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Determination of the Mechanical Properties of Parsley Stems Related to the Design of Processing Machines †

Mohammad Hosseinpour-Zarnaq [1,*], Saeid Minaei [1] and Pourya Bazyar [2]

[1] Biosystems Engineering Department, Tarbiat Modares University, Tehran 14115-111, Iran; minaee@modares.ac.ir
[2] Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj 77871-31587, Iran; pourya.bazyar@ut.ac.ir
* Correspondence: husenpour@ut.ac.ir

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Abstract: To develop a cutting, harvesting, crushing or grinding machine, knowledge of the crop's physical and mechanical properties is needed. In this study, the shear strength, shear energy and maximum shear force in cutting parsley stems is examined. The cutting of multiple stems (eight stems) was performed using blades with oblique angles of 0°, 20° and 40°. In order to examine the effects of the stem arrangement in the cutting operation, the stems were placed in row and bundle arrangements. Statistical analysis showed that the shear strength and maximum shear force decreased with the increasing oblique angle. The average values of the shear strength, specific cutting energy and maximum shear force for cutting eight stems laid in a row arrangement using a blade oblique angle of 0° were 0.49 MPa, 2.25 mJ mm^{-2} and 56.13 N, respectively, while at a blade angle of 40°, the values were 0.19 MPa, 4.12 mJ mm^{-2} and 18.2 N, respectively. A blade angle of 20°is recommended as it does not require more cutting energy compared to 0°, and the shear force is reduced, which lessens the effect of impacts on the cutting system.

Keywords: parsley stems; mechanical properties; blade angle; postharvest operations

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1. Introduction

Vegetables are a product that is cultivated on a large scale, and considerable energy is spent on this production. Thus, machines must be designed to mechanize the planting, harvesting and postharvest operations. In order to design a machine for the harvesting or processing of crops, it is necessary to determine the mechanical and physical properties of the materials [1,2]. In addition, reducing power consumption is an important machine design objective. Thus, the cutting process of plant stems must be investigated [3,4].

The important mechanical properties that need to be considered for crop cutting are the shear strength, bending strength, tensile strength, density and friction [5,6]. These properties are different at different stem heights [7]. The engineering characteristics are influenced by the species, variety, age, moisture content and cellular structure of the plant. The plant harvest time affects the mechanical properties, which is due to the changes in the moisture content of the plant.

At the first stage of plant maturity, the shear strength is the highest, while the modulus of elasticity increases continuously from the first growth stage to the final stage, and the rigidity modulus is not dependent upon the stage of harvesting [8]. Azadbakht et al. [9] investigated the energy consumption during the impact cutting of canola stalks. The highest cutting energy was measured as 1.1 kJ at a 25.5% (w.b.%) moisture content and 10 cm of cutting height. The minimum cutting energy was 0.76 kJ at a 11.6 (w.b.%) moisture content and 30 cm cutting height.

Blade shapes affect the shear strength. Esehaghbeygi et al. [10] showed that a smooth blade decreased the shear strength of wheat stems, and the shear strength values of wheat stems at 0, 15 and 30 blade oblique angles were 3.92, 3.58 and 3.36 MPa, respectively. The shear energy depends on the cutting speed. Mathanker et al. [11] reported that the shear energy required for cutting energy cane was found to increase with the cutting speed. On the other hand, to obtain good farm capacity for harvesting machines, the speed of the blade cannot be greatly reduced [11]. However, another study on the shear properties of various grasses showed that the loading rate and blade bevel angle had no effect on the shear strength and shear energy [12].

Galedar et al. [13] studied the mechanical properties of alfalfa stems. The average values of the shear strength and shearing energy at the highest moisture content (80% w.b.) were approximately two- and three-times greater than those at the lowest moisture level (10% w.b.). The tensile strength, bending strength, Young modulus, torsional strength and rigidity modulus at the lowest moisture content (10% w.b.) were around 3-, 3-, 5-, 6- and 7-times greater than those at the highest moisture content (80% w.b.), respectively. Ince et al. [14] also reported that the bending strength of sunflower stalks decrease with increasing stem moisture content, and the highest shear strength and specific shearing energy were reported as 1.07 MPa and 10.08 mJ mm^{-2}, respectively.

Measuring the mechanical properties can be used for estimation of the products quality. The mechanical properties of cotton shoots for topping were investigated [15]. In the higher parts of the plant (0–15 cm height), the diameter, shear force, moisture content, shear strength and specific shearing energy were 4.35 mm, 73 N, 72%, 4.94 MPa and 0.069 J mm^{-2}, respectively, while at the lower parts (15–30 cm height), they were 5.79 mm, 121 N, 64.8%, 4.65 MPa and 0.078 J mm^{-2} [15].

There are no studies investigating the mechanical properties of parsley. However, no reports were found describing the cutting processes based on stem arrangement. In this research, the cutting process was examined and the effects of the blade angle and stem arrangement on the mechanical properties of parsley stem were investigated. The results were used to design a vegetable cutting machine.

2. Materials and Methods

The aim of this study was to measure the shear strength, specific cutting energy and maximum shear force of parsley stems and to investigate the effects of the blade angle and arrangement of stems on the mentioned parameters. The full factorial experimental design was used to examine the effect of independent variables and their interaction (Table 1). All data were analyzed by ANOVA using SPSS software package (SPSS Inc., Chicago, IL, USA), and the tests were replicated six times.

Table 1. The independent and dependent variables studied in this research.

Independent Variables	Levels
Blade oblique angle	0°, 20° and 40°
Stem arrangement	Row and bundle

Dependent variables: the shear strength and specific cutting energy.

The experimental material was fresh parsley purchased from a market. The diameter of the samples were measured by a digital caliper (accuracy: ±0.01 mm), and then the cross sectional area was calculated. Since the cutting height may affect the shear properties, all experiments were conducted on stems with the height range of 4 to 8 cm (Figure 1D). The initial moisture content of the stems was determined by oven drying at 103 °C for 24 h and expressed on the wet basis. Table 2 shows the mean values of the two physical parameters of parsley stems.

Table 2. The physical properties of parsley stems.

Average cross Sectional Area	Average Diameter	Stem Moisture Content	Cutting Height
13.1 mm^2	4.1 mm	92% (Wet basis)	4–8 cm

In the experiments, the steel blades were properly sharpened (edge angle ≈ 20) to make a clean cut and to avoid stem tearing. The loading rate was 400 $mm.min^{-1}$. In order to study the effects of arrangement, eight parsley stems were laid out in row and bundle arrangements under the cutting blade, and cutting was performed using the different blade oblique angle (BOA) (Figure 1).

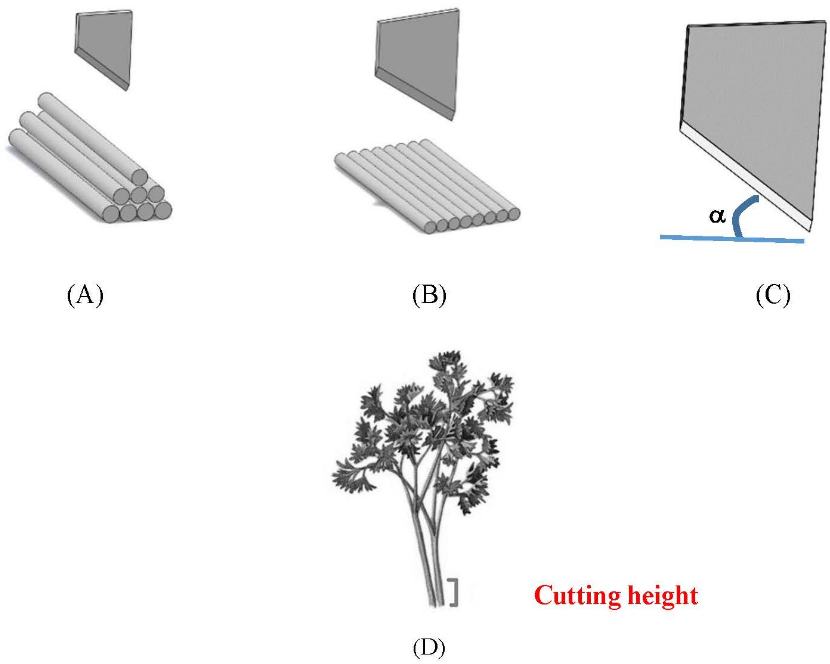

Figure 1. (**A**) Bundle arrangement, (**B**) row arrangement, (**C**) BOA (α = 0, 20 and 40°) and (**D**) cutting height.

Cutting tests were performed using a universal materials testing machine (UTM) (SANTAM Company, Model: STM 20, Tehran, Iran) (Figure 2). The shear (F_s) force values were obtained by UTM, and the shear strength (τ_{max}) was calculated using Equation (1).

$$\tau_{max} = F_{s\ max} / A \quad (1)$$

where $F_{s\ max}$ is the maximum shear force and A is the sample cross sectional area. The shear energy was obtained by calculating the surface area under the force-deformation curve up to the breaking point. The specific cutting energy (E_{SC}) was determined using Equation (2).

$$E_{SC} = E_S / A \quad (2)$$

where E_S is the shearing energy and A is the sample cross sectional area.

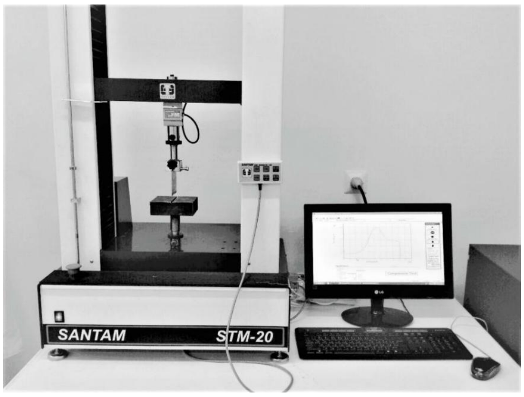

Figure 2. The materials testing machine used in the research.

3. Results and Discussion

Typical force-deformation curves are shown in Figure 3. Based on the results, as the blade cut through the stem cross section, the required shearing force for a complete cut increased. When the force reached its maximum value, it began to decrease since, at this point, half or more of the stem cross section was cut. Once the stem was completely cut through, the force diminished to zero. The blade edge collided with the stem at one point, and the contact area between the stem cross section and blade edge increased with the blade movement. By using a blade with large oblique angle, more of the blade edge was involved in the cutting process, and thus the required force was reduced.

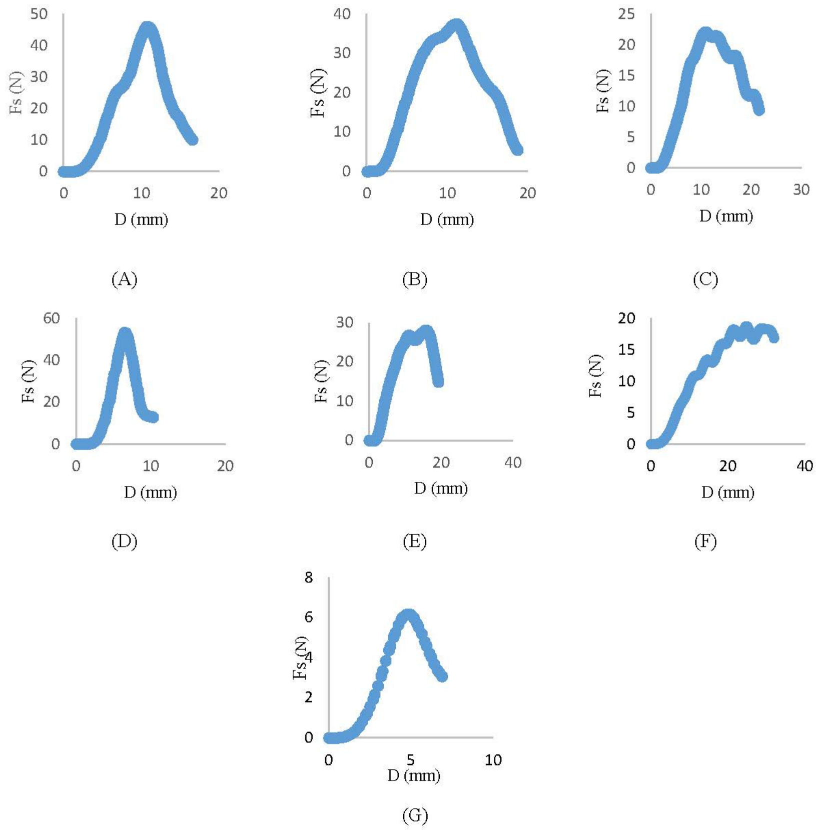

Figure 3. Typical force-deformation curves for cutting parsley stems at various blade oblique angles and stem arrangements: (**A**) BOA = 0°, eight stems, bundle arrangement; (**B**) BOA = 20°, eight stems, bundle arrangement; (**C**) BOA = 40°, eight stems, bundle arrangement; (**D**) BOA = 0°, eight stems, row arraignment; (**E**) BOA = 20°, eight stems, row arrangement; (**F**) BOA = 40°, eight stems, row arraignment; and (**G**) single stem and BOA = 0°.

Based on the results shown in Figure 3C, the blade with a 40° oblique angle caused more deformation in the diagrams and more displacement required for a full cut, while the maximum shear force was reduced. In addition, a blade with large BOA cut stems one after another (Figure 1B). When the BOA = 0°, the blade edge collided with the stems simultaneously, and more force was needed. In the row arrangement, the stems were laid in one line so that the stems could be cut easily at a large BOA, and the effect of the BOA was more pronounced.

The results showed that the blade oblique angle, stem arrangement and their interaction significantly affected the dependent variables (Table 3).

Table 3. The results of ANOVA for the specific cutting energy and shear strength.

Source of Variation	Dependent Variable	df	SS	MS	F Value
BOA	E_{SC}	2	10.58	5.29	28.6 **
	τ_{max}	2	0.34	0.17	127.24 **
Stem arrangement	E_{SC}	1	1.64	1.64	8.9 *
	τ_{max}	1	0.02	0.02	21.25 **
BOA × Stem arrangement	E_{SC}	2	2.76	1.38	7.47 *
	τ_{max}	2	0.04	0.02	15.43 **
Error	E_{SC}	30	5.55	0.185	
	τ_{max}	30	0.04	0.001	

df: degrees of freedom; and MS: mean square. * and **: significant at the 5% and 1% levels, respectively.

Multiple stems are not cut simultaneously at large blade angles, and thus the shear force for the complete cutting of stems is reduced. The shear strength is proportional to the shear force; thus, at higher blade angles, the shear strength is decreased. Figure 4 shows variations of the shear strength and maximum shear force with the blade oblique angle. Increasing the cutting angle from 0° to 40° decreased the average shear strength. At a 0° blade angle and in a bundle arrangement, the maximum shear force and shear strength values for cutting eight stems were 42.17 N and 0.45 MPa, while at 20°, they were 31.81 N and 0.32 MPa, respectively.

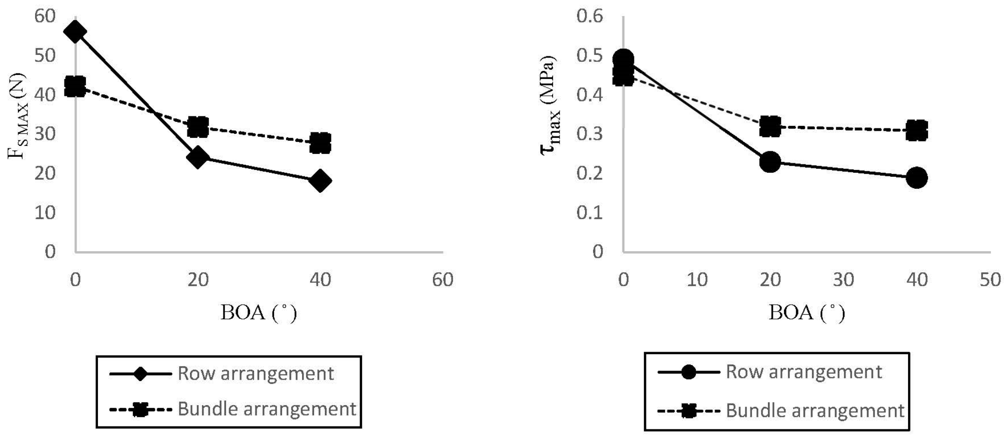

Figure 4. The maximum shear force and shear strength at 0°, 20° and 40° blade oblique angles for eight stems in row and bundle arrangements.

These values at 40° reached to 27.76 N and 0.31 MPa, respectively. BOYDAŞ et al. [16] reported that shearing force values of sainfoin stems obtained at an oblique angle of 28° were lower than those at an oblique angle of 0°. Similar results were reported by Yore et al. [17] for rice straw, by Allameh and Alizadeh, [18] for rice stems, by Ghahraei et al. [19] for kenaf stems and by Liu et al. [20] for peony stems. The proper design of the cutting equipment can maintain the quality of the harvested product while minimizing the force and energy needed to accomplish the task.

Multiple stems do not undergo cutting simultaneously. As a result, the specific cutting energy for cutting a single stem is higher than that for a bundle of stems. A blade with a greater oblique angle cuts the stems laid out in a row arrangement one by one; thus, a complete cut requires a lower shear force and higher blade displacement.

In the bundle arrangement and with cutting angles of 0° and 20°, the cutting energy is more than in the row arrangement (Figure 5). In the bundle arrangement and at a 20° blade angle, the cutting energy is lower than that at 0°, which is due to a sharp reduction in the shear force at high angles (Figure 4). At a blade angle of 40°, a complete cut requires a higher blade displacement, resulting in a higher specific cutting energy. Johnson et al. [21] reported that, by increasing the cutting angle from 0° to 60°, the energy needed to cut the Miscanthus x giganteus stems decreased from 10.1 J to 7.6 J. Similar results were reported by Maughan et al. [22] for Miscanthus cutting and by Eliçin et al. [23] for grape cane. Mathanker et al. [11] also reported a decrease in the shear energy with an increasing blade oblique angle for energycane stems.

The values of the shear energy per stem and specific cutting energy for cutting parsley stems at a 0° blade angle were 32.45 J and 2.25 mJ mm^{-2}, respectively. A smaller force can permit a more compact design of the mechanical parts of a cutting device. On the other hand, the power consumption may be decreased even when the shearing force is small. Consequently, it is important to minimize both the cutting force and energy consumption simultaneously [24]. In this research, a cutting angle of 20° reduced the shear force and shear strength of parsley significantly, and it used no more energy than at 0°. This means that a blade oblique angle of 20° could decrease the impact during the cutting process while the cutting system does not expend any more energy.

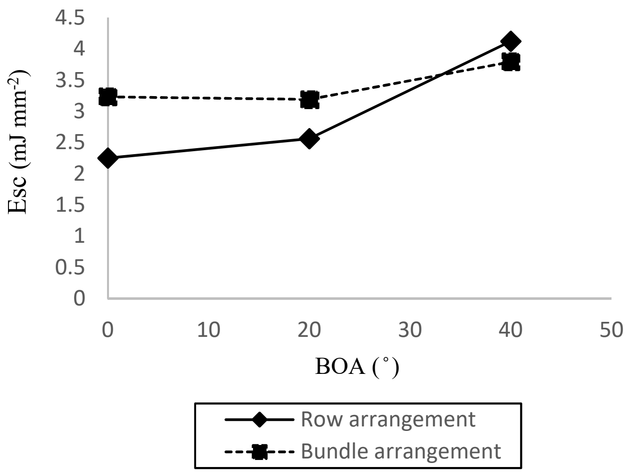

Figure 5. The specific cutting energy at 0°, 20° and 40° blade oblique angles for eight stems in row and bundle arrangements.

4. Conclusions

Cutting machinery can be designed optimally and economically based on knowledge of the material shear properties. Reducing the shear force must be considered regarding the required cutting energy. Increasing the blade oblique angle reduces the shear force corresponding to a decrease in shear strength. By increasing the blade angle, the force deformation curve may be stretched, and the cutting energy may be increased. In this research, the shear properties of parsley stems were determined under various blade angles and stem arrangements. A blade oblique angle of 20° decreased the shear force and shear strength significantly while expending no extra energy.

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Nomenclatures

BOA	blade oblique angle
A	stem cross sectional area, m^2
d	stem diameter, mm
D	deformation, mm
F_s	shear force, N
$F_{s\,max}$	maximum shear force, N
τ_{max}	shear strength, MPa
E_S	shear energy, J
E_{SC}	specific cutting energy, mJ mm^{-2}

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