

## Determination of some mechanical properties of parsley stems related to design of processing machines

Mohammad Hosseinpour-Zarnaq<sup>1\*</sup>, Saeid Minaei<sup>1</sup>, Alireza Mahdavian<sup>1</sup> and Mohammad Hadi Khoshtaghaza<sup>1</sup>

1. Biosystems Engineering Department, Tarbiat Modares University, Tehran, Iran

### Abstract

To develop cutting, harvesting, crushing or grinding machines, 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. Results of statistical analysis showed that shear strength and maximum shear force decrease 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<sup>-2</sup> and 56.13 N, respectively, while at blade angle of 40 degrees the values were 0.19 MPa, 4.12 mJ mm<sup>-2</sup> and 18.2 N, respectively. Blade angle of 20 degrees is recommended as it does not require more cutting energy compared to zero degrees and the shear force is reduced, which lessens the effect of impacts on the cutting system.

**Key words:** Parsley stems, Mechanical properties, Blade angle, Postharvest

\*Corresponding author

E-mail: E-mail: hosseinpour.moh1@gmail.com

### 1. Introduction

Vegetables are one of the products that are cultivated on a large scale and considerable energy is spent on their production. Accordingly, 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 various 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 changing 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 to be 1.1 kJ at 25.5% (w.b.) moisture content and 10 cm 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. Shear strength values were 3.92, 3.58, and 3.36 MPa at 0, 15, and 30 blade oblique angles, respectively. Shear energy depends on cutting speed. Mathanker *et al.* (2015) reported that the shear energy required for cutting energycane 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 loading rate and bevel angle of the blade 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 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<sup>-2</sup>, 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<sup>-2</sup>, 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<sup>-2</sup>.

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. 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 can be used for designing a vegetable cutting machine.

## 2. Material 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 experiment in a completely randomized design (CRD) was used to examine the effect of independent variables and their interactions (Table. 1). All of the data were analyzed by ANOVA using SPSS version 23 software package (SPSS Inc., Chicago, USA) and the tests were replicated for 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	

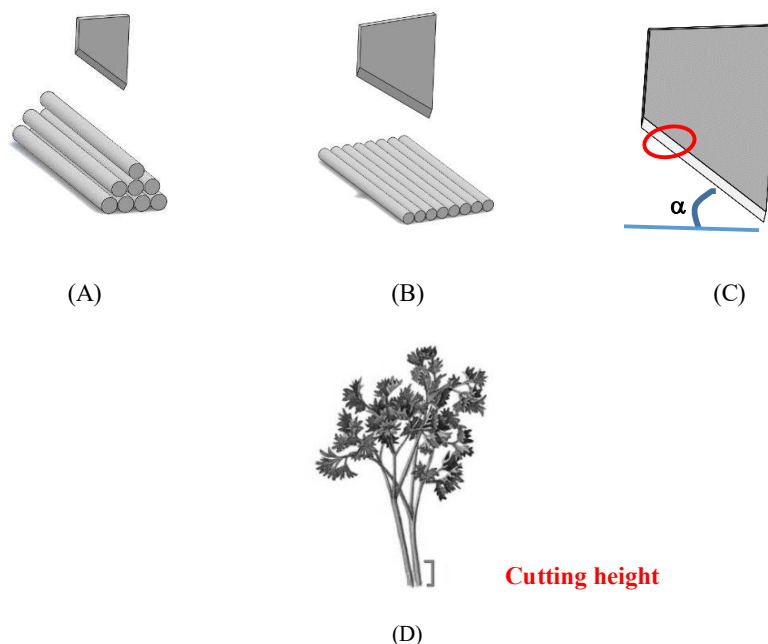
The experimental material was fresh parsley purchased from a market. The diameter of the samples were measured by a digital caliper (Accuracy: ±0.01 mm), then the cross sectional area calculated. Since the cutting height may affect the shear properties, all experiments were carried

out on stems with height range of 4 to 8 cm (Figure 1-D). The initial moisture content of the stems was determined by oven drying method at 103 °C for 24 hours and expressed on the wet basis (ASAE, 2006). Table 2 shows the mean values of the two physical parameters of parsley stem.

**Table 2. Physical properties of parsley stems in this research**

Average cross sectional area	Average diameter	Stem moisture content	Cutting height
13.1 mm <sup>2</sup>	4.1 mm	92% ( w.b%)	4-8 cm

Steel blades used in the experiments with different blade oblique angle (BOA) were properly sharpened (edge angle  $\approx 20$  degrees) to make a clean cut and avoid stem tearing. The loading rate was 400 mm.min<sup>-1</sup> to simulated cutting condition. In order to study the effects of arrangement, 8 parsley stems were laid out in row and bundle arrangement under the cutting blade (Figure 1).



**Figure 1. (A) Bundle arrangement, (B) Row arrangement, (C) BOA( $\alpha=0,20,40$  degrees) and blade sharpening angle (20 degrees) 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 the UTM with a 200 N load cell and shear strength was calculated using Eq (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 rupture point. The specific cutting energy ( $E_{sc}$ ) was determined using Eq (2):

$$E_{sc} = E_s/A \quad (2)$$

Where  $E_s$  is shearing energy and  $A$  is sample cross sectional area.

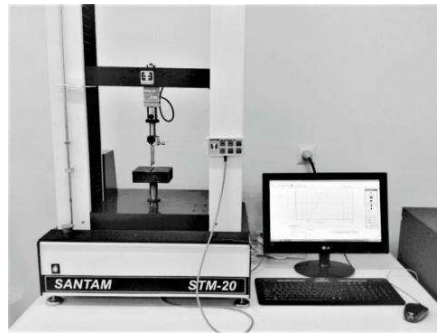


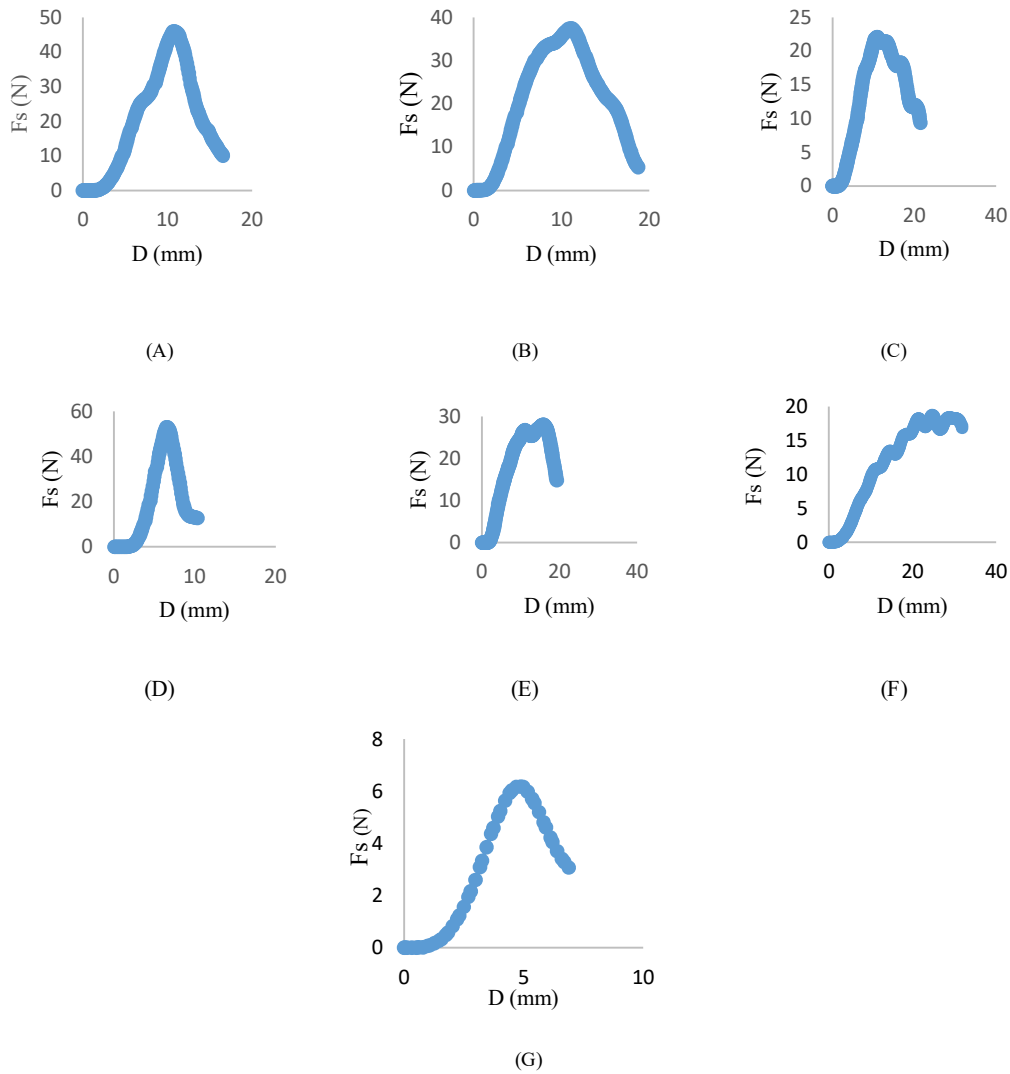
Figure 2. Material testing machine used in the research.

### 3. Results and Discussion

#### 3.1 Force-deformation curves

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 3-C, the blade with 40 degrees of 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 1-B). 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 degrees, 8 stems, bundle arrangement, (B) BOA= 20 degrees, 8 stems, bundle arrangement, (C) BOA= 40 degrees, 8 stems, bundle arrangement, (D) BOA= 0 degrees, 8 stems, row arraignment, (E) BOA= 20 degrees, 8 stems, row arraignment, (D) BOA= 40 degrees, 8 stems, row arraignment and (G) single stem and BOA= 0 degrees**

Results showed that 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**

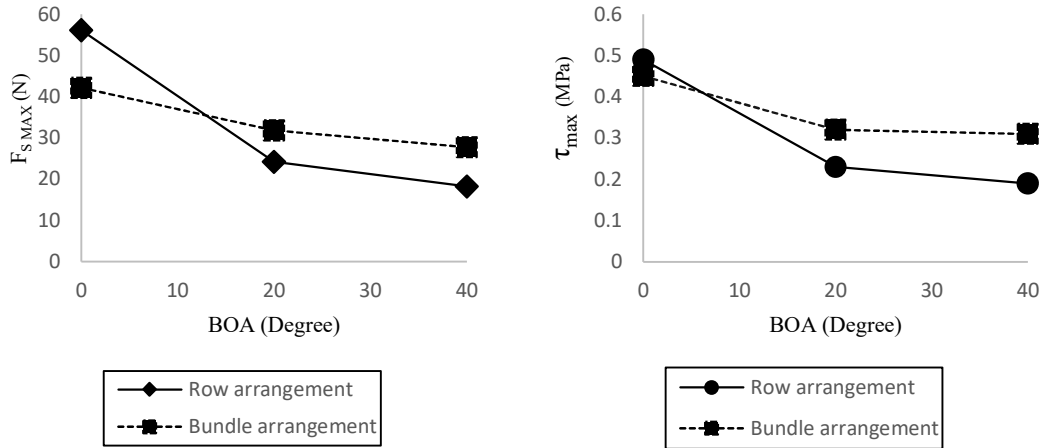
Source of variation	Dependent variable	df	SS	MS	F value
BOA	$E_{sc}$	2	10.58	5.29	28.6 **
	$\tau_{max}$	2	0.34	0.17	127.24 **
Stem arrangement	$E_{sc}$	1	1.64	1.64	8.9 *
	$\tau_{max}$	1	0.02	0.02	21.25 **
BOA × Stem arrangement	$E_{sc}$	2	2.76	1.38	7.47 *
	$\tau_{max}$	2	0.04	0.02	15.43 **
Error	$E_{sc}$	30	5.55	0.185	
	$\tau_{max}$	30	0.04	0.001	

df: degrees of freedom; MS: mean square.

\* and \*\* Significant at the 5% and 1% levels, respectively

### 3.2 Effects of Blade on Shearing Properties

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 degrees decreased the average shear strength. At zero degrees 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 degrees they were 31.81 N and 0.32 MPa, respectively. These values at 40 degrees reached 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 degrees were lower than those at an oblique angle of zero degrees. Similar results were reported by Yore *et al.* (2002) for rice straw, Allameh and Alizadeh, (2016) for rice stem, Ghahraei *et al.* (2011) for kenaf stems, and 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 at a time, 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 cutting angle of 20 degrees, cutting energy is lower than that of zero degrees, which is due to a sharp reduction in the shear force at high angles (Figure 4). At blade angle of 40 degrees, 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 reported by Maughan *et al.* (2012) for *Miscanthus* cutting and by Eliçin *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 zero degrees were 32.45 J and 2.25  $\text{mJ mm}^{-2}$ , respectively. A smaller force can permit more compact design of mechanical parts of a cutting devices. On the other hand, power consumption may be large 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 degrees



reduced shear force and shear strength of parsley significantly and it has no more energy than zero degrees. It means blade oblique angle of 20 degrees could decrease impacts during cutting process while cutting system do not spent more energy.

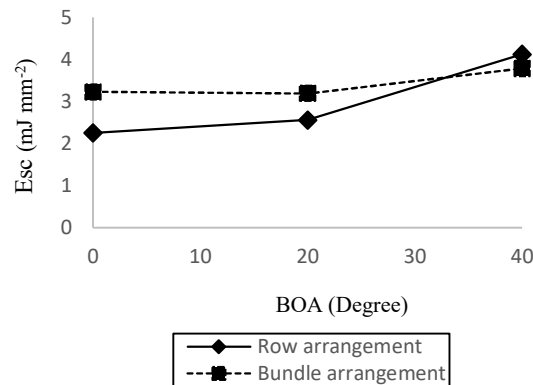


Figure 5. Specific cutting energy at 0, 20, and 40 degrees blade oblique angles for 8 stems in row and bundle arrangements

## Conclusion

Cutting machinery can be designed optimally and economically based on a knowledge of material shear properties. Reducing shear force must be done 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 angles and stem arrangement. Blade oblique angle of 20 degrees could decrease shear force and shear strength significantly by spending no extra energy.

### Nomenclatures

BOA	blade oblique angle, (degree)
A	Stem cross sectional area, (m <sup>2</sup> )
d	stem diameter, (mm)
D	deformation, (mm)
F <sub>s</sub>	shear force, (N)
F <sub>s max</sub>	maximum shear force, (N)
τ <sub>max</sub>	shear strength, (Mpa)
E <sub>S</sub>	shear energy, (J)
E <sub>SC</sub>	specific cutting energy, (mJ mm <sup>-2</sup> )

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