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Experimental and Theoretical Investigation of the Effects of Moisture Content and Internodes Position on Shearing Characteristics of Sugar Cane Stems

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ABSTRACT

In the present study, shearing properties of sugar cane stems were determined at five moisture content levels (46, 54, 62, 70 and 78% wb), three shearing speed (5, 10 and 15 mm min^{-1}) and at ten positions on the stem. For measuring the shearing forces, the stems were severed by using a computer aided cutting apparatus. Decrease in moisture content of stem from 78 to 46% wb led to 16.3 and 16.7% decrease in the shearing strength and specific shearing energy, respectively. The maximum and average values of shearing strength of the two moisture contents were found to be 3.482 and 3.1 MPa, and the specific shearing energies were 112 MJ mm^{-2} and, 102.6 MJ mm^{-2}, respectively. Both the shearing strength and the specific shearing energy were found to be higher in the lower region of the stem due to structural heterogeneity. Results showed that with the increase in shearing speed from 5 to 15 mm min^{-1}, shearing strength and the specific shearing energy increased 3.2 and 4.6%, respectively. The results of ANOVA indicated that effects of the mentioned factors were significant at 1% probability level. The shearing model assessment revealed that the third order polynomial model exhibited the best performance in fitting with experimental data and, by using this model, a significant correlation was found between shearing strength, specific shearing energy, and moisture content (R^2= 0.989 and SE= 0.001). Also, a significant correlation was found between shearing strength, specific shearing energy, and shearing speed by using Hoerl model (R^2= 0.989 and SE= 0.005).

Keywords: Mechanical properties of stem, Shear strength, Specific shearing energy, Sugar cane.

INTRODUCTION

Sugar cane, an excellent source of sugar, is an important crop producing in Iran. Information on the physical-mechanical properties of sugar cane stem is important for the design of machines. Increasing interest in harvesting and commercial use of sugar cane has prompted the need for engineering data on stem properties. (Persson, 1987) reviewed several studies on the shearing speed and concluded that cutting power is affected only slightly by shearing speed. Hence, it is necessary to determine the physical–mechanical properties such as the shearing stress and energy requirements for suitable knife design and operational parameters (Ince *et al.*, 2005). Lee and Yan (1984) investigated the shear force of rice stem at 50 mm min^{-1}. Also, they determined the relationship between spikelet attachment force and moisture content of two rice varieties. Measurement of the shear strength of six varieties of wheat straw by O'Dogherty and Huber (1995) showed mean values in the range of 5.4–8.5 MPa. Chen *et al.* (2004) found that the average values of the

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maximum force and the total cutting energy for hemp were 243 N and 2.1 J, respectively. Summers *et al*. (2002) investigated cutting properties of rice straw near the nodes. Diameter, weight, length and moisture of stem were measured and shearing force was determined. Results of their study showed that cutting place and number of stems affected cutting process. Influence of moisture content and nodes in stem on the mechanical properties of alfalfa was studied by Nazari Gelehdar *et al.* (2008). Results of their study proved that with increase in moisture content, shearing strength decreased and, also, by selecting nodes at high levels of the crop stalk, shearing strength decreased because of decrease in stem diameter. Hosseinzadeh *et al*. (2009) determined effect of three varieties of wheat and knife bevel angles, four levels of moisture content, and three shearing speeds of pendulum on the specific shearing energy of wheat straw. Results showed that the effects of variety, knife bevel angle, moisture content, and shearing speed on specific shearing energy were significant ($P< 0.01$). Specific shearing energy decreased with decreasing moisture content and bevel angle and with increasing shearing speed. Esehaghbeygi *et al.* (2009) reported that the shearing stress of wheat stems decreased as the moisture content decreased while the shearing force of stems decreased as the cutting height of stalk increased, because of a reduction in stalk diameter. In another research, Esehaghbeygi and Hosseinzadeh (2009) considered effect of three varieties, three nitrogen fertilizer levels (250, 400 and 550 kg ha^{-1}) and four moisture content levels (35, 43, 50 and 57%) on specific shearing energy using pendulum method. They found that the specific shearing energy increased as the moisture content decreased and amount of nitrogen fertilizer increased. Also, by using quasi-static method, Esehaghbeygi *et al.* (2010) reported that the amount of nitrogen fertilizer and variety affected canola shearing strength. The main objective of the present study was to determine the shearing strength of sugar cane stems, which can be used to determine power requirements associated with harvesting machine.

MATERIALS AND METHODS

The research was conducted in order to determine the shearing strength and the shearing energy of sugar cane stems as a function of moisture content, shearing speed, and level of the crop stalk.

Moisture content of stem can influence harvesting time, accordingly, based on existing references, five levels of moisture content in the range of 46 to 78% were considered (Kardany, 2008). O' Dogherty and Huber (1995), Hosseinzadeh *et al.* (2009), Mobli *et al.* (2003), and Tabatabaee Koloor and Borgheie (2006) expressed the importance of the speed factor on the shearing strength of stems. According to previous studies, the selected levels of speed were 5, 10, and 15 mm min^{-1}.

Stem diameter of sugar cane decreases towards the top of the plant, which means that the stem shows different physical-mechanical properties at different heights due to cross-sectional heterogeneity.

Considering the importance of stem diameter and cutting height on the shearing strength, these factors were selected for experimental study (Hosseinzadeh, 2008; Nazari Galedar *et al.*, 2008).

Therefore, the stem was divided equally into 10 height regions with 10 nodes to determine the variability of the mechanical properties on the stem length and measurements were made on each section with standard length. The test samples were selected from Ahwaz Farm randomly (Ahwaz is the capital of Khuzestan Province, located in the southwest of Iran, at 31.24 N latitude and 48.49 E longitude). To determine the average moisture content of the sugar cane, the stem samples gathered from the field were weighted and dried at $103^{\circ}C$ for 24 hours in the oven and then reweighed (ASABE, 2006). A complete randomized design was used in a factorial

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experiment with five replication using the SAS9.1 and MINITAB15 statistical packages. Means were compared using LSD tests ($P< 0.05$). The values of independent variables discussed in the study are detailed in Table 1. The shear strength was measured in double shear using a shear box consisting essentially of two fixed parallel hardened steel plates 6 mm apart, between which a third plate could slide freely in a close sliding fit. A series of holes with diameters ranging from 15 to 25 mm were drilled through the plates to accommodate samples of differing diameter. Shear force was applied to the specimens by mounting the shear box in the tension/compression testing machine (vers.5, SMT Machine Linker, SANTAM Company) as described in Figure 1. The sliding plate was loaded at the recommended range and, as for the shear test, the applied force was measured by a strain–gauge load cell and a force–time record was obtained until the specimen failed. The shear failure stress (or ultimate shear strength), of the τ_s specimen was calculated from Equation (1).

$$\tau_s = \frac{F}{2A} \tag{1}$$

Where, τ_s is shear stress (N cm^{-2}), F is shearing force (N), and A is effective area (cm^2).

The shearing energy was calculated by using the area under the shearing force versus displacement curve. One example of the force versus displacement curve is shown in Figure 2. The curve illustrates three sections: A, B and C. In section A, at

Table 1. Dependent and independent variables studied in the research.

Dependent variables	Independent variable	Values
Shearing strength	Moisture content (%)	78, 70, 62, 54 and 46%
Shearing energy	Shearing speed	5, 10 and 15 mm min^{-1}
	Inter node position	1,2,3,…,10

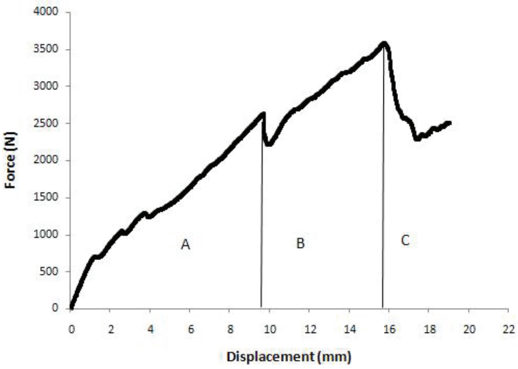
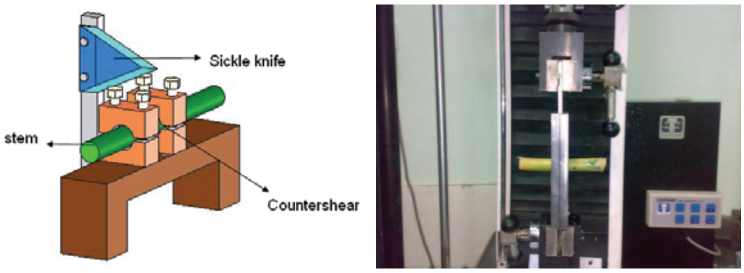


Figure 1. A typical force-displacement curve obtained from a sample having 78% moisture content (wb.).



(a) (b)

Figure 2. (a) Apparatus for measuring shear strength, (b) Apparatus for measurement of shearing force (vers.5, SMT Machine Linker, SANTAM Company) located in the Agricultural Faculty of Tehran University.

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the moment of knife contact with the stem, the force increased from zero until the collapse of the hollow core. Due to this failure in stem structure, the force decreased. As the knife moved, the cutting continued in the section C, and, then, the force decreased since the cutting was completed.

The sections A, B, and C denote, respectively, compression only, compression and cutting, and cutting only.

Shearing energy of some sugar cane stems was determined by dynamic method to compare the results with quasi-static method as shown at Figure 3. Shearing energy requirement was measured using the pendulum method by which, energy and knife velocity in its lowest position quantities were obtained using the theoretical Equations (2) and (3) (Persson, 1987; Chancellor, 1988; Esehaghbeigy and Hosseinzadeh, 2009). In the preliminary tests, the shearing device satisfied all conditions in which the equation was originally derived.

$$V = \omega.L = \sqrt{\frac{2.W_t.R(1-\cos[(\alpha_0)]}{I}\times L} \qquad (2)$$

$$E = W_t.R(\cos\alpha_c - \cos[(\alpha_0)] \qquad (3)$$

Where, V= Knife velocity in its lowest position (m s^{-1}); ω= Impactor angular velocity (rad s^{-1}); L= Length of swinging arm (m); W_t= total weight of swinging arm (N); R= Center of gravity of the swinging arm from the center of rotation (m); I= Moment of inertia of the swinging arm about the center of rotation (kg m^2); α_0 = Angular displacement from the vertical base line in a free swing (deg), and α_c= Angular displacement from the vertical base line after impact (deg)

Initial test results showed that the changes were identical in both methods and, given that in the quasi-static method loading rate is low, the number of output data increases, therefore, the process of stems cutting at different positions could be applied accurately. According to this procedure, quasi-static approach was chosen in this study.

Artificial Neural Network

Artificial neural network (ANN) was used to predict the shear strength and shearing energy of canola stem versus the different evaluated factors, namely, stem moisture content, cutting speed, and inter node position. The back-propagation algorithm was used for training of all ANN models. To obtain the best prediction by the network, several architectures were evaluated and trained using the experimental data. Several transfer functions including sigmoid, logarithmic and linear functions together with supervised training algorithms and feed forward back propagation approach were evaluated. To ensure that each input variable provided an equal contribution to the ANN, the inputs of the model were preprocessed and normalized, after which, 70 and 15% of 150 input patterns were devoted to training and validation of the data sets, respectively. The remaining part of the data was used for prediction. The learning rate of 0.2 and momentum of 0.1 were adjusted to all the tested networks. Optimum topologies were defined based on the highest R^2 and lowest *MSE* values. The complexity and size of the network was important, hence, the smaller

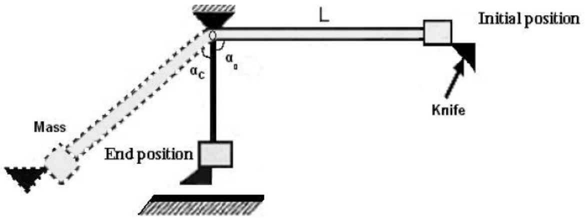

Figure 3. The pendulum impact testing of stem shear**.**

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ANNs had the priority to be selected. The required codes were developed by MATLAB 2010 software.

RESULTS AND DISCUSSION

The results of ANOVA indicated that effects of the moisture content, shearing speed, and level in the crop, were significant at 1% probability level (Tables 2).

Moisture Content

Analysis of the obtained data revealed that among the three quantitative variables, namely, moisture content, shearing speed, and sampling level in the crop, the dominant factor affecting the shearing force of the stem was moisture content. Shearing strength and specific shearing energy increased with an increase in stem moisture content. In Table 3, shearing strength and specific shearing energy are 3.482 MPa and 107.4 mJ mm^{-2}, respectively, at 78% moisture. This is significantly more than the corresponding data at 46% moisture (around 16.5 times). This conclusion was consistent with the findings of Esehaghbeygi *et al.* (2009) who reported that the specific shearing energy increases and bending stress and Young's modulus of canola stems decreased as the moisture content increased. Nazari *et al.* (2008), Persson (1987), and Lee and Yan (1984) studied the effect of moisture content on some physical-mechanical properties of different crops and reported that, as the moisture content increased, the shearing strength and specific shearing energy increased, similar to the results of the present study.

Shearing Speed

The results of ANOVA indicated that effect of the shearing speed was significant at 1% probability level. Shearing strength and specific shearing energy increased with

Table 2. Variance analysis of specific shearing energy and shear strength.

	specific shearing energy			shear strength.		
Source of change	*DF*	Sum of squares	*MSE*	*DF*	Sum of squares	*MSE*
moisture content	4	28818.500	7204.600 **	4	30.153	7.538 **
shearing speed	2	2594.200	1297.100 **	2	1.688	0.844 **
Inter node position	9	51863.500	5762.600 **	9	11.979	1.331 **
Moisture content × Shearing speed	8	1150.400	143.800**	8	1.147	0.143 **
moisture content × Inter node position	36	1617.000	44.900*	36	1.308	0.036 **
shearing speed × Inter node position	18	582.300	32.400 ns	18	0.504	0.028**
Error	672	19478.200	29.000	672	13.126	0.019
Total	749	106104.000		749	59.908	

* and ** significant at 1 and 5% level, respectively. ns: Non significant.

Table 3. Effects of moisture content on the shearing strength and specific shearing energy.

Moisture content (wb)	Shearing strength (MPa)*	Specific shearing energy (mJ mm^{-2})
46%	2.988±0. 165 d	92.112±9.045 d
54%	3.104±0. 234 c	95.651±10.180 c
62%	3.318±0.194 b	102.320±10.120 b
70%	3.487±0. 201 a	107.556±10.790 a
78%	3.482±0. 195 a	107.477±10.610 a

* Different letters in each column shows significant difference at 1% probability level (LSD).

Table 4. Effect of the shearing speed on the shearing strength and specific shearing energy.

Shearing speed (mm min^{-1})	Shearing strength (MPa)*	Specific shearing energy(mJ mm^{-2})
5	3.237±0.154 b	98.841±9.483 c
10	3.248±0.155 b	100.768±9.597 b
15	3.343±0.158 a	103.405±9.702 a

* Different letters in each column show significant difference at 1% probability level (LSD).

an increase in shearing speed. As shown in Table 4, at speed of 15 mm min^{-1}, shearing strength and specific shearing energy were 3.343 MPa and 103.4 mJ mm^{-2}, respectively. This is more than the data at speed of 5 mm min^{-1}. This conclusion was consistent with the findings of Persson (1987) who reported that with increase in shearing speed the consumed energy for shear increased.

There was a strong relationship for sugar cane stem shearing force as a function of moisture content. The best regression model for shearing force F (N), based on shearing speed V (mm min^{-1}) and stem diameter D (mm) was identified Equation (4) as follows:

$$F = 2340 - 253.9D - 14.7V + 11.88D^2 + 0.8443D \times V \quad (R^2 = 90.1\%, \text{RMSE} = 150.1) \quad (4)$$

Measured and estimated shearing force values were compared and were found to be similar to each other (Figure 4).

Position on the Stem

Shearing strength and shearing energy of different positions on the stem of sugar cane were investigated. The values of shearing strength varied from 3.407 MPa at lower level to 3.059 MPa at the upper level of stem. The reason for this difference may be due to the decrease in stem diameter with increasing plant height. The specific shearing energy also decreased towards the upper regions, from 112.200 to 86.020 mJ mm^{-2}; it was greater in the lower levels probably because of the accumulation of more mature fibers in the stem. The values of the shearing strength and specific shearing energy were significantly (at the 0.01 probability level) affected by position on the stem, according to LSD test results (Table 5); these values were different from each other for the distinct stem regions. The linear regression model with determination coefficient of 0.91 and standard error of 149.6 was chosen as the best model for representing the relation between shearing force and diameter of stem.

Some researchers have stated that at higher positions, stem diameter decreases and, thus, the cutting force will reduce (Esehaghbeygi *et al.*, 2010; Hosseinzadeh, 2008; and Peykani *et al.*, 2010). The present study for sugar cane shows similar results.

Table 5. Effects of level (node positions) on the shearing strength and specific shearing energy.

Node position	Shearing strength (MPa)*	specific shearing energy(mJ mm^{-2})
1	3.407±0.153 f	112.205±8.112 j
2	3.388±0.175 ef	110.103±6.464 i
3	3.360±0.127 e	108.308±6.299 h
4	3.352±0.067 d	106.203±4.984 g
5	3.350±0.097 cd	102.609±2.450 f
6	3.337±0.164 bc	101.602±3.424 e
7	3.300±0.077 bc	99.372±2.990 d
8	3.110±0.091 bc	93.129±4.023 c
9	3.096±0.094 ab	90.433±6.611 b
10	3.059±0.242 a	86.021±7.137 a

* Different letters in each column show significant difference at 1% probability level (LSD).

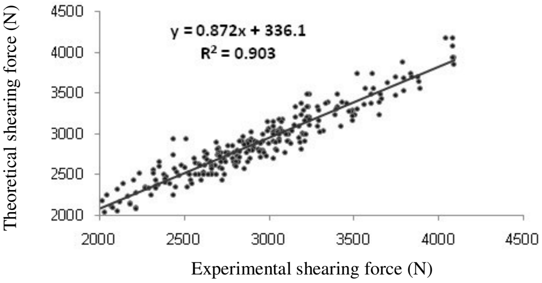


Figure 4. Correlation between the experimental data and the values of the theoretical model for shearing force (N) based on stem diameter (D) and shearing speed (V).

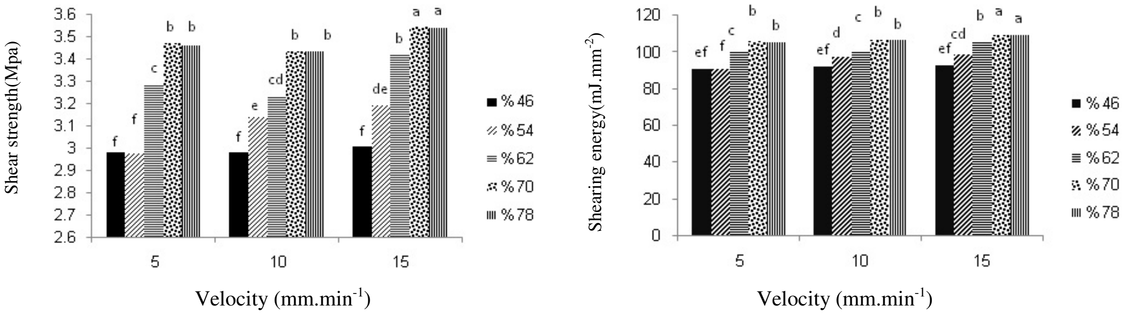
Interaction Effect of Moisture Content and Shearing Speed

Interaction effect of moisture content and shearing speed on shearing strength and shearing energy was significant at the 0.01 probability level, according to LSD test results (Figures 5 a & b). The shearing strength and shearing energy increased with increases in the shearing speed for all levels of moisture content. Also, the shearing strength and shearing energy increased with increases in the moisture content. The values of shearing strength varied from 2.980 to 3.544 MPa at the lower speed with the lowest moisture contents and the higher speed with the highest moisture content, respectively. The reason for this difference may be due to the viscous damping effect of moisture as reported by Persson (1987). The values of specific shearing energy varied from 91.021 mJ mm^{-2}, for the lower speed with the lowest moisture content, to 109.603 mJ mm^{-2} at the higher speed with the highest moisture content. Decrease of moisture content led to decrease in stem's diameter and its elasticity, thereby affecting stems strength.

Interaction Effect of Moisture Content and Position on the Stem

Interaction effect of moisture content and position on the stem on shearing strength and shearing energy was significant at the 0.01 probability level (Figures 6 a & b). The shearing strength and shearing energy decreased with higher positions on the stem for all moisture contents. The shearing strength and shearing energy increased with increases in the moisture content. The values of shearing strength varied from 2.781 MPa at the upper level with the lowest moisture contents to 3.629 MPa for the lower level with the highest moisture content.

It was observed that with a position change in the stem level from the lowest node (node No. 1) to the highest node (node No. 10) a decrease of 11.7, 12, 9, 11.2 and 11.3% in shearing strength and a decrease of 30.8, 34.1, 29.8, 23.9 and 30.4% in shearing energy occurred, respectively, at the moisture contents of 78, 70, 62, 54, and 46%. The shearing force and cross sectional area decrease as a result of a decrease in the stem diameter. Considering the equation used for calculating the shearing strength Equation (1), it becomes evident that the shearing strength is directly proportional to



(a) (b)

Figure 5. Interaction effect of moisture content and shearing speed on shearing strength (a), and specific shearing energy (b). (different letters in each column show significant differences at 1% probability level, LSD).

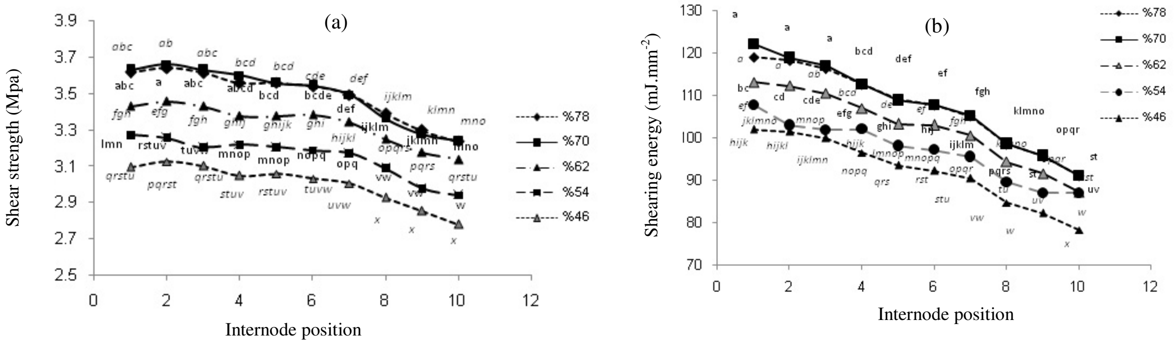


Figure 6. Interaction effect of moisture content and position on the stem on shearing strength (a) specific shearing energy (b). (Different letters in each column show significant difference at 1% probability level (LSD).

the shearing force and indirectly proportional to the stem cross sectional area. A decrease in stem diameter reduces both the stem cross sectional area and shearing force. Therefore, the main reason for lowering of the shearing strength by a decrease in the stem diameter could be due to the fact that the shearing force is more affected by the stem diameter as compared with the stem cross sectional area. The values of shearing force at the moisture contents of 78, 70, 62, 54 and 46% were obtained as 3108.4±174.9, 3120.1±185.2 2954±152.9, 2655.3±163.6, and 2673.1±197.1 N, respectively. The values of specific shearing energy varied from 78.2 mJ mm^{-2}, for the upper level with the lowest moisture contents, to 122.2 mJ mm^{-2}, for the lower level with the highest moisture content.

O'Dogherty and Huber (1995) reported that interaction effect of moisture content and the nodes statue on cutting force of wheat stem was significant. It has been indicated that shear strength varies between 4.91 up to 7.26 MPa (equivalent to 47%) with changing of moisture content and the nodes level. In the present study, the changes for sugar cane stem were determined as 30%.

The best regression model for shearing force, *F* (N), based on moisture content (%wb) and stem diameter, D (mm), was identified Equation (3) and the measured and the estimated shearing force values were compared (Figure 7).

$$F=46500+296.1Mc-6668D-1.755Mc^2-16.87Mc.D+306D^2+0.06803Mc^2D+0.2445McD^2-4.434D^3 \qquad (3)$$

(R^2= 87.6%, RMSE= 194.3)

In order to find the most suitable form of shearing model, different mathematical models were selected (Tables 6-7) and the experimental data were used to determine the pertinent coefficients for each model by applying the non-linear regression analysis technique. The goodness of fit was evaluated by calculating and comparing the statistical values of the coefficient of determination (R^2) and the standard error (SE) for each model. The best results were found for the approximation of different models with R^2= 0.989, and *SE*= 0.001 and 0.005 in third order Polynomial model and Hoerl model. The results showed that the measured values and estimated values were similar to each other.

ANN Models for Predicting the Shearing Strength of Sugar Cane

Several topologies were evaluated to

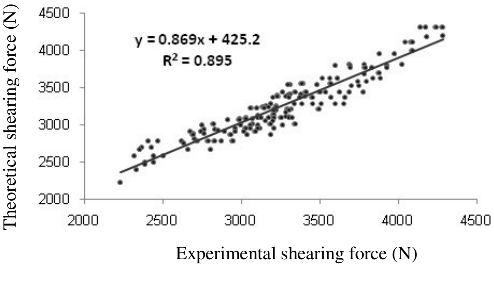


Figure7. Correlation between the experimental data and the values of the theoretical model for shearing force (N) based on stem diameter (D) and moisture content (%wb).

Table 6. Statistical results obtained from various models for shearing strength, (a) moisture content and (b) shearing speed.

(a) Models for shearing strength and moisture content		*a*	*b*	*c*	*d*	R^2	*SE*
Exponential Association	$\tau_s = a(1-exp(-b\times MC))$	3.819	0.032	-	-	0.958	0.053
3rd order Polynomial	$\tau_s = a+b\times Mc+c\times MC^2+d\times MC^3$	10.976	-0.444	0.007	-4.43E-05	0.989	0.001
Modified Exponential	$\tau_s = a\times exp(b/MC)$	4.504	-19.185	-	-	0.957	0.054
Logarithmic	$\tau_s = a+b\times ln(MC)$	-1.033	1.048	-	-	0.955	0.057
(b) models for shearing strength and shearing speed							
Quadratic	$\tau_s = a+b\times V+c\times V^2$	3.310	-0.023	0.001	-	0.989	0.021
Logistic Model	$\tau_s = \frac{a}{1+b\times \exp(-c\times V)}$	4.341	0.370	0.012	-	0.989	0.039
Hoerl Model	$\tau_s = a\times b^V \times V^c$	3.498	1.013	-	-	0.989	0.005
Exponential	$\tau_s = a\times \exp(b\times V)$	3.170	0.003	-	-	0.901	0.233

τ_s: Shearing strength (MPa); *MC*: Moisture content (wb%), *V*: Shearing speed (mm min^{-1}), *a; b; c, d*: Coefficients.

Table 7. Statistical results obtained from various models for specific shearing energy, (a) moisture content, and (b) shearing speed.

(a) Models for specific shearing energy and moisture content		*a*	*b*	*c*	*d*	R^2	*SE*
3rd order Polynomial	$E= a+ b\times MC+c\times MC^2+d\times MC^3$	339.662	-13.748	0.244	-0.001	0.989	0.084
Exponential, Association	$E= a(1-exp(-b\times MC)$	117.858	0.032	-	-	0.958	1.647
Exponential	$E= a\times exp(b\times MC)$	73.020	0.005	-	-	0.942	2.175
Quadratic	$E= a+b\times MC+c\times MC^2$	31.902	1.738	-0.009	-	0.962	1.881
(b) Models for specific shearing energy and shearing speed							
Quadratic	$E= a+b\times V+c\times V^2$	97.820	0.120	0.016	-	0.989	0.005
Logistic Model	$E = \frac{a}{1+b\times \exp(-c\times V)}$	173.187	0.796	0.010	-	0.989	0.009
Hoerl Model	$E = a\times b^V \times V^c$	72.462	1.855	0.116	-	0.989	0.001
Exponential	$E=a\times exp(b\times V)$	96.498	0.004	-	-	0.985	0.321

E: Specific shearing energy (mJ mm^2); *MC*: Moisture content (w.b.%), *V*: Shearing speed (mm min^{-1}), *a; b; c, d*: Coefficients.

obtain the maximum R^2 and minimum *MSE* values. The results are presented in Table 8. It can be inferred from the table that a network with 2 hidden layers (6 and 15 neurons in the first and second layer) and, subsequently, using Levenberg–Marquardt (LM) learning algorithm and tangent-sigmoid transfer function would provide an efficient response to predict the output parameter. A coefficient of determination (R^2) of 0.9999 and a training error of 0.00011 resulted from the network training (Figure 8).

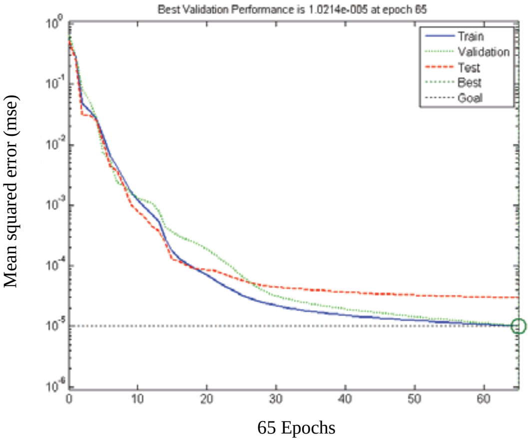


Figure 8. A sample Training Error curve.

CONCLUSIONS

In the current research, the specific shearing energy decreased with decrease in the moisture content resulting in lower stem elasticity. Indeed, with 32% decrease in stem moisture content, 16.3 and 16.7% decrease was observed in the values of specific shearing energy and shearing strength, respectively. An increase in loading rate within the range of 5-15 mm min^{-1} caused the specific shearing energy and shearing strength to increase. The nodes located at lower levels of stem had larger diameter than the higher nodes and, thereupon, they were able to sustain more loads as compared with the higher nodes. The results indicated that the shearing strength in the top node was 11% lower than that of the first node. The specific shearing energy for the tenth node (the topmost node) was 30% lower than that of the first node (the bottommost node). The highest energy was consumed in the second phase of shearing i.e. shear and compression phase; so that the energy consumption at the second phase of shearing was 17 and 50% more than that of the first phase (compression only) and the third phase (shear only), respectively. Different references have

Table 8. Summary of ANN models evaluations.

Activation function	Neurons in hidden layer1	Neurons in hidden layer2	Training error	*R* (training)	*R* (validation)	*R* (test)	Epoch
Log/Tan	10	0	0.00041	0.9999	0.9999	0.9999	98
Log/Tan	15	0	0.00035	0.9999	0.9999	0.9999	39
Tan/Log	10	0	0.00044	0.9999	0.9999	0.9999	53
Tan/Log	15	0	0.00032	0.9999	0.9999	0.9999	37
Log/ Log	10	0	0.00121	0.9999	0.9999	0.9999	48
Log/Log	15	0	0.00014	0.9999	0.9987	0.9979	31
Log/Tan/Tan	10	6	0.00013	0.9999	0.9999	0.9999	80
Log/Tan/Tan	15	6	0.01020	0.9868	0.9981	0.9989	45
Log/Tan/Tan	20	6	0.00020	0.9999	0.9999	0.9999	21
Log/Log/Tan	15	6	0.00011	0.9999	0.9999	0.9999	63
Log/Log/Tan	20	6	0.00034	0.9999	0.9999	0.9999	42
Log/Tan/Tan	10	6	0.00043	0.9999	0.9999	0.9999	31
Log/Tan/Tan	15	6	0.00056	0.9999	0.9999	1.0000	41
Log/Tan/Tan	20	6	0.00042	0.9999	1.0000	0.9999	34

reported that with increase in the position on the crop stem and decrease in moisture content, the cutting force will diminish. The results in this study for sugar cane are in agreement with those in the cited references.

The best regression model between the moisture and dependent variables (shear strength and shear energy) was 3rd order polynomial model with determination coefficient of 0.989 and the best regression model between the shearing speed and dependent variables (shear strength and shear energy) was determined by Horel model with a determination coefficient of 0.989.

The MLP neural network accompanied with the Levenberg–Marquardt algorithm and topology arrangement of 3-6-15-2 gave the best model to predict the shearing strength of the sugar cane stem. The values of train error and coefficient of determination for this model were 0.00011 and 0.999, respectively.

REFERENCES

1. ASABE Standards. 2006. *S358.2: 1:1 Measurement - forages*. ASABE, St. Joseph, Mich.
2. Baughman, D. R. and Liu, Y. A. 1995. *Neural Networks in Bio-processing and Chemical Engineering*. Academic Press, New York, 400-450.
3. Chen, Y., Gratton, J. L. and Liu. J. 2004. Power Requirements of Hemp Cutting and Conditioning. *Biosyst. Eng.,* **87(4):** 417-424.
4. Esehaghbeygi, A., Hosseinzadeh, B., Khazaii, M. and Masoomi, A. 2009. Bending and Shearing Properties of Alvand Variety of Wheat Stem. *WAS J.*, **6(8):** 1028-1032.
5. Esehaghbeygi, A. and Hosseinzadeh, B. 2009. Effect of Moisture Content and Urea Fertilizer on Bending and Shearing Characteristics of Canola Stems. *Appl. Eng. Agric.,* **25(6):** 947-951.
6. Esehaghbeygi, A., Hosseinzadeh, B. and Besharati, S. 2010. Nitrogen Use on Yield Components and Stem Shearing Strength of Canola. *Electronics J. Pol. Agr. Un.*, **13 (4):** 7-11.
7. Hosseinzadeh, B. 2008. Determining Shearing Strength of Canola Stems and Evaluation of Effective Parameters on Shearing Strength. MSc. Thesis, Shahre-Kord University, Iran.
8. Hosseinzadeh, B., Esehaghbeygi, A. and Raghami, N. 2009. Effect of Moisture Content, Bevel Angle and Cutting Speed on Shearing Energy of Three Wheat Varieties. *WAS J.*, **7(9):** 1120-1123.
9. FAO 2009. Food and Agricultural Commodities Production. Available at: < http://faostat.fao.org/site/567/default.aspx#ancor >.
10. Ince, A., Ugurluay, S., Guzel, E. and Ozcan, M. T. 2005. Bending and Shearing Characteristics of Sunflower Stalk Residue. *Biosyst. Eng.*, **92(2):** 175-181.
11. Kardany, M. 2008. Effect of Some Cutting Blade and Plant Factors on Specific Cutting Energy of Sugarcane Stalk. MSc. Thesis, Isfahan University of Technology, Iran.
12. Lee, S. W. and Yan, H. 1984. Threshing and Cutting Forces for Korean Rice. *Trans. ASAE,* **16(2):** 1654-1657.
13. Marquardt, D. 1963. An Algorithm for Least Squares Estimation of Non-linear Parameters. *J. Soc. Indust. Applied Math.*, **3**: 431–441.
14. Mobli, H., Tavakoli Hashjin, T., Oghabi, H. and Alimardani, R. 2003. Study of the Strength Properties of Pistachio Nuts and Cluster Stem Joints for the Design and Development of a Harvesting Machine. *J. Agric. Sci. Technol.*, **5:** 99-104.
15. Nazari Galedar, M., Jafari, A., Mohtasebi, S.S., Tabatabaeefar, A., Sharifi, A., O'Dogherty, M. J., Rafiee, S. and Richard, G. 2008. Effects of Moisture Content and Level in the Crop on the Engineering Properties of Alfalfa Stems. *Biosyst. Eng.,* **101(2):** 199 - 208.
16. O'Dogherty, M. J. and Huber, A. 1995. Study of Physical and Mechanical Properties of Wheat Straw. *Agric Engng. Res.,* **62:** 133-142.
17. Persson, S. 1987. *Mechanics of Cutting Plant Material.* ASAE, St Joseph, MI, USA. PP. 38-84.
18. Peykani, Gh. R., Kavoosi Kelashemi M., Shahbazi H. and Akrami A. H. 2010. A Determination of Suitable Sugar Cane Utilization System Using Total Factor Productivity (TFP) (Case Study: Imam Khomeini Cultivation and Processing Center

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in Khuzestan Province), *J. Agr. Sci. Tech.*, **12:** 511-521.

19. Summers, M. D., Jenkins, B. M. and Yore, M. W. 2002. Cutting Properties of Rice Straw. Paper. No. 026154. *An ASAE Meeting Presentation*, Saskatchewan, Canada.
20. Tabatabaee Koloor, R. and Borgheie, A. 2006. Measuring the Static and Dynamic Cutting Force of Stem for Iranian Rice Varieties. *J. Agric. Sci. Techol.*, **8:** 193-198.

بررسی عملی و نظری تاثیرات محتوای رطوبتی و ارتفاع ساقه محصول بر روی مشخصات برشی ساقه نیشکر

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چکیده

در این تحقیق خواص برشی ساقه تحت تیمارهای رطوبت ساقه (۷۸٪، ۷۰٪، ۶۲٪، ۵۴ %و ۴۶٪ بر پایه تر)، سرعت برش (۱۵، ۱۰ و ۵ میلیمتر بر دقیقه) و موقعیت میان‌گره تحت برش مورد بررسی قرار گرفت. نیروی برش ساقه‌ها با استفاده از دستگاه برش متصل به کامپیوتر اندازه‌گیری شد. نتایج حاصل از آزمایش نشان داد که با کاهش رطوبت ساقه از ۷۸٪ به ۴۶٪، مقاومت برشی و انرژی برشی ویژه به ترتیب ۱۶/۳٪ و ۱۶/۷٪ کاهش یافته است. حداکثر و متوسط مقاومت برشی و انرژی ویژه برش ساقه نیشکر در برش شبه استاتیکی به ترتیب برابر با ۳/۴۸۲ مگاپاسکال و ۱۱۲ مگاژول بر میلیمتر مربع و ۳/۱ مگاپاسکال و ۱۰۲/۶ مگاژول بر میلیمتر مربع بدست آمد. به علت متفاوت بودن مشخصات ساختمانی ساقه، مقادیر مقاومت برشی و انرژی برشی در میان‌گره‌های بالایی ساقه نسبت به نواحی پایین‌تر ساقه کمتر بدست آمد. نتایج نشان داد که با افزایش سرعت برش از ۵ به ۱۵ میلیمتر بر دقیقه، مقادیر مقاومت برشی و انرژی برشی ساقه به‌ترتیب به اندازه ۳/۲٪ و ۴/۶٪ افزایش یافت. نتایج تجزیه واریانس داده‌ها نشان داد اثر فاکتورهای مورد بررسی در تحقیق بر روی مقاومت برشی و انرژی برشی ویژه ساقه در سطح احتمال ۱٪ معنی‌دار بوده است. بررسی مدلهای ریاضی برش ساقه نشان داد که مدل ریاضی چند ضابطه‌ای درجه سوم بهترین تطابق را با داده‌های آزمایشی داشته است و با استفاده از مدل فوق همبستگی معنی‌داری بین مقاومت برشی، انرژی برشی و رطوبت ساقه وجود داشت (۰/۹۸۹ =R2 و SE=۰/۰۰۱) همچنین با استفاده از مدل Hoerl همبستگی معنی‌داری بین مقاومت برشی، انرژی برشی و سرعت برش ساقه بدست آمد (R2=۰/۹۸۹ و SE=۰/۰۰۵).

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