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

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Abstract: To develop a cutting, harvesting, crushing or grinding machine, knowledge of crop physical and mechanical properties is needed. In this study, shear strength, shear energy and maximum shear force in cutting parsley stems have been examined. Cutting of multiple stems (8 stems) was performed by using blades with oblique angles of 0, 20, and 40 degrees. In order to examine the effect of stem arrangement in cutting operation, stems were placed in row and bundle arrangements. Statistical analysis showed that shear strength and maximum shear force decreased with increasing oblique angle. The average values of shear strength, specific cutting energy and maximum shear force for cutting 8 stems laid in row arrangement, using blade oblique angle of zero degrees, were 0.49 MPa, 2.25 mJ mm^{-2} and 56.13 N, respectively, while at blade angle of 40 degrees the values were 0.19 MPa, 4.12 mJ mm^{-2} and 18.2 N, respectively. Blade angle of 20 degrees is recommended as it does not require more cutting energy compared to zero degree 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 one of the products that are cultivated on a large scale and considerable energy is spent on its production. Thus, machines must be designed to mechanize their planting, harvesting and postharvest operations. In order to design a machine for harvesting or processing of crops, it is necessary to determine the mechanical and physical properties of the materials (Ahangarnezhad et al., 2019; Bako and GARBA, 2020). In addition, reducing power consumption is an important machine design objective. Thus, the cutting process of plant stems must be investigated (Li et al., 2011; Azmi et al., 2013).

The important mechanical properties that need to be considered for crop cutting are shear strength, bending strength, tensile strength, density and friction (Chattopadhyay and Pandey, 1999; Sitkei, 1987). The amount of these properties is different at different stem heights (Li et al., 2013). The engineering characteristics are influenced by species, variety, age, moisture content and cellular structure of the plant. Plant harvest time affects mechanical properties, which is due to the change in moisture content of the plant. At the first stage of plant maturity, 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 (O'Dogherty et al., 1995). Azadbakht et al. (2015) investigated energy consumption during impact cutting of canola stalk. The highest cutting energy was measured as 1.1 kJ at 25.5% (w.b.%) moisture content and 10 cm of cutting height. This is while the minimum cutting energy was 0.76 kJ at 11.6 (w.b.%) moisture content and 30 cm cutting height. Blade shapes affect shear strength.

Esehaghbeygi et al. (2009) showed that a smooth blade can decrease the shear strength of wheat stems ans also shear strength values of wheat stems at 0, 15, and 30 blade oblique angles were 3.92, 3.58, and 3.36 MPa, respectively. Shear energy depends on cutting speed. Mathanker et al. (2015) 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 (Mathanker et al., 2015). However, another study on the shear properties of various grasses showed that the loading rate and blade bevel angle had no effect on shear strength and shear energy (McRandal and McNulty, 1980).

Galedar et al. (2008) studied the mechanical properties of alfalfa stem. The average values of the shear strength and shearing energy at the highest moisture content (80% w.b.) were approximately 2 and 3 times greater than those at the lowest moisture level (10% w.b.). 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. (2005) 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. Also measuring the mechanical properties could be used for estimation of the products quality. Mechanical properties of cotton shoots for topping were investigated (Aydın and Arslan, 2018). In the higher parts of the plant (0–15 cm height), 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) were 5.79 mm, 121 N, 64.8%, 4.65 MPa, and 0.078 J mm^{-2}.

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 examined and effect of blade angle and stem arrangement on the mechanical properties of parsley stem were investigated. The results were used for designing a vegetable cutting machine.

2. Materials and Methods

The aim of this study was to measure shear strength, specific cutting energy and maximum shear force of parsley stems and to investigate the effect of 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 6 times.

Table 1. Independent and dependent variables studied in this research.

Independent Variables	Levels
Blade oblique angle	0, 20 and 40 (degrees)
Stem arrangement	Row and bundle
Dependent variables: shear strength, 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) then the cross sectional area calculated. Since the cutting height may affect the shear properties, all experiments were carried out 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 stem.

Table 2. 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 avoid stem tearing. The loading rate was 400 $mm.min^{-1}$. In order to study the effects of arrangement, 8 parsley stems were laid out in row and bundle arrangement under the cutting blade and cutting performed using the diffrent blade oblique angle (BOA) (Figure 1).

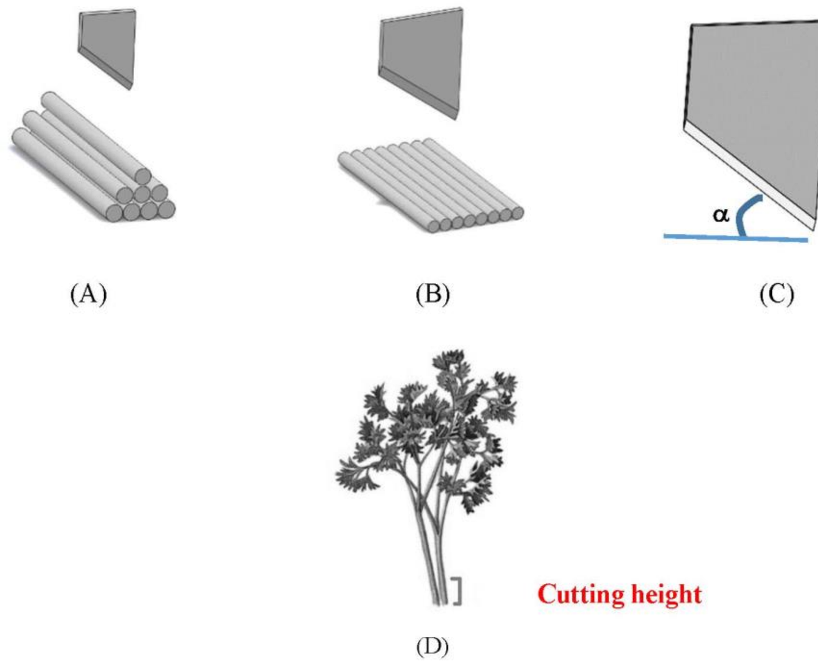

Figure 1. (**A**) Bundle arrangement, (**B**) Row arrangement, (**C**) BOA(α = 0, 20, 40°) and (**D**) cutting height.

Cutting tests were performed using a universal materials testing machine (UTM) (SANTAM Company, Model: STM 20, Tehran, Iran) (Figure 2). Shear force values were obtained by UTM and shear strength 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. 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 shearing energy and A is sample cross sectional area.

Figure 2. Material 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 cuts through the stem cross section, the required shearing force for a complete cut increases. When the force reaches its maximum value, it begins to decrease since at this point half or more of the stem cross section is cut. Once the stem is completely cut through, the force diminishes to zero. Blade edge collide to the stem at one point, and then contact area between stem cross section and blade edge increased by blade movement. By using a blade with large oblique angle, more of the blade edge could involve in cutting process, so the required force will be reduce. Based on the results shown in Figure 3C, the blade with 40° oblique angle has caused more deformation in the diagrams and more displacement required for full cut, while the maximum shear force is reduced. In addition, blade with large BOA cut stems one after another (Figure 1B). When BOA = 0, blade edge collide to the stems simultaneously, so more force is needed. In the row arrangement stems are laid in one line, so stems could be cut easily at large BOA and effect of BOA is more pronounced.

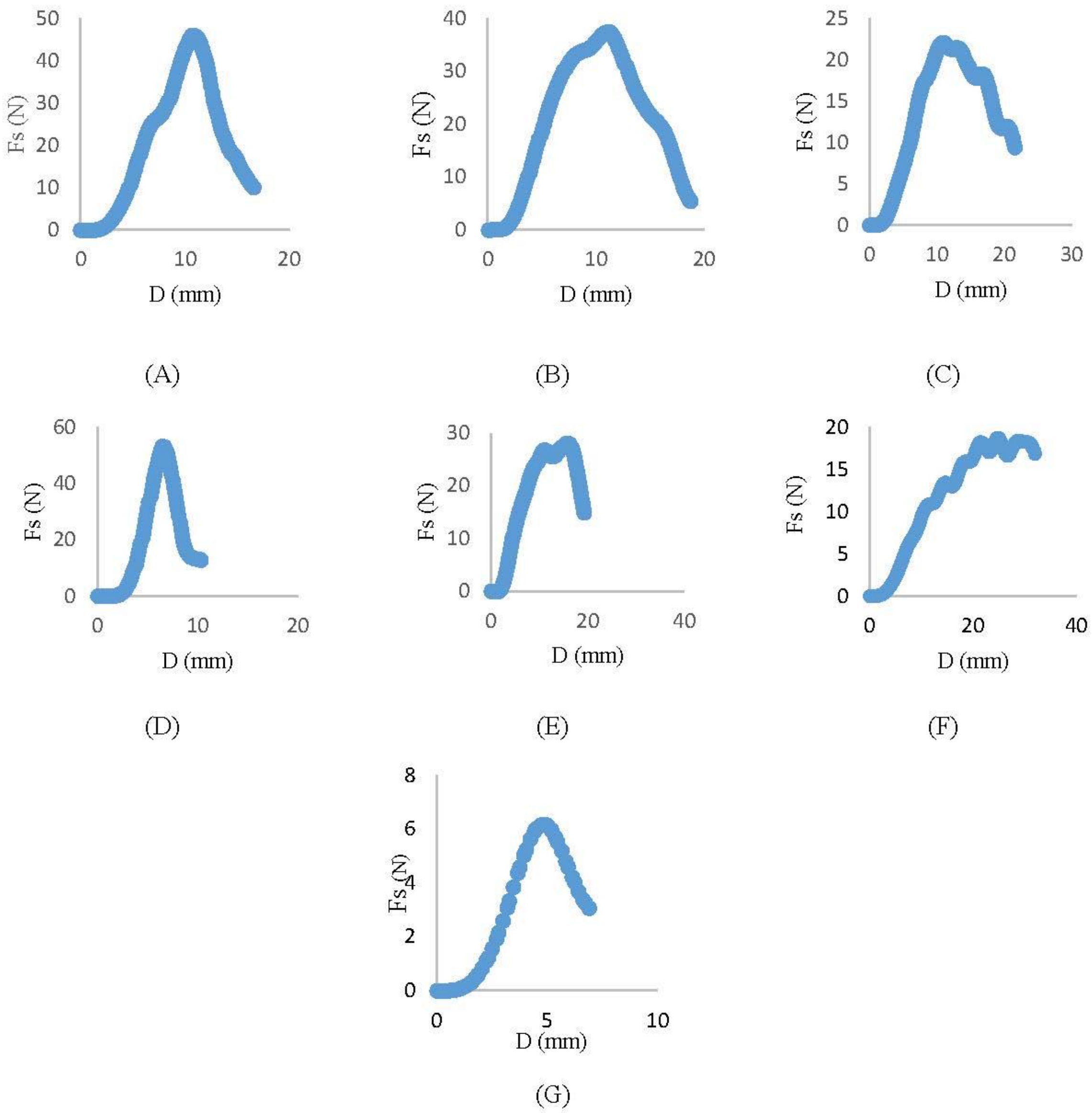

Figure 3. Typical force-deformation curves for cutting parsley stems at various blade oblique angle, stem arrangement: (**A**) BOA = 0°, 8 stems, bundle arrangement, (**B**) BOA = 20°, 8 stems, bundle arrangement, (**C**) BOA = 40°, 8 stems, bundle arrangement, (**D**) BOA = 0°, 8 stems, row arraignment, (**E**) BOA = 20°, 8 stems, row arraignment, (**D**) BOA = 40°, 8 stems, row arraignment and (**G**) single stem and BOA = 0°.

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

Table 3. Results of ANOVA for 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; MS: mean square.
* and ** Significant at the 5% and1% levels, respectively

Multiple stems are not cut simultaneously at large blade angles, thus the shear force for complete cutting of stems would be reduced. The shear strength is proportional to the shear force, so at higher blade angles the shear strength would be decreased. Figure 4 shows variation of shear strength and maximum shear force with blade oblique angle. Increasing the cutting angle from zero to 40 degree decreased the average shear strength. At 0° blade angle and in bundle arrangement, maximum shear force and shear strength values for cutting 8 stems were 42.17 N and 0.45 MPa while at 20° they were 31.81 N and 0.32 MPa, respectively. These values at 40° reached to 27.76 N and 0.31 MPa, respectively. BOYDAŞ et al. (2019) reported that shearing force values of sainfoin stem 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. (2002) for rice straw, by Allameh and Alizadeh, (2016) for rice stem, by Ghahraei et al. (2011) for kenaf stems and by Liu et al. (2020) for Peony stem. Proper design of the cutting equipment would maintain the quality of the harvested product while minimizing the force and energy needed to accomplish the task.

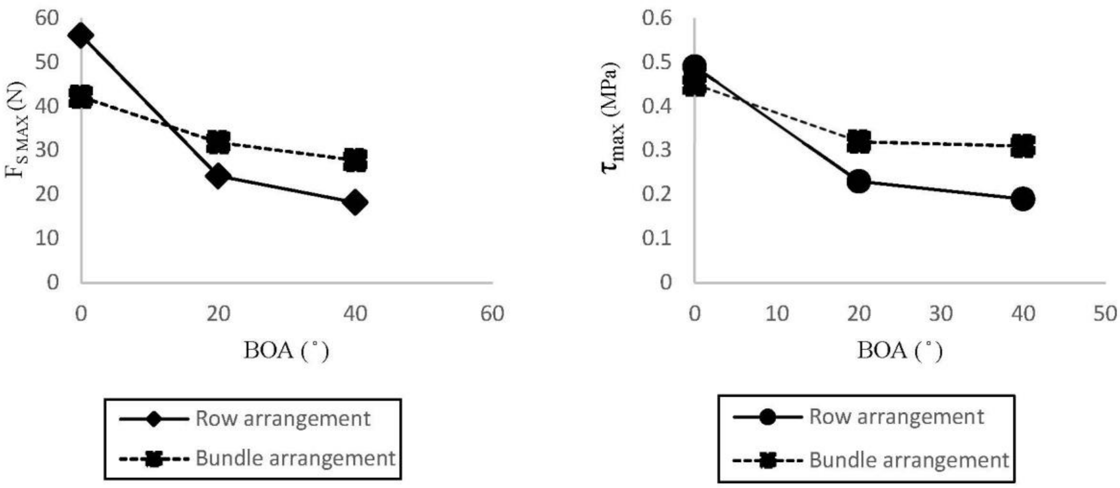

Figure 4. Maximum Shear force and shear strength at 0, 20, and 40 degrees blade oblique angles for 8 stems in row and bundle arrangements.

Multiple stems do not undergo cutting simultaneously. As a result, the specific cutting energy for cutting a single stem is higher than that of a bundle of stems. Blade with greater oblique angle cuts the stems laid out in row arrangement one by one, thus complete cut requires lower shear force and higher blade displacement. In the bundle arrangement and cutting angles of 0 and 20 degrees, cutting energy is more than that in the row arrangement (Figure 5). In the bundle arrangement and at 20° blade angle, cutting energy is lower than that of zero degree, which is due to a sharp reduction in the shear force at high angles (Figure 4). At blade angle of 40°, complete cut needs higher blade displacement, resulting in higher specific cutting energy. Johnson et al. (2012) reported that by increasing the cutting angle from 0 to 60 degrees, the energy needed to cut the Miscanthus x giganteus stems decreased from 10.1 J to 7.6 J. Similar results was repoerte by Maughan et al. (2012) for Miscanthus cutting and by Pekitkan et al. (2019) for grape cane. Mathanker et al. (2015) also reported a decrease in shear energy with increasing blade oblique angle for energycane stem. Values of shear energy per stem and specific cutting energy for cutting parsley stems at 0° blade angle were 32.45 J and 2.25 mJ mm^{-2}, respectively. A smaller force can permit more compact desigin of mechanical parts of a cutting devices. On other hand, power consumption may be decreased even when the shearing force is small. Consequently, it is important to minimise both cutting force and energy consumption simultaneously (Vu et al., 2020). In this research Cutting angle of 20° reduced shear force and shear strength of parsley significantly and it has no more energy than 0°. It means blade oblique angle of 20° could decrease impacts during cutting process while cutting system do not spent more energy.

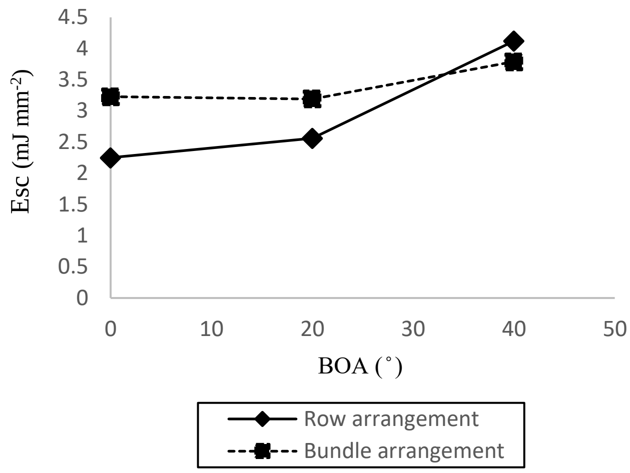

Figure 5. Specific cutting energy at 0, 20, and 40 degrees blade oblique angles for 8 stems in row and bundle arrangements.

4. Conclusions

Cutting machinery can be designed optimally and economically based on a knowledge of material shear properties. Reducing shear force must be don regarding to the required cutting energy. Increasing the blade oblique angle reduces the shear force corresponding to a decrease in shear strength. While by increasing blade angle, force deformation curve may be stretched and cutting energy may be increased. In this research shear properties of parsley stems were determined under various blade angels and stem arrangement. Blade oblique angle of 20° could decreased shear force and shear strength significantly by spending no extra energy.

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Conflicts of Interest:

Nomenclatures

BOA	blade oblique angle
A	Stem cross sectional area, m^2
d	stem diameter, mm
D	deformation, mm
Fs	shear force, N
Fs max	maximum shear force, N
τmax	shear strength, MPa
ES	shear energy, J

ESC specific cutting energy, mJ mm^{-2}

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