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EFFECT OF MOISTURE CONTENT AND INTERNODE POSITION ON CUTTING BEHAVIOUR OF PADDY STRAW

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SUMMARY

The mechanical characteristics of paddy straw were evaluated in terms of shear and tensile strength with respect to variety, moisture content and inter node position. The parameters were determined for two varieties (PB - 1121 and HB - 2) at three levels of moisture content (20, 35 and 50% (*wb*)) and five internode positions (IN1, IN2, IN3, IN4 and IN5). The results showed that shear strength decreased with increase in moisture content, whereas tensile strength increased with an increase in moisture content. The shear and tensile strength both increased from first internode to fifth internode in both the varieties. The shear and tensile strength of PB-1121 was significantly higher (9 %) than HB-2 at each internode and all levels of moisture content. The paddy varieties contained carbon, oxygen, aluminium, silicon and other elements as confirmed by Energy Dispersive Spectroscopy (EDS). The presence of more silicon in PB-1121 variety provided a strong reason for better mechanical properties as compared to variety HB-2.

Key words : Internode position, moisture content, paddy, shear strength, tensile strength

Rice-wheat cropping system is the major cropping system in North-Western Indian plains covering 4.1 million ha area and is the backbone of country's food security (Singh *et al*., 2018). In this system more than 75 % area is combine harvested and increasing continuously due to shortage of farm labour (Ingole *et al*., 2019a, Kumar *et al*., 2020). After combine harvesting, leftover straw is collected by using balers (Thakur *et al*., 2000, Kumar, *et al*., 2020b), straw combines (Kumar *et al*., 2010, Ujala *et al*., 2020) and is normally used as animal feed (Shrivastava *et al*., 2012, Kumar *et al*., 2014). The straw can also be managed by using head feed combines (Ingole *et al*., 2019, Kumar *et al*., 2020a). Due to mechanized harvesting of rice and wheat and use of straw for animal fodder the need of engineering data on stem properties have been prompted (Yore *et al*., 2002). The difference in physical properties of plant straws and the resistance of cutting equipment have to be known in order to know the behaviour of material. The mechanical properties of wheat and rice straw are important in the design of farm machinery and to analysis the behaviour of straw during harvesting and threshing (Kumar *et al*., 2020). The studies on mechanical properties of straw were mostly carried out during their growth stage using failure criteria (stress, force and energy) or their modulus of rigidity and Young's modulus. These studies were mainly focused on lodging processes, harvest optimization, industrial applications, animal nutrition and decomposition of straw in the soil (Annoussamy *et al*., 2000). The important properties of plants such as cutting, compression, shearing, tension, friction and bending depend on the variety, stem diameter, stem thickness, moisture content, maturity and structure (Bright and Kleis, 1964, Persson, 1987). The cutting force of rice stem increased with an increase in cross sectional area and decreased with an increase in moisture content (Koloor and Borgheie, 2006, Kumar *et al*., 2022). Zareiforoush *et al*. (2010) found that internode position had a significant effect on shear strength, shearing energy and Young's modulus, and did not have any significant impact on the bending strength in rice crop. The bending strength was affected only by the loading rate. The shear strength, shear energy, bending strength and Young's modulus varied from 8.45 to 20.22 MPa, 101.31 to 256.02 MJ, 6.70 to 9.81 MPa and 0.21 to 1.38 GPa, respectively. Alizadeh *et al*. (2011) reported that cutting energy was significantly ($P<0.01$) affected by internode position and dimensional characteristics of rice stem. They observed a highly significant and positive correlation between the cutting energy and stem wall thickness, major and minor diameters and cross-sectional area of rice stem. They also found that cutting energy of rice stem in the second internode was reduced by 32.5 % as compared to third internode position. Chandio *et al.* (2013) concluded that shear strength, cutting force and specific shearing energy of wheat and rice straw increased significantly with increased loading rate. The rice straw has significantly ($p<0.05$) higher shear strength, cutting force and specific shearing energy as compared to wheat straw. Muzamil (2016) observed that diameter and X-sectional area increased from the first internode to second and third internode in both paddy and wheat straw at all levels of moisture content. Therefore, a lot of work has been done on mechanical properties of wheat straw but even today no one has validated their results with morphological studies. The morphological analysis has been proved to be a crucial aspect to study the mechanism of the materials performance (Jakhar *et al.*, 2022, Antil *et al.*, 2022, Kharb *et al.*, 2020, Antil *et al.* 2020). This study was conducted to observe the mechanical properties of paddy straw and their validation with morphological studies, which will be helpful in proper designing of machinery and to study the behaviour of the straw during harvesting and threshing process.

MATERIALS AND METHODS

Materials selection

The most prominent paddy variety of Haryana State (PB-1121) and new variety of CCS HAU Hisar (HB-2) were selected to study the cutting behaviour of paddy straw. The straw samples were collected from farmer's field during harvesting season of 2019-20. The experiments were conducted in the laboratory

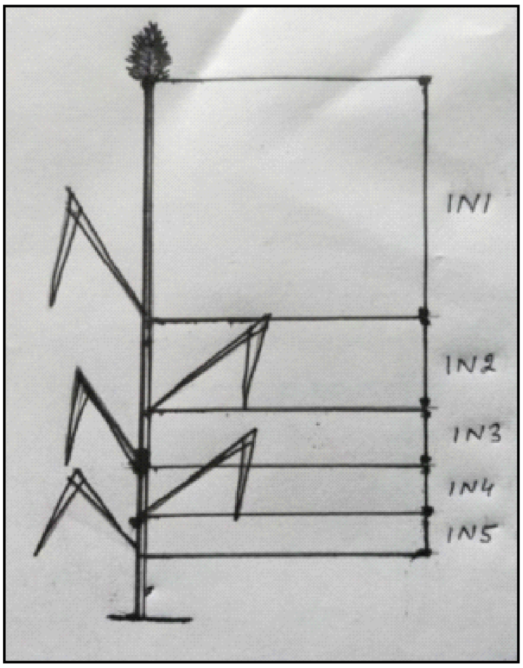

Fig. 1. Internodes position.

of Department of FMPE, CCS HAU, Hisar, Deptt. of Mechanical Engineering, IIT, Delhi and Deptt. of PFE, PAU, Ludhiana during the year 2019-20.

Straw internode preparation

The paddy stems were cut manually from ground level and samples were selected randomly. The internodes were separated according to their position down from the ear head (Annoussamy *et al.*, 2000, Yore *et al.*, 2002, Chandio *et al.*, 2013, Kumar *et al.*, 2020). The leaf blades and sheaths were removed prior to any measurement or observation. Five internodes of paddy stem, namely, first, second, third, forth and fifth internodes were studied (Fig. 1 and 2). The sixth

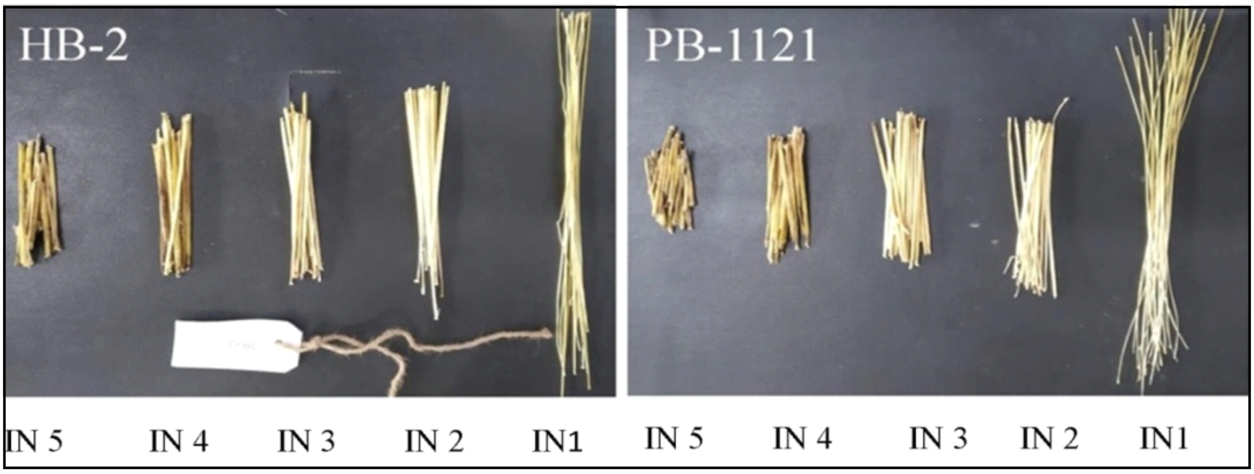

Fig. 2. Paddy varieties with variable internodes.

and other stem internodes were not considered because these internodes are usually left on the field.

Mechanical properties of paddy straw

Five samples of two varieties of paddy straw were tested for shear and tensile strength by using a texture analyzer from Stable Micro Systems, United Kingdom.

Shear strength

The shear strength of paddy straw was measured by using universal testing machine for texture analyzer (TA.XT.*plus* C). All the force displacement curves were recorded by computer data acquisition system during the process of cutting.

Tensile strength

The tensile strength of the straw was measured with the help of texture analyzer (TA.HD.*plus* C). The samples were tested at 2 KN load cell and cross head speed of 2 mm sec^{-1}. The load span was taken as one-third of the total span with span to depth ratio of 16:1. All the force displacement curves were recorded by computer data acquisition system during the process of tension.

Independent variables

The moisture content (20, 35 and 50%) and internode position (IN1, IN2, IN3, IN4 and IN5) were selected as independent parameters to study the mechanical properties of paddy straw. The moisture content was denoted by MC, internode position by IN and variety by V.

Morphological analysis of paddy straw

The morphological analysis of five samples each of two varieties of paddy straw was done with the Field Emission Scanning Electron Microscopic (FESEM) machine (JEOL JSM - 7800F) and elements characterization present in the paddy straw was done with Energy Dispersive Spectroscopy (EDS).

RESULTS AND DISCUSSION

Morphological inspection of Paddy straw

The morphological analysis of the paddy straw was done using Field Emission Scanning Electron Microscope (FESEM). The test specimen was cut from the centre of the straw and tested for the possible moisture and detecting the constituting elements. The observed images indicated that the moisture was mostly present in the inner layer of the straw in both the varieties (Fig. 3 & 6). whereas, the outer layer of the straw showed the absence of moisture, which meant that the straw showed dual behaviour during the harvesting process (Fig. 3 & 6). The outer layer of the straw showed brittle fracture, whereas, due to presence of moisture over the inner layer, the elasticity of the straw increased. This increase in elasticity turned brittle fracture behaviour into ductile fracture. The elements present in the straw of both the varieties are shown in Fig. 4 & 7. The EDS mapping analysis (Fig. 5 & 8) showed the spatial distribution of elements present in the straw. Different colour maps showed the presence of variable elements over the same area. The PB - 1121 variety straw contained carbon, oxygen, aluminium, silicon and other elements as confirmed by Energy Dispersive Spectroscopy (EDS). The presence of silicon in the variety of PB - 1121 provided a strong reason for better mechanical properties as compared to variety HB - 2.

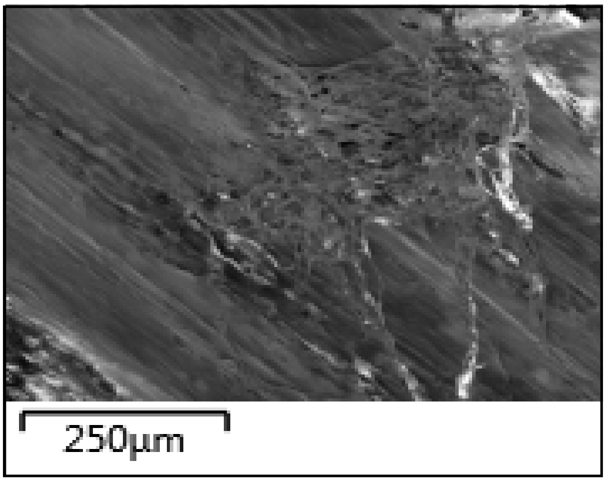

Fig. 3. FE-SEM image of PB - 1121 paddy straw.

Effect of variety, moisture content and internode position on shear strength of paddy straw

The effect of variety, moisture content and internode position on shear strength of paddy straw was significant; however, interaction of combined effect of variables was non-significant. The F - value for the internode position was highest (2991.71) indicating that it had a maximum effect on shear strength (Table 1). The effects of variety, moisture content and internode position on shear strength are

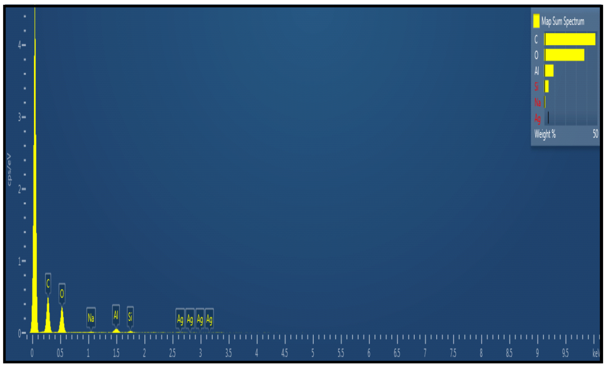

Fig. 4. Energy Dispersive Spectroscopy of PB - 1121 paddy straw.

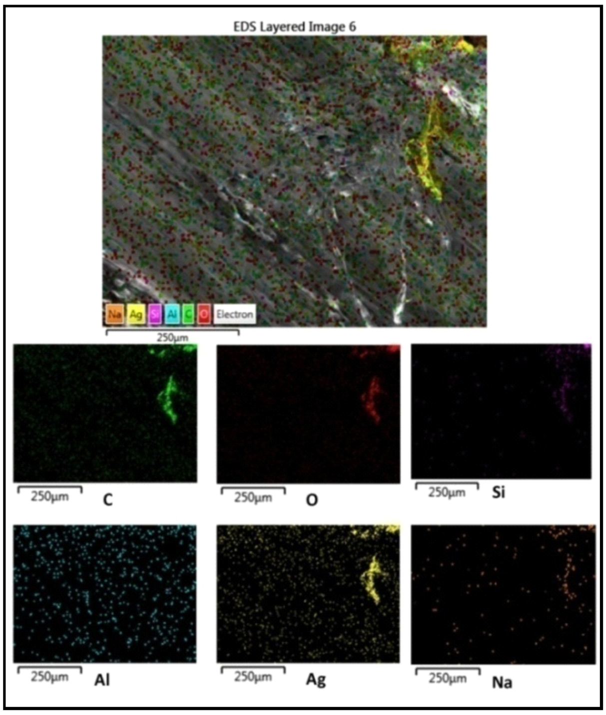

Fig. 5. Mapping analysis of PB - 1121 paddy straw.

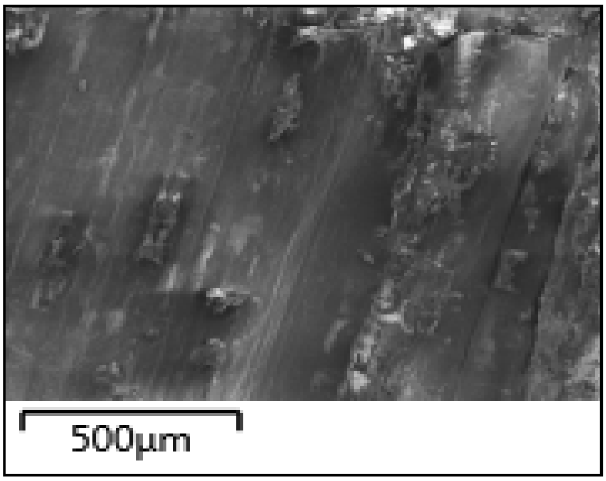

Fig. 6. FE-SEM image of HB - 2 paddy straw.

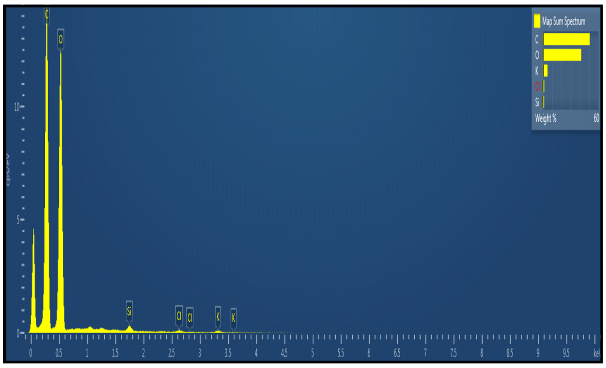

Fig. 7. Energy Dispersive Spectroscopy of HB - 2 paddy straw.

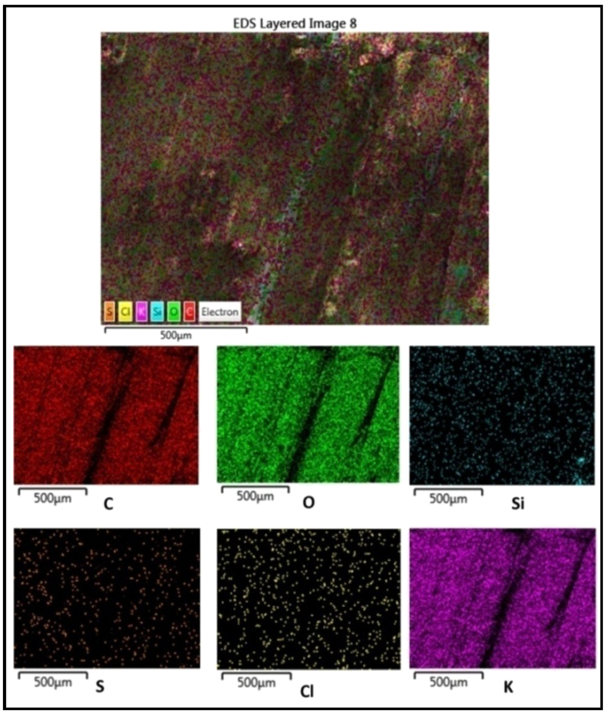

Fig. 8. Mapping analysis of HB - 2 paddy straw.

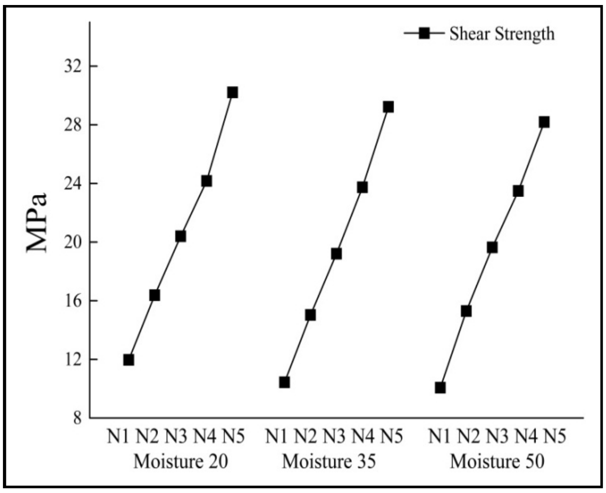

Fig. 9. Effect of moisture content (%) on shear strength (MPa) in paddy variety PB - 1121straw.

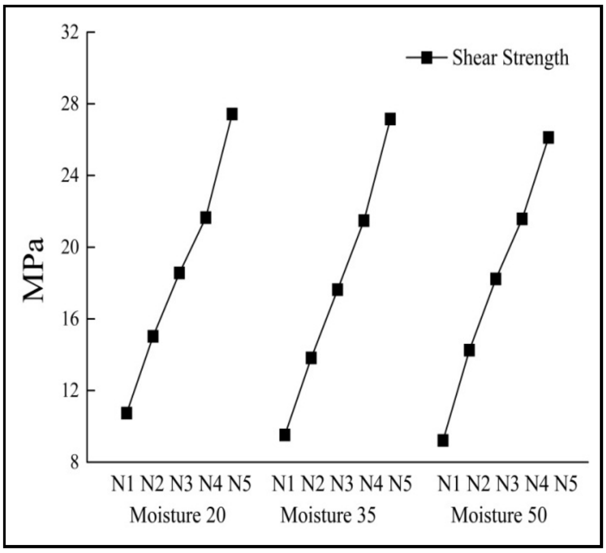

Fig. 10. Effect of moisture content (%) on shear strength (MPa) in paddy variety HB - 2 straw.

presented in Table 2. The variety V2 (HB - 2) has lower shear strength as compared to V1 (PB - 1121) at all levels of moisture content and internode position. The shear strength was maximum at fifth internode position and lower moisture content and decreased towards first internode position and increased moisture content in both the varieties. It decreased from 27.43 MPa at IN5 to 9.21 MPa at IN1 in variety V2 and 30.21MPa at IN5 to 10.07 MPa at IN1 in variety V1 as the straw moisture content increased from 20 to 50 %. The overall shear strength of V2 (18.16 MPa) was significantly lower than V1 (19.83 MPa). The average shear strength significantly decreased from 19.65 to 18.61 MPa as the moisture content increased from 20 to 50 %. The average shear strength increased significantly from 10.32 to 28.06 MPa from the first internode to the fifth internode position. The two way interaction effect of variety, moisture content and internode position are presented in Table 3. The interaction effects of moisture content - internode position and variety - internode position were significant, however, the interaction effect of variety - moisture content was non-significant.

TABLE 1

ANNOVA for effect of variety, moisture content and internode position on shear strength of paddy straw

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
V	1	104.895	104.895	223.551	0.0001
MC	2	32.666	16.333	34.809	0.0001
V x MC	2	1.562	0.781	1.665	0.19355
IN	4	5,615.10	1,403.78	2,991.71	0.0001
V x IN	4	10.503	2.626	5.596	0.00036
MC x IN	8	12.927	1.616	3.444	0.00133
V x MC x IN	8	0.278	0.035	0.074	0.99972
Error	120	56.307	0.469		
Total	149	5,834.24			

Effect of variety, moisture content and internode position on tensile strength of paddy straw

The effect of variety, moisture content and internode position on tensile strength of paddy straw was significant; however, the combined effect of variables was non-significant. The F - value for internode position was highest (266.411), indicating that it had a maximum effect on tensile strength (Table 4). The effects of variety, moisture content and internode position on tensile strength are presented in Table 5. The variety V1 (PB - 1121) has higher tensile strength as compared to V2 (HB - 2) at all levels of moisture content and internode position. The tensile strength was minimum at first internode and lower moisture content and increased towards the fifth internode position and increased moisture content in both the varieties. It increased from 126.32 MPa at IN1 to 181.68 MPa at IN5 in variety V1 and 117.42

TABLE 2

Effect of variety, moisture content and internode position on shear strength of paddy straw

Variety / Internode \ MC (%)	V1			V2			Overall mean (IN)
	MC1	MC2	MC3	MC1	MC2	MC3	
IN1	11.96	10.44	10.07	10.74	9.52	9.21	10.32
IN2	16.38	15.03	15.30	15.02	13.82	14.25	14.96
IN3	20.40	19.21	19.64	18.56	17.63	18.23	18.95
IN4	24.17	23.74	23.49	21.65	21.48	21.58	22.69
IN5	30.21	29.23	28.19	27.43	27.15	26.12	28.06
Overall mean (V)		19.83				18.16	
Overall mean (MC)	19.65			18.73		18.61	
CD (P = 0.05)	V = 0.22		MC = 0.27		IN = 0.35		V x MC x IN = NS

TABLE 3
Two way interaction effect of variety, moisture content and internode position on shear strength of paddy straw

	MC1	MC2	MC3		V1	V2		V1	V2
IN1	11.35	9.98	9.64	IN1	10.82	9.82	MC1	20.63	18.68
IN2	15.70	14.42	14.78	IN2	15.57	14.36	MC2	19.53	17.92
IN3	19.48	18.42	18.93	IN3	19.75	18.14	MC3	19.34	17.88
IN4	22.91	22.61	22.54	IN4	23.80	21.57	-	-	-
IN5	28.82	28.19	27.15	IN5	29.21	26.90	-	-	-
Interaction	MC x IN =0.61			Interaction	V x IN = 0.50		Interaction	V x MC = NS	

MPa at IN1 to 164.15 MPa at IN5 in variety V2 as the straw moisture content increased from 20 to 50 %. The overall tensile strength of V1 (156.09 MPa) was significantly higher thanV2 (143.11 MPa). The average tensile strength increased significantly from 142.35 to 156.69 MPa as the moisture content increased from 20 to 50 %. The average tensile strength increased significantly from 129.58 to 166.31 MPa from the first internode to the fifth internode position. The two way interaction between variety, moisture content and internode position are presented in Table 6. The interaction effect of variety - internode position was significant, however, the interaction effects of variety - moisture content and moisture content - internode position were non-significant.

Comparative analysis of mechanical properties of paddy varieties

The shear strength and tensile strength of paddy straw was significantly influenced by variety, moisture content and internode position (Table 1 & 4). The shear strength and tensile strength increased from internode 1 to internode 5 at all levels of moisture content in both the varieties (Table 2 & 5). It might be due to higher stem diameter and stem thickness. The increase in shear strength from internode 1 to internode 5 might also be due to more accumulation of mature fiber towards lower portion of stem (Ince *et al*., 2005). The comparative analysis of moisture content showed that shear strength in both varieties decreased with increase in moisture content (Fig. 9 & 10) whereas the tensile strength increased with increase in moisture content (Fig. 11 & 12). Similar to wheat crop, the tensile strength increased with increase in moisture content because of increase in ductility of the straws. The straw having comparatively low moisture content exhibits brittle deformation phenomenon which turned towards ductile with increase in moisture content. Usrey *et al*. (1992) also observed that tensile strength

TABLE 4
ANOVA for the effect of variety, moisture content and internode position on tensile strength of paddy straw

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
V	1	6,320.96	6,320.96	259.099	0.0001
MC	2	5,145.22	2,572.61	105.453	0.0001
V x MC	2	28.163	14.082	0.577	0.56301
IN	4	25,997.39	6,499.35	266.411	0.0001
V x IN	4	242.066	60.516	2.481	0.04749
MC x IN	8	81.341	10.168	0.417	0.90903
V x MC x IN	8	22.683	2.835	0.116	0.99855
Error	120	2,927.51	24.396		
Total	149	40,765.34			

TABLE 5
Effect of variety, moisture content and internode position on tensile strength of paddy straw

Variety / Internode \ MC (%)	V1			V2			Overall mean (IN)
	MC1	MC2	MC3	MC1	MC2	MC3	
IN1	126.32	134.75	141.38	117.42	125.95	131.63	129.58
IN2	139.14	147.78	154.50	126.49	137.20	143.76	141.48
IN3	150.07	157.50	165.10	135.96	143.75	148.04	150.07
IN4	160.23	165.37	175.85	147.11	154.11	160.75	160.57
IN5	168.51	173.18	181.68	152.16	158.16	164.15	166.31
Overall mean (V)		156.09			143.11		
Overall mean (MC)	142.35			149.78			156.69
CD (P = 0.05)	V = 1.60		MC = 1.96		IN = 2.53		V x MC x IN = NS

TABLE 6

Two way interaction effect of variety, moisture content and internode position on tensile strength of paddy straw

	MC1	MC2	MC3		V1	V2		V1	V2
IN1	121.87	130.35	136.51	IN1	134.15	125.00	MC1	148.86	135.83
IN2	132.82	142.49	149.13	IN2	147.14	135.82	MC2	155.72	143.83
IN3	143.02	150.63	156.57	IN3	157.56	142.59	MC3	163.70	149.67
IN4	153.67	159.74	168.30	IN4	167.15	153.99	-	-	-
IN5	160.34	165.67	172.91	IN5	174.46	158.16	-	-	-
Interaction	MC x IN = NS			Interaction	V x IN = 3.57		Interaction	V x MC = NS	

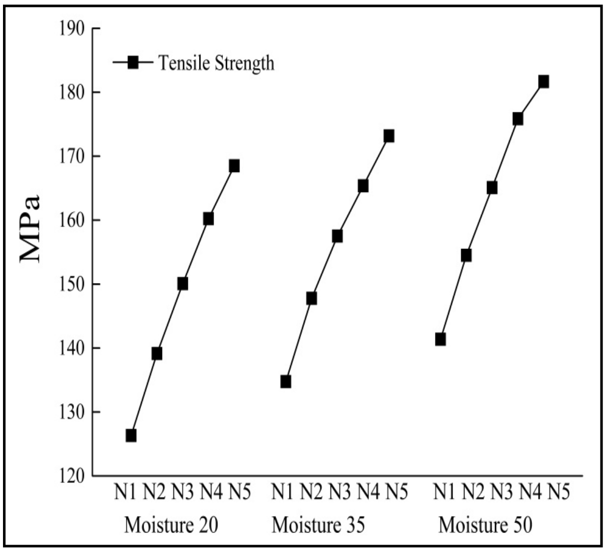

Fig. 11. Effect of moisture content (%) on tensile strength (%) in paddy variety PB - 1121 straw.

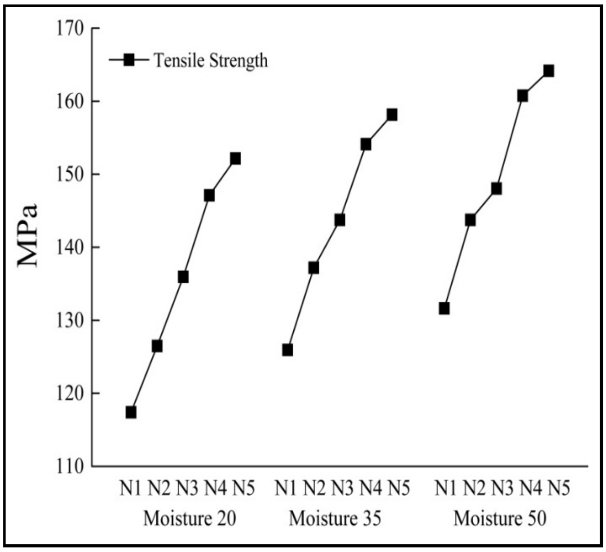

Fig. 12. Effect of moisture content (%) on tensile strength (%) in paddy variety HB - 2 straw.

increased with increase in moisture content in paddy crop. Koloor *et al*. (2006) reported that shear strength decreased with increase in moisture content of rice straw. Also, the morphological analysis showed that PB - 1121variety had higher silicon content as compared to HB - 2. The higher percentage of the silicon increased the resistance to deformation in tension which makes PB - 1121 harder to cut as compared to HB - 2. Balesta *et al*. (1989) also revealed that reduction of silica content decreased stem hardness.

CONCLUSION

The shear strength decreased with increase in moisture content whereas the tensile strength increased with increase in moisture content in both PB - 1121 and HB - 2 paddy varieties. The morphological analysis showed that PB - 1121variety had higher silicon content as compared to HB - 2 which improved the tensile and shear strength of PB - 1121. The study will be helpful for breeders and biotechnology scientists for developing new varieties having resistance to lodging as it is a very serious problem in rice wheat cropping system of Indo-Gangetic Plains of India.

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