Quasi-static and impact cutting behavior definition of privet stem

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Abstract: Some of agricultural operations such as privet stem pruning are slow, repetitive and occasionally dangerous for operators. Almost operators of privet trimmers are exposed to the unpleasant and dangerous arm and body vibrations and sound of pruning machines. The knowing of the shearing behaviors of privet stem have an important role in the design and fabricate of suitable pruning machine. So a series of experimental tests were performed to measure the shear force, shear consumption energy and shear strength of stem internodes of privet stalk under quasi-static and impact cutting at different loading rate, different internode position and moisture level 58% wet base. In the quasi-static cutting test, the stalk specimens were cut in the quasi-static process at four loading rates: 5, 10, 15 and 20 mm min^{-1} and three internode positions: fifth, tenth and fifteenth. In impact cutting test, the stalk specimens were served in impact process at four loading rates: 1, 2, 3 and 4 m s^{-1} and three internode positions: fifth, tenth and fifteenth. In quasi-static cutting, the variance analysis of the data indicated that the loading rate created significant effect on shear strength and shear consumption energy in probability level of 5%. Also the internode position and the interaction effect of loading rate and internode position, created significant effects on shear strength and shear consumption energy in probability level of 1%. Based on the statistical analysis, the average values of shear consumption energy and shear strength were obtained as 556.70 J from 95.35 to 1567.95 J and 29.12 MPa from 19.63 to 37.04 MPa respectively. In impact cutting, the variance analysis of the data results showed that the effects of loading rate, internode position and interaction effect of loading rate on internode position, created significant effect on shear consumption energy and shear strength in probability level of 1%. The data statistical analysis showed the average values of shear consumption energy and shear strength were obtained as 17.16 J from 3.19 to 28.60 J and 1.01 MPa from 0.21 to 2.53 MPa respectively.

Keywords: quasi-static cutting, impact cutting, shear energy, shear strength, privet

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1 Introduction

Some shrubs such as privet are usually planted in row and close to grass area in parks and its trimming has an important role to increase the beauty of parks view. The privet is an evergreen plant with a scientific name of *Ligustrum Ovalifolium* (*Oleaceae Sp*) that widely cultivated in the parks in Iran. Privet stem is pruned by manual hedge trimmer in small areas and gasoline powered hedge trimmer machine in wide areas. Privet stem pruning like some of agricultural applications is very slow, repetitive and occasionally dangerous for labors and current trimmer machines are not suitable and accountable. Nowadays, almost operators are exposed to the unpleasant and dangerous arms and body vibration and sound of the privet stem trimmer machines (Feyzi et al., 2016). To reduce the dangerous effects of vibration on operator's arms and also to increase the speed and quality of privet pruning, the design and fabricate of proper trimmer equipment are necessary. Thus, by determining the mechanical properties of privet stalk such as shear force, shear consumption energy and stem resistance to cutting, a suitable pruning machine can be designed. This study was also carried out to investigate the effect of quasi-static and impact shear force on cutting energy and

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cutting strength of privet stalk.

Koniger (1953) studied the principle of cutting plant material and stated that the mechanical separation occurred at a predetermined and well-defined location in the material in contrast to crushing where several failure planes usually developed randomly. Chancellor (1958) studied cutting forage crops and found that the specific energy increased with depth of material. Prince et al. (1958) stated that the cutting energy requirement for forage crops decreased more rapidly than the decrease in stalk cross-sectional area. Mohsenin (1963) stated that the mechanical properties of plant stalk were also different and depended on the heights of the plant stalk and loading rates. Bright and Kleis (1964) used a die and punch method of determination for material in the mass and found values of specific shearing energy from 5.3 to 22.8 MJ mm^{-2} for grass and lucerne with a linear decrease of energy with increasing moisture content. Halyk and Hulbut (1968) studied the shear strength of alfalfa between nodes intervals and showed that strength would be varying between 0.6 to 17.95 Mpa. Pickett et al. (1969) studied the rheological properties of maize stalk under transverse loading. They observed that both stalk stiffness and resistance to penetration were affected by the diameter of the stalk (Pickett et al., 1969). Dernedde (1970) used a shear box method to measure shear strength of an assemblage of forage material in two series of experiments. Dobler (1972) found that for single stems the energy requirement decreased to an almost constant value at speeds of 20 m s^{-1} and above and the cutting forces did not show a marked dependence on speed over a range of 7-26 m s^{-1}. Akritidis (1974) stated that the cutting with single element can be referred to as pure impact cutting and depends mainly on the knife speed, cutting edge sharpness and crop inertia. Prasad and Gupta (1975) stated that the cutting energy and maximum cutting force were directly proportional to the cross-sectional area and inversely proportional to the moisture content of the stalk. Also they used a pendulum type impact shear test apparatus to determine the cutting energy requirement of the stalk (Prasad and Gupta, 1975). Fisher et al. (1975) determined the energy requirement for cutting forage and they observed that the initial deformation of the stalk accounted for about 25% of the total cutting energy. Kanafojski and Karwowski (1976) considered that the cutting efficiency became less as the depth of material was increased. Also showed, the total cutting force fell rapidly at cutting speeds up to 20 m s^{-1} and then decreased relatively slowly (Kanafojski and Karwowski, 1976). McRandal and McNulty (1978) have classified the results into three broad categories: quasi-static shearing (at velocities less than 30 mm s^{-1}), cutting with a counter-edge (at velocities greater than 0-5 m s^{-1}) and impact cutting without a counter-edge. Also they evaluated the shearing strength of grasses stem with impact shear test and observed that the blade with velocity 20 m s^{-1} required 25% more cutting energy than the blade with velocity 60 m s^{-1}. (McRandal and McNulty, 1978). O'dogherty (1982) stated that the energy to cutting forage stems has been measured by many experimenters, covering a wide range of plant species, cutting velocity, moisture content and stem size. Majumdar and Dutta (1982) studied the required shearing energy for two varieties of rice and a variety of wheat in different cutting speeds and edge angles. Results showed that the effect of crop type and edge angles on shearing energy were significant (Majumdar and Dutta, 1982). Kushhwaha et al. (1983) experimented some tests at speed of 0.005, 0.007, 0.001 and 0.015 mm s^{-1} on the barely straw to observe the effect of velocity on shear strength and reported that the shear strength was independent of shear velocity. O'dogherty and Gale (1986) stated the energy required for the cutting unit of stalk cutter may be categorized as friction in the moving parts of the machine and air friction, kinetic energy required to accelerate the chopped material, energy required to overcome friction of the chopped material against the stationary parts of machine and energy required to cut the stalk. Persson (1987) stated that the properties of the cellular material that are important in cutting are: compression, tension, bending, shear, density, and friction. These properties are affected by many factors such as the species variety, stalk diameter, maturity, moisture content, and cellular structure (Persson, 1987). Chancellor (1988) stated that the biological materials commonly subjected to cutting can be classified into non-fibrous materials with uniform properties in all direction and fibrous material with high tensile strength fibers oriented in a common direction. O'dogherty et al. (1995) with studied straw wheat reported that the stem internode position for the fourth stage of maturity had some significant effects on the strength and elastic module. Skubize (2001) used mechanical and x-ray methods to determine the mechanical properties of the stems of winter rape varieties, and found that the character of the changes in the rigidity, bending stress, static shear energy, and the dynamic shear energy properties over the length of the stem was best expressed by a quadratic polynomial equation. Ince et al. (2005) stated that the specific shearing energy of sunflower stalk residue decreased towards the upper regions. Also reported that the different physico-mechanical properties at different heights due to cross-sectional heterogeneity and mechanical properties are also different at different height of plant stalk (Ince et al., 2005). Yiljep and Mohammed (2005) reported the high correlation between knife velocity, cutting energy requirement and cutting efficiency. Also they estimated the minimum cutting energy requirements for 20 and 120 mm stalk cutting height, 7.87 and 12.55 N m respectively, at corresponding knife velocities of 2.91 and 3.54 m s^{-1} (Yiljep and Mohammed, 2005). Tabatabaeefar and Borgheie (2006) studied shear cutting of four rice variety and stated that the dynamic shearing strength decreased from 234.4 to 137.4 Kpa with an increase in blade cutting angle speed from 0.6 to 1.5 m s^{-1}. Nazari Galedar et al. (2008) reported that the shearing energy of alfalfa stem decreased towards the upper regions of stem. Tavakoli et al. (2009) studied on the effect of moisture content levels 10%, 15% and 20% wet base, three loading rates 5, 10 and 15 mm min^{-1} and three internodes first, second and third internode, reported that both the shear strength and shearing energy increased with an increase in moisture content and loading rate and towards the third internode position. Taghijarah et al. (2011) measured shear strength and specific shearing energy of sugar cane stalks on 5, 10 and 15 mm min^{-1} loading rate, found that loading rate had a significant effect on the shear strength and specific shearing energy of the stalk and reported with increasing loading rate, the shear strength and specific shearing energy was increased. Dange et al. (2011) studied on the cutting energy and force required for the pigeon pea crops observed that the cutting energy and cutting force were directly proportional to cross-sectional area and moisture content at the time of harvesting of pigeon pea crop. Taghinezhad et al. (2013) investigated that the ultimate stress and specific shearing energy decreased with an increase in size of cutting section in sugarcane stalks. Mathanker et al. (2015) investigated that specific shearing energy increased with an increase in sugarcane stalks shear velocity. Azadbakht et al. (2015) studied impact cutting of canola and reported that at blade velocity 2.64 m s^{-1}, the maximum and minimum cutting energy was measured 1.1 kJ in 25.5% w.b. moisture content at 10 cm cutting height and 0.76 kJ in 11.6% w.b. moisture content and 30 cm cutting height respectively at the time of cutting.

Some pervious researches were performed to measure mechanical properties of crop plants stem such as barely, alfalfa, rice, sunflower, pigeon pea, wheat, grass and etc. Unfortunately, useful information related to the shearing behavior of privet stem is limited. Therefore the objective of this study was to investigate the effect of loading rate and internode position on some shearing properties, including shear consumption energy and shears strength of the privet stalk under quasi-static and impact cutting process.

2 Materials and methods

To know the shearing characteristics of privet stem, a series of experimental tests were conducted to measure the shear force, shear strength and shear consumption energy of privet stem as a function of a shear method, shear loading rate and internode position. In fact, this study was also carried out to investigate the effects of quasi-static and impact shear force on cutting energy and cutting strength of privet stalk. The privet stalk samples were collected at the first month of the summer season in 2016 (Figure 1). The ASAE standards was used to measure the average moisture content of privet stalks and the initial moisture content of the samples was measured to be 58% on wet base (ASAE, 2005). The shape of privet stalk cross-section area is similar to oval and also diameter decreases towards to the top of the privet stalk, that means it shows different physico-mechanical properties at different heights of stalk due to variable cross-section area (O'dogherty et al., 1995; Shahbazi and Nazari Galedar, 2012). Based on the cross-section area and height of privet stalk, it was equally divided into three regions downward from the top of stalk: (a) fifth internode position with small diameter range of 3.44 to 4.56 mm and large diameter range of 4.38 to 5.11 mm, (b) tenth internode position with small diameter range of 3.90 to 5.11 mm and large diameter range of 4.87 to 5.98 mm and (c) fifteenth internode position with small diameter range of 4.72 to 5.85 mm and large diameter range of 5.44 to 6.88 mm (Figure 1).

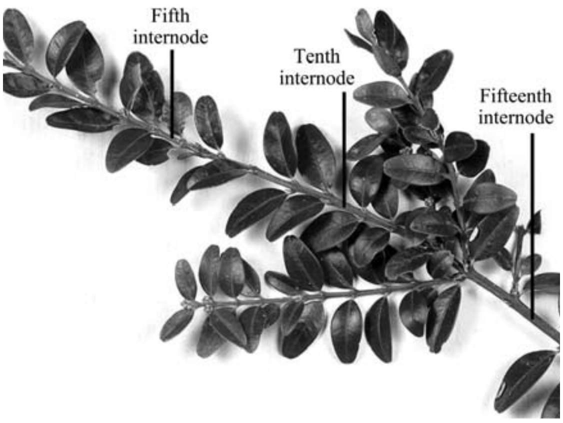


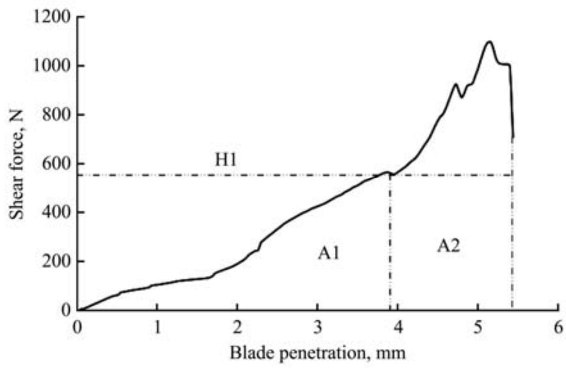
Figure 1 Diagram of privet stalk and three selected internode positions (fifth, tenth and fifteenth)

2.1 Shear test

This study was undertaken to gather and analyze the information as shear force, shear consumption energy and shear strength regarding to quasi-static and impact cutting of privet stalk while using trimmer machine. Quasi-static and impact shear are two different types of cutting forces that were applied to cutting the privet stalk samples. In quasi-static shear, the cutting force was applied in long time duration with speed rate of 5 to 20 mm min^{-1} and in impact shear, the cutting force was applied in short time duration with speed rate of 1 to 4 m s^{-1}. Finally, the shearing properties of privet stem, such as shear consumption energy, shear force and shear strength were determined by both of the quasi-static and impact test methods.

2.1.1 Quasi-static shear test

The quasi-static tests were used by means of an Instron tension/compression testing machine (Instron Universal Testing Machine, SMT-5, SANTAM Co, Iran). The quasi-static test of privet stalks was assessed using a shearing test similar to those described by O'dogherty et al. (1995), Ince et al. (2005), Nazari Galedar et al. (2008), Tavakoli et al. (2009). The shear tests were carried out in double shear using a shear box consisting of two fixed parallel plates with 6 mm apart and a sliding plate that was loaded at four rates of speeds 5, 10, 15 and 20 mm min^{-1}. In this process, the cutting force was affected by means of special cutters causing the simultaneous cutting of double surface of the privet stalk. The shear force was applied to the samples by mounting the shear box in the testing machine up to the sample failure. During the shearing test, the applied shearing force respect to sample displacement (blade penetration) were measured by machine load cells and the results were recorded by a computer system, using software specially has developed for the purpose. Figure 2 shows an example of the shear force versus displacement curve generated, through the Instron tester software and the shear-displacement profile was obtained up to the failure of the specimen.



Note: Speed cutting: 15 mm min^{-1} and internode position: fifteenth; A1: useless cutting energy, A2: useful cutting energy, H1: useless blade displacement.

Figure 2 Shearing force versus displacement curve

The shear strength of the privet stalk was computed from the maximum shearing loads that were applied to the privet stalk. By using Equation (1), the shear strength of privet stem was determined at different loading rates and different internode positions (Gere and Timoshenko, 2004; Mohsenin, 1963).

$$\tau = \frac{F_{max}}{2A} \tag{1}$$

where, F_{max} is maximum shear force in N; A is cross-section area of the stalk in mm^2 and τ is stem shear strength in MPa.

The major and minor diameters of the privet stem were recorded at the expected cutting location. The stem cross-section area was calculated using Equation (2) (Yiljep and Mohammed, 2005).

$$A = \frac{\pi}{4} d_1 \cdot d_2 \quad (2)$$

where, d_1 and d_2 are major and minor diameters of privet stalk in the cutting location in mm.

The shear consumption energy is equal to area under force versus blade displacement curve. For this aim, the area under the curve was divided into the basic geometrical shapes and the calculation of the area under the curve was made with the help of the force and displacement data by using a standard computer program (Chattopadhyay and Pandey, 1999; Chen et al., 2004; Gere and Timoshenko, 2004).

2.1.2 Impact shear test

It is difficult to characterize the impact shearing properties impact of privet stalk using conventional measurements apparatus. To determine the shearing properties of privet stalk in impact cutting process, a cutting tester similar Izod tester for metals, was fabricated. It was consisted of pendulum arm, cutting blade and data acquisition system. The cutting blade with sharpened angel of 23 degree, rake angle 90 degree and oblique angle of 60 degree was attached to end of pendulum arm. With releasing the pendulum arm, the cutting blade is accelerated to a constant rotational velocity by means of force of gravity. After calibration, the impact shear force was applied to the privet samples by releasing the pendulum arm at specified position in the testing machine up to the sample failure. The real-time applied force was measured by the apparatus data acquisition system (Kamandar and Massah, 2018). The shear consumption energy during the stem cutting process was determined by using Equation (3) (Yiljep and Mohammed, 2005; Alizade et al., 2011):

$$Es = W_t R(\cos\varphi_2 - \cos\varphi_1) \quad (3)$$

Where, E_s is shear consumption energy in J; φ_2 is maximum angular displacement of pendulum arm from vertical line after cutting in degree; φ_1 is maximum angular displacement of pendulum arm from vertical line before cutting in degree; W_t is total weight of the pendulum arm, in N and R is distance of the center of gravity of the pendulum from the axis of rotation in m.

To obtain the selected velocities, the pendulum arm was released from special angels in the vertical plane on the upswing and the cutting velocities were calculated related to these angels by Equation (4), are: 1, 2, 3 and 4 m s^{-1} (Yiljep and Mohammed, 2005; Alizade et al., 2011; Azadbakht et al., 2015).

$$V = \sqrt{[\frac{2w_t R(1-\cos\varphi_1)}{I}] \times L} \quad (4)$$

where, V is blade velocity in the lowest position of pendulum in m s^{-1}; I is mass moment of inertia of the pendulum arm about the axis of rotation in kg m^{-2} and L is distance of the blade from the axis of rotation in m.

The shear strength of the privet stalk was computed from the maximum shearing loads that were applied to the privet stalk. By using Equations (1) and (2), the shear strength of privet stem was determined at different loading rates and different internode positions.

3 Results and discussion

This study was planned as a completely randomized block design and the experimental tests were conducted with eight replications in each treatment. The shear strength and shear consumption energy (shear energy) were opted as dependent variables. Finally the collected data were analyzed using analysis of variances (ANOVA) and the means were separated by 5% and 1% probability levels applying Duncan's multiple range test in SPSS (Version 17, SPSS Inc., USA) software.

3.1 Quasi-static shear test analysis

The variance analysis of the data indicated that the internode position and their interaction of loading rate on internode position created a significant effect in probability level of 1% on shear strength and shear consumption energy. But the loading rate was found a significant effect in probability level of 5% (Table 1). Based on the statistical analysis, the average values of shear consumption energy and shear strength were obtained as 556.70 J from 95.35 to 1567.96 J and 29.12 MPa from 19.62 to 37.04 MPa respectively.

Table 1 The variance analyses of cutting privet stalk under different loading rates and internode positions

	Degree of freedom	Shear strength, MPa	Shear energy, J
Source of variation			
Loading rate (A)	3	38.41*	16552.03*
Internode position (B)	2	71.25**	707066.96**
Interaction A×B	6	1.82**	28851.7**
Error	11		

Note: ** and * significant in statistic level of 1% (P<1%) and 5% (P<5%).

The results of Duncan's multiple range tests for comparing the mean value of the shearing properties of the privet stem at different loading rate and internode position are presented in Table 2. In addition, according to the Duncan's multiple range tests, the maximum mean value of shear consumption energy and shear strength were obtained as 881.17 J and 33.32 MPa respectively at loading rate of 20 mm min^{-1} and the minimum mean value of shear consumption energy and shear strength were obtained as 351.02 J and 19.15 MPa respectively at loading rate of 5 mm min^{-1}. As demonstrated in Table 2, the shear strength and shear consumption energy increased with an increase in the loading rate of 5 to 20 mm min^{-1}.

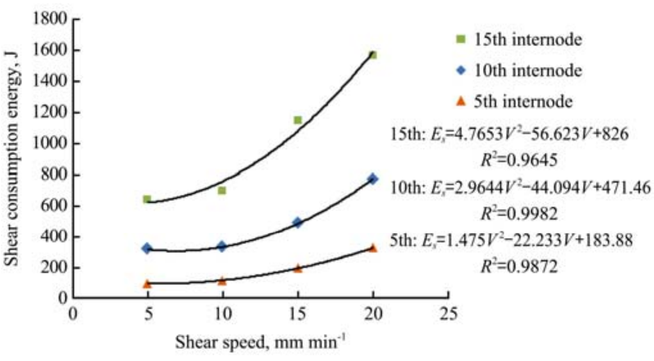
Table 2 The means comparison of loading rate and internode position effect on shearing properties of privet stalk at quasi-static cutting process

Independent variables	Dependent variables	
	Shear strength, MPa	Shear energy, J
Loading rate, mm min^{-1}		
5	19.15^a	351.02^a
10	29.12^b	378.81^a
15	29.33^b	609.08^b
20	33.32^c	881.17^c
Internode position		
Fifth internode	25.06^a	182.55^a
Tenth internode	30.10^b	476.12^b
Fifteen internode	32.86^c	1011.73^c

Note: Mean values followed by different letters are significantly different from others in the same column.

As shown in Table 2, the maximum mean values of shear consumption energy and shear strength were obtained as 1011.73 J and 32.86 MPa respectively at fifteenth internode and the maximum mean values of shear consumption energy and shear strength were obtained as 182.55 J and 25.06 MPa respectively at fifth internode of privet stalk. Based on Table 2, the shear consumption energy and shear strength were significantly affected by internode position and these values increased towards to lower region of privet stalk.

Figure 3 shows the interaction effect of loading rate and internode position on privet shear consumption energy. The maximum value of shear consumption energy was obtained as 1567.96 J at loading rate 20 mm min^{-1} at fifteenth internode and the minimum value was obtained as 95.35 J at loading rate 5 mm min^{-1} at fifth internode of the stalk. Its value varied from 95.35 to 324.63 J at fifth internode, 316.66 to 771.81 J at tenth internode and 641.23 to 1567.96 J at fifteenth internode at different loading rate. Due to Figure 3, the cutting energy increased with increase in loading rate for all regions of privet stalk and it is clear, the shear consumption energy at fifteenth internode is higher than fifth internode. The models fitted to the data using the regression techniques showed that the cutting energy increased polynomial shape with increasing the loading rate for all stalk regions. The relationship between shear consumption energy and loading rate can be expressed by the polynomial equations as shown in Figure 3. These effects of loading rate and internode position on shear consumption energy was also reported by O'dogherty et al. (1995) for wheat stem, Ince et al. (2005) for sunflower stalk, Nazari Galedar et al. (2008) for alfalfa stem, Tavakoli et al. (2009) for barley straw, Taghijarah et al. (2011) for sugarcane stalk, Hematian et al. (2012) for sugar cane stem, Shahbazi and Nazari Galedar (2012) for safflower stalk, Sessiz et al. (2013) for olive stalk, Taghinezhad et al. (2013) for sugarcane stalk and Xue et al. (2015) for cassava stalk.



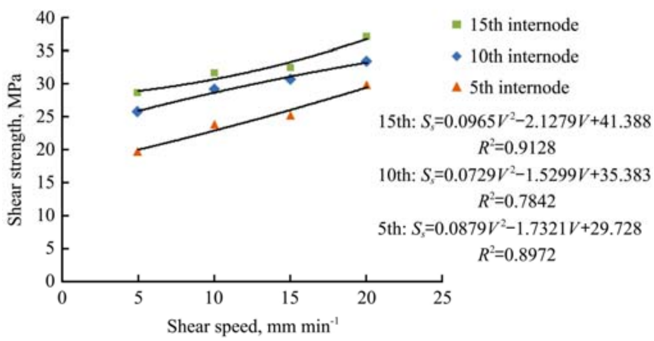
Note: E_s is shear consumption energy in J and V is shear velocity in mm min^{-1}.

Figure 3 Relationship between shear consumption energy and shear speed at different internode positions

By consider to Figure 3, the increment proportion of energy consumption at blade velocity of 20 mm min^{-1} to

5 mm min^{-1} is about 2.6 at fifteenth internode, 2.2 at tenth internode and 2 at fifth internode of privet stalk. It shows the shear consumption energy in high speed level of quasi-static cutting is 2 to 2.6 times higher than low speed level cutting.

Figure 4 presents the interaction effect of loading rate and internode position on privet shear strength. The highest value of shear strength was obtained as 37.04 MPa at the fifteenth internode and the loading rate of 20 mm min^{-1} and the lowest value was obtained 19.63 MPa at the fifth internode and loading rate of 5 mm min^{-1}. The shear strength increased polynomial with the increase in the loading rate for all the regions of privet stalk. It varies from 19.63 to 29.75 MPa at fifth internode, from 25.69 to 33.32 MPa at tenth internode and from 28.56 to 37.04 MPa at fifteenth internode of privet stalk. The models fitted to the data using the regression techniques showed that the shear strength increased polynomial shape with increasing the loading rate for all stalk regions. The relationship between shear strength and loading rate can be expressed by the polynomial equations as shown in Figure 4. These effects of loading rate and internode position on shear strength was also reported by El Hag et al. (1971) for cotton stalk, Kushwaha et al. (1983) for wheat stalk, Chattopadhyay and Pandey (1999) for sorghum stem, Ince et al. (2005) for sunflower stalk, Galedar et al. (2008) for alfalfa stem, Tavakoli et al. (2009) for barley straw, Esehaghbeygi et al. (2009) for wheat stem, Taghinezhad et al. (2013) for sugarcane stalk, Tabatabaeefar and Borgheie (2006) for rice stem, Taghijarah et al. (2011) for sugarcane stalk and Hematian et al. (2012) for sugar cane stem.



Note: S_s is shear strength in Mpa and V is shear velocity in mm min^{-1}.

Figure 4 Relationship between shear strength and shear speed at different internode positions

By consider to Figure 4, the increment proportion of shear strength at blade velocity of 20 mm min^{-1} to 5 mm min^{-1} is 1.4 at fifteenth internode, 1.3 at tenth internode and 1.5 at fifth internode of privet stalk. It shows the shear strength in high speed level of quasi-static cutting is around 1.3 to 1.5 times higher than low speed level cutting.

3.2 Impact shear test analysis

The variance analysis of the data revealed that the loading rate, internode position and their interaction of loading rate and internode position created significant effect in probability level of 1% on the shear consumption energy and shear strength (Table 3). Based on the statistical analysis, the average values of shear consumption energy and shear strength were obtained as 17.16 J from 3.19 to 28.60 J and 1.01 MPa from 0.21 to 2.53 MPa respectively. The results of Duncan's multiple range tests for comparing the mean value of the shearing properties of privet stem at different loading rate and internode position is presented in Table 4.

Table 3 The variance analyses of cutting privet stalk under different loading rates and internode positions

	Degree of freedom	Shear strength, MPa	Shear energy, J
Source of variation			
Loading rate (A)	3	1.06**	80.42**
Internode position (B)	2	0.82**	15.01**
Interaction A×B	6	12.49**	1.53**
Error	11		

Note: ** and *significant in statistic level of 1% (P<1%) and 5% (P<5%).

Looking over at Table 4 reveals that the loading rate has a significant effect on the energy requirement and shear strength and an increase of loading rate led to decrease the shearing properties of privet stalk. The minimum mean value of shear consumption energy and shear strength were obtained as 6.84 J and 0.41 MPa respectively at the loading rate of 4 m s^{-1} and the maximum mean value of shear consumption energy and shear strength were obtained as 22.25 J and 1.77 MPa respectively at the loading rate of 1 m s^{-1}. According to Duncan's multiple range test results, as shown in Table 4, the values of shear consumption energy and shear strength increased towards to the fifteenth internode of privet stalk. The minimum mean value of shear consumption energy and shear strength were obtained as

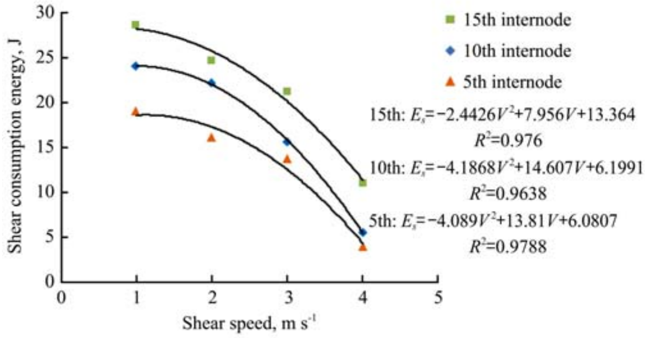
12.74 J and 0.61 MPa respectively at fifth internode and the maximum value was obtained as 16.51 J and 1.49 MPa respectively at fifteenth internode of stalk. As shown in Table 4, the shear consumption energy and shear strength were significantly affected by internode position and these values increased towards to lower region of privet stalk.

Table 4 The means comparison of loading rate and internode position effect on the shearing properties of privet stalk at impact cutting process

Independent variables	Dependent variables	
	Shear strength, MPa	Shear energy, J
Loading rate, m s^{-1}		
1	1.77^a	22.25^a
2	1.18^b	17.04^b
3	0.71^c	15.54^b
4	0.41^c	6.84^c
Internode position		
Fifth internode	0.61^c	12.74^c
Tenth internode	0.97^b	14.03^b
Fifteen internode	1.49^a	16.51^a

Note: Mean values followed by different letters are significantly different from others in the same column.

The interaction effect of loading rate and internode position on the shear consumption energy is presented in Figure 5. As demonstrated in Figure 5, the cutting energy strongly decreased with increase in the loading rate for all regions of privet stalk. The highest cutting energy was obtained 28.60 J for the fifteenth internode of stalk at the speed rate of 1 m s^{-1} and the lowest value was obtained 3.19 J for the fifth internode at the speed rate of 4 m s^{-1}. In all regions of Figure 5, the shear energy decreased polynomial shape with an increase of loading rate and its value varied from 3.19 to 19.22 J for fifth internode, 5.53 to 24.05 J for tenth internode and 11.07 to 28.60 J for fifteenth internode at different loading rate. The models fitted to the data using the regression techniques showed that the cutting energy decreased polynomial shape with increasing the loading rate for all stalk regions. The relationship between shear consumption energy and loading rate can be expressed by the polynomial equations as shown in Figure 5. These effects of loading rate and internode position on shear consumption energy was also reported by Prasad and Gupta (1975) for maize stalk, McRandal and McNulty (1978) for forge crops, Chattopadhyay and Pandey (2001) for sorghum stalk, Yiljep and Mohammed (2005) for sorghum stalk, Alizade et al. (2011) for rice stem, Koloor and Borgheie (2006) for rice stem and Azadbakht et al. (2015) for canola stem.



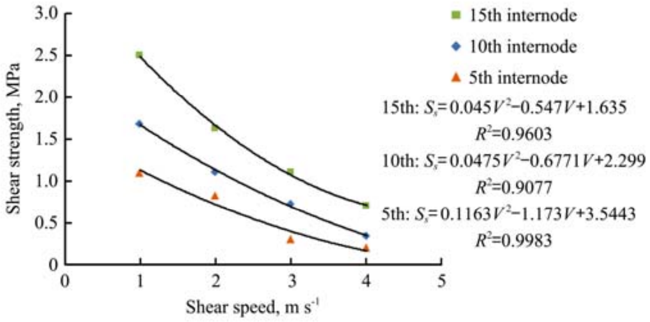
Note: E_s is shear consumption energy in J and V is shear velocity in m s^{-1}.

Figure 5 Relationship between shear consumption energy and shear speed at different internode positions

By consider to Figure 5, the reduction proportion of privet stalk cutting consumption energy at shear velocity of 4 m s^{-1} to 1 m s^{-1} is about 2.4 at fifteenth internode, 3.5 at tenth internode and 4.5 at fifth internode of privet stalk. It shows the shear consumption energy in low speed level of impact cutting is around 2.4 to 4.5 times higher than high speed level cutting.

Figure 6 shows the interaction effect of loading rate and internode position on privet stalk shear strength. The highest value of shear strength was obtained as 2.53 MPa for the fifteenth internode at the speed rate of 1 m s^{-1} and the lowest value was obtained as 0.21 MPa for the fifth internode at the speed rate of 4 m s^{-1}. The models fitted to the data using the regression techniques showed that the cutting strength decreased polynomial shape with increasing the loading rate for all stalk regions. The relationship between shear strength and loading rate can be expressed by the polynomial equations as shown in Figure 6. This effect of loading rate and internode position on shear strength was also reported by McRandal and McNulty (1978) for forge crops, Yiljep and Mohammed (2005) for sorghum stalk, Chattopadhyay and Pandey (2001) for sorghum, Tabatabaeefar and Borgheie (2006) for rice stem, Dange et al. (2011) for pigeon pea stem, Alizade et al. (2011) for rice stem and Azadbakht et al. (2015) for canola stem.

By consider to Figure 6, the reduction proportion of privet stalk resistance to cutting at shear velocity variation from 4 m s^{-1} to 1 m s^{-1} is about 2.5 at fifteenth internode, 4.25 at tenth internode and 4.8 at fifth internode of privet stalk. It shows the shear strength in low speed level of impact cutting is around 2.5 to 4.8 times higher than high speed level cutting.



Note: S_s is shear strength in Mpa and V is shear velocity in m s^{-1}.

Figure 6 Relationship between shear strength and shear speed at different internode positions

4 Conclusion

In this study, the effect of shearing loading rate of privet stem on shear strength and shear consumption energy was investigated according to the internode position and cutting method.

By consider to Figure 2, the privet stalk material is compressed up to a height H1 until the cutting resistance is overcame, and the energy required is given by the area A1 under the curve (useless cutting work to compression of stalk outer layer). The energy requirements of effective cutting are given by A2 (useful cutting work to stalk cutting) and the total shear consumption energy is the sum of A1 and A2. The analysis of shear force versus displacement curves showed the amount of A1 increased by shear speed increment. So the increase of deformation outer layer of privet stalk is the important reason for increase the shear consumption energy and shear strength. It seems the variation of the static cutting characteristics is a function of the layer deformation of privet stalk and with increasing preliminary compaction amount, the proportion of outer layer deformation work is increased and the shear consumption energy is increased (Mohsenin, 1963).

In practice, the cutting of privet stalk is not a quasi-static cutting but it is a dynamic process. The impact cutting process by a rapidly moving cutting blade, is similar to dynamic process and in impact cutting, with increasing loading rate, the primary compression of outer layer was decreased as a result's inertia and plastic behavior of privet stalk material and the shear consumption energy decreased. It is clear, in privet stalk impact cutting, with increasing the cutting velocity the shear energy requirements decreased considerably, and the proportion of useful cutting work increased (Sitkei, 1986).

At the other hand, the cutting consumption energy and cutting resistance of privet stalk at both cutting methods correspond to variations in the texture, primarily in the proportions of fibrous and ligneous of stalk material. The thickness and texture of privet stalks also vary as functions of height, and so the shear consumption energy and shear resistance to cutting also depend on the location of the cut and internode position. So in quasi-static and impact cutting, the mentioned parameters are highest close to the lower region of privet stalk and decreases going upwards (Sitkei, 1986).

Based on Table 2 and Table 4, the shear consumption energy and shear strength at both of quasi-static and impact cutting were significantly affected by internode position and these values increased towards to lower region of privet stalk because of more cross-section diameter and more accumulation mature fibers in the lower region of privet stalk (Ince et al., 2005).

The models fitted to the data using the regression techniques showed that the cutting energy and shear strength increased polynomial shape with increasing the loading rate for all stalk regions. Based on Figures 3, 4, 5 and 6, it is clear that the character of the changes in the shear consumption energy and shear strength properties was best expressed by a quadratic polynomial equation at both of quasi-static and impact cutting methods. These sort of shear consumption energy and shear strength changes were also reported for winter rape stalk by Skubisz (2001).

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