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Comparison of Mechanical Properties Between Two Varieties of Rice Straw

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Abstract: The objective of this work was to compare the mechanical properties between two varieties of rice straw (Hashemi and Alikazemi). The experiments were conducted at moisture contents of 71.6 and 70.8% w.b. for Hashemi and Alikazemi varieties, respectively and three internode positions down from the ear. The average shear strength for Hashemi variety was significantly higher ($p<0.05$) than that of Alikazemi variety. The values were 13.08 and 8.56 MPa for Hashemi and Alikazemi varieties, respectively. The shearing energy of Hashemi and Alikazemi varieties increased from 122.76 to 236.06 and 86.89 to 191.31 mJ, respectively, towards the third internode position. The bending strength and Young's Modulus of Hashemi variety were significantly higher ($p<0.05$) than those of Alikazemi variety. The results showed that the energy requirement for shearing of Hashemi variety is more than Alikazemi variety.

Key words: Shear strength, shearing energy, straw, rice and Young's modulus

INTRODUCTION

Rice (*Oryza sativa* L.) is among the oldest of cultivated crops and ranks as the most widely grown food grain crop, serving as the staple food for about half the world's population. In Iran, rice is widely cultivated on an area of about 6.15×10^3 ha with an annual production of about 3.0×10^6 t (FAO, 2007).

Several million tonnes of straw are produced from this crop annually. These straws usually serve as feed for animals and sometimes are incorporated into the plowed layer or used as mulch. For these purposes, straw must be processed after harvesting. It is necessary to know physical and mechanical properties of rice straw, for selecting design and operational parameters of equipment relating to harvesting, threshing and processing.

Most studies on the mechanical properties of plants have been carried out during their growth using failure criteria (force, stress and energy) or their Young's modulus and the modulus of rigidity. Studies have focused on plant anatomy, lodging processes, harvest optimisation, animal nutrition, industrial applications and the decomposition of wheat straw in soil (McNulty and Mohsenin, 1979; Annoussamy *et al.*, 2000). The properties of the cellular material that are important in cutting are compression, tension, bending, shearing, density and friction. These properties depend on the species, variety, stalk diameter, maturity, moisture content and cellular structure (Bright and Kleis, 1964; Persson, 1987). These physical properties are also different at different heights of the plant stalk (İnce *et al.*, 2005). Methods and procedures for determining most mechanical and rheological properties of agricultural products have been described by Mohsenin (1986).

Several studies have been conducted to determine mechanical properties of plants. O'Dogherty *et al.* (1989) measured the shear strength of six varieties of wheat straw. They found that the mean ultimate shear strength was in the range of 5.39 to 6.98 MPa for five varieties of winter wheat and was equal to 8.53 MPa for a spring wheat (var. Alexander) having moisture contents ranging from 10 to 15% w.b. Kushaha *et al.* (1983) reported mean values of shear strength of wheat straw in the range of 7-22 MPa with some dependence on moisture content. Other researchers have measured the specific energy required to shear materials. Shinners *et al.* (1987) found that longitudinal shearing of alfalfa stems required less than 1/10 the energy to shear alfalfa transversely. McRandal and McNulty (1980) conducted shearing experiments on field grasses and found that the mean shearing stress was 16 MPa and the mean specific shearing energy was 12.0 mJ mm^{-2}. O'Dogherty *et al.* (1995) showed that the Young's modulus for wheat straw varied between 4.76 and 6.58 GPa. Chattopadhyay and Pandey (1999) found that the bending stress for sorghum stalks at the seed stage and forage stage were 40.53 and 45.65 MPa, respectively.

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Similar works have been conducted in recent years such as: Chen *et al.* (2004) on hemp stems, İnce *et al.* (2005) on sunflower stalks, Nazari Galedar *et al.* (2008) on alfalfa stems and Tavakoli *et al.* (2009) on barely straw.

There is no published work relating to the mechanical properties of rice straw. Therefore, the objective of this study was to determine mechanical properties, namely, shear strength, shearing energy, bending strength and Young's modulus of two Iranian rice varieties.

MATERIALS AND METHODS

The rice straws (Hashemi and Alikazemi varieties) used for the present study were from the prevalent varieties of rice in Iran and were obtained from the agronomy farm of the Rice Research Institute, Rasht, Iran. The straws were collected at harvesting time and their internodes were separated according to their position down from the ear (Fig. 1). Leaf blades and sheaths were removed prior to any treatment or measurement. To determine the average moisture content of the rice straws, the specimens were weighed and oven-dried at 103ºC for 24h (ASAE Standards, 2006) and then reweighed. The average moisture contents of Hashemi and Alikazemi varieties were 71.6 and 70.8% w.b., respectively. Three internodes of the rice straws, namely, first, second and third internodes were studied in this research (Fig. 1). The fourth and lower stem internodes from the ear were not considered because these internodes are usually left on the field. Each internode was described by measuring its length (to the nearest 1 mm), its major and minor diameters and thickness of the elliptical wall (to the nearest 1 μm) using a digital caliper.

Experimental procedure: The mechanical properties of rice straw were assessed using a shearing test similar to those described by İnce *et al.* (2005), Nazari Galedar *et al.* (2008) and Tavakoli *et al.* (2009) (Fig. 2a) and a three-point bending test similar to those described by Annoussamy *et al.* (2000), Nazari Galedar *et al.* (2008) and Tavakoli *et al.* (2009) (Fig. 2b). The measurements were made using a proprietary tension/compression testing machine (Instron Universal Testing Machine /SMT-5, SANTAM Company, Tehran, Iran). All experiments were conducted in October 2009, in Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering & Technology, University of Tehran, Karaj, Iran.

Shearing test: The shear strength was measured in double shear using a shear box (Fig. 2a) consisting essentially of two fixed parallel hardened steel plates 6 mm apart, between which a third plate can slide freely in a close sliding fit. A series of holes with diameters ranging from 1.5 to 5 mm were drilled through the plates to accommodate internodes of differing diameters. Shear

Fig. 1: Rice straw internodes

force was applied to the straw specimens by mounting the shear box in the tension/compression testing machine. The sliding plate was loaded at a rate of 10 mm min^{-1} and, as for the shear test, the applied force was measured by a strain-gauge load cell and a force-time record obtained up to the specimen failure. The shear failure stress (or ultimate shear strength), τ_s, of the specimen was calculated from:

$$\tau_s = \frac{F_s}{2A} \quad (1)$$

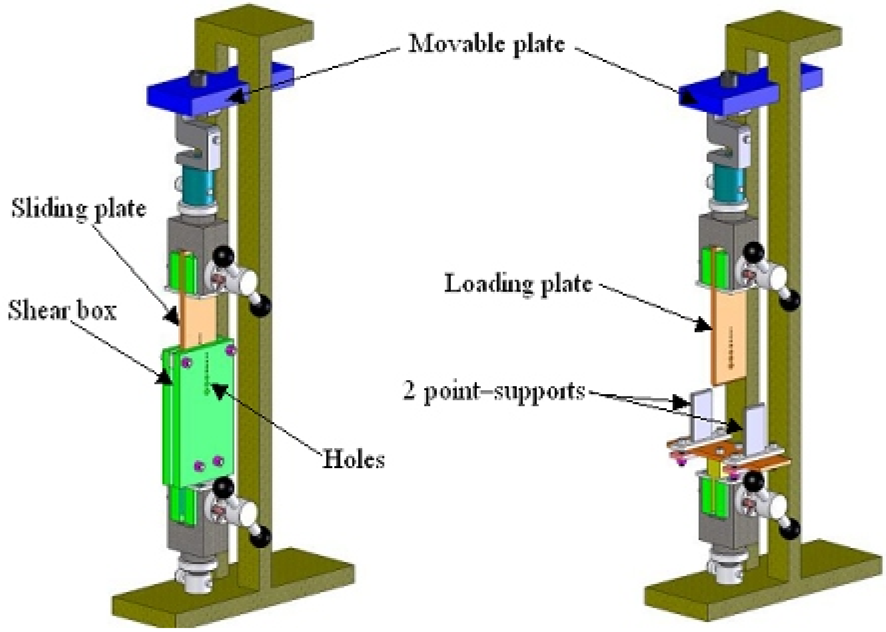
where: τ_s is the shear strength (MPa), F_s is the shear force at failure (N) and A is the wall area of the specimen at the failure cross-section (mm^2).

The shearing energy, E_s, was calculated by integrating the area under curves of shear force and displacement (Chattopadhyay and Pandey, 1999; Chen *et al.*, 2004; Nazari Galedar *et al.*, 2008) using a standard computer program (vers. 5, SMT Machine Linker, SANTAM Company, Tehran, Iran).

Bending test: To determine Young's modulus and maximum bending strength, the specimens were arranged with the major axis of the cross-section in the horizontal plane and placed on two rounded metal supports 50 mm apart and then loaded midway between the supports with a blade driven by the movable supports. The loading rate was 10 mm min^{-1} and the applied force was measured by a strain-gauge load cell and a force-time record obtained up to the failure of the specimen. Most specimens were slightly elliptical in cross-section and second moment of area in bending about a major axis (I_b) was calculated as (Gere and Timoshenko, 1997):

$$I_b = \frac{\pi}{4}\left[ab^3 - (a-t)(b-t)^3\right] \quad (2)$$

where: I_b is the second moment of area (mm^4), a is the semi-major axis of the cross–section (mm), b is the



(a) shearing test (b) bending test

Fig. 2: Apparatus used to measure (a) shearing, and (b) bending strength of rice straw internodes

semi-minor axis of the cross-section (mm) and t is the mean wall thickness (mm).

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

$$E = \frac{F_b l^3}{48 \delta I_b} \quad (3)$$

where: E is the Young's modulus (MPa), F_b is the bending force (N), l is the distance between the two metal supports (mm) and δ is the deflection at the specimen centre (mm).

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

$$\sigma_b = \frac{F_b a l}{4 I_b} \quad (4)$$

where: σ_b is the bending stress (MPa).

Experimental design and statistical analysis: This study was planned as a completely randomized block design. The mechanical properties were determined with five replications in each treatment. Experimental data were analysed using analysis of variance (ANOVA) and the means were compared at the 1 and 5% levels of significance using the Duncan's multiple range tests in SPSS software (vers. 15, SPSS, Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Shear strength: The mean values for shear strength of rice straw at different internode positions are presented at Table 1. Its values varied from 8.81 to 20.22 and 7.12 to 11.16 MPa for Hashemi and Alikazemi varieties, respectively. The shear strength of Hashemi variety decreased towards the third internode, while there was no distinct trend for that of Alikazemi variety. As shown in Fig. 3 the shear strength values for Hashemi variety were significantly greater ($p<0.05$) than those of Alikazemi variety. It indicates that the Hashemi variety has more shearing resistance in comparison with Alikazemi variety.

Shearing energy: The values of the shearing energy varied from 122.76 to 236.06 and 86.89 to 191.31 mJ, for Hashemi and Alikazemi varieties, respectively (Table 1). The shearing energy of both varieties increased significantly ($p<0.01$) towards the third internode (Fig. 4). It was greater in the third internode because of the accumulation of more mature fibres in the stem (İnce *et al.*, 2005). This effect of plant height on shearing energy requirement was also reported by Annoussamy *et al.* (2000) for wheat straw, İnce *et al.* (2005) for sunflower stalk and Nazari Galedar *et al.* (2008) for alfalfa stem. According to the Duncan's multiple range tests, the values of the shearing energy for Hashemi variety were significantly higher ($p<0.01$) than those of Alikazemi variety. This means that the energy requirement for shearing of Hashemi variety is more than Alikazemi variety.

Table 1: Mechanical properties of Hashemi and Alikazemi varieties

	Hashemi			Alikazemi		
height	IN1	IN2	IN3	IN1	IN2	IN3
N	5	5	5	5	5	5
τ_s(MPa)	20.22_a (3.49)	10.20_{bc} (0.91)	8.81_{bcd} (0.73)	11.16_b (2.04)	7.12_d (1.81)	7.48_{cd} (1.90)
E_s (mJ)	122.76_c (17.04)	228.18_a (47.45)	236.06_a (43.25)	86.89_c (13.37)	140.72_{bc} (43.19)	191.31_{ab} (26.15)
σ_b(MPa)	8.29_a (1.78)	8.70_a (1.91)	9.81_a (1.30)	10.19_a (2.19)	4.19_b (0.69)	8.01_a (1.83)
E (GPa)	1.21_a (0.23)	0.50_b (0.19)	0.35_{bc} (0.08)	1.25_a (0.16)	0.20_c (0.04)	0.18_c (0.06)

*Figures in parentheses are standard deviation. a-d: means followed by different letters are significantly different from others in the same line (P<0.05). N: number of observations; IN1, IN2 and IN3: first, second and third internodes, respectively; and: shear strength and bending strength, respectively. E_s: shearing energy. E: Young's modulus.

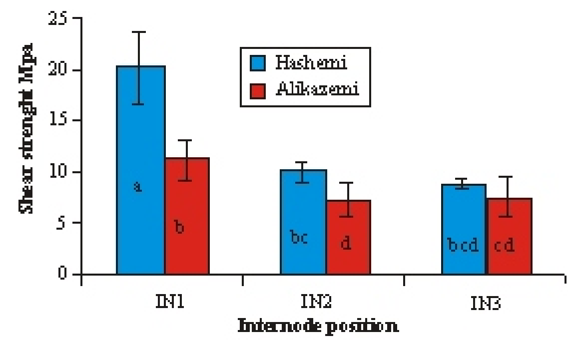


Fig. 3: Shear strength of rice straw at different internode positions; means with the same letter are not significantly different (P>0.05)

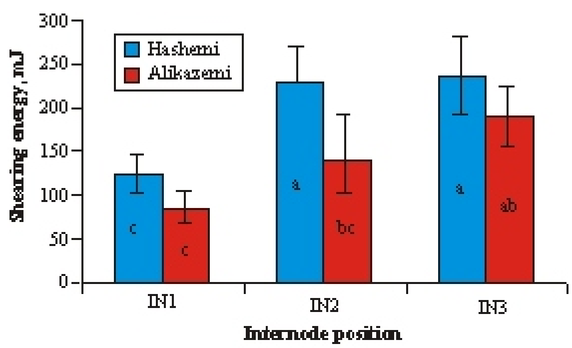


Fig. 4: Shearing energy of rice straw at different internode positions; means with the same letter are not significantly different (P>0.05)

Bending strength: The bending strength of rice straw at different varieties and internodes are shown in Table 1. The average values of the bending strength for Hashemi and Alikazemi varieties were 8.93 and 7.46 MPa, respectively. The bending strength of Hashemi variety was significantly higher (p<0.05) than that of Alikazemi variety (Fig. 5). The higher values of the bending strength for Hashemi variety in comparison with Alikazemi variety indicate that the Hashemi variety is more brittle.

Young's modulus: The Young's modulus in bending for both varieties decreased towards the third internodes (Table 1). Similar result was reported by Annoussamy *et al*. (2000) for wheat straw and Nazari Galedar *et al.* (2008) for alfalfa stem. The range of values was from

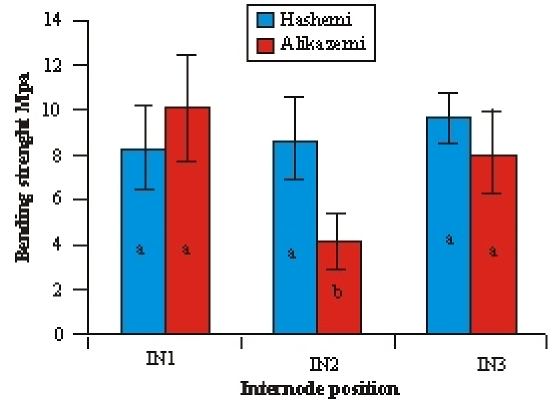


Fig. 5: Bending strength of rice straw at different internode positions; means with the same letter are not significantly different (P>0.05)

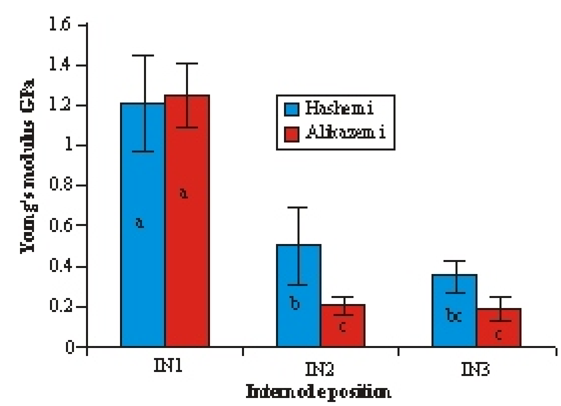


Fig. 6: Young's modulus of rice straw at different internode positions; means with the same letter are not significantly different (P>0.05)

0.35 to 1.21 and 0.18 to 1.25 GPa, for Hashemi and Alikazemi varieties, respectively. According to the Duncan's multiple range tests, the effect of internode position on the Young's modulus of both varieties was significant at the 1% significance level and Hashemi variety had significantly higher (*P*<0.05) values than Alikazemi variety (Fig. 6).

CONCLUSION

In this study, the mechanical properties of two varieties of rice straw at three internode positions were compared. Results showed that the average shear strength and shearing energy of Hashemi variety were significantly higher than those of Alikazemi variety. Therefore, Hashemi variety has more shearing resistance. The average values of the bending strength for Hashemi and Alikazemi varieties were 8.93 and 7.46 MPa, respectively. The Young's modulus of Hashemi and Alikazemi varieties varied from 0.35 to 1.21 and 0.18 to 1.25 GPa, respectively.

This paper concludes with information on engineering properties of rice straw which may be useful for designing the equipment used for harvesting, threshing, and processing.

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