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Soybean Stems Cutting Energy and the Effects of Blade Parameters on it

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Abstract: In order to aid in engineering design and modification of cutting mechanisms in soybean harvesters and to investigate the effects of parameters on cutting energy, an impact shear test apparatus was designed and constructed to measure the energy required for cutting soybean plant stems. Experiments were carried out on Iranian Sahar variety, in different blade velocities (2.5, 3.75, 4.5 and 5.45 m s^{-1}) to determine the optimum values of blade bevel angles (18, 23, 28, 33 and 38 degrees), oblique angles (10, 20, 30, 40 and 50 degrees) and tilt angles (15, 25, 35, 45 and 55 degrees). The results show that the optimum value of Specific Cutting Energy (SCE) was obtained at blade bevel angle of 23°, oblique angle of 30° and tilt angle of 25° and blade velocity of 3.75 m s^{-1}.

Key words: Impact cutting, blade velocity, cutting energy, oblique angle, bevel angle

INTRODUCTION

The soybean (*Glycine max*) is going to be one of the most important oilseeds in Iran. Iran produced about 198 (ton×1000) per year from 82 (ha×1000) with an average of 1947 (kg ha^{-1}) in 2005 (FAO, 2005). In Iran harvesting of the soybean is commonly done by hand or cereal combines that always has its own difficulties. Design a new harvester or modification of the cutting mechanisms of cereal combines needs new engineering data on the cutting properties of soybean stem. Determination of cutting energy is considered to be an important criterion for comparing the effectiveness of any cutting system.

Researchers, in general, agree that in impact cutting the energy consumed to overcome the shearing resistance of the stem is equal to the energy required for quasi-static cutting plus the energy expended in overcoming friction (Persson, 1987). The effects of different bevel angles of the cutting edge of mower knives were investigated by Fisher *et al*. (1975). Using bevel angles of 14-30°, they found that the optimum characteristic and minimum wear occurred at a bevel angle of 23° was optimum for impact cutting of maize. Rajput and Bhole (1973) reported that force and energy requirements in impact cutting of paddy were lowest with a 30° blade bevel angle. Visvanathan *et al.* (1996) suggested that the specific cutting energy of the tuber was a minimum for cutting velocities in the region of 2.5 m s^{-1}, shear angles of 60 to 75° and bevel angles of 30 to 45°. Summers *et al*. (2002) investigated the cutting properties of rice straw to aid the development of header system for combines. Results show that cutting location and number of stems are significant factors in cutting force.

The objectives of the present study were, (1) to study the effects of blade parameters such as bevel angle, oblique angle, tilt angle on the cutting energy and to determine their optimum values and (2) to investigate the effect of blade velocity on cutting energy.

MATERIALS AND METHODS

The experiments were conducted on Iranian local soybean variety of Sahar grown in experimental field of Agricultural Faculty in Sari, Iran. Samples of the stem were cut from the ground level and brought to the laboratory in sealed plastic bags and were tested on the day of harvesting. The cutting velocities used in the experiments were 2.5, 3.75, 4.5 and 5.45 m s^{-1}. The blade bevel angles were 18, 23, 28, 33 and 38° (Fig. 1a) and oblique angles were 10, 20, 30, 40 and 55° (Fig. 1b). The various tilt angles selected for the study were 15, 25, 35, 45 and 55° (Fig. 1).

An impact shear test apparatus (Fig. 2) was fabricated and used in this study. A cutting blade is attached to the end of the pendulum arm and this arm is dropped from various heights by releasing a spring loaded lock. The cutting is performed when the blade is in its lowest position. A pointer is connected to the end of the shaft and indicates the position of the swinging arm on a round scale divided into degrees. To obtain different cutting velocities of the blade, the pendulum arm was

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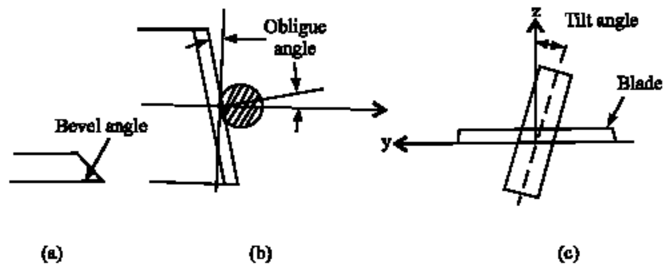

Fig. 1: Blade angles in relation to cutting

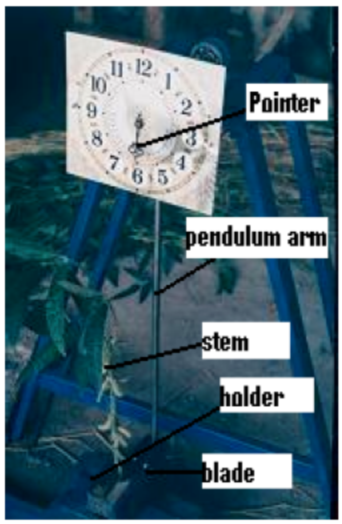

Fig. 2: Shear test apparatus

released from different angular positions. Stems positioned in the wooden stem holder directly beneath the lowest position of the blade.

After each experiment, the moisture content of the stem was determined by drying samples in an oven at 80°C for 24 h and was expressed on a wet basis. As the size of stem varies, the cutting energy was calculated per unit area of the cut stem measured over the cutting plane and express as specific cutting energy. In all cases the cross-sectional area of the cut stem was determined by a micrometer. All the experiments were replicated three times and the averages of the calculated specific cutting energy are reported.

Energy calculation: When the pendulum arm is in the equilibrium position the potential energy is zero. But when it is raised to an angle, θ, with the equilibrium position, the potential energy stored is given by:

$$E_s = W_t R(1 - \cos\theta) \quad (1)$$

Figure 3 shows the pendulum arm angles before and after releasing while there is no stem in holder. If the pendulum arm is released from θ, in the absence of cutting, moves through an angle θ_o on the other side of the equilibrium position. Then the energy lost due to friction and air resistance by the pendulum will be

$$E_f = W_t R[(1 - \cos\theta) - (1 - \cos\theta_o)]$$
$$E_f = W_t R(\cos\theta_o - \cos\theta) \quad (2)$$

When a blade is attached to the pendulum arm it will cut the stem and move through an angle, θ_c on the upswing after cutting. The energy utilized in cutting the stem E_c, is the difference between the initial potential energy, E_s and the potential energy available in the pendulum arm after cutting, E_o and the energy lost in friction and air resistance, E_f. This is expressed as:

$$E_c = E_s - (E_f + E_o)$$
$$E_c = W_t R(\cos\theta_c - \cos\theta_o) \quad (3)$$

The velocity of the blade at the equilibrium position was calculated by equating potential energy and rotational kinetic energy as given below:

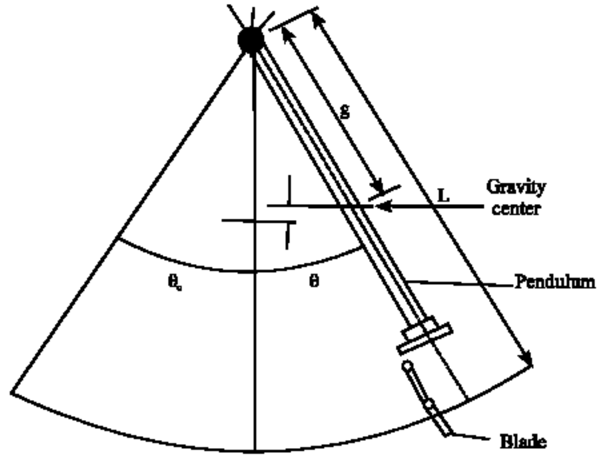

Fig. 3: Angles of pendulum arm before and after releasing without stem

$$W_t R(1-\cos\theta) = \frac{1}{2} I\omega^2 \quad (4)$$

If L is the distance between the center of the blade and axis of the rotation, the peripheral velocity of the cutting blade, V_c at its lowest position is given by,

$$V_c = \omega L = \sqrt{\frac{2W_t R(1-\cos\theta)}{I}} L \quad (5)$$

A measure, called the Specific Cutting Energy (SCE) has been defined for its practical importance for relating the required cutting energy to the amount of material being cut.

RESULTS AND DISCUSSION

Cutting velocity: The specific cutting energy was a minimum at velocities of about 2.24 to 3.75 m s^{-1}. It increased at a blade velocity less than 2.24 m s^{-1} and increased sharply when the velocity was increased beyond 3.75 m s^{-1}(Fig. 4). This may happen due to the fact that at lower velocities, impact is too less to sufficiently fail the stem and hence energy requirement is increased. At the higher velocities, the increase in the specific cutting energy may be owing to the kinetic zenergy imparted by the pendulum to the separated parts of the stem after cutting.

Bevel angle: The extreme values encountered in the replications are shown by vertical points. The results show that cutting energy per unit area is a minimum for 23° bevel angle. It decreases from 18 to 23° and then increases only after the angle exceeds 23°. The energy requirements is a result of interaction among frictional, compression and shear forces. With less bevel angle, the frictional forces are more, as the sliding surface on the bevel edge is increased (Fig. 5). The energy loss in friction is less when the slope of blade bevel angle approaches the static frictional angle. The static friction angle of soybean stem and blade material is expected to vary from 21 to 30° and hence the energy requirement is a minimum at about 23°. For a bevel angle more than 23°, blade requires more force to penetrate through the hard outer layer of the stem and thereby increasing energy requirement. This is similar to results of Prasad and Gupta (1975) who found that an angle of 24° for cutting paddy stem was the most efficient and small bevel angles resulted in rapid wear and dulling.

Oblique angle: It is evident from the (Fig. 6) that specific cutting energy decreased with increase in oblique angle

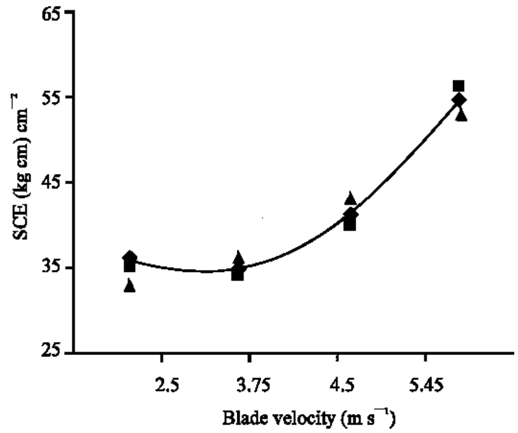

Fig. 4: Effect of cutting velocity on specific cutting energy(bevel angle of 28°; oblique angle of 30°; tilt angle of 35°)

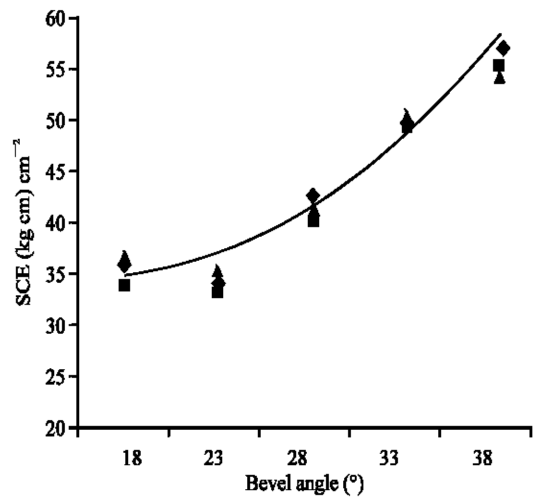

Fig. 5: Relationship between bevel angle and Specific Cutting Energy (SCE) (blade velocity of 4.5 m s^{-1}; oblique angle of 30°; tilt angle of 25)

and it is a minimum at about 30°. The increase in cutting energy for small approach angles is explained by the greater wedging action of the blade edge. When the blade approach angle is higher, sliding occurs which in turn decreases the impact effect of the blade and hence energy requirement is increased.

Tilt angle: Figure 7 shows the relationship between the specific cutting energy and blade tilt angle. The results represent that the specific cutting energy was a minimum for a tilt angle range of about 15 to 25°. As the tilt angle decreases from 55°, area of stem being cut increases, thereby decreasing the cutting energy per unit area. This effect is prevalent as long as the energy lost in overcoming friction between blade surface and stem

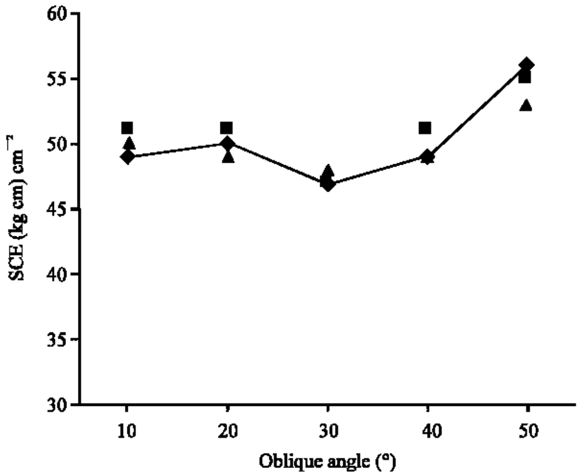

Fig. 6: Effect of oblique angle on specific cutting energy (blade velocity of 3.75 m s^{-1}; bevel angle of 23°; tilt angle of 25°)

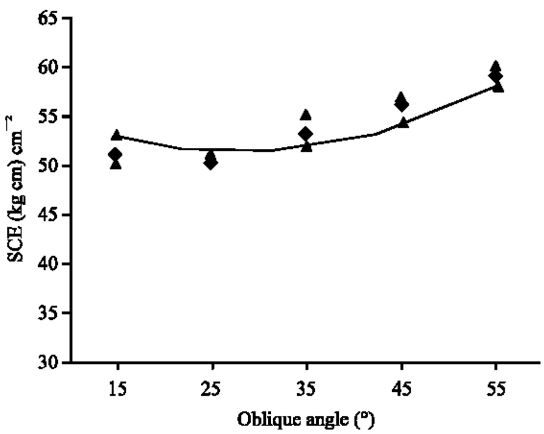

Fig. 7: Effect of tilt angle on specific cutting energy (blade velocity of 4.5 m s^{-1}; bevel angle of 28°; oblique angle of 30°)

material is not pronounced. According to Fig. 7 an angle of about 25° is optimum. This revealed that as the tilt angle was further decreased beyond 25°, the frictional forces became significant resulting in increased specific cutting energy.

CONCLUSIONS

The following results can be drawn through the analysis of investigations reported in this research.

- The studies on the effect of blade velocity indicated that the specific cutting energy was a minimum at velocity of 3.75 m s^{-1}.
- A blade bevel angle of 23° was observed to be optimum corresponding to minimum value of specific cutting energy.
- Optimum oblique angle and tilt angle were reported to be about 30° and 25°, respectively.

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