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FULL LENGTH ARTICLE

Energy consumption during impact cutting of canola stalk as a function of moisture content and cutting height

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Abstract This study surveys the needed energy for cutting canola stems in different levels of cutting height and moisture content. The canola was harvested from the experimental farm in Gorgan, Iran. Test device fabricated and then calibrated. The device works on the principle of conservation of energy. The tests were repeated 15 times for any level of moisture content and cutting height and they were analyzed using split plot design. The results showed the effect of height and moisture content on cutting energy is significant ($P < 1\%$), but their interaction is not significant. The highest cutting energy was 1.1 kJ in 25.5 (w.b.%) moisture content and 10 cm cutting height. Also the minimum cutting energy was 0.76 kJ in 11.6 (w.b.%) moisture content and 30 cm cutting height. Blade velocity was 2.64 m/s in cutting moment.

Introduction

Canola plant produces a main stem and many lateral branches will be divaricated from it. At the end of winter, first main stem extends and after blooming the main stem, lateral branches begins extending. The branching depends on environment, variety, plant nutrition, farming techniques, etc. Stem height varies from 50 to 200 cm in different varieties (Appelquist and Ohlson, 1972). Thus, given that there are some lateral branches in cut place by blade, needed energy will vary for cutting.

McRandal and McNulty (1978) reported that rotary harvester machines are used increasingly in terms of ease in construction, low cost for repair and maintenance and ability to cut all stems with large and small diameters. One of the most important factors in designing the types of grain combine and harvesters is resistance to cut in agricultural crops during harvesting (Annoussamy et al., 2000). So it is important to determine resistance to cut rate in canola plant. Cutting a stem by one-edge device has difference with a two-edge device. The latter, cutting is done by two elements with opposite action. The stem is kept between the blades and then the blades do their work. Cutting with a single element can be largely affected by blade speed, product inertia and the sharpness of cutting edge. Leaning stem crop against knife pressure and preventing penetration to interior materials occurs to some extent. Cutting process depends on stem inertia for overcoming opposite force (Thakare and Bhaskara, 2011).

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Nomenclature

w.b.	wet basis, %	h_3	situation of blade after cutting, cm
Δ_{1-2}	energy variance, J	R	length of arm, cm
ΔT	kinesthetic energy variance, J	E	stalk cutting energy requirement, J
ΔV_g	potential energy variance, J	α_1	maximum angular displacement before cutting, °
M	mass of blade and arm, kg	α_2	maximum angular displacement after cutting, °
g	gravity, ms^{-2}	θ_o°	maximum angular upswing deflection without cutting, °
h_1	situation of blade before cutting, cm		
h_2	difference between h_1 and h_3, cm		

According to many researches, needed energy for the cut unit of stem in cutter bar consists of as follows: overcome on air friction, chopping of crops, overcome on the friction of chopped products, friction in some parts of machine and cutting stem (Dernedde and Peters, 1971; O'Dogherty et al., 1995; Kronbergs, 2000; Blevins and Hansen, 1956; Chattopadhyay and Pandey, 2001; Liljedahl et al., 1961). Cutting energy in the stem of agricultural crops shows that how much energy is needed for cutting stems in agricultural crops. Harvesting machines and harvesters should be redesigned for lowering energy consumption (Kushwaha et al., 1983). Expressions for determining cutting energy requirement and peripheral knife speed for other crops were given as stated by (Feller, 1959; Prsad and Gupta, 1975; Mohammed, 1990; Yiljep and Mohammed, 2005). Hoseinzadeh et al. (2009) reported that needed energy for cutting wheat stem is affected by moisture content of the wheat stem, variety type, blade angle and cutting speed. With decreasing moisture content and blade angle and increasing cutting speed, cutting energy will decrease. The effect of variety on cutting energy is remarkable (Hoseinzadeh et al., 2009). In terms of product type and physical and mechanical properties of stem in crops, the estimation of harvesting energy in agricultural products can be completely different (Yiljep and Mohammed, 2005).

The aim of this study is to survey needed energy for cutting canola stems in different levels of height and moisture content. The most appropriate moisture content and height for cutting canola plant based on obtained results will recommend.

Materials and methods

Sample preparation

Canola variety of Hyola-401 harvested from the experimental farm in Gorgan, Iran, was used in the study. Product management was done completely from planting time to growing period and harvesting time. During harvesting time, built device was placed in farm and the tests were done in the farm. During the test, only single-branch stems were selected. So the height levels of cutting were selected under 30 cm e.g. 10, 20 and 30 cm.

In order to obtain different levels of moisture, the tests were done in three different times and one time for 10 days. Different levels of 11.6%, 18.5% and 25.5% (w.b.%) were obtained for canola stem.

Height cutting and moisture content measurement

Cutting height was measured by a ruler with an accuracy of 0.1 cm. Moisture content was determined using the standard oven drying procedure ASAE Standard S.352 (ASAE, 1979). The canola stalk sample for the determination of moisture content was collected immediately upon the completion of test-run. At least 15 canola stalk samples were collected. The mass of the collected moist canola stalk samples was determined using a scale balance with an accuracy of 0.01 g, and placed in a constant temperature oven for drying at a temperature of about 105 °C for a minimum drying period of 24 h as described by Yiljep and Mohammed (2005).

Measurement of blade speed

When the blade is released with a 90°, its initial velocity is zero. But when it reaches the stem, it has the highest velocity based on physics laws in cutting moment. The blade was modeled using software Crocodile Physics-V605 and then calculated the velocity in any moment. Figs. 1–3 show releasing, impact and free diagram of force and blade speed states, respectively. Also, Figs. 4–6 show displacement – velocity diagram and also kinetic and potential energy curves. According to Fig. 5 blade velocity was 2.64 m s^{-1} in cutting moment.

Making device

For cutting test, a pendulum system was designed and constructed based on (Azadbakht et al., 2012; Yiljep and Mohammed, 2005) (Fig. 7).

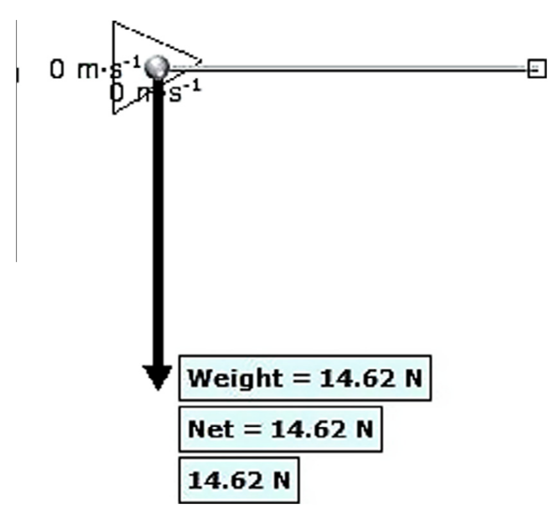

Figure 1 Releasing state.

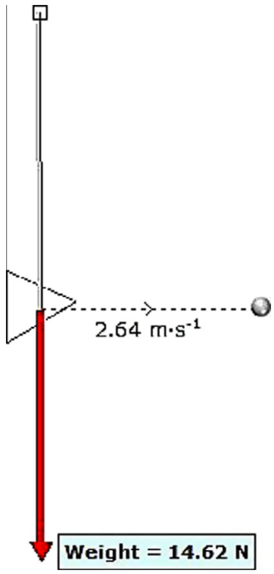

Figure 2 Impact state.

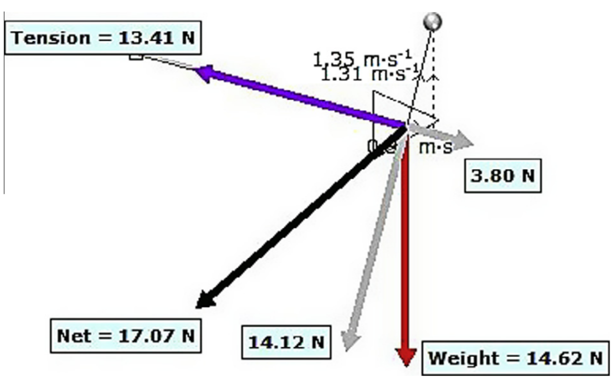

Figure 3 Modeling shear forces and free diagram of force and blade speed.

It consists of the beams, pivot axle, pendulum arm, frame, blade and finger. The pendulum consists of a rod which is attached from bottom to a blade and from top to a pivot axle. It has swinging movement around it. The second edge of cutting is a finger. The pendulum is placed into the device as the blade can pass through it (Fig. 8).

Test device calibration

As can be seen in Fig. 9 there is a linear relation between the releasing angle and final angle of pendulum with a proper estimate ratio. Using the least squares method, regression equation will determine the maximum deviation angle shown in Eq. (1). This equation has many similarities with earned equation by Yiljep and Mohammed (2005).

$$\theta_o^{\circ} = 1.038\alpha_1 - 2.562 \quad (1)$$

where,

θ_o° = maximum angular upswing deflection without cutting (°); and

α_1 = initial angular deflection of swinging arm (°).

Principle of operation

The device works on the principle of conservation of energy that was employed by some researcher (Azadbakht et al., 2012; Yiljep and Mohammed, 2005) (Fig. 10).

According to the Fig. 10 and principal of work and energy, the amount of work between place 1 and 2 is equal to sum of change of kinesthetic and potential energy (Andy and Rudra, 2010).

$$\Delta_{1-2} = \Delta(T + V_g) \quad (2)$$

After impact, the situation of blade with considering of friction, will be in place 2. Kinesthetic energy in place 1 and 2 is zero, so the amount of work after impact is:

$$\mathrm{E} = \Delta_{1-2} = \Delta v_g = Mg[\mathrm{h}_1 - \mathrm{h}_3] = Mg[\mathrm{h}_1 - (\mathrm{h}_1 - \mathrm{h}_2)] = Mg\mathrm{h}_2 \quad (3)$$

$$\mathrm{h}_2 = R\cos\alpha_2 \quad (4)$$

where, E is stalk cutting energy requirement (J), h_1 is situation of blade before cutting, h_3 is situation of blade after cutting, h_2 is the difference between h_1 and h_3, α_1 is maximum angular displacement before cutting (°), α_2 is maximum angular displacement after cutting (°).

During the test, it has been tried to the device be a proper model from common cutting devices. Because of this, the device is designed as it can take the stem between its arms in farm and the stem is cut via passing blade through finger lips. Pendulous arm is released from initial angle α_1 and it continues its path until it reaches the maximum speed and passes from between finger lips and consequently after cutting the stem, it comes up in the other side at an angle α_2. The tests were

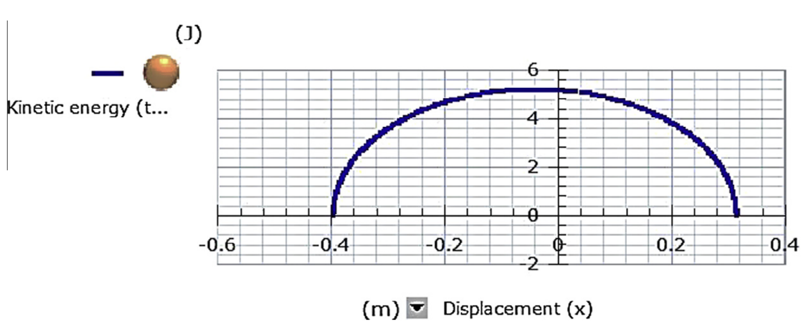

Figure 4 Diagram of displacement-kinetic energy.

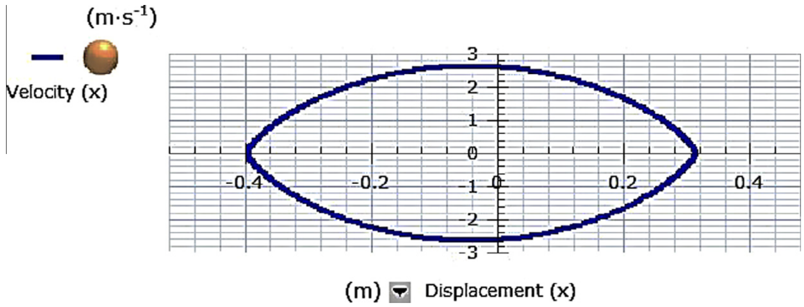

Figure 5 Diagram of displacement-velocity.

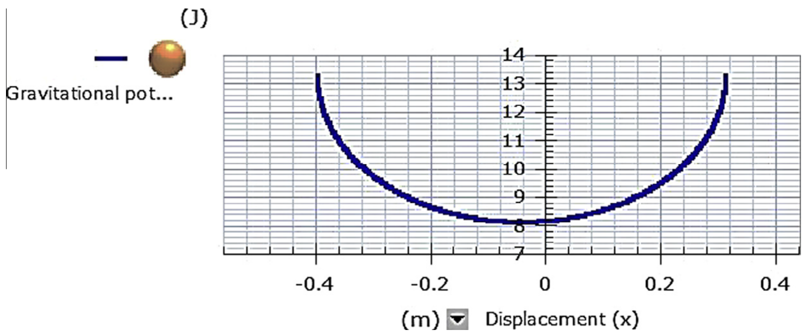

Figure 6 Diagram of displacement-potential energy.

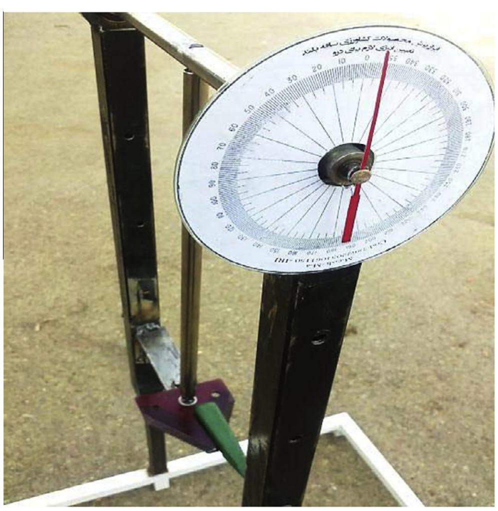

Figure 7 Pendulum impact system.

repeated 15 times for any level of moisture and height and they were analyzed using split plot design and SAS software.

Results and discussion

Table 1 shows results of a variance analysis of canola stalk cutting under different height and primary moisture content. Effect of height and moisture content on cutting energy in probability level of 1% is significant, but their interaction is not significant.

Figure 8 Blade and finger statue during impact cutting.

Table 2 shows comparison of cutting energy in different moisture content. It was observed that the highest cutting energy was 1.1 kJ in 25.5% moisture content. Also the minimum cutting energy was 0.8 kJ in 11.6% moisture content. Relation of moisture content and cutting energy is shown in Fig. 11 as can be seen, cutting energy is increased by increasing moisture content. When moisture content of stalk is low, stalk is dry and knife impact occurs breaking the stalk. This failure makes easier cutting, while the stalk that has high moisture content is resistant against failure. High moisture content will cause conglutination of the stalk tissue and consequently, more energy cutting will be a requirement. These findings are similar to researche results that announced an increase in cutting

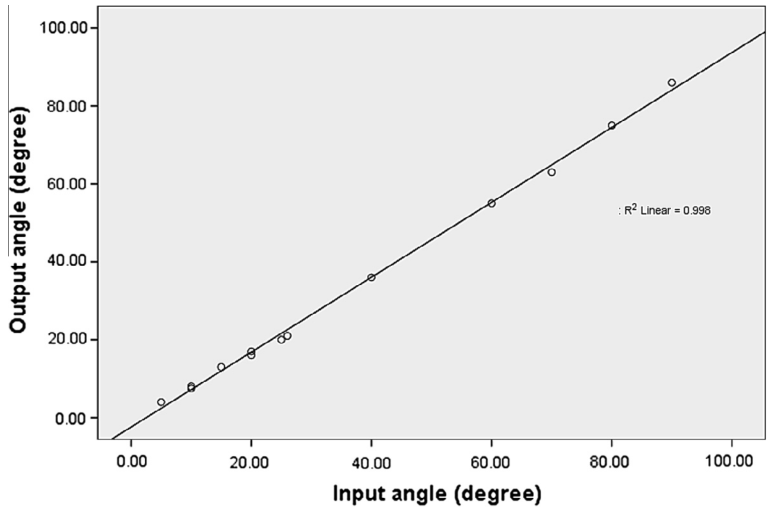

Figure 9 Relation the initial releasing angle and the final angle of pendulum.

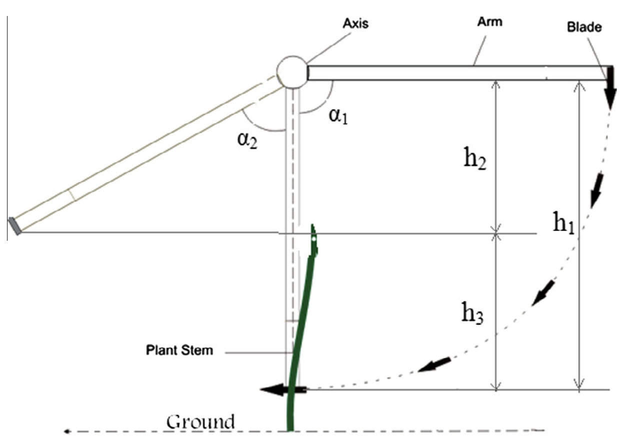

Figure 10 Impact and after impact angle.

Table 1 Variance analysis of cutting canola stalk under different cutting height and primary moistures.

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*-value
Moisture (mc)	2	2.5	1.23	69.95**
Height (cm)	2	10.3	0.72	40.94**
cm × mc	4	0.13	0.03	1.9ns
Error	84	1.48	0.01	

**Significant in statistic level of 1% ($P < 1\%$) and 5% ($P < 5\%$) ns not significant.

Table 2 Comparison of cutting energy in different moisture content.

Moisture (w.b.%)	Energy (kJ)
11.6	0.8C
18.5	0.92B
25.5	1.1A

Same capital letters in column show not significant different.

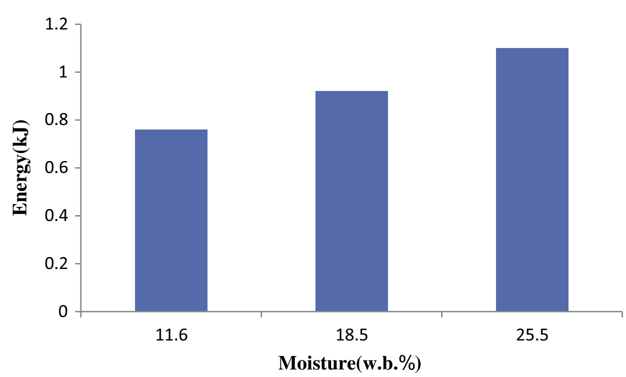

Figure 11 Relation of moisture content and cutting energy.

Table 3 Comparison of cutting energy in different cutting height.

Cutting height(cm)	Energy (kJ)
10	1.1A
20	0.9B
30	0.8C

Same capital letters in column show not significant different.

energy of corn stalk and wheat stalk by increasing moisture content (Chen et al., 2007; Hoseinzadeh et al., 2009).

Table 3 shows comparison of cutting energy in different cutting height. It was observed that the highest cutting energy was 1.1 kJ in 10 cm cutting height. Also the minimum cutting energy was 0.8 kJ in 30 cm cutting height. Relation of cutting height and cutting energy is shown in Fig. 12. The cutting energy is decreased by increasing cutting height. Considering that stalk diameter decreases with increasing height. Therefore the energy requirement for cutting of small diameter stalks will

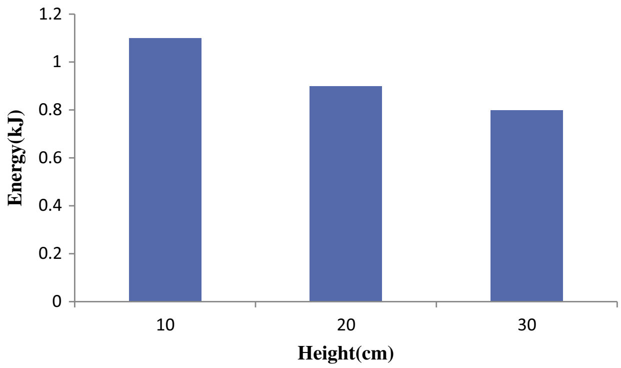

Figure 12 Relation of cutting height and cutting energy.

be lower than large diameter. These findings are similar to research results of Alizadeh et al. (2011) who that announced a decrease in cutting energy of rice stem by decreasing stalk diameter.

Conclusions

Cutting energy in the stalk of agricultural crops shows that how much energy is needed for cutting stalks in agricultural crops. Needed energy for the cut unit of canola stalk in this research consists of as follows: overcome on air friction, overcome on the friction of chopped products, friction in some parts of machine and cutting stalk. Effect of cutting height and moisture content on cutting energy based on statistics was significant, but their interaction was not significant. The cutting energy was increased by increasing moisture content and the cutting energy was decreased by increasing cutting height.

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