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Modeling and Optimization of Aloe-Vera Static Shearing by Response Surface Methodology (RSM) and Artificial Neural Network (ANN) Methods

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ABSTRACT

Knowledge of plants' mechanical properties and behavior is one of the essential factors in the design of harvesting and post-harvesting devices. In this study, horticulture, medicinal, and food plants of Aloe Vera were cut using a flat blade. Aloe Vera leaves are cut from the cross-section, and the force and energy required for cutting them were measured using Zwick /roll universal testing machine. The effect of cutting angle (0, 30, and 45 degrees), cutting speed (150, 250, 350, and 450 mm/min), and thickness of Aloe Vera leaves (1, 2, and 3 cm) on the force and energy required for cutting were investigated. To achieve this, response surface methodology was used, the results of which were compared with the artificial neural network method. The results of this study indicated that by increasing the cutting angle, cutting rate (cutting speed), and thickness of the leaves of the Aloe Vera plant, the energy required for its cutting decreased. The most optimal case for cutting the Aloe Vera plant in the case of cutting angle is 45 degrees, the cutting speed is 450 mm/min, and the thickness of Aloe Vera leaves is 3 cm, in which the required energy for cutting and cutting force is equal to 3.45 J and 4.99 N respectively. This study showed that Response Surface Methodology (RSM) is suitable for evaluating optimum conditions in Aloe Vera cutting experiments and is more accurate than the Artificial Neural Network (ANN) method.

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INTRODUCTION

Complex carbohydrates are important compounds in human nutrition and life that are abundantly found in natural resources such as plants (pectin), animals (chitosan), and microorganisms (dextrans) (Maan et al., 2018). One of the most important plant sources having complex carbohydrates is Aloe Vera, which contains approximately 75 different nutrients (Misir et al., 2014). Aloe Vera from the *Liliaceae* family, scientifically known as *Aloe barbadensis* (MILLER), is a medicinal plant containing various minerals and vitamins (Subasree & Murthykumar, 2016). Aloe Vera leaves are known worldwide as a food-drug source of the anticancer, antioxidant, anti-inflammatory, immune regulator, liver protector, anti-ulcer, and antidiabetic source (Sánchez-Machado et al., 2017). The central part of the leaves of this plant is parenchymal or mesophilic cells containing slimy transparent liquid (Figure1), which contains a high concentration of anthraquinone compound. The first step in removing the gel from the leaves of this plant is cutting it. Factors affecting cutting force and shear energy can be categorized as plant factors that depend on the characteristics of the plant regardless of cutting. These characteristics include plant type, moisture content, processing rate, plant stem diameter, and plant density (the number of solids located in the plant). Factors related to the procedure include feeding rate, advancing speed, the thickness of materials undercutting, initial compression, cutting height, blade speed, and other effective factors . Design factors include shear width, sharp edge thickness, blade thickness, blade sharpness angle, blade type, ridding distance, inclination angle, slip angle, etc. (Pekitkan et al., 2019, Persson, 1987).

Figure 1. Leaf of Aloe Vera

In a study, cutting force and energy required for cutting and pruning grape tree branches were investigated by knife type, cutting angle, and cutting rate. This study showed that a flat knife is more suitable for cutting branches of the grape tree than a serrated knife. It was also found that the use of larger cutting angles and higher cutting speed reduces the cutting force and energy required for cutting (Eliçin et al., 2019). The modulus of mass density, crush resistance coefficient, and the useful cutting coefficient for rosemary were investigated in the research. The effect of petal diameter (as a parameter that represents flower growth), blade mode (one and two blades), cutting angle, and cutting rate on these traits were studied. The results showed that the effect of the cutting angle on the modulus values of mass density, crush resistance coefficient, and cutting coefficient was significant at 5% level. The modulus of mass density and crush resistance coefficient decreased, and the useful cutting coefficient increased by increasing the cutting angle (Rabbani et al., 2015). The effect of cutting rate, flower diameter, blade mode, and cutting angle on elasticity modulus, shear strength, and shear energy per unit area of rosemary stem were studied. By increasing the cutting angle from 0 to 25 and 45 degrees, it was observed that shear strength and energy consumption per unit area of stem decreased. By increasing the cutting rate, the shear strength, elasticity modulus, and energy consumption per unit area of the stem decrease. Young's modulus, shear, and bending stress were determined at four moisture levels and three different varieties of Canola. The results showed that the three traits were reduced by increasing moisture content. Also, cultivar difference significantly affects these traits (Hoseinzadeh & Shirneshan, 2012). The comparison of mechanical properties of two varieties of rice showed that the mean shear strength and bending stress and Young's modulus had a significant difference at a 5% level with cultivar change (Tavakoli et al., 2010). Stem slices of rapeseed were studied in three levels of stem diameter, three levels of cutting rate, and three cutting angles .In this study, cutting parameters including maximum cutting force, shear strength, cutting energy, power consumption, and cutting work were investigated. Tests continued for each stem until complete incision. The data requirements were obtained from the force-deformation curve. The results showed that by increasing the diameter and angle of cutting, the values of cutting force, shear strength, cutting energy, cutting power, and cutting work increased . In addition, by increasing the cutting speed, cutting force, shear strength, cutting energy, cutting power, and cutting work decreased. In this study, artificial neural networks were used to predict shear outcomes. The results showed that neural networks could be used in intelligent cutting mechanisms and predict the mechanical properties of stem products (Azadbakht et al., 2016). In this study, maize stem shear strength and energy were investigated. The results showed that they decreased with increasing velocity, resistance, and shear energy in direct cutting (Prasad & Gupta, 1975). The effect of moisture content on shear stress and energy per unit area of sunflower stem was investigated in a study. This study showed that energy and shear stress are higher in the upper part of the stem than in its lower part (İnce et al., 2005). In a study on the flexural and shear properties of wheat stalks of the Alvand variety, they found that the shear stress for wheat stalks decreases due to reduced moisture .The shear force for the stem decreases due to increasing the cutting height. For angles of 30 degrees, shear stress is lower than 0 and 15-degree angles. Bending stress and elasticity modulus increase with decreased moisture and increased cutting height (Esehaghbeygi et al., 2009). A study was conducted to determine the effect of blade velocity on energy and shear efficiency in sorghum stem cutting. This study showed that the required shear energy has a negative linear correlation with the shear force of blade and stem moisture and shear efficiency has a positive linear correlation with these parameters. Also, cutting efficiency is higher at higher speeds (Yiljep & Mohammed, 2005). There are also many studies on the use of RSM and ANN in the modeling of agricultural behavior as well as other products such as: Equilibrium, kinetic and thermodynamic study of diazinon adsorption from water by clay/ GO/ Fe_3O_4: Modeling and optimization based on response surface methodology and artificial neural network (Sohrabi et al., 2021), Response surface methodology and its applications in agricultural and food sciences (Khuri, 2017). Which all previous researches mentioned that application of ANN and also RSM are the suitable methods for modelling the materials behavior.

Despite the suitability of response surface methodology and artificial neural networks, they have rarely been used to optimize different parameters in the cutting field. Therefore, the necessary force for cutting and energy cutting of the Aloe Vera plant has been investigated in the present study. The effect of leaf thickness (as a parameter of plant age and its moisture content), cutting rate, and cutting angle using response surface methodology and artificial neural network as new methods on shear characteristics of Aloe Vera plant have been investigated. The results of this study effectively design and optimize the equipment related to the processing of this medicinal plant from basic information.

MATERIALS AND METHODS

The Aloe Vera leaves prepared from the planting complex in Qasr-e-Shirin city of Kermanshah province- Iran. Then, the samples were transferred under special conditions to the physical and mechanical properties laboratory of agricultural products in the Biosystem engineering department at Razi University-Kermanshah. A digital caliper with 0.01 mm accuracy was used to measure the thickness of the samples at the cutting site. Each sample was cut into three parts, and each part's thickness was measured separately. Samples were weighed with 0.01 g accuracy using a digital scale and placed in an oven at 103°C for 24 hours. They were then weighed and their moisture content was obtained based on wet weight.

Mechanical test (cutting test)

In this study, a smooth blade with galvanized iron and a sharp angle of 4.23 degrees was used for cutting. Cutting force and energy consumption for cutting and modulus of Aloe Vera elasticity were obtained using a Zwick /roll universal testing machine equipped with a load cell with a capacity of 500 N and a precision of 0.001 N (Figure 2). The displacement force curve was drawn from the moment of contact with the blade until the complete cutting of the samples. The maximum shear force was the peak point of the force-displacement curve obtained from this diagram. Also, the surface under the force-displacement curve is the energy consumed for cutting.

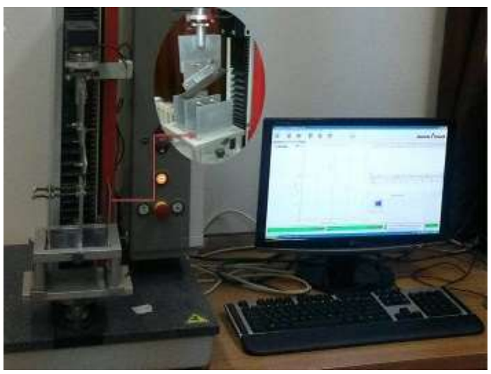

Figure 2. The designed cutting jaws

To investigate the effect of cutting angle, cutting rate, and thickness of Aloe Vera leaves on cutting force and energy consumption, response surface methodology and Design Expert-11 software were used (Sohrabi et al., 2021). For this purpose, the randomized optimal design was used; their variables and surfaces are shown inTable 1. Repetition of central interval points was considered four times for this study. Each experiment designed by software with three replications was performed to remove random effects, and their mean was used.

Table 1. Independent variables and the coding levels in the experiments

Independent variables	Coded	Unit	Factorial and center level			
			1 level	2 level	3 level	4 level
Angle	X_1	degree	0	30	45	-
Speed	X_2	mm/min	150	250	350	450
Thickness	X_3	cm	1	2	3	-

A Multi-sentence model was used to analyze the obtained data based on Design Expert software recommendations. This model described based on Eq.1 includes predictive expressions of variables that show the relationship between dependent variables (Y) and independent variables (X1 to X3).

$$Y_{1\,\mathrm{and}\,2} = \beta_0 + \sum_{i=1}^{4}\beta_i X_i + \sum_{i=1}^{4}\sum_{j=1}^{4}\beta_{ij} X_i X_j + \sum_{i=1}^{4}\beta_{ii} X_i^2 + \varepsilon \qquad (1)$$

Where Y_1 and Y_2 are the energy consumption for cutting and shear force, β0 is the model constant, βi is linear coefficients, βij are interactive coefficients, βii are quadratic coefficients, ε is residual time, Xi, Xj, etc. are independent variables, which are the cutting angle, cutting speed and thickness of Aloe Vera leaves. Then, based on the obtained results, independent variables were determined using analysis of variance and F-test value. Then, the predicted results were compared with the experimental results, and the correlation coefficient (R^2) was obtained. Other statistics used to evaluate the quality and efficiency of the model, such as standard deviation (SD), coefficient of variation (CV%), desirability function (DF), and appropriate accuracy (AP) calculated by the software, were investigated .

In addition, an artificial neural network (ANN) was used to investigate the cutting process of Aloe Vera. For this purpose, the data used in the response surface methodology were utilized. The neural network can display hidden relationships between data and is used in various scientific fields. This method has a nonlinear nature and works better than statistical methods for solving complex problems and analyzing them**.** It is more stable against possible changes, and if we have enough data, the ability of this method will also increase. The artificial neural network used was a multilayer neural network with three input layers, output, and hidden layer, which included the studied parameters, the output layer of dependent variables, and the hidden layer containing neurons that characterize the function. The function used in the hidden layer is the sigmoid transfer function (tansig) and the output layer of the linear transfer function. To compare the performance of the artificial neural network with the equation obtained by the RSM method, error values were calculated using Eq.2 to Eq.4, and according to their values, the performance of these two methods was compared in process prediction.

$$MAE = \sum_{i=1}^{m} |(y_i - \hat{y}_i)| \Big/ m \qquad (2)$$

$$MAPE = \frac{100}{m} \sum_{i=1}^{m} \left(|y_i - \hat{y}_i| \Big/ y_i \right) \qquad (3)$$

$$RMSE = \sqrt{\sum_{i=1}^{m} (|\hat{y}_i - y_i|)^2 \Big/ m} \qquad (4)$$

In these equations, MAE is the value of the absolute mean error, MAPE is the absolute mean value of the error percentage, RMSE is the root mean square of the error, which are the values of the actual efficiency predicted by the model, respectively (Cheng et al., 2008).

RESULTS AND DISCUSSION

The results showed that the moisture content of stems was 92.5% (w.b), which can be due to the structure of the gels of the inner tissue of these leaves. The results of the Central Composite Design (Design Expert) are initially the design of the experiments, based on which the cutting experiments of the Aloe Vera plant were performed. Then, the data obtained from experiments were fed to the software. In the first step, the assumption of normality of the data was investigated, for which the normal distribution diagrams and box-cox were investigated (Figure 3). As can be seen, the standard distribution diagram for cutting energy and cutting force (Figure 3-a and b) by scattering around the line and not having the "S" shape pattern indicates the normality of the data distribution (Shi et al., 2020). Also, based on the box-cox diagram (Figure 3-c and d), the gain value of the current models is 1, while the best value for cutting energy is 0.98, which is in the confidence range of 95% equal from 0.33 to 1.56. In addition, the best gain value for cutting force was 0.57, which ranged from -0.14 to 1.27. Therefore, both models are in the 95% confidence range and do not require a transfer function. Then, the equations indicating the relationship between independent and dependent variables were investigated in Eq. 5 and Eq.6

$$\begin{aligned} Y_1 &= 48.49 - 3.27X_1 + 0.17X_2 + 22.11X_3 \\ &+ 0.004X_1X_2 - 0.25X_1X_3 - 0.04X_2X_3 + 0.03X_1^2 - 0.0004X_2^2 \end{aligned} \qquad (5)$$

$$Y_2 = 13.12 - 0.144X_1 - 0.007X_2 + 0.39X_3 \qquad (6)$$

In the above equations, Y1 and Y2 are energy consumption for cutting, and cutting force; while X1, X2, and X3 are cutting angle, cutting speed, and thickness of Aloe Vera leaves, respectively. As can be seen, the equation governing the energy of the second-degree shear and the first-degree cutting force is observed in the results of their analysis of variance. As can be seen, the coefficient of the model's description related to energy consumption for cutting is 0.975, and the standard deviation, mean, and coefficient of variation were 6.30, 37.40, and 16.85%, respectively. In addition, the coefficient of explanation related to the prediction of the model was obtained as 0.910, which shows that the model has a high ability to predict the data, and the data obtained from the experiments are very closely related to the data estimated by the model. Also, the model's description coefficient related to the cutting force was 0.934, and the standard deviation, average, and coefficient of variation were 0.79, 8.44, and 9.37%, respectively. These values indicate the low dispersion of data and their proximity to the average value. Also, since the coefficient of variation is less than 10%, the obtained model is reproducible (Bagheri et al., 2017; Sohrabi et al., 2021). Ap statistics of the energy consumption model for cutting and cutting force were calculated as 27.03 and 26.28, indicating noise signal rate. If the value is greater than 4, it means a sufficient signal (Horng et al., 2008). In addition, as can be seen, both models are significant at the probability level of 99%, and the lack-of-fit value is related to both non-meaningful models, indicating that the obtained models have the high predictive ability (Table 2). Then, each non-meaningful effect was removed from the models, and the modified model was reported in Eq. 5 and Eq. 6.

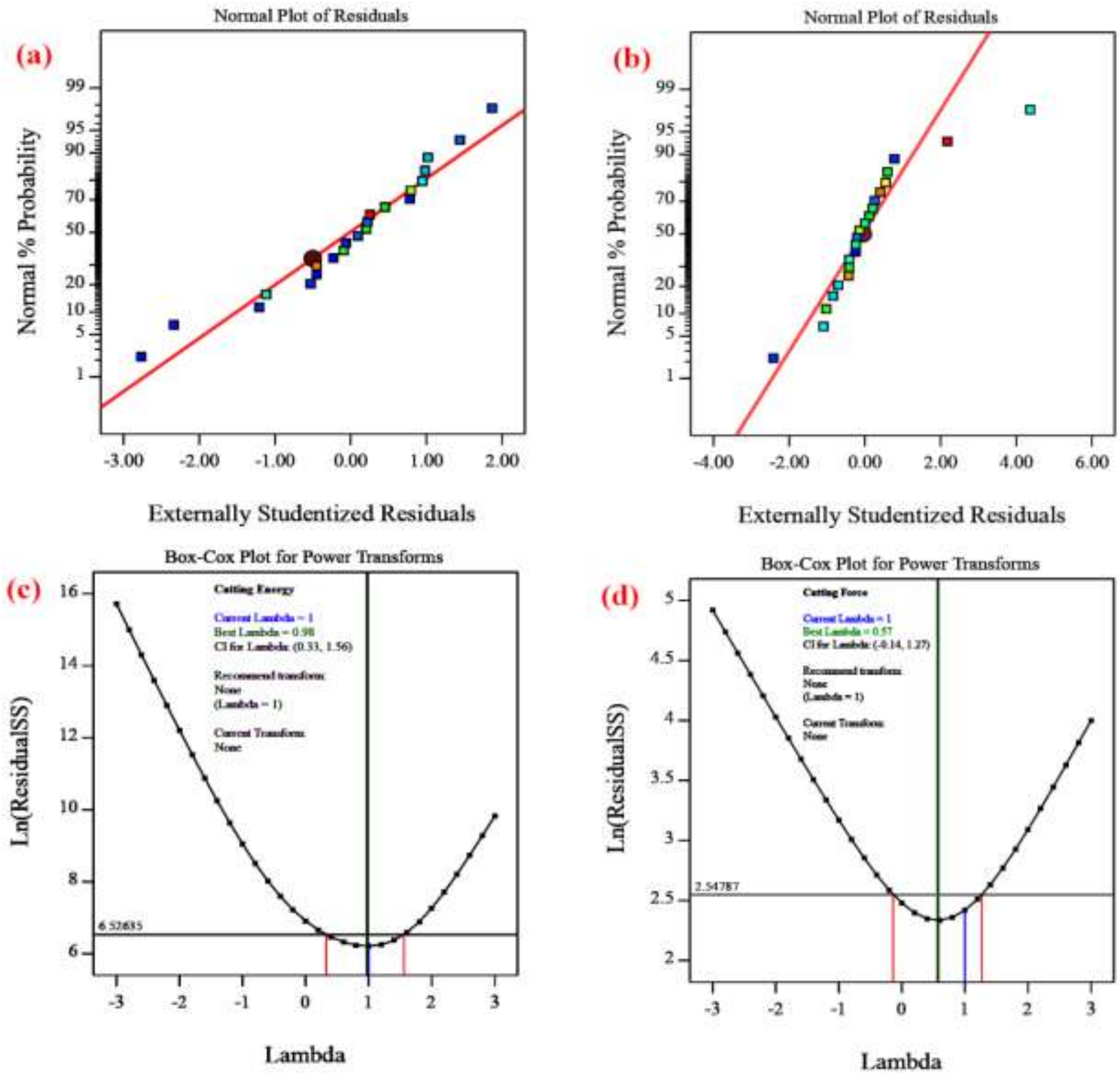

Figure 3. a) Normal distribution graph for cutting energy, b) Normal distribution graph for cutting force, c) Box-Cox graph cutting energy, d) Box-Cox graph cutting force

Table 2. Analysis of variance (ANOVA) for the modified Aloe Vera cutting model

Source	Cutting Energy			Cutting Force		
	df[a]	MS[b]	F-value	df	MS	F-value
Model	9	2140.88**	51.80	3	53.23**	85.28
X_1	1	9812.66**	237.42	1	130.92**	209.73
X_2	1	2041.40**	49.39	1	11.54**	18.49
X_3	1	418.00**	10.11	1	1.93*	3.10
X_1X_2	1	1372.67**	33.21	-	-	-
X_1X_3	1	264.58*	6.40	-	-	-
X_2X_3	1	243.52*	5.89	-	-	-
X_1^2	1	666.29**	16.12	-	-	-
X_2^2	1	391.27**	9.47	-	-	-
X_3^2	1	20.27ns	0.4903	-	-	-
Residual	12	41.33	-	18	0.6242	-
Lack of Fit	8	43.73ns	1.20	14	0.7609ns	5.22
Pure Error	4	36.54	-	4	0.1457	-
Cor Total	21	-	-	21	-	-

Model Summary Statistics

Response	Std. Dev.(SD)	Coefficient of Variance (C.V%)	R^2	Adj-R^2	Pred-R^2	AP
Y_1	6.30	16.85	0.975	0.956	0.910	27.03
Y_2	0.79	9.37	0.934	0.923	0.884	26.28

[a] Degree of freedom, [b] Mean of Square, ** Significant relationship at 1%, * Significant relationship at 5%, ns Not significant

In Eq. 5 and Eq. 6 coefficients related to variables are shown. The positive and negative effect of increasing that variable on energy consumption for cutting and cutting force is determined. The coefficients of the cutting angle and shear rate variables are negative, which shows that by increasing their amount, the amount of energy necessary for cutting and cutting force has decreased. However, the coefficient of Aloe Vera leaf thickness is positive, i.e., by increasing it, the amount of energy required for cutting and cutting force has increased. These models are insufficient to express the effect of independent variables because they only show coefficients. Therefore, the scatter diagram plotted the independent variables' impact (Figure 4). As seen in the energy diagram (Figure 4-a), the curves related to the speed and angle of the cutting are quadratic, which can also be seen in Eq. 5. However, in this diagram, the effect of Aloe Vera leaf thickness was linear. The quadratic term in Eq. 5 was not significant and was removed from the model. In Figure 4-b, it can be observed that the effect of variables on cutting force is linear, and the governing equation is also a linear relationship.

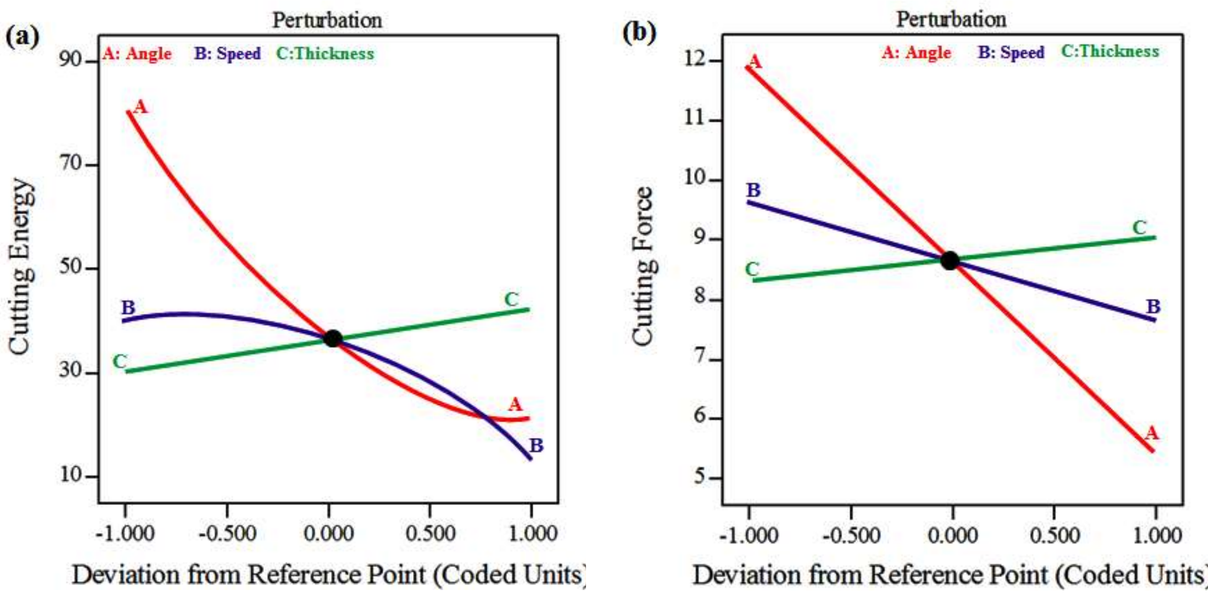

Figure 4. Perturbation graph of a) Cutting Energy and b) Cutting Force

In Figure 4 and Eq. 5 and Eq. 6 the sensitivity of response to independent variables is observed. However, the values of independent variables are absolute values, and the numerical value of that variable influences the magnitude values of coefficients. The Pareto diagram was plotted in coded form to investigate the effect of independent variables and interactions. The Pareto diagram for both dependent variables is shown in Figure 5. As can be seen, the first power of the cutting angle has the most significant impact on the amount of energy required for cutting, and the interaction between cutting rate and leaf thickness has the least effect on this variable (Figure 5-a). In addition, the Pareto diagram of cutting force also shows that the cutting angle is the most effective parameter on this variable (Figure 5-b).

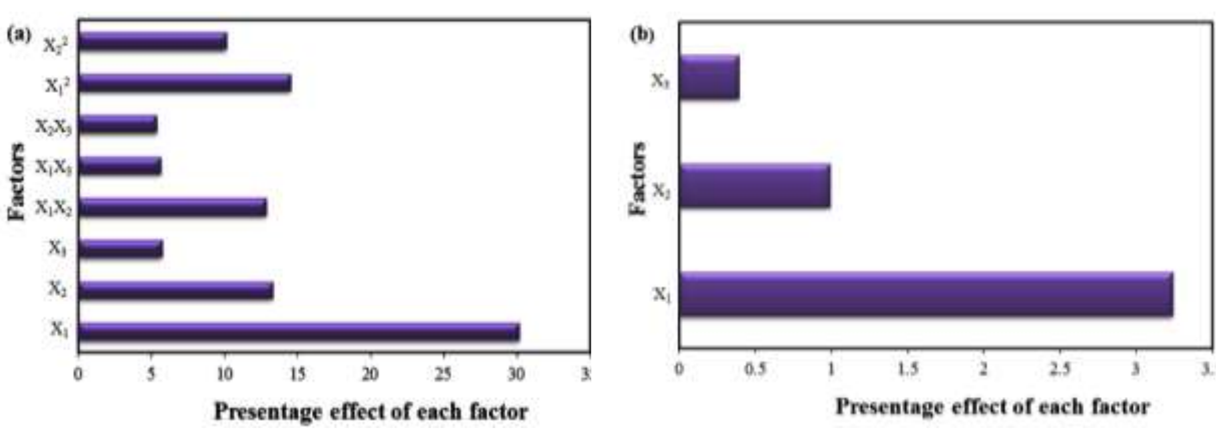

Figure 5. Pareto chart for all significant factors a) Cutting Energy and b) Cutting Force

As can be seen from Eq. 5 and Eq. 6. Figure 5, and Table 2 the interaction of variables on the energy required for cutting is significant and on cutting force is insignificant. Therefore, the effect of variables on the energy required for cutting 3D diagrams in which interactions are observed was investigated (Figure 6). As can be seen, the interaction between the speed and angle of the cut (Figure 6-a) shows that at low speeds, the change of angle has a greater impact on the energy required for cutting. Also, the effect of velocity changes on the energy required for cutting is more significant at low cutting angles. In addition, it is observed that at an angle of 45 degrees at all cutting speeds, the energy required to cut is almost the same amount. Therefore, it can be concluded that considering the appropriate cutting angle at different speeds, the cutting process can be done with less energy. The interaction of cutting angle and leaf thickness is shown in Figure 6-b. As can be seen at a cutting angle of 45 degrees compared to lower cutting angles, changes in the thickness of Aloe Vera leaves have less effect on the energy required for cutting. But angle changes have almost the same effect on the energy necessary for cutting in different thicknesses.

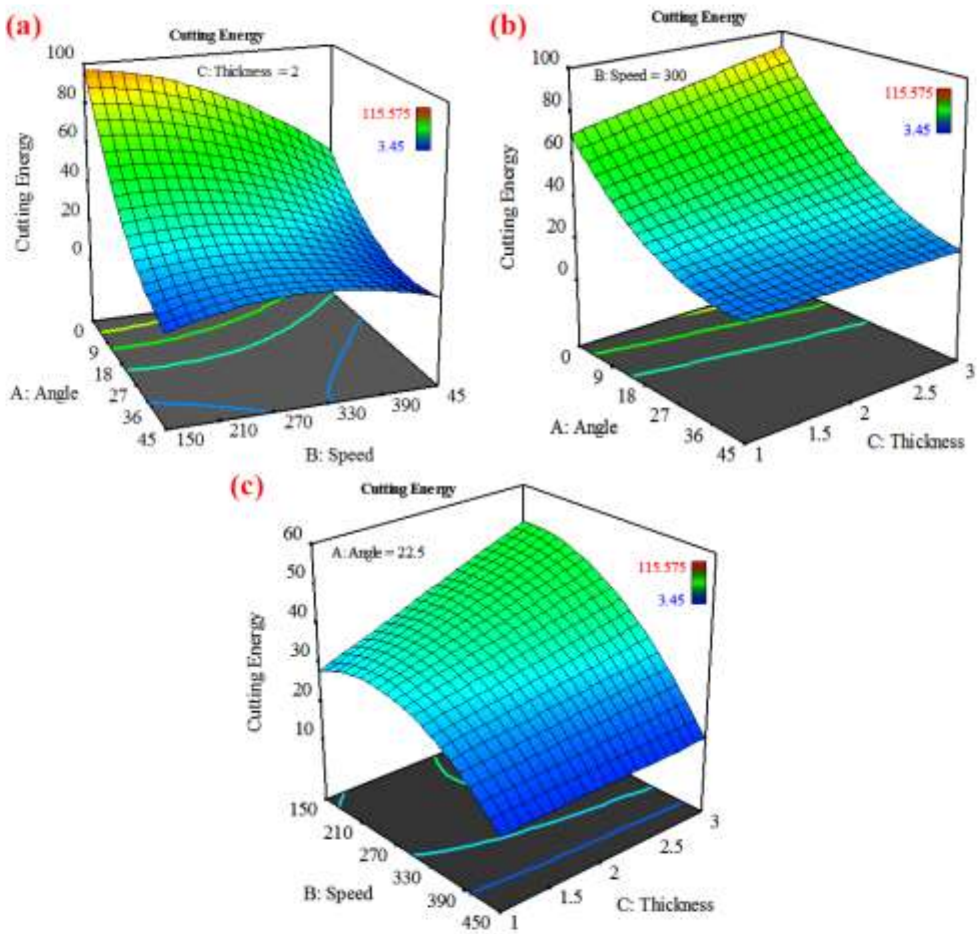

Figure 6. Diagrams of the interactions of independent variables on the cutting energy a) Cutting angle-cutting speed, b) Cutting angle-thickness of Aloe Vera leaf, c) Cutting speed-thickness of Aloe Vera leaf

In 3D diagrams, the optimal conditions related to independent variables were shown two by two at the central point of the third variable. But to determine the optimal overall conditions, these diagrams are not sufficient. Also, in 3D diagrams, optimal conditions cannot be applied. Therefore, parameters were optimized to find conditions where all variables are desirable and optimal with the energy required for cutting and minimum cutting force. Figure 7 shows the real profiles of each independent variable in which the optimal points are specified, along with the diagram of the maximum and minimum energy required for cutting and cutting force. Since the Aloe Vera plant increases its leaf thickness at ripening, the maximum amount was considered in optimum leaf thickness. As can be seen in the process of cutting Aloe Vera leaves with a thickness of 3 cm, at a cutting angle of 45 degrees and a cutting speed of 450 mm/min, the amount of energy required for cutting and cutting force to the projections are predicted to be 4.75 J and 4.84 N, respectively. The cutting experiment was performed under the mentioned conditions to evaluate these results, and the required energy was calculated for cutting and cutting force. The obtained values of energy required for cutting energy and cutting force in experiments are 3.45 J and 4.99 N, respectively. This small difference indicates that the optimal design and response surface methodology can effectively investigate the cutting process conditions of the Aloe Vera plant and determine the optimal conditions.

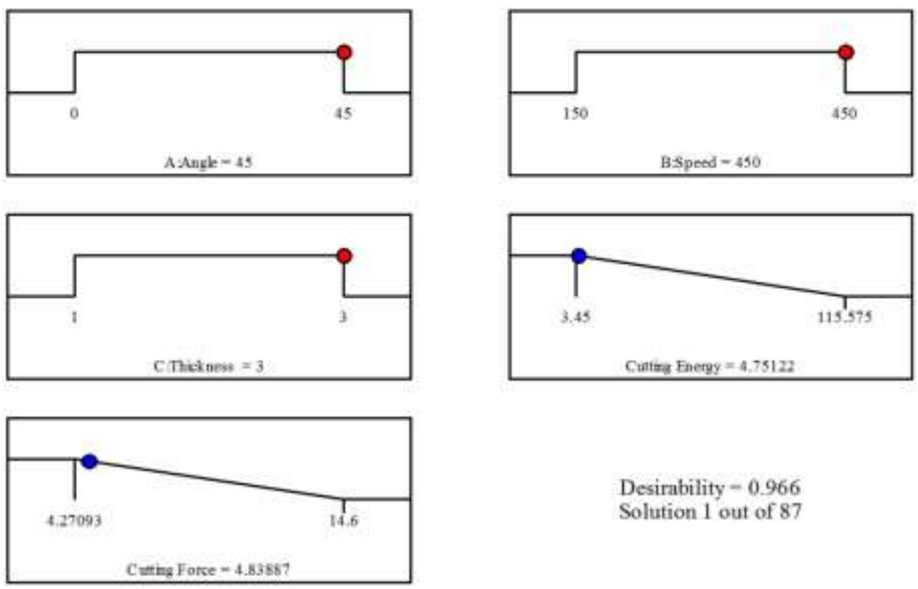

Figure 7. Actual profiles with predicting points of optimal condition for cutting Aloe Vera

Artificial neural network results

The study of experimental data using an artificial neural network showed that a neural network with ten neurons in a hidden layer has the best efficiency (low RMSE and high explanation coefficient) for data modeling (Fig 8). The experimental data were divided into three categories of training, validation, and test data. The results of this study are shown in Fig 8; as can be seen, the correlation coefficient of all three of these data is higher than 0.93. Also, the data were evaluated using the designed network, and the correlation coefficient was 0.935, which showed the increased ability of an artificial neural network designed to fit the experimental data. The model's ability obtained from response surface methodology and artificial neural network was compared. For this purpose, the experimental data were first compared with the data estimated by both models; then they were calculated to investigate the difference between the actual data and the data obtained from the modeling of different error values (Table 2). The results of calculating different amounts of error show that the response surface methodology has a higher ability than the artificial neural network method to express the cutting process of the Aloe Vera plant based on the cutting angle, cutting rate, and thickness of Aloe Vera leaves.

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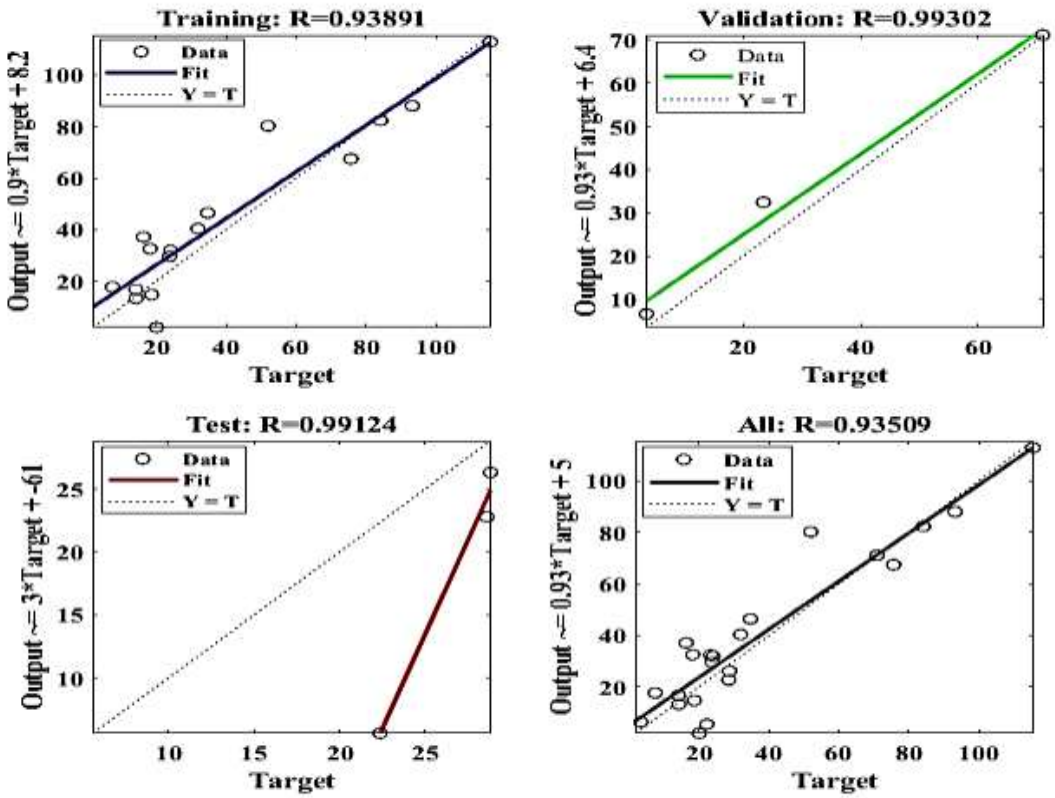

Figure 8. The regression graphs for ANN

This study showed that by increasing the cutting angle and cutting rate, Aloe Vera cutting could be done effectively with less power and energy. This result has also been observed in the study of the force and energy required for cutting other crops such as grape tree branches (Eliçin et al., 2019), rose (Rabbani et al., 2015), canola stem (Azadbakht et al., 2016), maize stalks (Prasad & Gupta, 1975), and sorghum (Yiljep & Mohammed, 2005). The results showed that increasing the thickness of Aloe Vera leaves reduces the strength and energy required for cutting this plant. As mentioned above, with increasing age, the leaves of the Aloe Vera plant increase the part of the gels inside it, and as a result, the moisture of the leaves increases. Therefore, increasing moisture reduces the strength and energy required for cutting this plant, which has been observed in other crops such as canola (Hoseinzadeh & Shirneshan, 2012), sunflower (İnce et al., 2005) and wheat (Esehaghbeygi et al., 2009).

Table 2. Amounts of errors for ANN and RSM

Performance	ANN	RSM
MAE	8.546	3.727
MAPE	40.90	19.103
RMSE	11.095	4.844
Minimum Absolute Error	0.169	0.07
Maximum Absolute Error	28.277	12.49
R^2	0.874	0.956

MAE: mean absolute error, MAPE: mean absolute percentage error

CONCLUSIONS

This study aimed at investigating the force and energy required to cut Aloe Vera. In this study, the parameters affecting cutting such as cutting speed (four levels: 150, 250, 350, and 450 mm/min), cutting angle (three levels: 0, 30, and 45 degrees), and thickness of Aloe Vera leaves (three levels: 1, 2 and 3 cm) were optimized to reduce the force and energy required for cutting. For this purpose, response surface and artificial neural network methods were used. This study showed that the most optimal condition for cutting leaves of the Aloe Vera plant at cutting angle of 45 degrees, cutting speed of 450 mm/min, and thickness of Aloe Vera leaves is 3 cm. The simultaneous effect of cutting speed and angle showed that at 45 degrees angle at all cutting speeds, almost the energy required for cutting is the same amount. Therefore, given the appropriate cutting angle at different speeds, the cutting process can be done with less energy. In general, the results of this study show that by increasing plant growth, less energy is needed for cutting. Therefore, according to the above, it is suggested that the plant be harvested in the last stage of growth of maximum thickness. Also, cutting speed and larger cutting angles should be used in Aloe Vera processing sites. The results of ANN and RSM showed that this two method can significantly use for modelling of shearing parameters of Aloe Vera.

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