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BIOCHEMICAL ANALYSIS OF STEM IN LODGING TOLERANT AND SUSCEPTIBLE WHEAT (*TRITICUM AESTIVUM* L.) GENOTYPES UNDER NORMAL AND LATE SOWN CONDITIONS

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SUMMARY

A field experiment was conducted with six wheat genotypes including three lodging tolerant (HD-2329, Raj-4014 and Raj-3765) and three lodging susceptible (HD-2913, C-306 and RR-3) at three different dates of sowing *viz.* normal, late and very late sowing to assess the inter-relationship between lodging, physiological and biochemical traits in lodging tolerant and susceptible wheat genotypes. The experiment was laid out in randomized block design with three replications. Results indicated that the stem strength and lodging resistance factor index were significantly higher in tolerant genotypes than the susceptible one. Lodging tolerance was associated with higher concentrations of nutients like potassium, calcium, magnesium and minerals like silica, and cell wall components like lignin and hemi-cellulose content in the stem of tolerant genotypes.

Key words: **Wheat, Lodging, Stem strength, Potassium, Calcium, Silica, Lignin, Hemi-cellulose.**

INTRODUCTION

Lodging is an important problem in cereal crops. The lower part of the plant supports the heavier upper part, including the ear, leaves, and upper stem. The proportionality between the sturdiness of the lower part and the weight of the upper part determines the vulnerability of a given cultivar to lodging. Many studies have indicated that the lodging resistance is not only due to morphological and anatomical stem characters, but also well associated with physiological processes and chemical ingredients (Wang and Li 1996). Huang (1988) reported positive correlation between the carbohydrate content and lodging resistance. Plant cell walls are composed of a strong fibrillous netted structure that provides mechanical support to the entire plant body (Li *et al.* 2000). Cellulose, hemi-cellulose and lignin as the main components of the cell wall, seem to have an intrinsic correlation with lodging resistance (Bernards and Lewis 1998). For example, Taylor *et al.* (1999) and Jones *et al.* (2001) reported that lignin and cellulose content are related to stem rigidity. Huang (1988) reported that the lignin content of basal internodes of strong stems was higher compared to week stems.

Zhu *et al.* (2004) and Jones *et al.* (2001) emphasized that the lignin content of stems is more important than the cellulose content for increasing the mechanical support. In contrast, Wang *et al.* (2006) reported that the cellulose content is more important in mechanical support in comparison to the lignin content. In addition, several authors have investigated the relationship between some nutrient elements and mineral like silica with lodging resistance. The stem of wheat contains 2.3-4.6% silicon, which is mostly present in the epidermis of wheat culms and considered to contribute

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to lodging resistance (Li 1979). Silicon in the cell wall has been reported to contribute to mechanical strength in rice stems (Takahashi 1995). Gartner *et al.* (1984) observed significantly higher silicon content in the epidermis and mechanical tissue of culms in the lodging resistant variety. In addition, the cellulose, lignin, and silicon contents of the stem influence its mechanical strength (Ma *et al.* 2002, Tanaka *et al.* 2003). Other elements, like K, Ca and Mg are also reported to provide lodging resistance (Takahashi 1995). Hence, the present investigation has been conducted to analyze different biochemical parameters and their impact on lodging resistance with different dates of sowing.

MATERIALS AND METHODS

A field experiment was conducted during *rabi* (winter) season of 2006-07 with three different dates of sowing *viz*. normal (20^{th} November), late (10^{th} December), and very late sowing (30^{th} December) with three lodging tolerant (HD-2329, Raj-4014 and Raj-3765) and three lodging susceptible (HD-2913, C-306 and RR-3) wheat genotypes at Research field of Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi. The experiment was laid out in randomized block design with three replications. Nitrogen, P_2O_5, K_2O were applied at the rate of 120, 60 and 40 kg ha^{-1}. Irrigation and other inter-culture operations were carried out as per standard recommendations.

Stem strength was measured by using the prostrate tester (DIK-7400, Daiki Rika Kogyo Co. Ltd., Tokyo, Japan) at the milk stage according to the method of Xiao *et al.* (2002). The internodes were numbered from top to bottom. The prostrate tester was set perpendicularly at the middle of the second inter-node of the plant. The stem strength was measured when the plant was pushed to an angle of 45 from the vertical, and estimated using the following formula:

$$\text{Stem strength (g stem}^{-1}) = [(\text{test reading} \div 40) \times (1000 \div \text{number of stems})].$$

Chain weight was measured as the chain weight, which balances with the bending strength of the stem (Cruz *et al.* 2005), and the unit was expressed as gram.

Lodging resistance factor index (LRFI) was calculated as given by Murphy *et al.* (1958):

$$\text{LRFI} = (\text{Chain weight / plant weight}) \times 100$$

Potassium was estimated by flamephotometeric method of Jackson (1962 a,b). Calcium, magnesium and silica were estimated by the method given by Piper (1950). Lignin, cellulose and hemi-cellulose were estimated by gravimetric method of Sadasivam and Manickam (1992). The data collected on different parameters were subjected to statistical analysis following the procedure described by Cochran and Cox (1957).

RESULTS

Stem strength

Among the genotypes, Raj-3765 recorded the highest stem strength at all the dates of sowing, followed by HD-2329 and Raj-4014, while C-306 recorded the lowest stem strength, preceded by RR-3 and HD-2913 (Fig. 1). The increases in stem strength in Raj-3765 were 13.84 and 27.18 %, whereas in case of C-306 the increases were 17.36 and 17.34 % under late and very late sowings, respectively, over the normal sowing.

Lodging resistance factor index (LRFI)

There was significant increase in LRFI with increasing dates of sowings (Fig. 2). HD-2329 recorded highest LRFI at all the dates of sowing, followed by Raj-3765 and Raj-4014, while C-306 recorded lowest LRFI. The increases in LRFI in HD-2329 were 5.44 and 25.90 %, whereas in case of C-306 the increases were 91.52 and 171.40 % under late and very late sowings, respectively, over the normal sowing.

Potassium content

The potassium contents varied significantly at different dates of sowing in different genotypes (Table 1). The potassium content increased significantly under late and very late dates of sowing over the normal sowing. Among the genotypes, HD-2329 recorded highest potassium content at all the dates of sowing

Table 1. Effect of dates of sowing on potassium content (mg g^{-1}), calcium content (mg g^{-1}), magnesium content (mg g^{-1}) and silica content (mg g^{-1}) in wheat genotypes at 80 DAS.

Genotypes	Potassium content (mg g^{-1})				Calcium content (mg g^{-1})				Magnesium content (mg g^{-1})				Silica content (mg g^{-1})			
	Dates of sowing			MEAN	Dates of sowing			MEAN	Dates of sowing			MEAN	Dates of sowing			MEAN
	I	II	III		I	II	III		I	II	III		I	II	III	
Tolerant genotypes																
HD-2329	32.64	34.09	34.63	**33.79**	4.84	5.05	5.13	**5.01**	1.27	1.33	1.35	**1.32**	41.30	43.14	43.82	**42.75**
Raj-4014	30.92	32.29	32.81	**32.01**	5.55	5.80	5.89	**5.75**	1.08	1.13	1.15	**1.12**	40.74	42.55	43.23	**42.17**
Raj-3765	31.24	32.63	33.15	**32.34**	5.19	5.42	5.50	**5.37**	1.11	1.16	1.18	**1.15**	42.21	44.09	44.79	**43.70**
MEAN	**31.60**	**33.00**	**33.53**		**5.19**	**5.42**	**5.51**		**1.15**	**1.21**	**1.23**		**41.42**	**43.26**	**43.95**	
Susceptible genotypes																
HD-2913	25.34	28.25	29.24	**27.61**	4.19	4.66	4.83	**4.56**	0.85	0.95	0.98	**0.93**	21.36	28.81	30.65	**26.94**
C-306	27.74	30.91	32.00	**30.22**	4.32	4.81	4.98	**4.70**	0.79	0.88	0.91	**0.86**	23.62	29.33	31.25	**28.07**
RR-3	25.99	28.97	29.99	**28.32**	4.41	4.91	5.09	**4.80**	0.88	0.98	1.02	**0.96**	22.03	30.05	32.41	**28.16**
MEAN	**29.35**	**31.45**	**32.19**		**4.81**	**5.15**	**5.28**		**1.02**	**1.09**	**1.12**		**33.24**	**37.32**	**38.59**	
TOTAL MEAN	**28.98**	**31.19**	**31.97**		**4.75**	**5.11**	**5.24**		**1.00**	**1.07**	**1.10**		**31.88**	**36.33**	**37.69**	
CD at 5%																
T			3.965				0.649					0.324			4.053	
G			5.607				0.918					0.459			5.732	
T*G			9.712				1.590					0.795			9.929	

followed by Raj-3765 and Raj-4014, while HD-2913 recorded the lowest potassium content preceded by RR-3 and C-306. The increases in potassium content in HD-2329 were 4.44 and 6.16 %, whereas in case of HD-2913 the increases were 11.56 and 15.41 % under late and very late sowings, respectively, over normal sowing.

Calcium content

The calcium (Ca^{2+}) content was significantly higher in lodging tolerant genotypes as compared to susceptible genotypes (Table 1). The results revealed the significant increase in Ca^{2+} content under late and very late sowings over normal sowing. Among the genotypes, Raj-4014 recorded highest Ca^{2+} content at all the dates of sowing, followed by Raj-3765 and HD-2329, while HD-2913 recorded the lowest calcium content, preceded by C-306 and RR-3. The increases in Ca^{2+} content in Raj-4014 were 4.52 and 6.07 %, whereas in case of HD-2913 the values were 11.22 and 15.28 % under late and very late sowings, respectively, over normal sowing.

Magnesium content

The Mg^{2+} content varied significantly at different dates of sowing in various genotypes (Table 1). Among the genotypes, HD-2329 recorded highest Mg^{2+} content at all the dates of sowing, followed by Raj-3765 and Raj-4014, while C-306 recorded the lowest Mg^{2+}, preceded by HD-2913 and RR-3. The increases in Mg^{2+} content in HD-2329 were 4.68 and 6.34 %, whereas in case of C-306 the values were 11.38 and 15.18 % under late and very late sowings, respectively, over normal sowing.

Silica content

The data shows that silica content varied significantly at different dates of sowing among the various genotypes

(Table 1). Among the genotypes, Raj-3765 recorded the highest silica content at all the dates of sowing, followed by HD-2329 and Raj-4014, while HD-2913, recorded the lowest silica content, preceded by RR-3 and C-306. The increases in silica content in Raj-3765 were 4.48 and 6.18 %, whereas in case of HD-2913 the increases were 34.85 and 43.47 % under late and very late sowings, respectively, over normal sowing.

Lignin content

The data revealed that lignin content varied significantly at different dates of sowing among various genotypes (Table 2). Among the genotypes, Raj-3765 recorded the highest lignin content at all the dates of sowing, followed by HD-2329 and Raj-4014, while HD-2913 recorded the lowest lignin content, preceded by C-306 and RR-3. The increases in lignin content in Raj-3765 were 4.46 and 6.06 % under late and very late sowings, respectively, over normal sowing.

Cellulose content

Among the genotypes, HD-2329 recorded the highest cellulose content at all the different dates of sowing, followed by Raj-3765 and Raj-4014, while C-306 recorded the lowest cellulose content, preceded by RR-3 and HD-2913 (Table 2). The increases in cellulose content in HD-2329 were 4.55 and 6.08 %, whereas in case of C-306 the increases were 11.54 and 15.47 % under late and very late sowings, respectively, over normal sowing.

Hemi-cellulose content

Among the various genotypes, HD-2329 recorded the highest hemi-cellulose content at all the dates of

Table 2. Effect of dates of sowing on lignin (mg g^{-1}), cellulose (mg g^{-1}) and hemi-cellulose (mg g^{-1}) in lodging tolerant and susceptible wheat genotypes at 80 DAS.

Genotypes	Lignin (mg g^{-1})				Cellulose (mg g^{-1})				Hemi-cellulose (mg g^{-1})			
	Dates of sowing			MEAN	Dates of sowing			MEAN	Dates of sowing			MEAN
	I	II	III		I	II	III		I	II	III	
Tolerant genotypes												
HD-2329	78.33	81.82	83.12	**81.09**	306.92	320.61	325.70	**317.74**	158.01	165.06	167.68	**163.58**
Raj-4014	77.55	81.01	82.29	**80.28**	297.68	310.95	315.89	**308.17**	150.34	157.04	159.54	**155.64**
Raj-3765	79.25	82.78	84.10	**82.04**	300.38	313.78	318.76	**310.97**	146.24	152.76	155.19	**151.40**
MEAN	**78.38**	**81.87**	**83.17**		**301.66**	**315.11**	**320.12**		**151.53**	**158.29**	**160.80**	
Susceptible genotypes												
HD-2913	59.59	66.42	68.76	**64.92**	300.13	334.53	346.29	**326.98**	92.96	123.62	130.26	**115.61**
C-306	60.92	67.91	70.29	**66.37**	295.5	329.36	340.95	**321.94**	100.59	132.12	135.06	**122.59**
RR-3	61.77	68.85	71.27	**67.30**	297.83	331.96	343.64	**324.48**	87.71	117.76	131.20	**112.22**
MEAN	**60.76**	**67.73**	**70.11**		**297.82**	**331.95**	**343.63**		**93.75**	**124.50**	**132.17**	
TOTAL MEAN	**69.57**	**74.80**	**76.64**		**299.74**	**323.53**	**331.87**		**122.64**	**141.39**	**146.49**	
CD at 5%												
T			5.400				5.557				4.618	
G			7.637				7.859				6.530	
T*G			13.228				13.612				11.311	

sowing, followed by Raj-4014 and Raj-3765, while RR-3 recorded the lowest hemi-cellulose content, preceded by HD-2913 and C-306 (Table 2). The increases in hemi-cellulose content in HD-2329 were 4.39 and 6.05 %, whereas in case of RR-3 the increases were 34.28 and 49.63 % under late and very late sowings, respectively, over normal sowing.

Grain yield

The grain yield showed significant reductions under late and very late sowings over normal sowing (Table 3). Among the genotypes, Raj-4014 recorded the highest grain yield at all the dates of sowing, followed by HD-2329 and Raj-3765, while HD-2913 recorded the lowest grain yield, preceded by RR-3 and C-306. The reductions in grain yield in Raj-4014 were 16.48 and 58.26 %, whereas in case of HD-2913, the reductions in grain yield were 17.24 and 26.56 % under late and very late sowings, respectively, over normal sowing.

Harvest index

The data showed significant increase under late and very late sowings over normal sowing (Table 3). Among the genotypes, HD-2329 recorded the highest HI at all the dates of sowing, followed by Raj-3765 and Raj-4014, whereas HD-2913 recorded the lowest HI, preceded by RR-3 and C-306. The increases in HI in HD-2329 were 1.04 and 4.24 %, whereas in case of HD-2913, the increases were 1.92 and 10.25% under late and very late sowings, respectively, over normal sowing.

DISCUSSION

The present study showed that potassium, calcium, magnesium, silica, lignin and hemi-cellulose were significantly higher in lodging tolerant genotypes as compared to lodging susceptible genotypes under all the dates of sowing, while cellulose content were higher only under normal sowing. Many researchers suggested that

Table 3. Effect of dates of sowing on grain yield and harvest index in lodging tolerant and susceptible wheat genotypes at harvest.

GENOTYPES	Grain yield (g m^{-2})				Harvest index (%)			
	Dates of sowing			MEAN	Dates of sowing			MEAN
	I	II	III		I	II	III	
Tolerant genotypes								
HD-2329	300.25	239.33	114.67	**218.08**	42.50	42.95	44.29	**43.25**
Raj-4014	312.64	261.21	130.44	**234.76**	40.83	41.34	43.27	**41.81**
Raj-3765	278.16	247.56	121.62	**215.78**	41.78	42.23	44.36	**42.79**
MEAN	**297.02**	**249.37**	**122.24**		**41.70**	**42.17**	**43.97**	
Susceptible genotypes								
HD-2913	135.66	112.36	99.63	**115.88**	28.32	28.74	31.11	**29.39**
C-306	153.78	116.24	93.65	**121.22**	30.46	32.33	33.90	**32.23**
RR-3	141.11	112.98	100.48	**118.19**	29.81	31.26	33.10	**31.39**
MEAN	**143.52**	**113.86**	**97.92**		**29.53**	**30.77**	**32.70**	
Total mean	**220.27**	**181.61**	**110.08**		**35.62**	**36.47**	**38.34**	
CD at 5%								
Treatments (T)			3.966				0.725	
Genotypes (G)			7.343				1.938	
T*G			12.718				3.357	

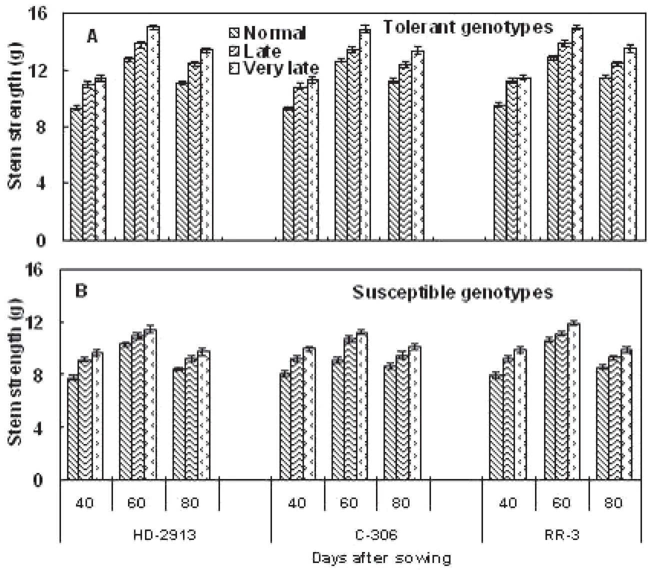

Fig. 1. Effect of dates of sowing on stem strength (g) in lodging tolerant and susceptible wheat genotypes at different growth stages

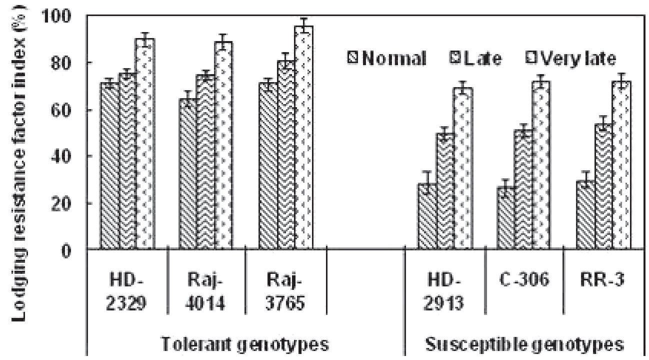

Fig. 2. Effect of dates of sowing on lodging resistance factor index (LRFI) (%) in lodging tolerant and susceptible wheat genotypes at 80 DAS

potassium, calcium, magnesium, silica, lignin, cellulose and hemi-cellulose are having major role in enhancing the stiffness of the stem against lodging (Li 1998, Taylor *et al.* 1999, Yang *et al.* 2001). Similar reports have been reported by Tanaka *et al.* (2003) and Takahashi (1995). Interestingly increase in lodging resistance was also observed in susceptible genotypes under late sown conditions as compared to the normal date of sowing due to increase in content of potassium, calcium, silica, lignin and hemi-cellulose.

Lodging tolerant genotypes showed significantly higher stem strength and lodging resistance factor index as compared to the susceptible one under normal sown condition. Lodging susceptible genotypes also showed increases in stem strength and LRFI under late sown conditions as compared to normal sown condition. Huang (1988) suggested that LRFI reflected the ability of plant to resist against lodging, i.e. higher the index value higher will be the lodging resistance.

Results on grain yield and harvest index indicate that the lodging tolerant genotypes exhibit significantly higher values over lodging susceptible genotypes. Jedel and Helm (1991) and Easson *et al*. (1993) also reported the similar results. Though there was reduction in grain yield under late sown conditions as compared to the normal sowing, harvest index recorded slight increase under late sowings. The present data indicate that the reduction in yield due to late sowing was significantly greater than the reduction in yield due to lodging under normal sown condition. It is thus evident that the increase in various cell wall components, mineral contents, and higher LRFI under late sown condition could not compensate the loss in yield due to late sowing. The increase in HI under late sown conditions was due to reduction in biomass and not due to increase in grain yield.

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