02	9.26	9.798*
		Silicon	1.44	1.44	0.000^{NS}
	SP 351	Potassium	8.34	8.99	2.153*
		Silicon	2.00	1.60	4.743*
	SP 353	Potassium	8.04	9.52	6.843*
		Silicon	1.84	1.68	0.712^{NS}
	SP 360	Potassium	8.29	10.17	7.472*
		Silicon	2.16	1.60	5.252*
	SP 70	Potassium	8.03	10.59	7.870*
		Silicon	2.24	1.76	4.810*

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

However, nitrogen contents of the culm didn't differ much between lodging susceptible and tolerant varieties; moreover they were higher in strong culm lines.

Table 5: Correlation between histological-biochemical parameters and physical strength of the culm in rice

Sl. No.	Histological- biochemical parameters of culm	Correlation coefficient with physical strength of culm (r)	
		50% flowering stage	Full ripening stage
1.	Number of vascular bundles	0.954**	0.909**
2.	Thickness of epi/hypodermal sclerenchyma	0.953**	0.922**
3.	Total nitrogen content	0.720**	0.387^{NS}
4.	Total potassium content	0.626**	0.749**
5.	Total silicon content	0.813**	0.628*

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

Correlation between the number of vascular bundles in the culm and physical strength of culm and between the thickness of epi/hypodermal sclerenchyma and physical strength of culm, at both 50% flowering and full ripening stages was worked out and presented in the table 5. These results showed that physical strength of rice culms is highly significantly correlated to both number of vascular bundles of culm and thickness of epi/hypodermal sclerenchyma of culm. The present study also reports a significant correlation between physical strength of the culm and culm N and K contents at both 50% flowering and full ripening stages, which are in agreement with the findings of Yang *et al*.[17] and Zhang *et al.*[18]. However, it should pointed out that the current study shows that Nitrogen content of culms played a significant role in physical strength of culms at 50% flowering, but not at full ripening stage (Table 5).

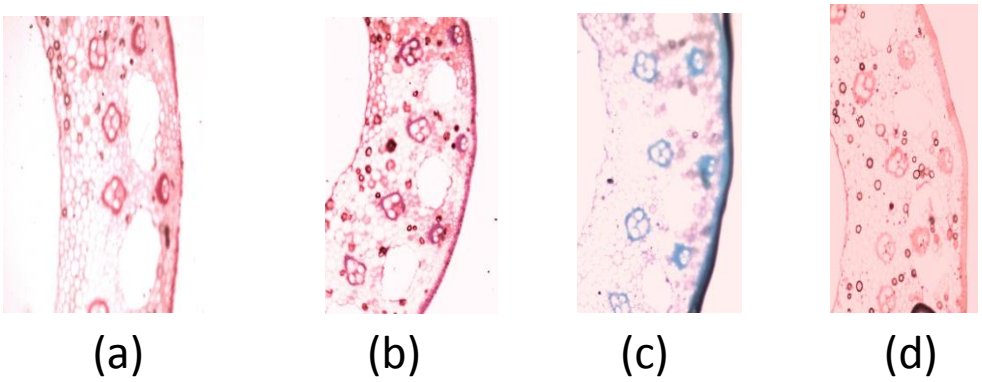


Fig. 1: Transverse sections of basal internode (3rd internode) of rice culm (100 xs)
(a) Swarna at 50% flowering stage (b) Swarna at full ripening stage
(c) BPT 5204 at 50% flowering stage (d) BPT 5204 at full ripening stage

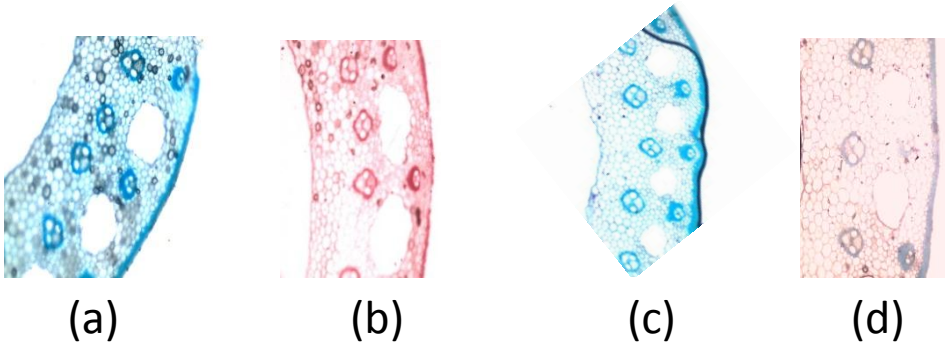


Fig. 2: Transverse sections of basal internode (3rd internode) of rice culm (100 xs)
(a) Tellahamsa at 50% flowering stage (b) Tellahamsa at full ripening stage
(c) RNR 15048 at 50% flowering stage (d) RNR 15048 at full ripening stage

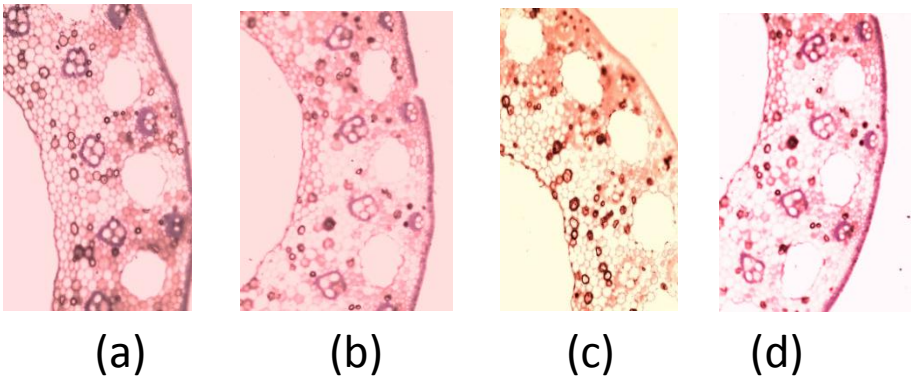


Fig. 3: Transverse sections of basal internode (3rd internode) of rice culm (100x)
(a) MTU-1112 at 50% flowering stage (b) MTU-1112 at full ripening stage
(c) MTU-1121 at 50% flowering stage (d) MTU-1121 at full ripening stage

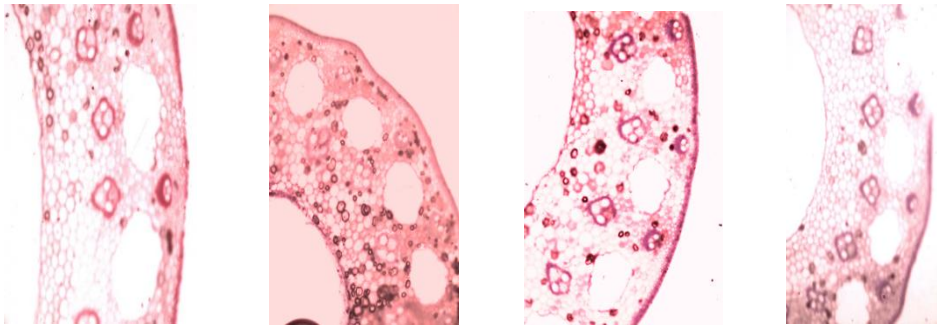


Fig. 4: Transverse sections of basal internode (3rd internode) of rice culm (100 xs)

(a) MTU-1166 at 50% flowering stage (b) MTU-1166 at full ripening stage

(c) MTU-1001at 50% flowering stage (d) MTU-1001at full ripening stage

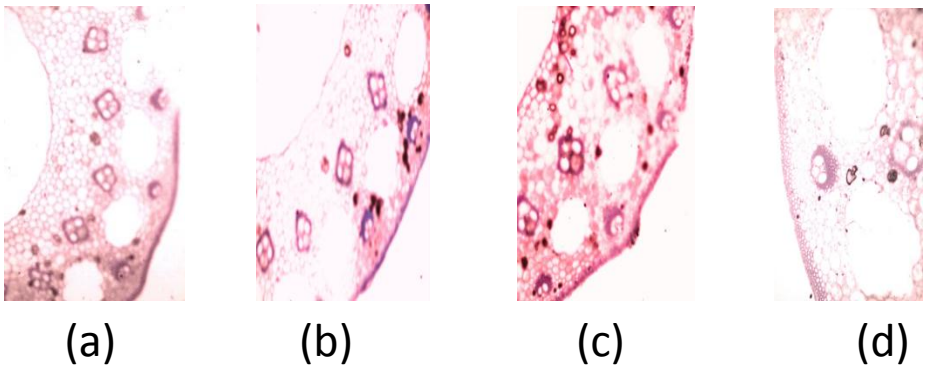


Fig. 5: Transverse sections of basal internode (3rd internode) of rice culm (100x)

(a) SP-351 at 50% flowering stage (b) SP-351 at full ripening stage

(c) SP-353 at 50% flowering stage (d) SP-353 at full ripening stage

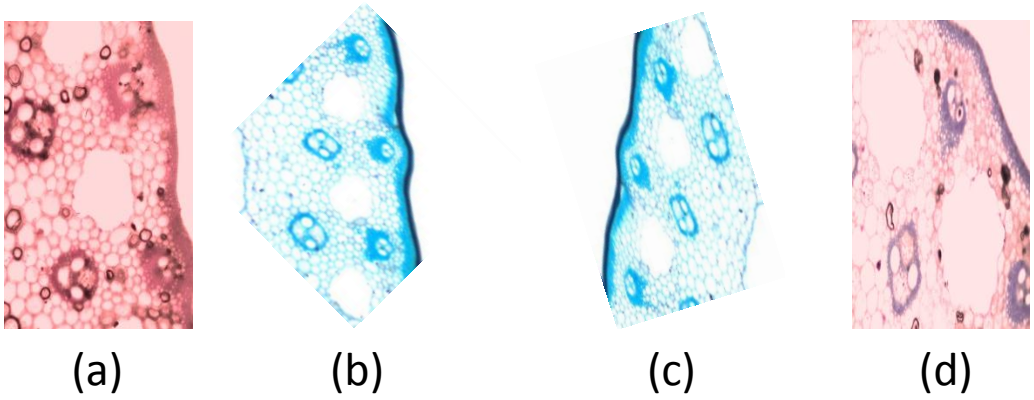
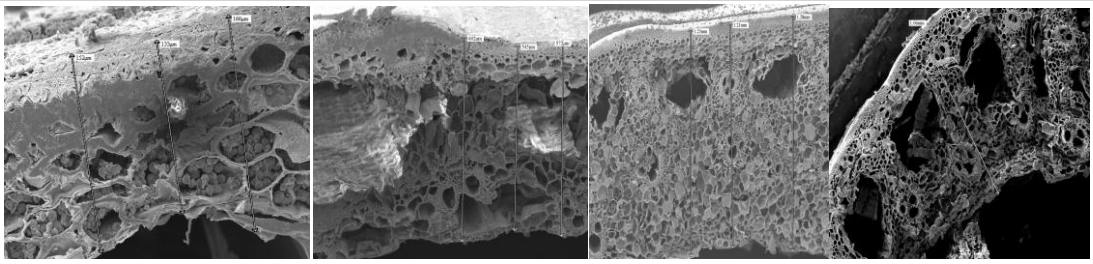


Fig. 6: Transverse sections of basal internode (3rd internode) of rice culm (100x)

(a) SP-360 at 50% flowering stage (b) SP-360 at full ripening stage

(c) SP-70 at 50% flowering stage (d) SP-70 at full ripening stage



(a) (b) (c) (d)

Fig. 7: scanning electron micrographs of transverse sections of basal internode (3rd Internode) of rice culm at full ripening stage

(a) SP-351 (1000x) (b) SP-353 (700x)

(c) SP-360 (400x) (d) SP-70 (700x

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