Bulgarian Journal of Agricultural Science, 19 (No 6) 2013, 1452-1458
Agricultural Academy

EFFECT OF LOADING RATE ON MECHANICAL CHARACTERISTICS OF WHEAT AND RICE STRAW

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Abstract

CHANDIO, F. A., C. YI, A. A. TAGAR, I. A. MARI, C. ARSLAN, D. M. CUONG and H. FANG, 2013. Effect of loading rate on mechanical characteristics of wheat and rice straw. *Bulg. J. Agric. Sci.,* 19: 1452-1458

This study was designed to evaluate mechanical characteristics of wheat and rice straw keeping in view the importance of straw application in the field. Technical data about mechanical properties of straw such as bending strength shearing energy and young's modulus still need to update. These properties were evaluated on three internodes positions (N1, N2 and N3) down from ear at average moisture content of 18.10%. Three loading rates (15, 20 and 25 mm min^{-1}) were employed by TMS- Pro machine with computer program for data acquisition and a steel plate was fabricated for holding straw at different internode's position. Some other physical parameters like length, diameter and cross sectional area were also measured for the determination of mechanical properties. Results showed that when loading rate increased, bending strength of wheat and rice straw decreased from 23.93 to 7.49 and 15.99 to 7.17 MPa respectively, shearing energy increased from 124.28 to 265.44 and 111.69 to 215.44 mJ respectively, and young's modulus varied from 1.20 to 0.22 and 0.72 to 0.20 GPa respectively. The bending strength and young's Modulus of wheat straw were significantly higher ($p<0.05$) than those of rice straw whereas the shearing energy had significantly effect of loading rate on rice and wheat straw ($p<0.01$). It was concluded that more energy can be saved by harvesting and threshing machines with decreasing the loading rate on wheat and rice straw toward the first, second and third internode's positions which will be helpful in designing of wheat and rice straw equipment, harvesting machines and tillage implements.

Key words: bending strength; shearing energy; Young's modulus; rice and wheat straw

Introduction

Rice and wheat are the two largest cereal food crops in China and their production accounts for 70% of the total grain production. In the middle and lower reaches of the Yangtze River, the annual double cropping of rice and wheat accounts for more than 8 x 10^6 ha (Wang, 2005). The average yield of rice and wheat yield were produced about 13.88 $t.ha^{-1}$ and 10.45 $t.ha^{-1}$ respectively at downstream of Yangtze River (Yang, 2000). Rice straw production in the world lies between 2 to 9 t ha^{-1} (Hesham, 2007). From several years, farmers have been spreading the plant residue / straw and incorporating into soil as mulch (Pervaiz, et al., 2009; Hesham, 2007) to reduce water evaporation, improve the soil stability, organic matter and to maintain the temperature and moisture content in the field conditions, but technical data on this improvement is still missing for designer of agricultural machines. The huge availability of these straws encourage interest in harvesting and commercial use of wheat and rice straw that prompted the need of mechanical data on straw properties (Yore et al., 2002). The dissimilarities in the physical and mechanical characteristics of wheat and rice straw the resistance afford against cutting equipment needed to be known to understand the behavior of material.

In order to design agricultural machinery used for harvesting, threshing and processing purpose, mechanical properties of wheat and rice straw play important role and need to be considered. For this purpose, some studies were designed to

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evaluate the failure criteria of wheat straw at different growing phases with respect to forces, shearing specific energy and modulus of rigidity (Liljedhal et al., 1961; McNulty and Mohsenin, 1979; Annoussamy et al., 2000). Some other properties of crop are also important to study along with mechanical properties like diameter, length, variety, maturity and structure of plant straw (Bright and Kleis, 1964; Persson, 1987).

Until no work regarding relationship of mechanical characteristics of the wheat and rice straw at different loading rates was done. Therefore, this study was conducted to investigate the change in mechanical characteristics of wheat and rice straw such as bending strength, shearing energy and young's modulus at three loading rates.

Materials and Methods

The wheat (Nanjing wheat 13) and rice (Wu yungen rice 23) straw were obtained at the time of harvesting from Jiangpu agricultural experimental farm of Nanjing Agricultural University, Jiangsu Province of China. The experiment was conducted at Agricultural Material Characteristics Research Laboratory, Department of Agricultural mechanization, College of Engineering, Nanjing Agricultural University, Nanjing, China during the year 2011.

Experimental Design

Moisture Content

The average moisture content of wheat and rice straw was measured by standard oven dry method at 105^{o}C for 24 hours[11], it was 18.10%.

Straw internode's preparation

The wheat and rice straw were chopped manually from top to lower level into three lengths (70, 130 and 190 mm) and labeled as N1, N2, and N3 respectively.

Fabrication of loading plate

The loading plate was fabricated with 3 mm steel sheet of 110 mm x 60 mm dimensions (Figure 2). Six holes of 2 mm to 7 mm were drilled into the center of loading plate to accommodate different diameters of straw internode's position as per requirement of the experiment. The loading plate was then attached to the compression testing machine through wedge grip at upside then loaded.

Test equipment

In this research TMS- Pro machine with computer program for data acquisition (TMS-Pro computer-controlled texture measurement system with attached force sensor load up to 1000 N for accuracy 5%) was used to measure the mechanical characteristics of wheat and rice straw (Figure 1).

Bending test

Three loading rates of 15, 20 , 25 mm min^{-1} were applied and failure forces at three internode's position were measured by S type loading cell which was further used for determining mechanical characteristics. Specimens were placed midway between two rounded metallic supports having 60 mm separation and load was applied by a vertical moveable plate (Tavakoli et al., 2009b, Zareiforoush et al., 2010). TMS-Pro computer-controlled measurement system was used for data

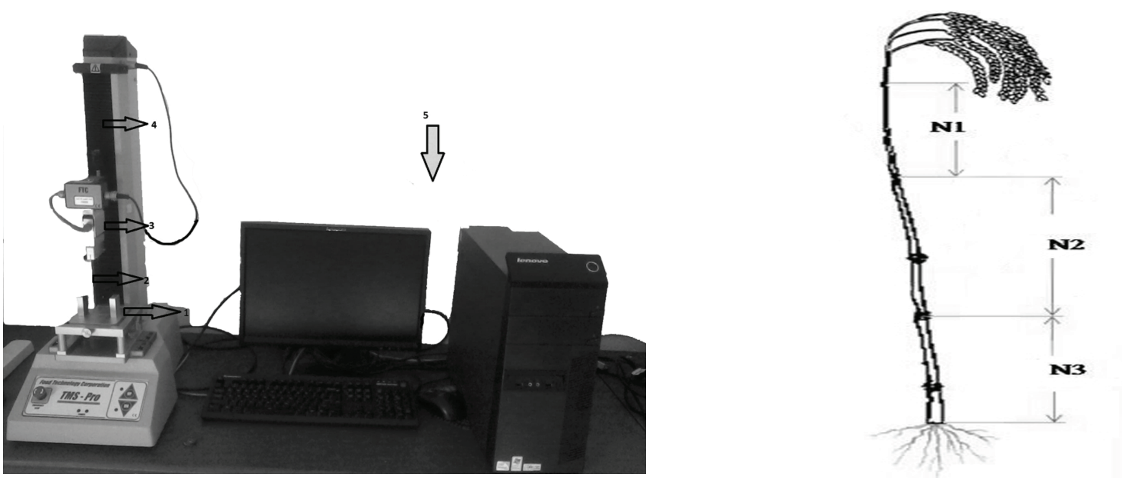

Fig. 1. a - Configuration of analyzer machine used to measure the mechanical characteristics of wheat and rice straw: 1. Metallic supports; 2. Loading plate; 3. S- type force sensor; 4. Compression mode; 5. Data acquisition system (Computer system attached with machine).
b - Wheat and Rice straw internode positions (N1, N2 and N3 are first, second and third, respectively).

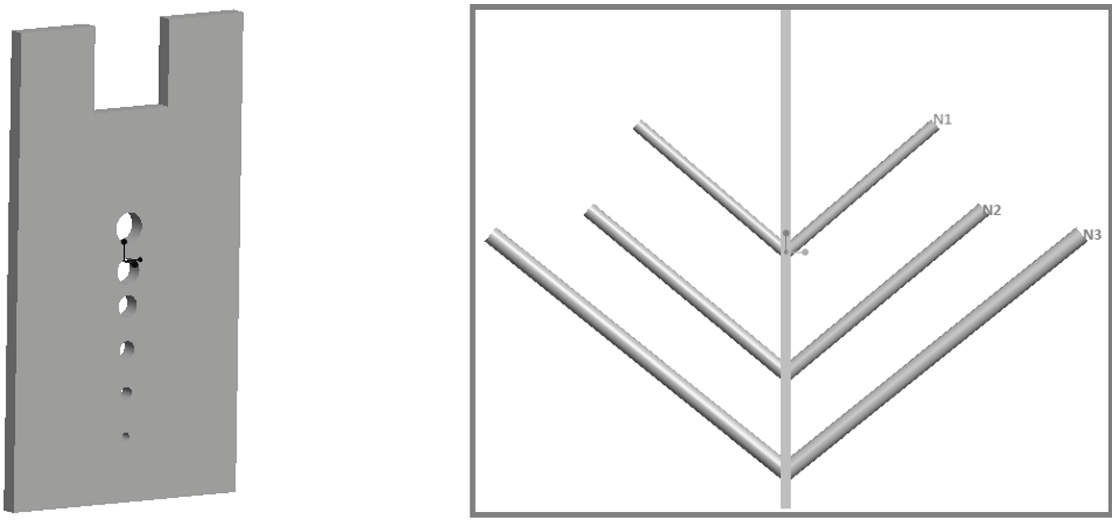

Fig. 2. a - Thematic view of loading plate; b - Wheat and rice straw Internode positions after experiment

acquisition and shearing energy calculation by integrating area under the curve produced by program (Chattopadhyay and Pandey, 1999; Chen et al., 2004; Nazari Galedar et al., 2008; Zareiforoush et al., 2010). Second moment of area in about a major axis, I_b, was expressed by following expression (Gere and Timoshenko, 1997):

$$I_b = \frac{\tau}{4}\left[ab^3 - (1 - t)(b - t)^3\right]$$

The bending strength σ_b is defined by the following expression (Gere and Timoshenko, 1997; Crook and Ennos, 1994):

$$\sigma_b = \frac{F_b a l}{4 I_b},$$

where:
- F_b = bending force, N
- L = distance between the two metal supports, mm
- a = deflection at the specimen centre, mm
- I_b = second moment of area, mm^4

The Young's modulus was calculated from the following expression for a simply supported beam loaded at its centre (Gere and Timoshenko, 1997):

$$E = \frac{F_b l^3}{48 \sigma I_b},$$

where:
- E = Young's modulus
- a = semi-major axis of the cross-section
- b = semi-minor axis of the cross-section
- t = wall thickness, mm

Statistical analysis

Randomized Complete block design (RCBD) with five replications was adopted in this research. Statistically analysis of data (ANOVA) was performed through SPSS (Version-16) using Duncan's multiple range tests (DRMT) at probability 5 %.

Table 1
Specific physical characteristics of wheat and rice straw at different internode positions

Parameters	Wheat straw			Rice straw		
	N1	N2	N3	N1	N2	N3
Thickness, mm	0.473^b	0.433^c	0.543^b	0.503^a	0.476^b	0.395^c
$Diameter_1$, mm	3.33^b	3.87^a	3.90^a	3.96^c	4.21^b	4.31^a
$Diameter_2$, mm	3.05^c	3.41^b	3.37^b	3.56^a	3.87^b	3.91^b
x- sectional $area_1$, mm^2	8.70^c	11.75^b	11.93^a	12.31^c	13.91^b	14.58^a
x- sectional $area_2$, mm^2	7.30^b	9.12^b	8.91^a	9.94^c	11.75^c	12.01^b
Length of straw, mm	70^b	130^c	190^b	70^a	130^b	190^c

* N1, N2 and N3: first, second and third internode position, thickness, diameter cross-sectional area and length of straw, respectively.
a-c: resources followed by superscript letters in a column are significantly different from others in the same path ($p<0.05$)

Results

Statistical analysis indicated that the effect of loading rate was significant on the bending strength, young's modulus ($p<0.05$) and shearing energy ($p<0.01$). Duncan test showed that there were significant differences among the three loading rates ($p<0.05$) on bending strength, young's modulus and shearing energy. The results are widely discussed as follow.

Specific Physical Characteristics of straws

Average values of physical characteristics of wheat and rice straw are presented in (Table 1). These values were used in the calculation of bending strength, young's modulus and Duncan's test was showed significantly difference at every column ($p<0.05$).

Effect of Loading Rate on Bending Strength

The average values of bending strength for internode positions of wheat and rice straw with three loading rates are presented in Figure 3. The parameters obtained are shown in the Table 2. The results of internodes N1, N2 and N3 of wheat straw varied from 21.18 to 7.49, 20.64 to 8.51 and, 23.93 to 9.64 MPa, respectively, while the rice straw varied from 10.88 to 7.17, 14.04 to 8.16 and, 15.99 to 9.03 MPa at N1, N2 and N3, respectively. Moreover increasing the loading rates from 15 to 25 mm min^{-1} trend showed bending strength had decreased while the average value of bending strength for both wheat and rice straw increased at N3 and then decreased at N1 and N2. However, the loading rate slightly increased as with increase in bending strength internode third of wheat and rice straw were 23.93 and 15.99 and decreased at internode first were 7.49 and 7.17. Over all bending strength lowest found of rice straw at N1, N2, N3 and highest of wheat straw at N1, N2 and N3, respectively. The bending strength of rice straw showed significantly different lower than wheat straw ($p<0.05$) at three loading rates.

Effect of Loading Rate on Shearing Energy

The average values of shearing energy for internode's positions of wheat and rice straw with three loading rates are presented in Figure 4. The parameters obtained are shown in the table 3. The results of internodes N1, N2 and N3 of wheat straw varied from 124.28 to 187.50, 174.89 to 249.32 and, 197.87 to 265.44 mJ, respectively, while the rice straw varied from 111.69 to 167.24, 150.38 to 203.25 and 147.75 to 215.44 at N1, N2 and N3, respectively. The shearing energy had highest magnitude on third internode of wheat and rice straw at 25 mm min^{-1} while lowest found on first internodes of rice straw at 15 mm min^{-1}. Moreover, increasing the loading rate from 15 to 25mm min^{-1} trend showed shearing energy had

Table 2
Bending strength for wheat and rice straw at different internodes position under different loading rates

	Bending strength, MPa					
Loading rates, mm min^{-1}	Wheat straw			Rice straw		
	N1	N2	N3	N1	N2	N3
15	21.18^{b}	20.64^{a}	23.93^{c}	10.64^{c}	13.95^{a}	15.99^{b}
20	12.51^{a}	13.25^{b}	14.98^{c}	10.88^{b}	14.04^{a}	11.56^{c}
25	7.49^{b}	8.51^{a}	9.64^{a}	7.17^{c}	8.16^{b}	9.03^{c}

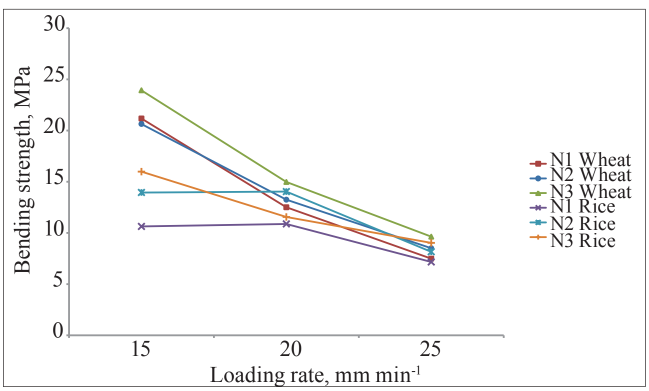

Fig. 3. Bending strength of wheat and rice straw at different internode's positions under 15, 20 and 25 mm min^{-1}

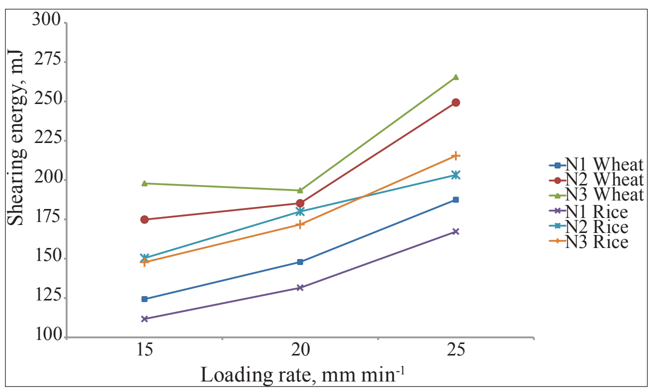

Fig. 4. Shearing energy of wheat and rice straw at different internode's positions under 15, 20 and 25 mm min^{-1}

increased while the average value of shearing energy for both wheat and rice straw increased at N3 from 15 to 25 mm min^{-1} and then decreased at N1 and N2. Over all shearing energy lowest found of rice straw at N1, N2, N3 and highest of wheat straw at N1, N2 and N3, respectively.

Effect of Loading Rate on Young's Modulus

The average values of young's modulus for internode's positions of wheat and rice straw with three loading rates are presented in Figure 5. The parameters obtained are shown in the Table 4. Young's modulus at internodes N1, N2 and N3 of wheat straw varied from 0.52 to 1.20, 0.29 to 0.99 and 0.22 to 0.77 GPa respectively, while the rice straw varied from 0.44 to 0.72, 0.26 to 0.47 and, 0.20 to 0.33 at N1, N2 and N3, respectively. Similarly, increasing the loading rates from 15 to 25 mm min^{-1} trend showed young's modulus had decreased at third internodes, while decreased on N1 at 15 mm min^{-1}. Over all young's modulus lowest found of rice straw at N1, N2 and N3, and highest of wheat straw at N1, N2 and N3, respectively. The young's modulus of rice straw showed significantly different lower than wheat straw ($p<0.05$) at three loading rates.

Discussion

In order to evaluate the performance of wheat and rice straw under the different loading rate on mechanical characteristics like as bending strength, shearing energy and young's modulus.

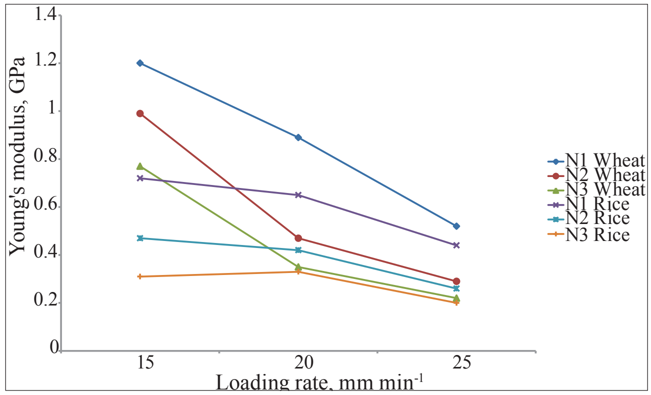

Fig. 5. Young's modulus of wheat and rice straw at different internode's positions under 15, 20 and 25 mm min^{-1}

The present study showed that the bending strength was highest at N3, while lowest at N1 for wheat and rice straw at loading rate of 25 mm min^{-1}. The bending strength of wheat straw was significantly higher ($p<0.05$) than rice straw at similar loading rate as diameter of wheat straw was more than that of rice straw. A similar trend was found by Tavakoli et al. (2009a) in study mechanical properties of barley and rice straw. At highest bending strength on third internode's position of barley and rice straw. Furthermore increasing the loading rate decrease the bending strength trend at 25 mm min^{-1}. The decreasing trend in bending strength was also reported by with Zareiforoush et al. (2010) they observed rice straw from 9.81 to 6.70 MPa as loading rate increase from 5 to 15 mm min^{-1}. The average values obtained from present

Table 3
Shearing energy for wheat and rice straw at different internodes position under different loading rates

Shearing energy, mJ						
Loading rates, mm min^{-1}	Wheat straw			Rice straw		
	N1	N2	N3	N1	N2	N3
15	124.28^{c}	174.89^{b}	197.87^{a}	111.69^{c}	150.38^{c}	147.75^{a}
20	147.89^{c}	185.26^{b}	193.42^{ac}	131.53^{c}	180^{c}	171.75^{c}
25	187.5^{c}	249.32^{b}	265.44^{a}	167.24^{bc}	203.25^{c}	215.44^{c}

Table 4
Young's modulus for wheat and rice straw at different internodes position under different loading rates

Young's modulus, GPa						
Loading rates, mm min^{-1}	Wheat straw			Rice straw		
	N1	N2	N3	N1	N2	N3
15	1.20^{c}	0.99^{b}	0.77^{a}	0.72^{a}	0.47^{b}	0.31^{a}
20	0.89^{b}	0.47^{a}	0.35^{b}	0.65^{b}	0.42b	0.33^{a}
25	0.52^{c}	0.29^{b}	0.22^{c}	0.44^{c}	0.26b	0.20^{bc}

* Values are averages of five replicates.
* N1, N2 and N3: first, second and third internode position, respectively. a-c: resources followed by superscript letters in a column are significantly different from others in the same path ($p<0.05$)

research of wheat and rice straw were lower than those of sorghum straw at forage stage (Chattopadhyay and Pandey, 1999; Nazari Galedar et al., 2008; Tavakoli et al., 2009a). From research observed the weakest internode position at N3 from measured values also was determined and found more flexible then wheat straw.

The average shearing energy of wheat and rice straw were calculated ranging from 124.28 to 256.44 and 111.69 to 215.44 mJ, respectively. Increasing the loading rate from 15 to 25 mm min^{-1} increase the shearing energy but save energy of 51.54 and 48.16% at 15 mm min^{-1} cause of wheat straw inflexible as need force require to deflect the higher energy in wheat straw can be used then rice straw during the harvesting time. It had maximum value at third internode position because of the accumulation of more mature straw. Effect of loading rate on shearing energy of wheat and rice straw significantly increase ($p<0.01$) at N3. Thus agreeing the report of Tavakoli et al. (2009b) observed the values of specific shearing energy of wheat straw ranged from 21.85 to 36.26 mJ mm^{-2}. Similar results were drawn by Galedar et al. (2008) reported that the average values of the shearing energy of alfalfa straw had increased from upper level to lower level at 10 to 80% w. b. Duncan test showed that there were significant differences columns among the three loading rates ($p<0.05$) and significantly ($p<0.01$) at N1, N2 and N3 of rice straw higher then wheat (Table 3).

The highest values of young's modulus were 1.20, 0.72 GPa was observed on N1 at 15 mm min^{-1}, while lowest 0.22, 20 GPa on N3 at 25 mm min^{-1} of wheat and rice straw trend. Increasing the loading rate from 15 to 25 mm min^{-1} decreased young's modulus. Results agreement with Zareiforoush: et al. (2010) they were found mean young's modulus of rice straw was 1.38 to 0.21 GPa. Similar results were drawn by O'Dogherty et al., 1995; Nazari Galedar et al., 2008; those were observed the young's modulus trend highest to lowest values of wheat and alfalfa. Duncan test (Table 4) showed that there were significant differences among the three loading rates at column ($p<0.05$) higher then rice straw.

Conclusions

The bending strength and shearing energy increased towards the N3 at 25 mm min^{-1}, while decreased at first internode position at 15 mm min^{-1} for both of wheat and rice straw trend. Increasing the loading rate decrease the young's modulus at N3 of both wheat and rice straw, while increased at N1, and N2, respectively. With respect the findings of mechanical characteristics highest found of wheat then rice straw. The results of present study indicated that by lowering the loading rate, shearing energy could be saved which would be helpful in reducing energy requirement for threshing. It will be helpful to the designer of wheat and rice straw equipment, harvesting machines, tillage implements and great knowledge provide to tractor drivers after the incorporation of straw into soil.

Acknowledgments

Authors are grateful to Natural Science Foundation of China for their financial support via grant number 51275250 and also acknowledge Professor Chen Kunjie for providing facilities to conduct research experiments at Agricultural Material Characteristics Research Laboratory, College of Engineering, Nanjing Agricultural University, China.

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Received December, 8, 2012; accepted for printing June, 2, 2013.