Forage Res., **48**(1) : pp. 118-124 (2022) **http://forageresearch.in**

CUTTING FORCE REQUIREMENT OF WHEAT STRAW FOR USE AS ANIMAL FODDER

ANIL KUMAR[1]*, VIJAYA RANI[1], SANDEEP KUMAR ANTIL[2] AND AJAY CHILLAR[3]

[1]Department of FMPE, CCS Haryana Agricultural University, Hisar-125004 (Haryana), India
[2]KVK, Sonipat-131001 (Haryana), CCS HAU
[3]Department of Mechanical Engineering, DSEU, New Delhi
(e-mail : anilsaroha@hau.ac.in)

(Received : 16 April 2021; Accepted : 10 June 2022)

SUMMARY

The mechanical characteristics of wheat 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 (WH - 1105 and HD - 2967) at three levels of moisture content (5, 10 and 15% (*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 strength of WH - 1105 was significantly higher (30 %) than HD - 2967 at each internode and all levels of moisture content. Similarly, the tensile strength of WH - 1105 variety was 10 % higher than HD - 2967 variety. The presence of carbon and oxygen as key elements in both the varieties was confirmed by the Energy Dispersive Spectroscopy (EDS). The WH - 1105 wheat straw contains higher carbon content as compared to HD - 2967 which provided a strong reason for better mechanical properties.

Key words : Wheat straw, cutting force requirement, animal fodder

The rice-wheat cropping system is pre dominant in North-Western Indian plains of Punjab, Haryana, Western Uttar Pradesh and Uttarakhand covering 4.1 million ha area and is the backbone of country's food security (Singh *et al*., 2018). In these plains around 75 % area is combine harvested and increasing continuously due to shortage of agricultural labour. After combine harvesting, leftover straw of wheat is collected by using straw combines (Kumar *et al*., 2010) and balers (Thakur, *et al*., 2000) and is normally used as animal feed (Shrivastava *et al*., 2012). 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. 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 plant anatomy, lodging processes, harvest optimization, industrial applications, animal nutrition and decomposition of straw in the soil (Annoussamy *et al*., 2000). The important properties of cellular materials 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). Kushwaha *et al*. (1983) observed that moisture content of 8-10% was optimum for cutting the wheat straw into pieces and corresponding shear strength varied from 7-11 MPa. O'Dogherty *et al*. (1995) observed that stem diameter and wall cross-sectional area increased from first to fourth internode in wheat crop. The tensile strength, shear strength, Young's modulus and rigidity modulus varied from 21.2 to 31.2 MPa, 4.91 to 7.26 MPa, 4.76 to 6.58 GPa and 267 to 547 MPa, respectively. Tavakoli *et al*. (2009) concluded that physical properties increased with increased moisture content in wheat crop. The shear strength varied from 6.81-10.78, 7.02-11.49, and 7.12-11.78 MPa for the first, second and third internode positions, respectively. They observed maximum specific shearing energy of 36.26 MJ mm^{-2} at a moisture content of 22.6 % (*w.b*.) at third internode position. The bending strength and Young's modulus increased with decreased moisture content and towards 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. Ahmed *et al*. (2015) observed that the tensile strength of wheat straw was significantly ($P<0.05$) affected by moisture content, internode positions and loading rate. The highest tensile strength of 30.61MPa was observed at 22.8 % moisture content, third internode and 30 mm min^{-1} loading rate, whereas, the lowest 19.20 MPa was obtained at 9.5 % moisture content, first internode and 10 mm min^{-1} loading rate. 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. This study was conducted to observe the mechanical properties of wheat 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 prevalent wheat varieties (WH - 1105 and HD - 2967) of Haryana State were selected for this study. The straw samples were collected during harvesting period from farmer's field which was located at longitude of 75.64 and latitude of 29.15. The experiments were conducted in the laboratory of Department of FMPE, CCS HAU, Hisar, Deptt. of Mechanical Engineering, IIT, Delhi and Deptt. of PFE, PAU, Ludhiana during the year 2019.

Straw internode preparation

The wheat 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 wheat stem, namely, first, second, third, forth and fifth internodes were studied (Fig. 1 and 2). The sixth and other stem internodes were not considered because these internodes are usually left on the field.

Mechanical properties of wheat straw

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

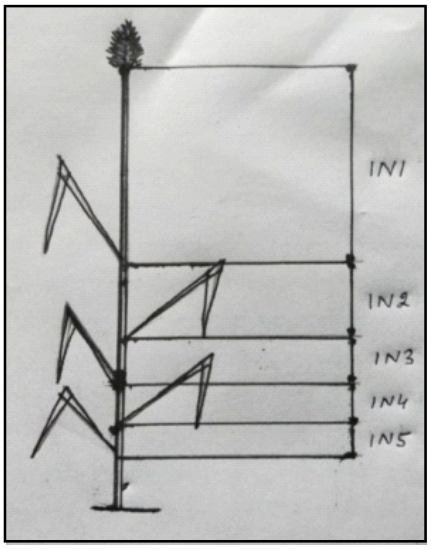

Fig. 1. Internodes position.

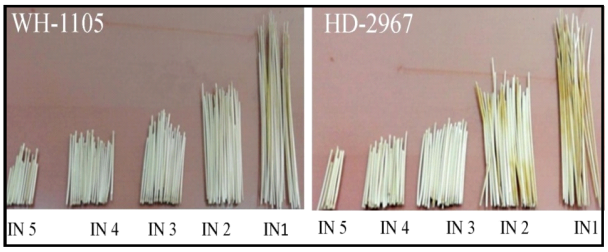

Fig. 2. Wheat varieties with variable internodes.

Shear strength

The shear strength of wheat 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.

Morphological analysis of wheat straw

The morphological analysis of five samples

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

RESULTS AND DISCUSSION

Morphological inspection of wheat straw

The morphological analysis of the wheat 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 presence of the moisture is visible over the straw surface (Fig. 3 & 6). The observed images indicated that the moisture was mostly present in the inner layer of the straw, 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 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 presence of carbon and oxygen as key elements in both the varieties was confirmed by the Energy Dispersive Spectroscopy (EDS). The WH - 1105 wheat straw contains 56.6 % carbon and 43.4 % oxygen as compared to 55.6 % carbon and 44.4 % oxygen in HD - 2967 variety. The presence of higher carbon content in the variety WH - 1105 provided a strong reason for better mechanical properties as compared to variety HD - 2967 (Fig. 4 & 7).

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

The effects of variety, moisture content and internode position on shear strength are presented in Table 1 and Fig. 9 - 10. The effect of variety, moisture content and internode position on shear strength of wheat straw was significant; however, the interaction of variety - moisture content - internode position was non-significant. The variety V1 (WH - 1105) has higher shear strength as compared to V2 (HD - 2967) at all levels of moisture content and internode position. The shear strength was maximum at fifth internode and lower moisture content and decreased towards first internode position and increased moisture content in both the varieties. It decreased from 34.13 MPa at IN5 to 9.60 MPa at IN1 in variety V1 and 21.45 MPa at IN5 to 9.47 MPa at IN1 in variety V2 as the straw moisture content increased from 5 to 15 %. The overall

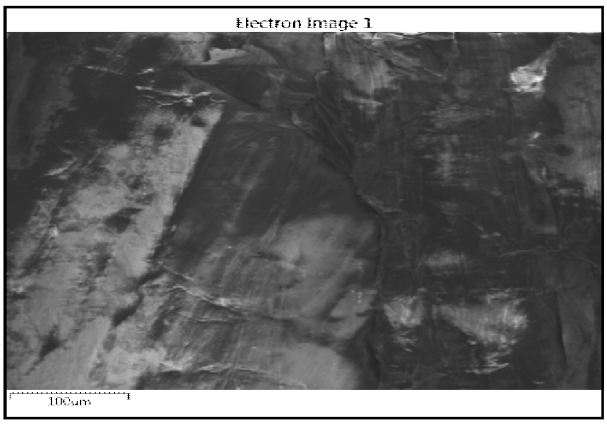

Fig. 3. FE-SEM image of WH - 1105 wheat straw.

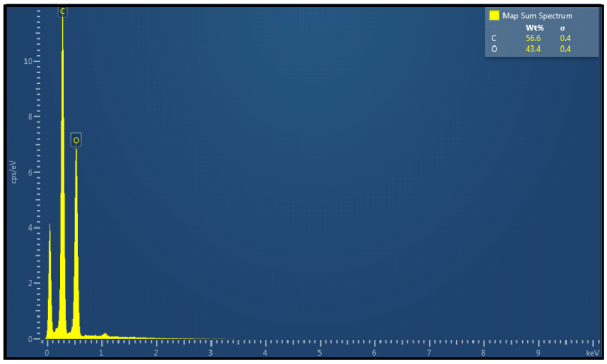

Fig. 4. Energy Dispersive Spectroscopy of WH - 1105 wheat straw.

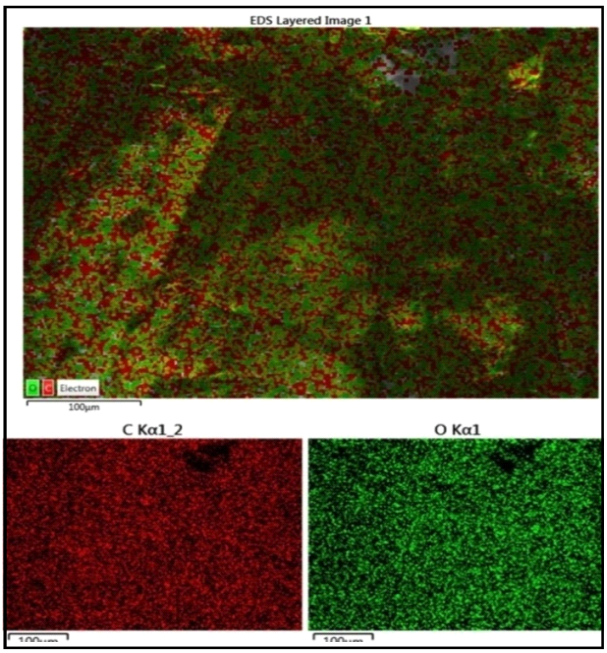

Fig. 5. EDS mapping analysis of elements in WH - 1105 wheat straw.

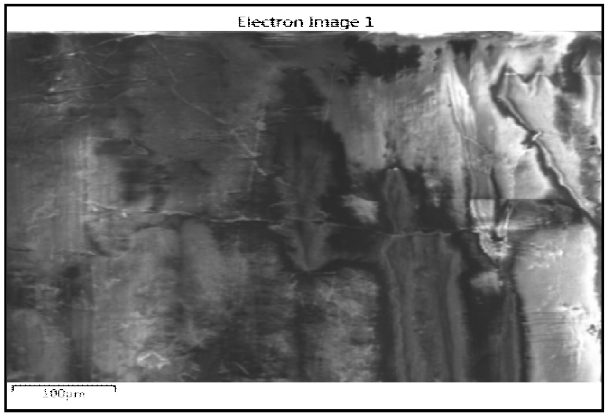

Fig. 6. FE-SEM image of HD - 2967 wheat straw.

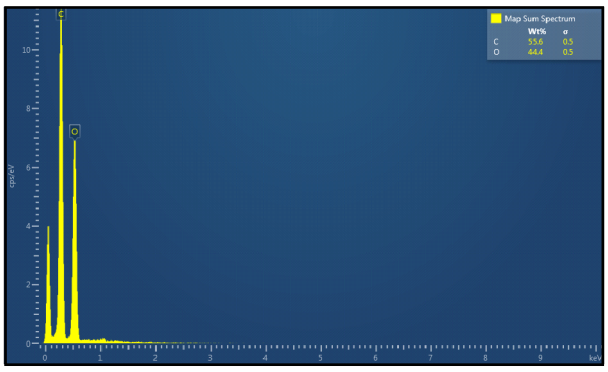

Fig. 7. Energy Dispersive Spectroscopy of HD - 2967 wheat straw.

shear strength of V1 (19.06 MPa) was significantly higher thanV2 (13.21 MPa). The average shear strength decreased significantly from 19.32 to 14.45 MPa as the moisture content increased from 5 to 15 %. The average shear strength increased significantly from 11 to 25.39 MPa from the first internode to the fifth internode. The two way interaction between variety, moisture content and internode position for shear strength of wheat straw is presented in Table 2. The interaction between moisture content - internode position and variety internode position was significant,

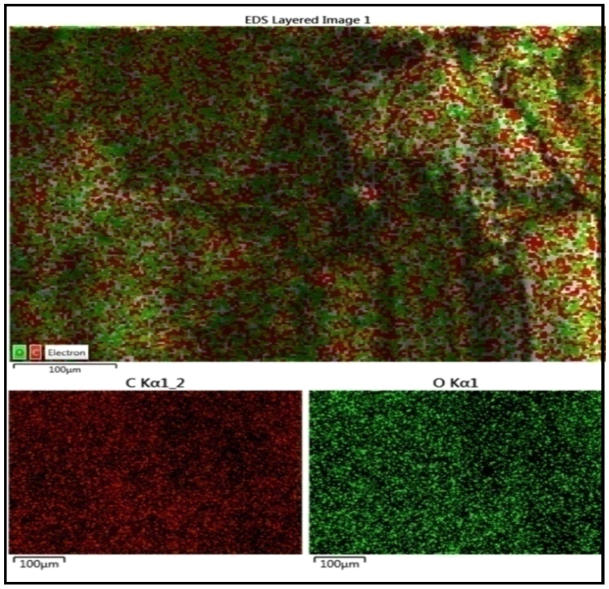

Fig. 8. EDS mapping analysis of elements in HD - 2967 wheat straw.

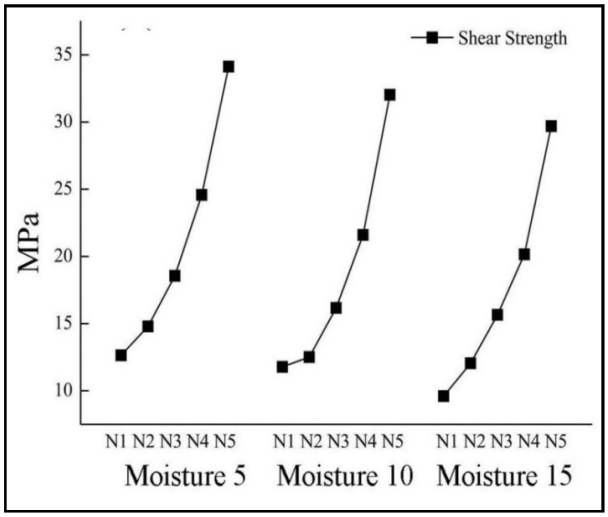

Fig. 9. Effect of moisture content (%) on shear strength (MPa) of variety WH - 1105 straw.

TABLE 1
Effect of variety, moisture content and internode position on shear strength of wheat straw

Variety / MC (%) / IN	V1			V2			Overall mean (IN)
	MC1	MC2	MC3	MC1	MC2	MC3	
IN1	12.64	11.78	9.60	11.46	11.03	9.47	11.00
IN2	14.79	12.51	12.04	12.04	11.14	9.62	12.02
IN3	18.55	16.16	15.65	13.23	12.98	10.21	14.46
IN4	24.58	21.60	20.15	15.79	13.14	11.59	17.81
IN5	34.13	32.03	29.70	21.45	18.49	16.50	25.39
Overall mean (V)		19.06				13.21	
Overall mean (MC)	19.32			17.26			14.45
CD (P = 0.05)	V = 0.40		MC = 0.49	IN = 0.63		V x MC x IN = NS	

TABLE 2
Two way interaction effect of variety, moisture content and internode position on shear strength of wheat straw

	MC1	MC2	MC3		V1	V2		V1	V2
IN1	12.05	11.40	9.53	IN1	11.34	10.65	MC1	20.94	14.80
IN2	13.42	11.82	10.83	IN2	13.11	10.93	MC2	18.82	13.36
IN3	15.89	14.57	12.93	IN3	16.79	12.14	MC3	17.43	11.48
IN4	20.18	17.37	15.87	IN4	22.11	13.51	-	-	-
IN5	27.79	25.263	23.10	IN5	31.95	18.82	-	-	-
Interaction		MC x IN = 1.09		Interaction	V x IN = 0.89		Interaction	V x MC = NS	

TABLE 3
Effect of variety, moisture content and internode position on tensile strength of wheat straw

Variety / MC (%) / IN	V1			V2			Overall mean (IN)
	MC1	MC2	MC3	MC1	MC2	MC3	
IN1	78.97	84.95	91.74	71.74	75.68	82.84	80.99
IN2	84.23	86.14	94.68	76.58	80.35	83.05	84.17
IN3	86.17	94.02	98.48	78.77	82.84	88.01	88.05
IN4	92.76	98.03	104.73	81.58	86.25	95.14	93.08
IN5	108.15	110.74	115.01	96.13	105.28	108.50	107.30
Overall mean (V)		95.25				86.18	
Overall mean (MC)	91.18		92.46			95.05	
CD (P = 0.05)	V = 0.94		MC = 1.15		IN = 1.48		V x MC x IN = 3.63

however, interaction of variety and moisture content was non significant. The shear strength decreased significantly from 27.79 MPa at IN5 to 9.53 MPa at IN1 as moisture content increased from MC1 to MC2 and internode position from IN5 to IN1. Similarly, the interaction of variety and internode position was also significant. The shear strength of variety V1 and V2 decreased from 31.95 MPa to 11.34 MPa and 18.82 to 10.65 MPa from IN5 to IN1. The effect of moisture content among varieties is non significant.

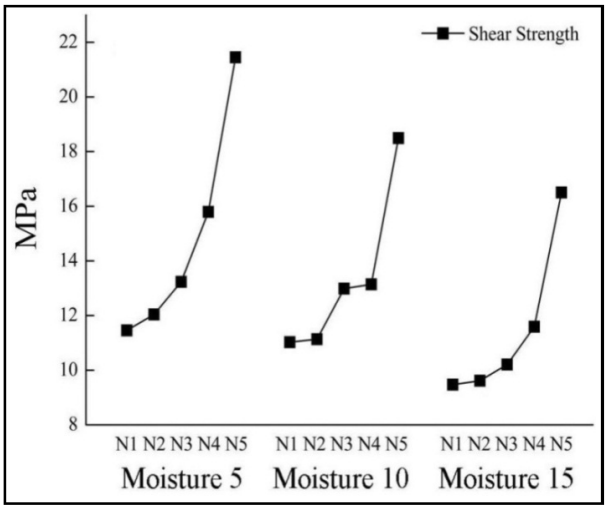

Fig. 10. Effect of moisture content (%) on shear strength (MPa) of variety HD - 2967 straw.

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

The effects of variety, moisture content and internode position on shear strength are presented in Table 3 and Fig. 11 - 12. The effect of variety, moisture content, internode position and combined effect of interaction of variables on tensile strength of wheat straw was significant. The variety V2 (HD - 2967) had lower tensile strength as compared to V1 (WH - 1105) at all levels of moisture content and internode position. The tensile strength was minimum at first internode and lower moisture content and increased towards fifth internode position and increased moisture content in both the varieties. It increased from 71.74 MPa at IN1 to 108.50 MPa at IN5 in variety V2 and 78.97 MPa at IN1 to 115.01 MPa at IN5 in variety V1 as the straw moisture content increased from 5 to 15%. The overall tensile strength of V2 (86.16 MPa) was significantly lower than V1 (95.25 MPa). The average tensile strength increased significantly from 91.18 to 95.05 MPa as the moisture content increased from 5 to 15 %. The average tensile strength increased significantly from 80.99 to 107.30 MPa from the first internode to the fifth internode. The two way interaction between variety, moisture content and internode position for tensile strength of wheat straw

is presented in Table 4, however the interaction among different variables on tensile strength were non significant.

Comparative analysis of mechanical properties of wheat varieties

The comparative analysis of mechanical properties of wheat varieties WH - 1105 and HD - 2967 are portrayed in Fig. 9 - 12. The shear strength and tensile strength increased from internode 1 to internode 5 in both the varieties similar to the results revealed by Tavakoli *et al*. (2009) which might be due to higher stem diameter and stem thickness. The effect of moisture content on shear strength is shown in Fig. 9 & 10. The available trend showed that shear strength decreased with increase in moisture content and increased from the first internode to the fifth internode in both the varieties. The graph showed that maximum shear strength is obtained at internode five at each level of moisture content and in both the varieties. The shear strength of WH - 1105 was significantly higher than HD - 2967 at each internode and all levels of moisture content. The shear strength of WH - 1105 variety was 30 % higher than HD - 2967 variety. The effect of moisture content on tensile strength is shown in Fig. 11 & 12. The available trend showed that tensile strength increased with increase in moisture content and internode position. The tensile strength increased from internode 1 to internode 4 uniformly for each moisture content level but showed a steep increase from internode 4 to internode 5. The tensile strength of WH - 1105 was significantly higher than HD - 2967 at each internode position and all levels of moisture content. The tensile strength of WH - 1105 variety was 10 % higher than HD - 2967 variety. The comparative analysis of moisture content showed that shear strength increased with decrease in moisture content whereas, the tensile strength decreased with decrease in moisture content in both the varieties. The main reason behind these trends was due to increase in ductility of the straws. The straw having comparatively low moisture content exhibits brittle deformation phenomenon which attained ductility with increase in moisture content. Yaoming *et al*. (2018) observed that in case of wheat straw the shear

TABLE 4
Two way interaction effect of variety, moisture content and internode position on tensile strength of wheat straw

	MC1	MC2	MC3		V1	V2		V1	V2
IN1	75.36	80.32	87.29	IN1	85.22	76.76	MC1	90.06	80.96
IN2	80.41	83.25	88.87	IN2	88.35	80.00	MC2	94.77	86.08
IN3	82.47	88.43	93.25	IN3	92.89	83.21	MC3	100.93	91.51
IN4	87.17	92.14	99.93	IN4	98.51	87.66	-	-	-
IN5	102.14	108.01	111.76	IN5	111.30	103.31	-	-	-
Interaction		MC x IN = NS		Interaction	V x IN = NS		Interaction	V x MC = NS	

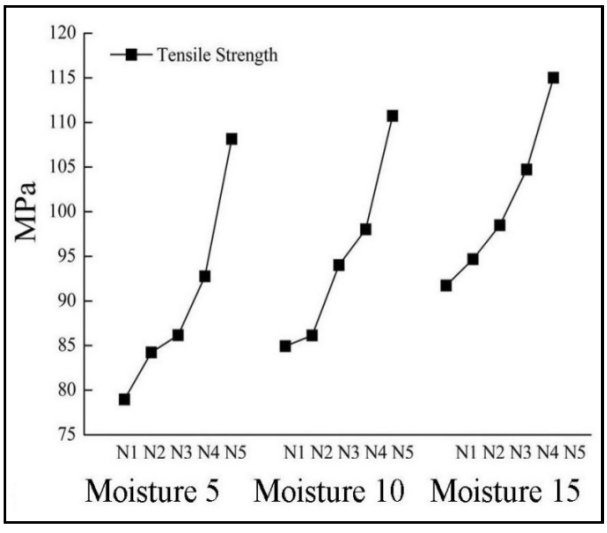

Fig. 11. Effect of moisture content (%) on tensile strength (MPa) of variety WH - 1105 straw.

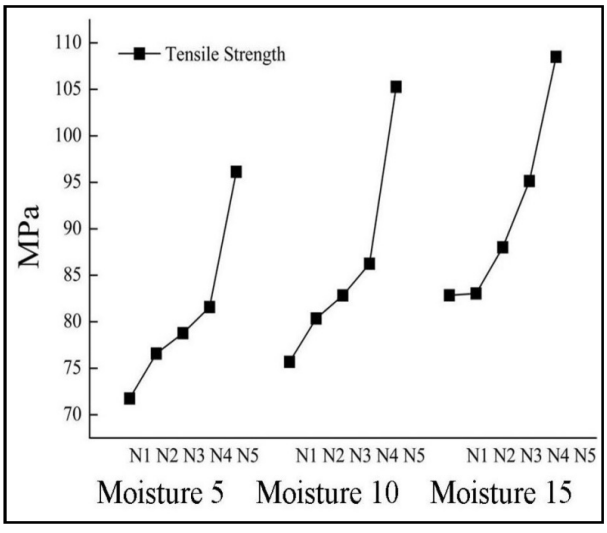

Fig. 12. Effect of moisture content (%) on tensile strength (MPa) of variety HD - 2967 straw.

resistance increased with an decrease in the moisture content, whereas deformation increased with the increase of moisture content. Similar results were also found for stalk, where the cutting force in dry stalk decreased with increase in moisture content because the ratio of material per unit area was higher than the high moisture content (Javed *et al*., 2014). In contrast to shear strength, the tensile strength increased with increase in moisture content in wheat straw. Ahmed *et al*., 2015 also observed similar results. In addition, the morphological analysis also showed that WH - 1105 had higher carbon content as compared to HD - 2967, which increased yield stress and ultimate tensile stress. The higher percentage of carbon also increased the resistance to deformation, which makes WH-1105 harder to cut as compared to HD-2967.

CONCLUSION

The shear strength decreased with increase in moisture content whereas the tensile strength increased with increase in moisture content in both the varieties WH - 1105 and HD - 2967. The morphological analysis showed that WH - 1105 variety had higher carbon content as compared to HD - 2967 variety which improved the shear and tensile strength of WH - 1105. The shear strength of WH - 1105 was significantly higher (30 %) than HD - 2967 at each internode and all levels of moisture content. Similarly, the tensile strength of WH - 1105 variety was 10 % higher than HD - 2967 variety. 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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