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FUZZY LOGIC MODEL TO PREDICT WHEAT STRAW MECHANICAL PROPERTIES UNDER VARYING MOISTURE CONTENT AND LOADING RATE

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A fuzzy algorithm was designed for the evaluation of wheat straw mechanical properties such as shear strength, bending strength and young's modulus under influence of moisture contents and loading rates. Wheat straw mechanical properties were measured under controlled moisture contents, i.e. 9.5%, 15.1% and 22.8%, on distinguished internode positions, i.e. IN_1, IN_2 and IN_3 (first, second and third internode, respectively), and with three loading rates, i.e. 10, 20 and 30 mm/min, respectively during year 2013. The results showed that moisture content, loading rate at various internode regions significantly ($P<0.05$) influenced the shear strength, bending strength and young's modulus. Shear strength (yang mai 16, verity) increased with escalating moisture content and loading rate toward third internode. Whereas bending strength and young's modulus dropped off with the raise of moisture content and loading rate in the direction of the third internode. The proposed mamdani min- max 27 rule based fuzzy model was evaluated with a sub data set from experimental results. Coefficients of determination of relationships for shear strength, bending strength and young's modulus were 0.96, 0.92 and 0.75j, respectively, indicating that the fuzzy logic algorithm for mechanical properties prediction of wheat straw could be regarded as an substitute under the selected experimental conditions.

Keywords: Fuzzy logic model, mechanical properties, moisture content, wheat straw.

INTRODUCTION

Being the second largest source of food supply, the world wheat production was estimated to be $7.04\text{x}10^8$ tons annually. Only in China, the cultivated area for wheat production amounts to 24,270,480 ha delivering an annual grain yield of about $11.74\text{x}10^7$ tons (FAO 2011). Due to this high biomass yield, abundant crop residue is left in the post-harvested wheat field. Now a days, wheat straw is being considered as a valuable agricultural byproduct, which is finding its use in a number of places such as livestock feeding, valuable organic input to the farming land, potential bio-fuel material and bio-resource materials for industries. For most cases, straw properties (physical, biological and mechanical) play an important role in its handling and processing. Mechanical properties of straw not only influence the crop stand and the stand's lodging characteristics, but in the post-harvest process, also govern the performance of tillage and seeding tools especially in zero tillage conditions. Even in the baling, transportation and industrial processing process people have to consider the mechanical behavior of wheat straw.

Minimum and zero tillage practices are being practiced by the farmers all over the world for sustainable crop production and conservation of energy during the crop production; cutting and incorporation of the crop residue into the soil are challenging tasks yet under this system. Most of the straw is not cut properly and producing the hair pining phenomenon in the furrow. Therefore, knowledge of engineering properties of the each variety of wheat straw is essential for the design and operation of the machinery. As the cellular material properties (bending, shear, density, compression, tension, friction, etc) are influenced by straw thickness, crop growth, and cellular structure (Persson, 1987).

In general, most of the previous studies dealt with the mechanical properties of plants during their growth (Annoussamy *et al.*, 2000). The wheat straw is mostly brittle at low moisture content and hence easy to shear (Kushwaha *et al.,* 1985). The properties of straw (physical and mechanical) are changed with the change of moisture content along with the height of the plant (Galedar *et al.*, 2008; Tavakoli *et al.*, 2009a). At four maturity stages of wheat straw, O'Dogherty *et al.* (1995) measured mechanical properties and reported the mean value of the shear strength in a range of 4.91-7.26 MPa and Young's modulus mean value was in range of 4.76 to 6.58 GPa. Similar trends were reported for alfalfa crop, as enhancement in wetness level of alfalfa stalk caused reduction in bending strength. However, the shear strength increased towards lower region (Galedar *et al.,* 2008). Tavakoli *et al.* (2009c) determined the values of shear strength (6.81-11.78 MPa), bending strength (6.81-

11.78 MPa) and Young's modulus (0.65-1.82 GPa) of wheat straw (Alvand, Iranian variety). Consequence of moisture content, loading rate and stalk region on barley straw shear and bending properties has also been reported (Tavakoli *et al.*, 2009a,b). Shear strength (rice and wheat) of straw increased with loading at all stem regions (Zareiforoush *et al.*, 2010; Chandio *et al.*, 2013). Recently, changes in mechanical properties were also reported by Shahbazi and Galedar (2012) for safflower and by Hoseinzadeh and Shirneshan (2012) for canola stem.

Various soft computing techniques (image processing, artificial intelligence, fuzzy modeling and neural network) are being exploited for uncertain data analysis in near past. Fuzzy modeling can be applied to various domains of problems, as signal processing, pattern recognition, in grading processes to define the degrees of overlap, construction of decision process and control. The imprecision data can manipulate using fuzzy theory which was first introduced by Zadeh (1965). To analyze complex processes, fuzzy logic facilitates a formal mathematical process (Zimmermann, 1996).

A fuzzy decision support system (DSS) was introduced by utilizing fuzzy logic concepts to facilitate the decisions regarding to the quality based division of tomatoes (Verma, 1995). Lorestani *et al.* (2006) designed a FIS model for grading of apples based on their color and size. Recently, the fuzzy model in order to predict the shear properties of rice stem exposed the predictive acceptability of fuzzy logic. The truthfulness of model for shear energy of rice stem was in range of 86 to 97% (Zareiforoush *et al.*, 2012). Similarly, fuzzy logic approach was used to develop a model for estimation of shearing stress and bending stress in barley straw with model accuracy ranging from 71.4 to 88.9% (Mahdavian *et al.*, 2012).

There is no study on the influence of moisture content and the loading rate on some engineering properties of wheat straw at the time of maturity stage and reliable model to estimate these properties using soft computing technology. Therefore, the objective of present study was to design a fuzzy algorithm to estimate the shear, bending strength and young's modulus of wheat straw based on the moisture content and loading rate at various internodes' position using fuzzy logic.

MATERIALS AND METHODS

The study was conducted during summer season (June to July, 2013) using Yang Mai 16 wheat varieties (a prevalent variety in China which is originally prepared by Yangzhou University, China). The wheat straws were collected at harvesting time from research farm of Nanjing Agricultural University, Nanjing, Jiangsu, China. All the experimental analyses were performed at Agricultural Material Characteristics Research Laboratory, College of Engineering, Nanjing Agricultural University. The internodes were divided considering their positions down from the ear internode positions and then were labeled as IN_1, IN_2 and IN_3 (first, second and third), respectively (Fig.1).

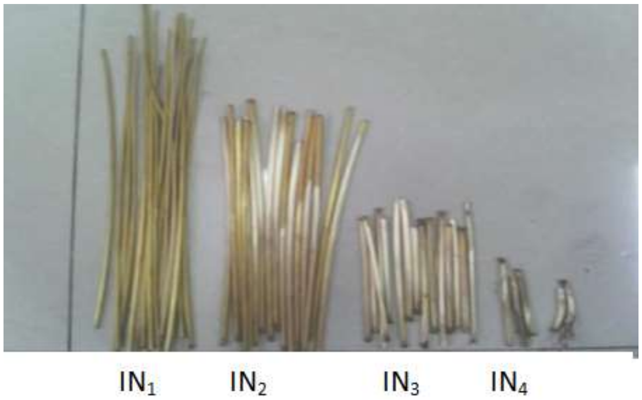

Figure 1. Internodes presentation of wheat straw.

The internode IN_4 and IN_5 represent the stubble of wheat plant and mostly left in field hence were not used in the experiment. Before any experimental analysis entire leaf blades and sheaths were taken away as described earlier (Annoussamy *et al.*, 2000). Oven drying method was applied to find out the moisture content of wheat straw (ASAE, 2006). Three different levels of moisture content, MC, (9.5, 15.1, 22.8% w.b) and loading rate, LR, (10, 20 and 30 mm min^{-1}) were used throughout the study period. The properties of wheat straw were measured through TMS- Pro machine (Fig. 2) using lab texture pro-computer program for data acquisition with using load cell having capacity up to 1000 N for accuracy 5%. To measure shear properties of wheat, similar shear test (Ince *et al.*, 2005; Galedar *et al*., 2008; Tavakoli *et al.*, 2009a,b,c ; Zareiforoush *et al*., 2010) was used and a bending test (Crook and Ennos, 1994; Galedar *et al*., 2008; Tavakoli *et al*., 2009a,b; Zareiforoush *et al.*, 2010) was used to measure bending strength of wheat straw.

The shear box made of steel having dimensions of 130 × 90 × 25 mm (Fig. 2A) was attached within compressive testing machine. The shear box has six holes of 2 to 7 mm for the passage of straw internode between the plates (Chandio *et al.*, 2013). Three loading rate, LR (10, 20 and 30 mm min^{-1}) were applied on the sliding plate. The shear force was computed by S-type load cell and a force-time was recorded up to the specimen failure of straw in shear test. The following equation was used to calculate the ultimate shear strength, τ_s, (shear failure stress) of the specimen (Tavakoli *et al.*, 2009b; Zareiforoush *et al.*, 2010).

$$\tau_s = \frac{\mathbf{Fs}}{2A} \qquad (1)$$

Where, Fs = Shear force at failure (N), A = The wall area of the specimen at the failure cross-section (mm) .

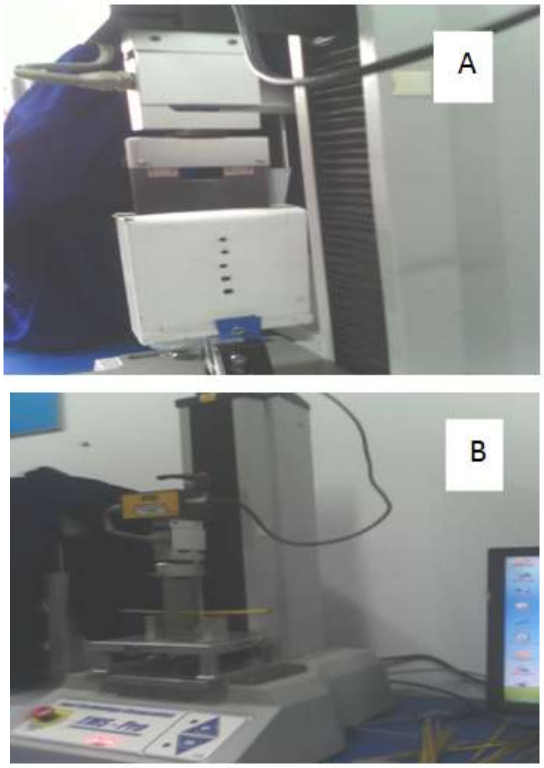

Figure 2. TMS-Pro texture analyzer testing machine used to measure: (A) shear strength, (B) bending strength of wheat straw.

Bending test was conducted to measure the force at failure section of straw at three loading rates (10, 20 and 30 mm min^{-1}). Bending strength and Young's modulus were then calculated by measured force. The straw was positioned on two rounded, 55 mm apart metallic supports and then loading plate developed load in the middle of the supports (Fig.2b) (Tavakoli *et al.*, 2009a and c). The straw specimens were considered little extent elliptical in cross-section. The second moment of area, I_b, in bending was articulated by following expression (Gere and Timoshenko, 1997):

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

The bending strength σ_b was calculated by the following equation (Crook and Ennos, 1994; Gere and Timoshenko, 1997):

$$\sigma_b = \frac{F_b a l}{4 I_b} \qquad (3)$$

The following equation was used to determine the Young's modulus, E (Gere and Timoshenko, 1997):

$$E = \frac{F_b l^3}{48 \delta I_b} \qquad (4)$$

Where, F_b = Bending force (N), E = Young's modulus (Gpa), I_b = Second moment of area (mm^4), a = Semi-major axis of the cross-section (mm), b = Semi-minor axis of the cross-section (mm), δ = Deflection in the straw spacimen (mm), l = Distance between the two metal supports (mm), t = wall thickness (mm)

The data were analyzed using a statistical program Statistix (version 8.1, Analytical Software, Tallahessee, USA). A completely randomized 3^3 factorial experimental design was used by keeping moisture content, loading rate and height regions as the independent variables and shear strength, bending strength and young's modulus as dependant variables. Least significant difference (LSD) test was used to determine the significant difference among means and pair wise comparisons at 5% probability level.

***Fuzzy model development*:** The MATLAB 7.10 (fuzzy logic toolbox) for MS Windows was used for the model development by executing the fuzzy set theory. Briefly, for the prediction of shear strength, bending strength and Young's modulus of wheat straw, the moisture content, internodes and loading rates were used as input variables in fuzzy interface system (FIS) (Fig. 3).

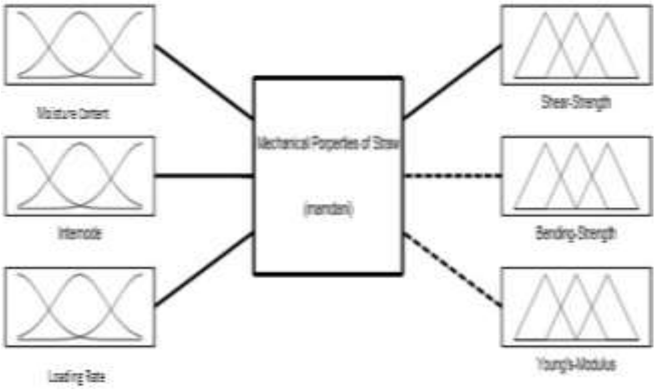

Figure 3. Fuzzy interface system structure.

For input and output mapping mamdani max–min inference system was used and the linguistic inputs very low, low, middle, high and very high denoted by VL, L, M, H and VH respectively were used for the fuzzification of these factors. Fuzzy set is the base of Fuzzy logic and an addition of a classical set which was earlier defined (Zadeh, 1965) as if X is set of all elements; x denotes all elements and the universe of discourse, and then a fuzzy set A in X.

$$A = \{x, \mu A(x) \mid x\ X\} \qquad (5)$$

Where, $\mu A(x)$ is the membership function (or MF) of x in A. The membership function map of each constituent of X was membership value that varied between 0 and 1.The triangular form membership functions (trimf) were used for both independent and dependent variables in fist step of fuzzify input (Fig. 4 and 5). Quantity of membership functions selection and their preliminary values depend on the existence knowledge and the experimental situations. The triangular curve is a function of a vector, x, which depend on three scalar variables a, b and c.

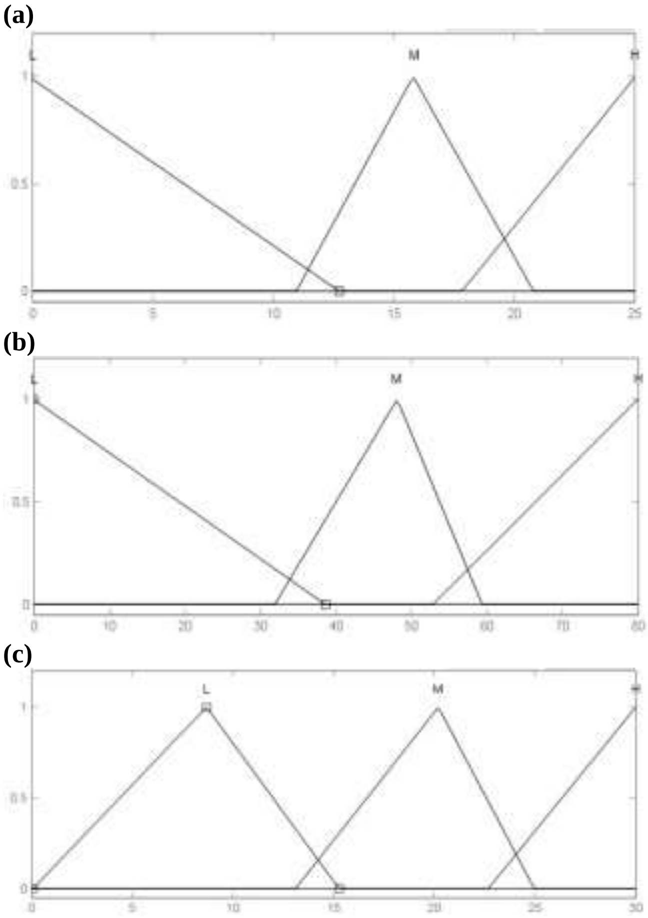

Figure 4. The membership functions of input variables: (a) Moisture content membership function, (b) Internodes membership function, (c) Loading Rate membership function.

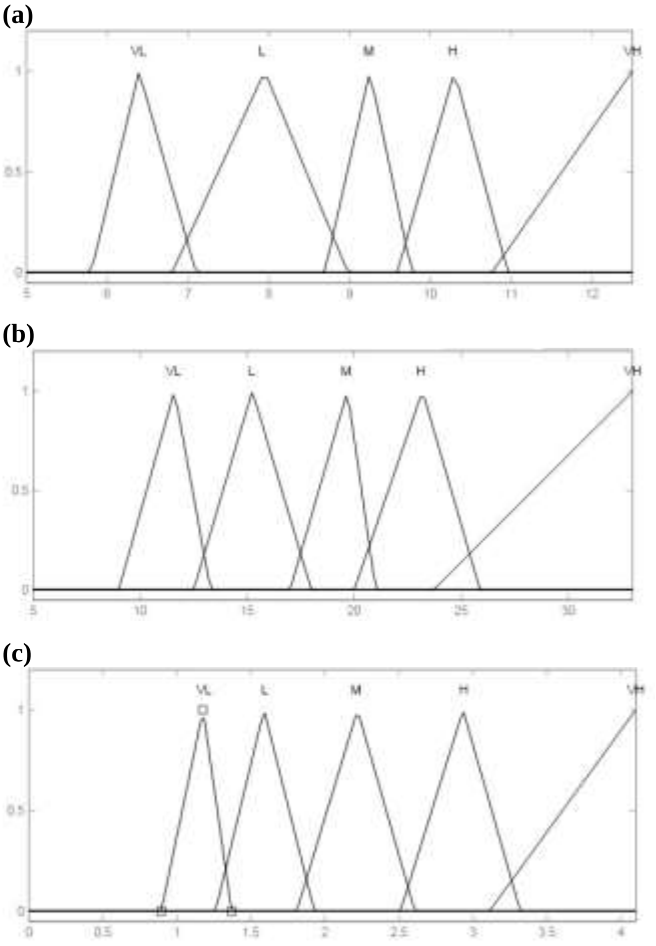

Figure 5. The membership functions of output variables: (a) Shear strength membership function (b) Bending Strength membership function (c) Young's modulus membership function.

The following equation represents the triangular membership function mathematically (Zadeh, 1965).

$$f(x;a,b,c)=\begin{Bmatrix} 0, & x\le a \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ \dfrac{c-a}{c-b}, & b\le x\le c \\ 0, & c\le x \end{Bmatrix} \quad (6)$$

The equation (6) in a more compacted form can be written as

$$f(x;a,b,c)=\max\left[\min\left[\frac{x-a}{b-a},\frac{c-x}{c-b}\right],0\right] \quad (7)$$

The a and c parameters were at the feet of the triangle whereas b parameter was at the peak of the triangle. Fuzzy logic is based on the themes of fuzzy sets and fuzzy operators. Fuzzy logic contains the conditional statements which were formulated by If-Then rule statements. A single fuzzy If-Then rule supposes the form:

IF x is A THEN y is B (8)

Where, A and B are linguistic values defined by fuzzy sets on the ranges (UoD) X and Y, respectively. The antecedent or premise section consists on The If-Then part of the rule "x is A", while the then-part of the rule "y is B" is known as consequent or conclusion. In general, rules can be written in combined form, that is:

R_i: IF x_i is A_i AND y_i is B_i THEN z_i is C_i (9)

Where, i = 1, 2, n (n is the number of the rules). A_i, B_i and C_i are the fuzzy sets for the inputs (x_i & y_i) and the output z_i, respectively in the i-th rule, R_i. The values of Ci are the linguistic terms (Mamdani and Assilian, 1975). A total of 27 rules were generated using IF and Then rules. Parts of Fuzzy rules are presented in the Table 1. The units of the used factors were: Moisture content (%), internodes (cm), loading rate (mm/min^{-1}), shear strength (MPa), shear strength and Young's modulus (GPa). The crisp values of output variables were determined from the aggregate output fuzzy set in the

Table 1. Fuzzy inference system rules.

Rule	Input variables						Output variables		
	Moisture content		Internodes		Loading rate		Shear strength	Bending strength	Young's modulus
Rule 1	L		H		L		VL	VH	VH
Rule 2	L		H		M		VL	VH	VH
Rule 3	L	And	H	And	H	Then	VL	H	VH
Rule 25	H		L		L		VH	VL	VL
Rule 26	H		L		M		VH	VL	VL
Rule 27	H		L		H		VH	VL	VL

last step of FIS implementation. In this study, a common center of gravity (COG) method was used for executing the defuzzification step. Defuzzification is the method of generating a quantifiable outcome in fuzzy logic. The extended information of independent variables and dependent variables and used methodology in each step of Fuzzy Inference System (FIS) execution to develop model are presented in Table 2.

Table 2. Particulars of executed methods in FIS implementation.

Number of inputs	3
Number of outputs	3
Number of rules	27
and Method	'min'
or Method	'max'
Implication method	'min'
Aggregation method	'max'
Difuzzification method	'centroid'

RESULTS

The mean values for mechanical properties of wheat straw (yang mai 16: variety) are presented in Table 3. The effect of moisture content, loading rate and stem level on wheat straw mechanical properties was significant ($p<0.05$). The detailed results are described below.

Shear strength**:** The results of present study indicate that the wheat straw shear strength (yang mai 16 variety) was significantly ($P<0.05$) influenced by the wetness level, loading rates and internodes positions. The interactional effects of MC × LR, MC × IN, IN × LR and MC × LR × IN on shear strength were not significant ($P>0.05$). The mean values of shearing strength were 7.010, 9.394 and11.319 MPa for moisture content 9.5, 15.1 and 22.8 %, respectively (Table 3**)**. The interactional effect of the MC and internode position on τ_s is presented in Fig. 6. The shear strength increased from 6.275 to 10.713, 7.126 to 11.738 and 7.63 to 11.868 MPa for the first, second and third internode with the increase in moisture contents from 9.5 to 22.8%.

Table 3. Effect of moisture content, loading rate and internode position on mechanical properties of wheat straw.

Factors	Levels	Means of shear strength (MPa)	Means of bending strength (MPa)	Means of Young's modulus (Gpa)
Moisture content %	9.5	7.010^{c}	21.021^{a}	2.496^{a}
	15.1	9.394^{b}	17.392^{b}	2.052^{b}
	22.8	11.319^{a}	13.079^{c}	1.817^{b}
Loading rate mm/ min	10	9.065^{b}	18.841^{a}	2.342^{a}
	20	9.215^{ab}	17.590^{b}	2.150^{ab}
	30	9.443^{a}	15.062^{c}	1.874 ^{b}
Internode positions	IN1	8.669^{a}	21.944^{a}	3.210^{a}
	IN2	9.306^{b}	15.353^{b}	1.747^{b}
	IN3	9.747^{c}	14.195^{b}	1.409^{b}

Mean values sharing the same superscript letter, for a factor, in a column do not differ significantly at p = 0.05.

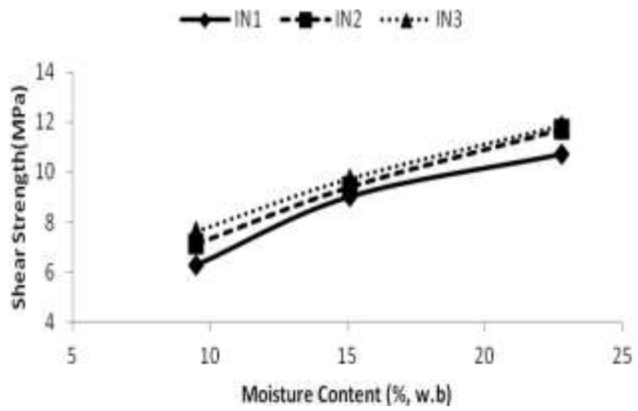

Figure 6. Effect of moisture content on shear strength of wheat straw at different internode.

The interactional effect of the loading rate and internode position on τ_s is presented in Fig.7. The mean values of the shear strength at loading rates 10, 20 and 30 mm/min were 9.065, 9.215 and 9.443 MPa respectively (Table 3) expressed significant increase ($P<0.05$) with an increase in the LR

(8.481 to 8.856, 9.171 to 9.473 and 9.519 to 9.999 MPa) for first, second and third internode position.

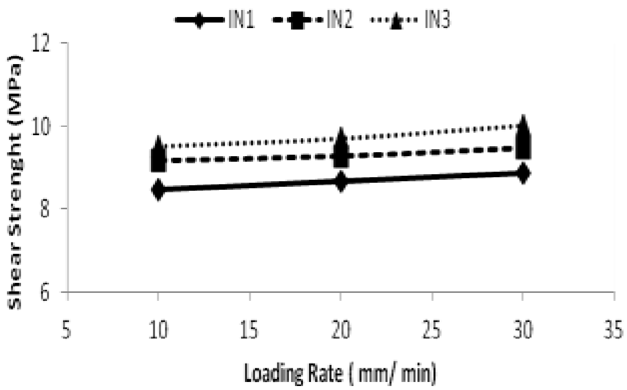

Figure 7. Effect of loading rate on shear strength of wheat straw at different internode.

***Bending strength*: ** The interaction of moisture content and internode position on the bending strength has been presented in Fig. 8. The bending strength is significantly ($P< 0.05$) influenced by MC, LR and internode positions. The mean values of bending strength at moisture contents; 9.5, 15.1 and 22.8% were 21.021, 17.392 and13.079 MPa, respectively (Table 3). The bending strength decreased from 29.132 to 14.818, 17.62 to 12.77 and 16.311 to 11.65 MPa for IN_1, IN_2 and IN_3 as the moisture content changed from 9.5 to 22.8%.

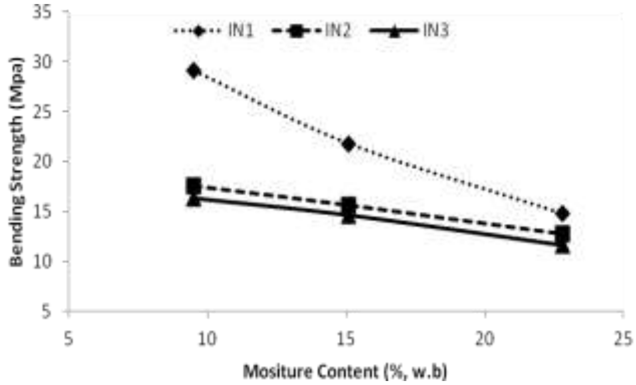

Figure 8. Effect of moisture content on bending strength at different internode.

The bending strength was affected significantly ($p<0.05$) by MC and its levels. The interaction effect of the LR and internode position on the bending strength has been shown in Fig. 9. The mean values of the, σ_b ,bending strength were 18.841,17.590 and 15.062 MPa at loading rate 10, 20 and 30 mm/min, respectively in the current study (Table 3) which showed a significant ($P<0.05$) decrease in bending strength (23.160 to 20.512, 17.343 to 12.706 and 16.02 to 11.966 MPa) for IN_1, IN_2 and IN_3. The second and third internode positions had significantly lower values ($P<0.05$) than the first internode position in present study. The interaction effects between moisture content and internode on bending strength was significant ($P<0.05$) whereas the interaction effects of MC × LR, , internode position × LR and MC × LR × internode position on bending strength were not significant ($P>0.05$).

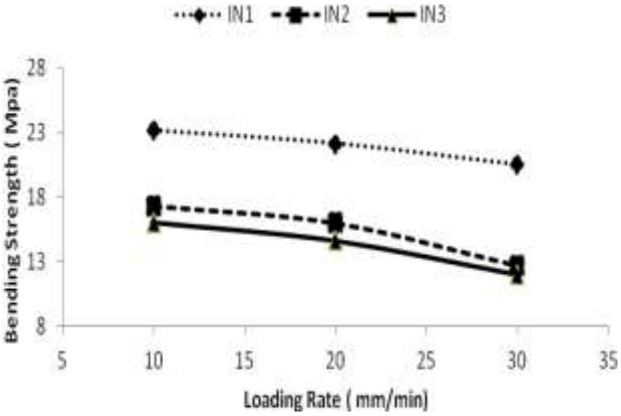

Figure 9. Effect of loading rate on bending strength of wheat straw at different internode.

***Young's modulus*: ** Moisture content, loading rate and internode position significantly ($P<0.05$) influenced the Young's modulus of wheat straw in present study. A decreasing trend of the young's modulus was also observed with the raise in moisture content for all stem level. The interactional effect of the moisture content and internode position on the young's modulus is presented in Fig. 10. The mean values of Young's modoulus were 2.496, 2.052 and 1.817 GPa at moisture content 9.5, 15.1 and 22.8 % respectively (Table 3). The values of Young' modulus decreased from 3.681 to 2.868, 2.005 to 1.533 and 1.801 to 1.049 GPa for the IN_1, $\text{IN}_2$and IN_3 as MC increased from 9.5 to 22.8%.

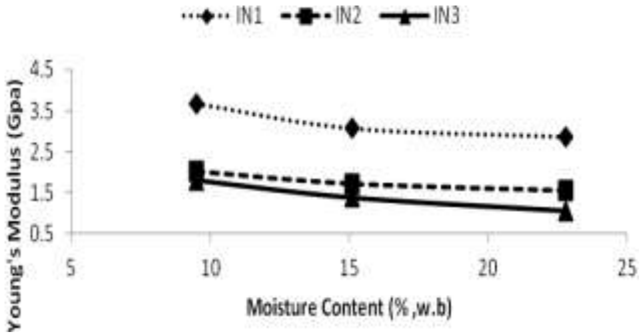

Figure 10. Effect of moisture content on young's modulus of wheat straw at different Internode.

The mean values of the Young’s modulus were 2.342, 2.150 and 1.874 GPa when the LR was 10, 20 and 30 mm/min (Table 3). It was viewed that the Young’s modulus of the straw reduced significantly ($P < 0.05$) with an addition in the LR from first to third internode position. The Young’s modulus decreased from 3.362 to 2.975, 2.085 to 1.471 and 1.577 to 1.179 GPa for the IN_1, IN_2 and IN_3 internode by increasing from 10 to 30 mm/min. The interaction effect of the loading rate and internode region on the bending strength is shown in Fig. 11. Furthermore, the effect of the internode position remained significant at 5% probability level in present study. The value of the Young’ modulus decreased from first internode to the third internode. The average values of Young’s modulus were 3.210, 1.747 and 1.409 GPa for IN_1, $IN_2$and IN_3 internode. The interaction effects of MC× LR, internode × MC, internode × LR and MC × LR × internode on Young’ s modulus were significant (P>0.05).

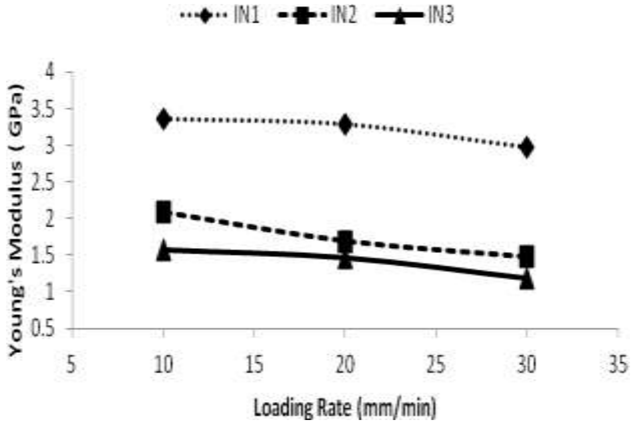

Figure 11. Effect of loading rate on young’s modulus of wheat straw at different internode.

***Fuzzy model*:** A fuzzy knowledge based model was developed using input variables (moisture content, internodes positions and loading rate) and dependent factor (shear strength, bending strength and Young’s modulus). The results of FIS execution for prediction of independent –dependent variables relations for wheat straw are shown in Fig. 12. These surfaces were obtained from the spatial interpretation of fuzzy “IF-THEN” rules using test data. The fuzzy rule assessment, the comparison between FIS results and experimental results has been shown in Fig. 13. The correlation within measured and predicted values of shear strength, bending and young’s modulus in different moisture and loading conditions was given in Fig. 14. A significant positive correlation coefficient was found in shear strength, bending strength and young’s modulus 0.959, 0.917and 0.750, respectively.

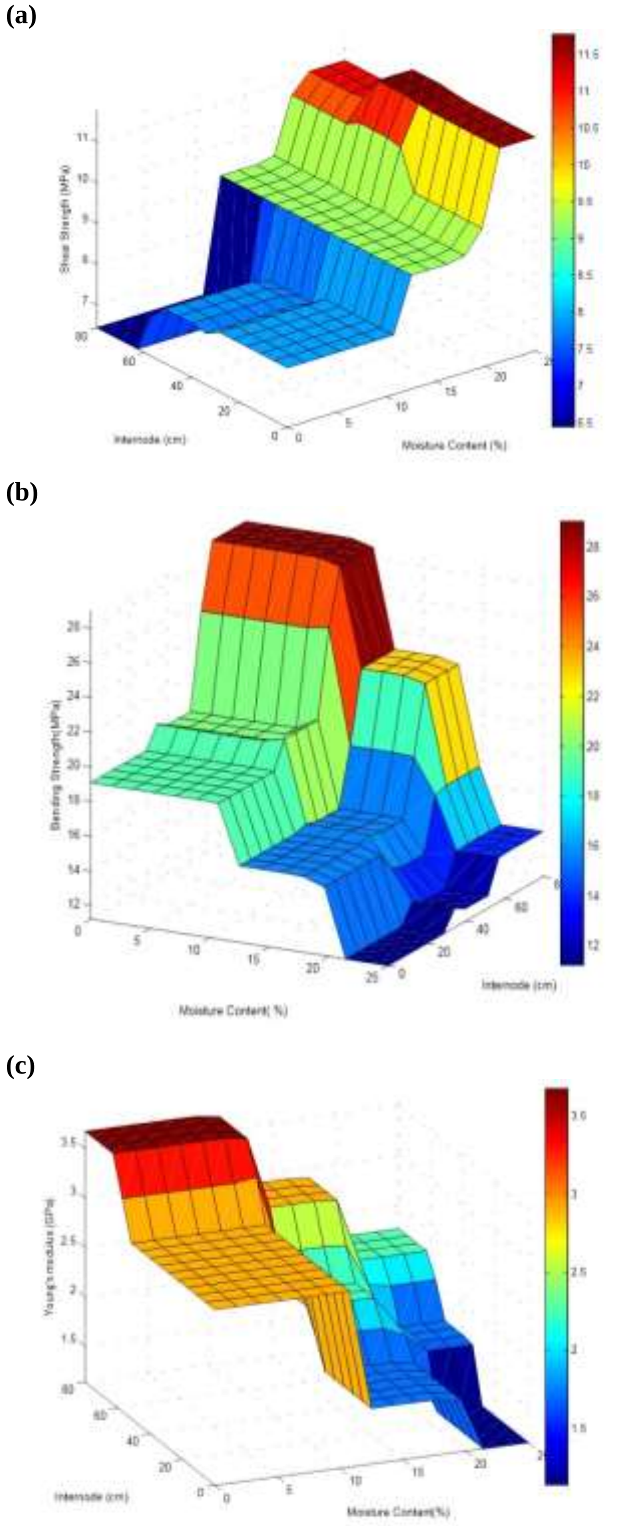

Figure 12. Evaluation surface for (a) shear strength (b) Bending Strength (c) Young’s Modulus of wheat straw by FIS.

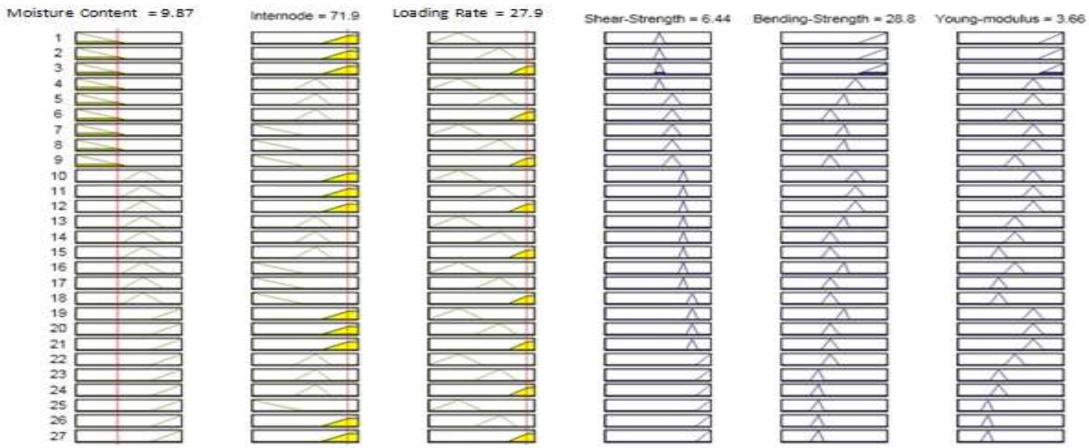

Figure 13. Fuzzy rules assessments in MATLAB software.

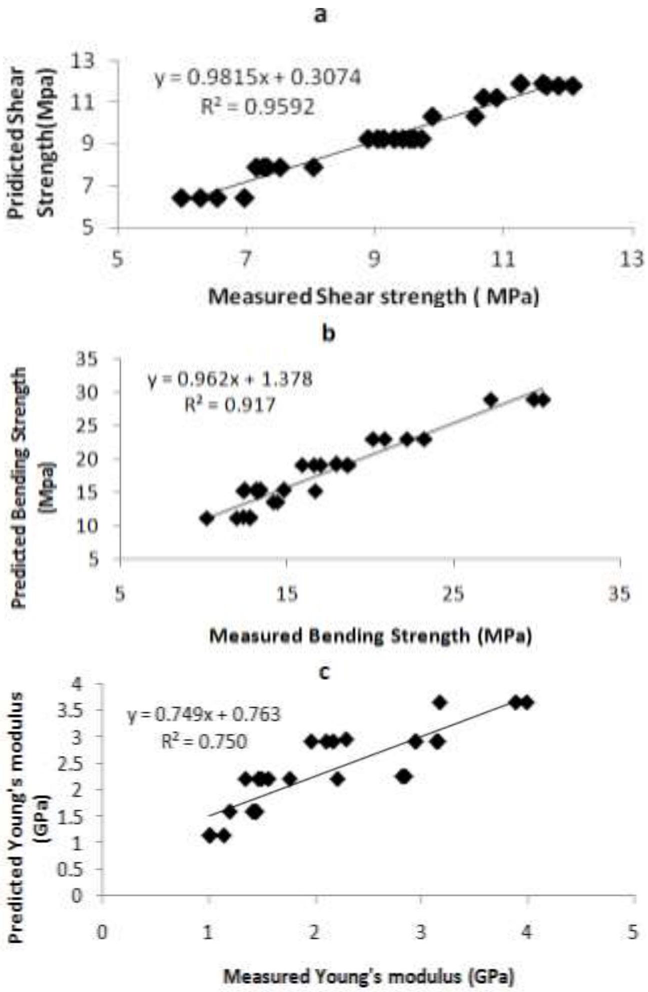

Figure 14. Relationship between measured and predicted values of: (a) shear strength, (b) bending strength and (c) young's modulus of wheat straw.

DISCUSSION

The study indicated that the shear strength rose towards the IN_3 internode position (Table 3). Moreover, it has been observed that the wheat straw shear strength increased with increase of moisture content for all internode positions. This observation is in agreement with previous reports on mechanical properties of wheat straw (Annoussamy *et al.*, 2000; Galedar *et al.*, 2008; Esehaghbeygi *et al.*, 2009). Similar pattern was also reported in wheat straw of Iranian variety (Tavkoli *et al.*, 2009c). The results related to the interactional effect of the moisture content and internode position on the shear strength are also consistent with previous studies on sunflower stalk (Ince *et al.*, 2005), alfalfa stem (Galedar *et al.*, 2008), barley straw (Tavakoli *et al.*, 2009b) and safflower stalk (Shahbazi and Galedar, 2012). The effect of loading rate on shear strength has been reported in cotton stalk (El Hag *et al.*,1971), barley straw (Tavakoli *et al.*, 2009a) and rice straw (Zareiforoush *et al.*, 2010) and showed similar increasing trend as in present study. For rice straw (Zareiforoush *et al.*, 2010) studies concluded that the average shear strength varied from 12.18 to 20.22 MPa by changing loading rate from 5 to 15 mm/min.

With the increase in moisture content a decreasing trend of bending strength was observed from first towards third internode which indicate a reduction in the fragility of the stalk with increase of moisture contents. A similar trend has also been reported previously in wheat straw (Annoussamy *et al.*, 2000). Likewise Tavakoli *et al.* (2009c) reported that increasing moisture content from 10.24 to 22.61% at loading rate 10 mm/min from first to third internode led to a decreased bending strength; 19.31 to 8.92 MPa in wheat straw. This effect of moisture content on bending strength has also been documented in other plant species like sunflower stalk (Ince *et al.*, 2005), alfalfa stem (Galedar *et al.*, 2008), barley straw (Tavakoli *et al.*, 2009a) and safflower stalk, (Shahbazi and Galedar, 2012). Change in bending stress with loading rate was observed in barley and rice straw and showed the similar trend (Tavakoli *et al.*, 2009a; Zareiforoush *et al.,* 2010).

The reduction of the Young's modulus with the enhancement of moisture content and for all regions of straw has been reported earlier (O'Dogherty *et al.,* 1995; Tavakoli *et al.,* 2009c). Results of sunflower stalk (Ince *et al*., 2005), alfalfa stem (Galedar *et al.*, 2008), barley straw (Tavakoli *et al.*, 2009b) and safflower stalk (Shahbazi and Galedar, 2012) also showed the similar decreasing trend. Influence of loading rate on Young's modulus has also been reported by Tavakoli *et al.* (2009a) for barley straw. The value of Young's modulus was reported by Zareiforoush *et al.* (2010) in rice straw which ranged from 0.21 to1.38 GPa at loading rates of 5 -15 mm/min.

The results are in agreement with wheat straw, sunflower stalk, alfalfa stem and barley straw, safflower stem which were reported by O'Dogherty *et al*. (1995) , Ince *et al*. (2005), Galedar *et al.* (2008), Tavakoli *et al.* (2009a) and Shahbazi and Galedar (2012), respectively.

The developed Mamdani min- max model using fuzzy interface system (FIS) can be used to predict the shear strength, bending strength and Young's modulus in wheat straw. The correlation results were in agreement with other fuzzy models developed by Mahdavian *et al.* (2012) for barley and Zareiforoush *et al.* (2012) for rice.

Conclusions**:** The present study was aimed to develop a knowledge based fuzzy logic algorithm for shear strength, bending strength and Young's modulus for wheat straw under different moisture content and loading rate. Based on results, it is concluded that the shear strength increased with increase in the moisture content and towards the lower regions at all loading rate. Bending strength and Young's modulus decreased with the increase in loading rate toward third internode. Loading rate significantly affect the shear strength, bending strength and Young's modulus of the wheat straw.

The developed Mamdani min- max model using fuzzy interface system (FIS) can be used to predict the shear strength, bending strength and Young's modulus in wheat straw. The correlation coefficient for shear strength, bending strength and young's modulus was found 0.959, 0.917 and 0.75, respectively. Based on evaluation norms of envisaged performance of designed fuzzy knowledge-based algorithm was established to be legitimate. The developed model can be used for instrument actions based on the artificial intelligence system and can also be used as a reference for further study. Furthermore, neural network addition to the system along with increasing the knowledge rules one, the model can be advanced. The results of this study may be supportive to design the control systems for the crop harvesting equipment and for other industrial usage.

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