Middle-East Journal of Scientific Research 11 (3): 374-381, 2012
ISSN 1990-9233

Modelling of Shearing Energy of Canola Stem in Quasi-Static Compressive Loading Using Artificial Neural Network (ANN)

[1]*Alireza Mahdavian,* [1]*Ahmad Banakar,* [2]*Abazar Mohammadi,*
[3]*Mohsen Beigi and* [1]*Bahram Hosseinzadeh*

[1]Deptartment of Mechanics of Agricultural Machinery, Faculty of Agriculture,
Tarbiat Modares University, P.O. Box 14115-111, Tehran 14114, Iran
[2]Payame-Noor University, Farsan, Chahar Mahal-e-Bakhtiari, Iran
[3]Department of Mechanics, Tiran Branch, Islamic Azad University, Isfahan, Iran

Abstract: The objective of this study was to determine the shear energy of canola stems in terms of the crop variety, stem moisture content, loading rate, knife type and the amount of fertilizer used in the crop production with the emphasis on the modelling of shearing behaviour of canola stem using artificial neural networks (ANN). The research was conducted to three varieties of winter canola, namely, Zarfam, Opera and Okapi, three levels of urea fertilizer (250, 400 and 550 kg/ha), two types of cutting knives including smooth-edge and serrated-edge knifes and four levels of moisture content (35.02%, 42.89%, 50.11% and 56.94% w.b.). Shear force was applied to the stem samples by mounting the shear box on the tension/compression testing machine. Artificial neural network (ANN) was used to predict the shearing energy of canola stem versus the different evaluated factors. The results indicated that the regression models provided acceptable relationships between the shearing energy of the canola stem and the factors affecting the value of shearing energy when developing the model just using two effective parameters. However, using regression models did not result in good conformity with the variables when four parameters were used to develop the model; this was whilst the developed neural network made a good prediction from the experimental data in the same condition. The MLP neural network accompanied with the Levenberg-Marquardt algorithm and topology arrangement of 4-6-15-1 gave the best model to predict the shearing energy of the canola stem. The values of train error and coefficient of determination for this model were 0.00015 and 0.999, respectively.

Key words: Canola · Shear strength · Shearing energy · Neural network

INTRODUCTION

Canola is one of two cultivars of rapeseed or Brassica campestris (*Brassica napus* L. and *B. campestris* L.) family. It is one of the top five oilseed crops cultivated worldwide [1]. In Iran, canola is widely cultivated and harvested on an area of about 137000 ha with an annual production of about 264000 ton. In order to proper design of cutting blades being used in windrowers, hay bin harvesters, combine harvesters and all reciprocating feature cutter bar mowers, it is necessary to study the shearing strength of agricultural crops stems. 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 [2].

Recently, several studies have been conducted to determine the mechanical properties of agricultural crops. Most studies on mechanical properties of agricultural crops 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 optimization, animal nutrition, industrial applications and decomposition of wheat straw in soil [3]. The amounts of fertilizer have been reported as an effective factor on the physical and mechanical properties of crops stems [4].

Corresponding Author: Ahmad Banakar, Deptartment of Mechanics of Agricultural Machinery, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-111, Tehran 14114, Iran.
Tel: +98-2148292466; Fax: +98-2148292466.

Skubisz [5] showed that sowing density had significant effect on lodging characteristics and mechanical strength of rape stalks. Persson [2] suggested that stem cutting power is slightly affected by cutting speed. The effects of wheat variety, knife bevel angle, stem moisture content and shearing speeds of pendulum on the shearing energy of wheat stem were investigated by Hosseinzadeh *et al.* [6]. They showed that shearing energy increased with increasing moisture content and bevel angle; whilst increasing the shearing speed caused the shearing energy to decrease. Their results also revealed that the effects of variety, knife bevel angle, moisture content and shearing speed on shearing energy were significant. Esehaghbeigi *et al.* [7] reported that the shearing stress of wheat stems decreased with decreasing the moisture content. It was reported that the shearing force of stems was lower at higher levels of the stem. They suggested that this result might be attributed to a reduction in stalk diameter at higher levels of the stem. Several studies on cutting energy requirements of different crops such as winter rape [5], wheat [6], hemp [8], pea [9], rice [10], soya bean stalks [11] and pyrethrum flowers [12] have been also reported in the literature. Results of all studies showed that the cutting energy is germane to the physical and mechanical properties of the crops stem. Most of the studies have been conducted using pendulum or simple shearing type apparatuses, which may not be fully representative to show the cutting processes using reciprocating knives.

The objective of this study was to determine the shear energy of canola stems in terms of the crop variety, stem moisture content, loading rate, knife type and the amount of fertilizer used in the crop production with the emphasis on the modelling of shearing behaviour of canola stem using artificial neural networks (ANN). Results of this study could be useful to predict the power requirement associated with the crop harvesting machines and cutting blades and consequently optimise the design of the equipments.

MATERIAL AND METHODS

Experimental Procedure: The research was conducted to three varieties of winter canola, namely, Zarfam, Opera and Okapi, three levels of urea fertilizer (250, 400 and 550 kg/ha), two types of cutting knives including smooth-edge and serrated-edge knifes and four levels of moisture content (35.02%, 42,89%, 50.11% and 56.94% w.b.). Samples of canola stems used in the shearing tests were obtained through breeding the canola seeds in experimental pots at then taking the samples from the pots at the harvest time. In order to obtain the four moisture levels, the harvesting time of the samples was delayed under control till the different moisture contents were attained. The interval in which the moisture content of canola reduced from 57.94 to 35.02% (w.b.) was 15 days. The samples were taken in polyethylene bags to control their moisture content. The moisture content of canola stem was determined by oven drying method at 103°C for 24 h [13]. The sample stems were cut from 20 mm above the pots soil surface and then delivered to the laboratory. A digital caliper with an accuracy of 0.01 mm (Mytotoyu, Japan) was used to measure the stems thickness. 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 can slide freely in a close sliding fit (Fig. 1). A series of holes with diameters ranging from 5 to 20 mm were drilled through the plates to accommodate internodes of differing diameters. Shear force was applied to the stem samples by mounting the shear box on the tension/compression testing machine. The sliding plate was loaded at a rate of 10 mm/min 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 shearing energy (E_s) was calculated by integrating the area under curves of shear force and displacement [5], using a standard computer program (vers. 5, SMT Machine Linker, SANTAM Company, Tehran, Iran).

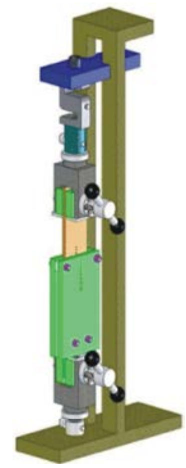


Fig. 1: Schematic of apparatus used for measuring the shearing strength of canola stem internodes

Experimental Design And Statistical Analysis: The experiments were conducted to a factorial statistical design. 72 treatments were applied on the basis of randomised complete block design. At each treatment, the experiments were replicated ten times and the average values were reported. The mean, standard deviation and correlation coefficient of the shearing energy were determined using Microsoft Excel 2007 software program. The effects of the factors were evaluated using analysis of variance (ANOVA) and mean significant differences were compared through the least significant difference (LSD) test at 5% significant level using SPSS 18 software.

Artificial Neural Network: Artificial neural network (ANN) was used to predict the shearing energy of canola stem versus the different evaluated factors, namely, stem moisture content, variety, type of the cutting knife and the amount of urea fertilizer. ANN models have been successfully used in the prediction of problems in bio-processing and chemical engineering [14]. In essence, ANN is a system modeled on the human brain usually consists of an input layer, some hidden layers and an output layer. The back-propagation algorithm was used for training of all ANN models. ANN with back-propagation algorithm learns by changing the weights and these changes are stored as knowledge. Back-propagation training algorithms gradient descent and gradient descent with momentum are often too slow for practical problems because they require small rates for stable learning. Moreover, success in the algorithms depends on the user-dependent parameters learning rate and momentum constant. Faster algorithms such as conjugate gradient, quasi-Newton and Levenberg-Marquardt (LM) use standard numerical optimization techniques. LM method is in fact an approximation of the Newton's method [15]. The LM algorithm uses the second-order derivatives of the cost function so that better convergence behaviour can be obtained. In the ordinary gradient descent search, only the first order derivatives are evaluated and the parameter change information contains solely the direction along which the cost is minimized, whereas the Levenberg-Marquardt technique extracts a biter parameter change vector. To obtain the best prediction by the network, several architectures were evaluated and trained using the experimental data. This algorithm uses the supervised training technique where the network weights and biases are initialized randomly at the beginning of the training phase. The error minimization process is achieved using the gradient descent rule. A fully connected multi-layer perceptron (MLP) was used. This model benefits from simplicity and accuracy making it highly applicable in shearing simulation. 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 provides an equal contribution to the ANN, the inputs of the model were preprocessed and normalized, after which, 70 % and 15 % of 72 input patterns were devoted to training and validation data sets, respectively. The remaining part of data was specified for the 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, so the smaller ANNs had the priority to be selected. The required codes were developed by MATLAB 2010 software.

RESULTS AND DISCUSSION

Results of Statistical Analysis: The results of ANOVA indicated that effects of the evaluated factors (variety, moisture content, amount of nitrogen fertilizer and type of the blade) on the canola shearing energy were significant at 1% probability level. The maximum value of the shearing energy (11.037 mJ/mm^2) was attributed to the Opera variety stems; whilst Zarfam variety with the shearing energy of 9.215 mJ/mm^2 had the minimum value among the varieties. The most friction was existed between the serrated-edge knife and the stem. Similar results were also reported by other researchers [16]. The results of LSD test method showed that there was a significant difference between the shearing energy of the three varieties (Fig. 2). The Difference could be due to the different physical and physiological properties of the stem varieties [17]. A study was accomplished by Esehaghbeigi *et al.* (2009) to evaluate the effects of variety, amount of nitrogen fertilizer and moisture content on the specific shearing energy of wheat stem using pendulum test method [18]. They reported that there was an increase in the shearing energy, together with an increase in the amount of nitrogen fertilizer and a decrease in the stem moisture content.

Based on the ANOVA, the interaction effect of variety and fertilizer on the shearing energy of canola stem was significant at the 1% probability level. This result is may be pertain to the different structural characteristics of the varieties which could result in different reaction trends to the amount of fertilizer. Generally, the effect of fertilizer is determined by crop efficiency; but in this study the effect on the shearing energy of canola stem was evaluated when the crop

Table 1: Regression models to explain the relationship between the amount of urea fertilizer and shearing energy of canola stem for the different varieties and moisture contents evaluated in the case of smooth-edge and serrated-edge knifes

Smooth-edge knife									
Moisture content (w.b.)	Zarfam	R^2	SE	Opera	R^2	SE	Okapi	R^2	SE
57%	$E_s=8.237+0.0091F-1.88E^{-5}F^2$	0.95	0.274	$E_s=10.703+0.0053F-1.41E^{-5}F^2$	0.98	0.176	$E_s=11.392-0.001F-5.19E^{-6}F^2$	0.98	0.159
50%	$E_s=8.365+0.0092F-1.88E^{-5}F^2$	0.95	0.274	$E_s=10.867+0.0054F-1.43E^{-5}F^2$	0.98	0.178	$E_s=11.566-0.001F-5.26E^{-6}F^2$	0.98	0.162
43%	$E_s=8.896+0.0098F-2.00E^{-5}F^2$	0.95	0.292	$E_s=11.56+0.0058F-1.52E^{-5}F^2$	0.98	0.190	$E_s=12.304-0.001F-5.60E^{-6}F^2$	0.98	0.172
36%	$E_s=9.237+0.0101F-2.06E^{-5}F^2$	0.95	0.301	$E_s=11.98+0.0059F-1.57E^{-5}F^2$	0.98	0.196	$E_s=12.757-0.0012F-5.78E^{-6}F^2$	0.98	0.178
Serrated-edge knife									
Moisture content (w.b.)	Zarfam	R^2	SE	Opera	R^2	SE	Okapi	R^2	SE
57%	$E_s=8.382+0.0091F-1.86E^{-5}F^2$	0.95	0.271	$E_s=10.858+0.0053F-1.41E^{-5}F^2$	0.98	0.176	$E_s=11.55-0.001F-5.20E^{-6}F^2$	0.98	0.160
50%	$E_s=8.511+0.0092F-1.88E^{-5}F^2$	0.95	0.274	$E_s=11.023+0.0054F-1.43E^{-5}F^2$	0.98	0.179	$E_s=11.725-0.001F-5.27E^{-6}F^2$	0.98	0.163
43%	$E_s=9.115+0.0099F-2.01E^{-5}F^2$	0.95	0.294	$E_s=11.798+0.0058F-1.53E^{-5}F^2$	0.98	0.192	$E_s=12.548-0.001F-5.63E^{-6}F^2$	0.98	0.174
36%	$E_s=9.459+0.0102F-2.08E^{-5}F^2$	0.95	0.303	$E_s=12.16+0.0060F-1.58E^{-5}F^2$	0.98	0.197	$E_s=12.940-0.0012F-5.79E^{-6}F^2$	0.98	0.179
57%	$E_s=8.382+0.0091F-1.86E^{-5}F^2$	0.95	0.271	$E_s=10.858+0.0053F-1.41E^{-5}F^2$	0.98	0.176	$E_s=11.55-0.001F-5.20E^{-6}F^2$	0.98	0.160

E_s: Stem shearing energy (mJ/mm^2); F: The amount of urea fertilizer (kg/ha)

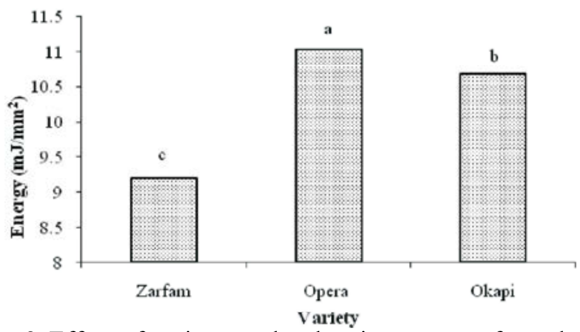


Fig. 2: Effect of variety on the shearing energy of canola stem. The means with the same letter are not significantly different (a=0.05) based on the LSD test.

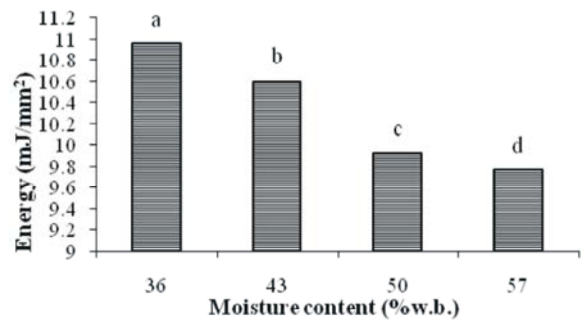


Fig. 4: Effect of moisture content on the shearing energy of canola stem. The means with the same letter are not significantly different (a=0.05) based on the LSD test.

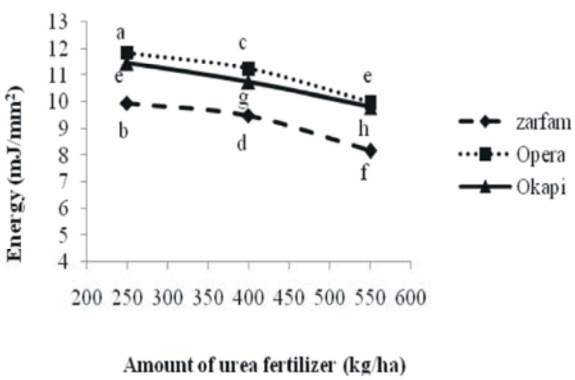
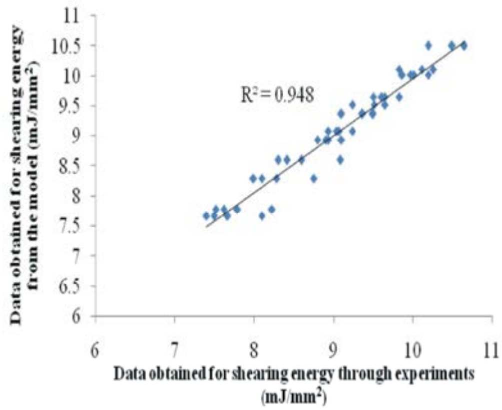


Fig. 3: Effect of variety and urea fertilizer on the shearing energy of canola stem. The means with the same letter are not significantly different (a=0.05) based on the LSD test.

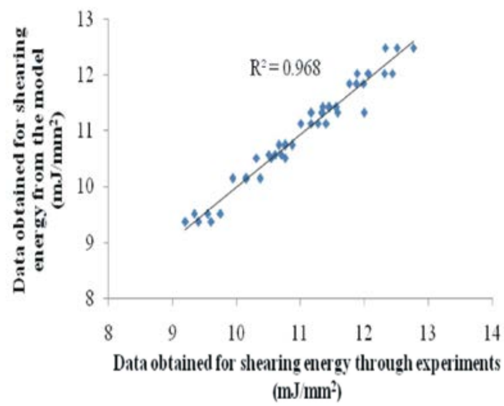
combine harvesting. The results indicated that with an increase in the amount of urea fertilizer, the value of the stem shearing energy decreased 22%, 18% and 16.8%, respectively for Zarfam, Opera and Okapi varieties, respectively (Fig. 3). Using urea fertilizer increase plant growth and taller plant has low stem diameter because of low supportive tissues as low development of collenchymas and peculiarities of stem architectonics [4].

The means comparison of shearing energy through the LSD method considering the effect of moisture content is presented in Fig. 4. The shearing energy of canola stem increased with decreasing the stem moisture content. As shown, 21% decrease in moisture content was accompanied with 12.1% increase in the stem shearing energy. The most value of shearing energy (10.963 mJ) was observed at the 36% (w.b.) moisture content and the lowest value of shearing energy (9.774 mJ) was attributed to the moisture content of 57% (w.b.). Moisture content has been reported as an effective factor on the shearing strength of the different crops [2, 6, 7, 10 and 18].

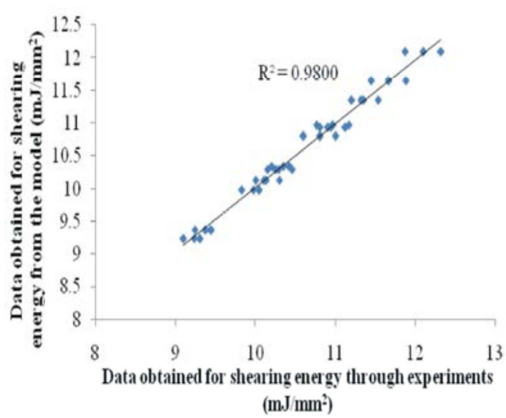
Single Regression Models to Explain the Shearing Energy of Canola Stem: In Tables 1 some regression equations are presented to explain the relationship between the shearing energy and the amount of urea fertilizer for the different varieties and moisture contents



(A)



(B)



(C)

Fig. 5: The ratios of shearing energy when cutting the stem by the smooth-edge knife which obtained through the experimental data and the data gotten from a) Eq. (1) for Zarfam variety; b) Eq. (2) for Opera variety and c) Eq. (3) for Okapi variety

considering the type of cutting knifes. For all of the moisture contents and varieties investigated, the quadratic function was the best equation to description the relationship between the experimental data.

Two-Variable Regression Models to Express the Shearing Energy of Canola Stem: One of the noticeable defects accompanied by simple regression models is their low accuracy to present a fitting relationship when more than 2 fixed factors are involved in the experiments. The equations (1) to (6) were used to develop the regression relationships between the shearing energy of canola stem and the amount of urea fertilizer considering the type of cutting knife, stem moisture and variety. For all of the following equations, E_s is the shearing energy of the stem (mJ/mm²), *M* is the moisture content of the stem (%w.b.) and *F* is the amount of urea fertilizer (kg/ha).

In the case of Zarfam variety when cutting the stem by the smooth-edge knife the below equation is existed:

$$E_s = -15.26 + 176.5M + 0.01085F - 410.6M^2 + 0.0002328.MF - 2.452 \times 10^{-5} F^2 + 304.1M^3 - 0.005988M^2F\ 1.082 \times 10^{-5} MF^2$$
$$(R^2 = 0.99, MSE = 0.001341) \quad (1)$$

For the Opera variety when the stem is cut by the smooth-edge knife the following equation is obtained as:

$$E_s = -18.14 + 216.9M + 0.00576F - 504.3M^2 + 0.002853MF - 1.866 \times 10^{-5}F^2 + 372.8M^3 - 0.006456M^2F + 8.285 \times 10^{-6}MF^2$$
$$(R^2 = 0.99, MSE = 0.001346) \quad (2)$$

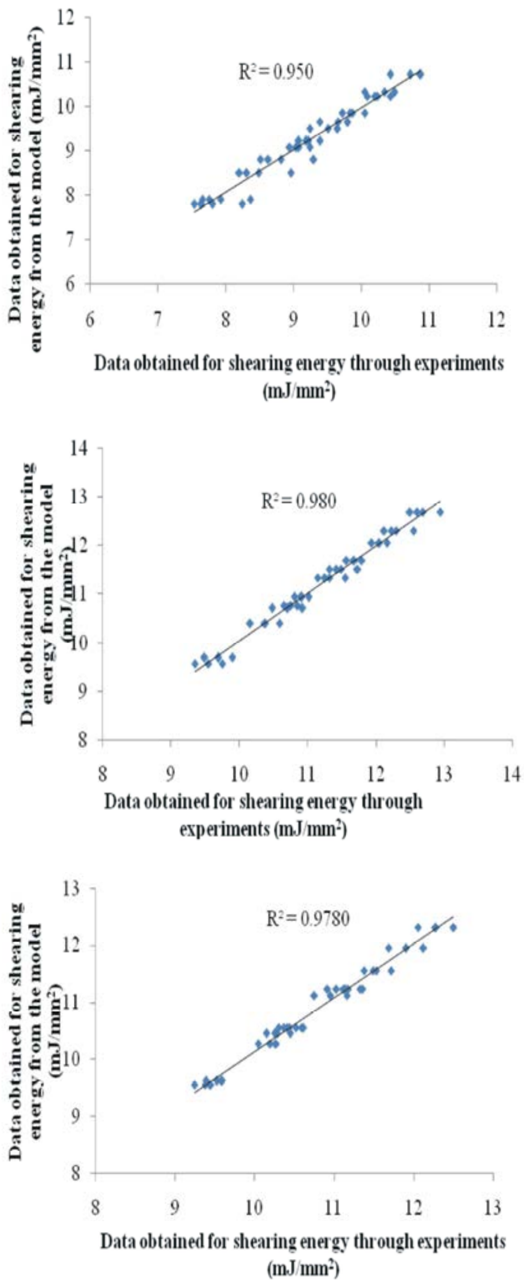
The relationship between the shearing energy of Okapi variety and the moisture content and amount of urea fertilizer when the stem is cut by the smooth-edge knife could be represented through the following equation:

$$E_s\ -16.11 + 208.8M - 0.002633F - 486.7M^2 + 0.005956MF - 6.868 \times 10^{-6}F^2 + 359.7M^3 - 0.005703M^3F + 3.036 \times 10^{-6}MF^2$$
$$(R^2 = 0.99, MSF = 0.001164) \quad (3)$$

Fig. 5 shows the ratios of shearing energy for Zarfam, Opera and Okapi varieties when cutting the stems by smooth-edge knife. The figures were obtained using ANN and through the experimental data and the data gotten from the Equations (1), (2) and (3).

In Eq. (4) the relationship between the shearing energy of Zarfam variety stem when cutting by serrated-edge knife and the stem moisture content and amount of urea fertilizer is presented:

$$E_s\ -21.64 + 221.8M - 0.001092F - 509.4M^2 + 0.0002228MF - 2.478 \times 10^{-5}F^2 + 375.1M^3 - 0.006178M^3F + 1.123 \times 1\ 0^{-5}MF^2$$
$$(R^2 = 0.99, MSF = 0.001432) \quad (4)$$



(A) (B) (C)

Fig. 6: The ratios of shearing energy when cutting the stem by /the serrated-edge knife which obtained through the experimental data and the data gotten from a) Eq. (4) for Zarfam variety; b) Eq. (5) for Opera variety and c) Eq. (6) for Okapi variety.

The following equation expresses the relationship of shearing energy to the stem moisture content and the amount of urea fertilizer for the Opera variety when cutting the stem by serrated-edge knife:

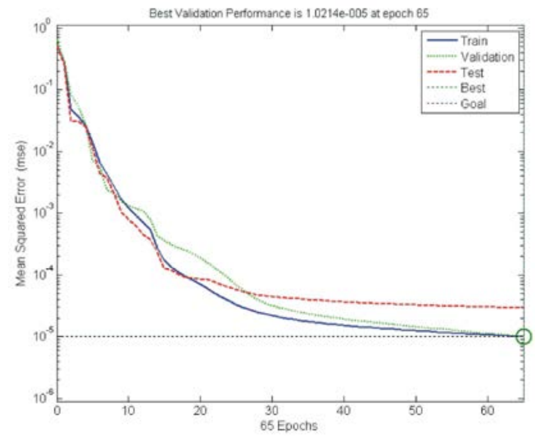


Fig. 7: A sample Training error curve

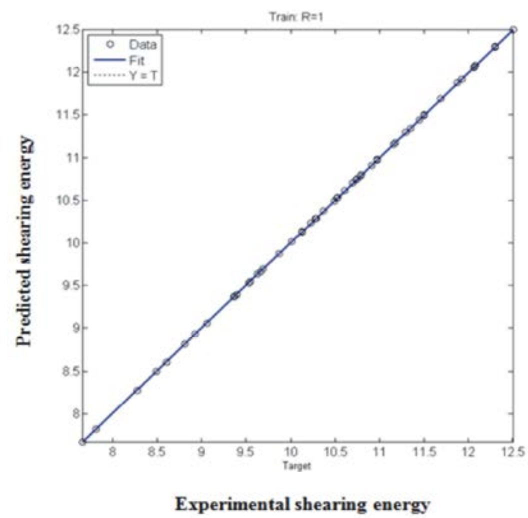


Fig. 8: Predicted outputs versus measured values for the Training Stage

$$E_s\ -28.78 + 287.9M - 0.006076F - 656.1M^2 + 0.001565MF - 1.877 \times 10^{-5}F^2 + 479.1M^3 - 0.005087M^3F + 8.347 \times 10^{-6}MF^2 \quad (R^2 = 0.99,\ MSF = 0.001540) \qquad (5)$$

For Okapi variety, when the stem is cut by a serrated-edge knife, the relationship between the shearing energy, stem moisture content and amount of urea fertilizer could be explained by the following equation:

$$E_s\ -26.52 + 287.3M - 0.002409F - 635.6M^2 + 0.004856MF - 6.888 \times 10^{-6}F^2 + 465M^3 - 0.004496M^3F + 3.044 \times 10^{-6}MF^2 \quad (R^2 = 0.99,\ MSF = 0.001338) \qquad (6)$$

The ratios of shearing energy for Zarfam, Opera and Okapi varieties when cutting the stems by serrated-edge knife are illustrated in Fig. 6. The figures

Table 2: Summary of ANN models evaluations

Activation function	Neurons in hidden layer1	Neurons in hidden layer 2	Training error	R (training)	R (validation)	R (test)	Epoch
Log/Tan	10	0	0.00031	0.9999	0.9999	0.9999	100
Log/Tan	15	0	0.00018	0.9999	0.9999	0.9999	62
Tan/Log	10	0	0.00014	0.9999	0.9999	0.9999	43
Tan/Log	15	0	0.00027	0.9999	0.9999	0.9999	27
Log/ Log	10	0	0.0012	0.9999	0.9999	0.9999	40
Log/Log	15	0	0.00018	0.9999	0.9987	0.9979	29
Log/Tan/Tan	10	6	0.00018	0.9999	0.9999	0.9999	50
Log/Tan/Tan	15	6	0.01020	0.9868	0.9981	0.9989	59
Log/Tan/Tan	20	6	0.00020	0.9999	0.9999	0.9999	15
Log/Log/Tan	10	6	0.00033	0.9999	0.9999	0.9999	45
Log/Log/Tan	15	6	0.00015	0.9999	0.9999	0.9999	65
Log/Log/Tan	20	6	0.00031	0.9999	0.9999	0.9999	46
Log/Tan/Tan	10	6	0.00024	0.9999	0.9999	0.9999	38
Log/Tan/Tan	15	6	0.00024	0.9999	0.9999	1.0000	44
Log/Tan/Tan	20	6	0.00022	0.9999	1.0000	0.9999	47

were obtained using ANN and through the experimental data and the data gotten from the Equations (4), (5) and (6).

ANN Models For Predicting The Shearing Energy Of Canola Stem: Several topologies were evaluated to obtain the maximum R^2 and minimum MSE values. The results are presented in Table 2. It can be inferred from the table that a network with 2 hidden layers (6 and 15 neurons in first and second layer, consequently) 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 0.00015 resulted from the network training (Fig 7). Results showed that artificial neural network was advantageous in the prediction of moisture content variations. A regression analysis of experimental data and network outputs is illustrated in Fig 8. The maximum value of R^2 for training, validation and prediction stages was 0.9999.

CONCLUSION

- The effects of stem moisture content, variety, type of cutting knife and amount of urea fertilizer were all significant on the shearing energy of canola stem at the 1% level of probability ($P<0.01$).
- The shearing energy of the canola stem increased with decreasing the moisture content. For the serrated-edge knife the value of shearing energy was higher than that of the smooth-edge knife. This was probably because of more frictional forces between the knife and stem in the case of serrated-edge knife as compared with the smooth-edge knife.
- Increasing the amount of urea fertilizer caused the value of shearing energy to decrease that was may be due to a decrease in the stem diameter as a result of increasing the amount of fertilizer.
- The values of shearing energy of canola stem for the different varieties evaluated in the current research were different from each other. This was most possibly attributed to the difference in structural and morphological properties of the crop. The most value of shearing energy (11.037 mJ/mm^2) was obtained for Opera variety; whilst the lowest shearing energy (9.250 mJ/mm^2) observed was allied to Zarfam variety.
- The results indicated that the regression models provided acceptable relationships between the shearing energy of the canola stem and the factors affecting the value of shearing energy when developing the model just using two effective parameters. However, using regression models did not result in good conformity with the variables when four parameters were used to develop the model; this was whilst the developed neural network made a good prediction from the experimental data in the same condition.
- The MLP neural network accompanied with the Levenberg-Marquardt algorithm and topology arrangement of 4-6-15-1 gave the best model to predict the shearing energy of the canola stem. The values of train error and coefficient of determination for this model were 0.00015 and 0.999, respectively.

ACKNOWLEDGMENTS

The authors would like to thank the University of Shahrekord and Tarbiat Modares University for supporting the research expenditures.

REFERENCES

1. Shahidi, F., 1990. Canola and rapeseed: Production, chemistry, nutrition and processing Technology pp: 3. New York: Van Nostrand Reinhold Company Inc.
2. Persson, S., 1987. Mechanics of Cutting Plant Material. ASAE, St Joseph, MI, USA.
3. Annoussamy, M., G. Richard, S. Recous and J. Guerif, 2000. Change in mechanical properties of wheat straw due to decomposition and moisture. Applied Engineering in Agriculture, 16(6): 657-664.
4. Berry, P.M., J.H. Spink, A.P. Gay and J. Craigon, 2003. A comparison of root and stem lodging risks among winter wheat cultivars. J. Agricultural Sci., 141(2): 191-202.
5. Skubisz, G., 2001. Development of studies on the mechanical properties of winter rape stems. International Agrophysics, 15: 197-200.
6. Hosseinzadeh, B., A. Eshaghbeigi and N. Raghami, 2009. Effect of moisture content, bevel angle and cutting speed on shearing energy of three wheat varieties. World Applied Sciences J., 7(9): 1120-1123.
7. Eshaghbeygi, A., B. Hosseinzadeh, M. Khazaii and A. Masoomi, 2009. Bending and Shearing Properties of Alvand Variety of Wheat Stem. World Applied Sciences J., 6(8): 1028-1032.
8. Chen, Y., J.L. Gratton and J. Liu, 2004. Power requirements of hemp cutting and conditioning. Biosystems Engineering, 87(4): 417-424.
9. Skubisz, G., T.I. Kravtsova and L.P. Velikanov, 2007. Analysis of the strength properties of pea stems. International Agrophysics, 21: 189-197.
10. Lee, S.W. and H. Yan, 1984. Threshing and cutting forces for Korean rice. Transactions of the ASAE, 16(2): 1654-1660.
11. Mesquita, C.M. and M.A. Hanna, 1995. Physical and mechanical properties of soybean crops. Transactions of the ASAE, 38(6): 1655-1658.
12. Khazaei, J., H. Rabani, A. Ebadi and F. Golbabaei, 2002. Determining the shear strength and picking force of pyrethrum flower. AIC Paper No. 02-221, CSAE, Mansonville, Que. Canada.
13. ASABE Standards, 2006. Moisture measurement of forages. S358.2 DEC99. St Joseph, MI, USA.
14. Baughman, D.R. and Y.A. Liu, 1995. Neural Networks in Bio-Processing and Chemical Engineering. Academic Press, New York.
15. Marquardt, D., 1963. An algorithm for least squares estimation of non-linear parameters. Journal of the Society for Industrial and Applied Mathematics, 11(2): 431-441.
16. Jafari-Naeem, K., 1996. Construction of shear force measuring system and design of a triplex harvesting machine. MSc. Thesis, Tarbiat Modarres University, Tehran, Iran.
17. Skubisz, G. and L. Vielikanov, 2000. Assessment of susceptibility of rape stems to shearing. International Agrophysics, 14: 427-430.
18. Eshaghbeigi, A. and B. Hosseinzadeh, 2009. Effect of Moisture Content and Urea Fertilizer on Bending and Shearing Characteristics of Canola Stems. Applied Engineering in Agriculture. 25(6): 947-951.