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Cutting energy and force as required for Pigeon pea stems

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The cutting energy and force required for the pigeon pea crops were investigated. The average moisture content in the pigeon pea stem at the time of harvesting was found to be 43 % (w.b.). Commercially available blades, sharpened at 30^0 and 45^0 bevel angle were selected for the experiment. It was attached to the lower end of the arm of pendulum type dynamic tester, which cuts the stalk at 90^0 to the stalk axis with knife velocity ranging between 2.28 m/s to 7.23 m/s. The blade 45^0 bevel angle required 23.74 per cent more cutting energy than the blade with 30^0 bevel angle for 30 mm diameter stem. Whereas the blade with 45^0 bevel angle required 16.05 percent more cutting force than the blade with 30^0 bevel angle. There was 21.65 % higher blade velocity required for 45^0 bevel angle as compared to 30^0 bevel angle blade. The study investigated 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.

Key words: Cutting energy, force, pendulum type dynamic tester, moisture content, pigeon pea.

Introduction

Anatomical investigation has been made on the stem of pigeon pea (*Cajanas cajan* (L) Millsp.). The vascular bundles of the stem are collateral and arranged in a ring (Shahanara, *et al.*, 2007). The principle of operation of the cutting element employed in any harvesting tool or equipment can be broadly classified under two categories viz., (i) cutting by impact and (ii) cutting by a counter-edge. Two types of cutting mechanism, reciprocating type and rotary impact type, used for harvesting sorghum harvesting, forage harvesting, weeding, lawn mowing, etc. The latter is being increasingly used in these operations due to its simplicity in construction, low maintenance cost and ability to but both small and large diameter stalks (McRandal *et al.*, 1978). Effectiveness of impact cutting system as a viable alternative to the counter edge cutting is being progressively explored.

Cutting using single element differs greatly from that using two opposed elements. The latter case is cutting with counter-edge and thus, the stalk is

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supported in the vicinity of the cutting element. In this case, there is little or no energy wasted in the stalk deflection before cutting. 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. Stalk resistance to bending is insufficient by itself to provide the force necessary to oppose the knife pressure required to penetrate the material; the cutting process depends on the stalk inertia to give the required opposing force (Prasad *et al*, 1975). Koloor *et al.* (2007) studied the engineering design and modification of cutting mechanism of soybean harvester. The optimum specific cutting energy value was found at blade bevel angle 23^0, oblique angle of 30^0 and blade velocity of 3.75 ms^{-1}. Reza (2007) designed and constructed a pendulum type impact shear test apparatus for paddy stems cutting energy and bale optimum parameters. The results show that blade bevel angle of 28^0, oblique angle of 30^0, tilt angle of 35^0 and blade velocity of 2.24 ms^{-1} are optimum. 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 (O'Dogherty *et al.*, 1986).

Despite the extensive studies conducted on properties of plants, stems and blade characteristics in relation to cutting performance (cutting energy) none was able to provide such comprehensive relationship for thick-stemmed crops as pigeon pea, sorghum, millet and maize. Therefore, an attempt was made to investigate the cutting energy and force require for pigeon pea stems when they were subjected to impact cutting by pendulum type dynamic tester.

Material and methods

The experiment was carried out at Dr. Panjabrao Deshmukh Krishi Vidhyaptha, Akola during the year 2007-2008. A pendulum type dynamic tester was fabricated in the Department of Farm Power and Machinery. The pendulum type dynamic tester is given in Fig.1. The line sketch (Fig. 2) shows the different forces acting on the blade edge and pivot point in order to find out the cutting forces in laboratory which enables to assess the designed cutting energy for different pigeon pea stem diameter and moisture content. The physical parameters like stem diameter, moisture content, etc. of pigeon pea stems were calculated through standard methods. The study was conducted with three replications and four independent variables which were moisture content and diameter of stem, blade bevel angle and speed.

Pendulum type dynamic tester

Principle of operation

During experiment swinging angle (θ_s) and θ_1 were initially recorded by allowing the pendulum to swing freely before the crops were clamped in the vice. A pigeon pea stem of selected diameter was first clamped in the vice. The pendulum was then subsequently released through the same angle and the clamped crops were severed. Angle θ_2 was recorded during the process of severing. Two replications of θ_2 were taken and the average value was then found out. Cutting energy was then measures by substituting the values of W, L, θ_2 and θ_1 in equation 1. The maximum blade velocity V corresponding to θs was then calculated from equation 2.

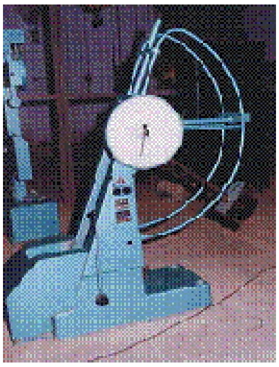

Fig 1. Pendulum type dynamic tester

Construction details

It consisted basically of a pendulum suspended on two ball bearings (UCS-204). It has a fixed hand vice for holding the stems. Cutting blade could be mounted on the tip of the pendulum. On the top there was a fixed circular aluminum plate graduated in degrees also called dial. A pointer actuated by a pin projecting from the upper arm of the pendulum showed the angle of swing of the pendulum on this graduated scale. The bench vice could be moved at right angle to the plane of the pendulum swing in order to vary the height of cut.

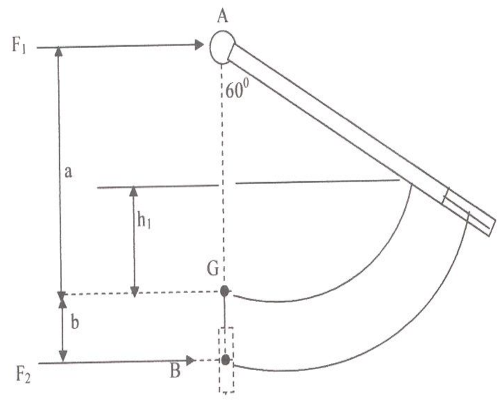

Fig 2. Line sketch of pendulum type dynamic tester

Where,

F_1 and F_2- Force acting at pivot (A) and at cutting point of blade (B)
Distance between pivot point and centre of gravity
Distance between centre of gravity and cutting point of blade (B)
h_1- Distance between centre of gravity and centre of gravity of pendulum at releasing angle

Cutting energy

The cutting energy of the stem was determined by the difference between θ_2 and θ_1 Expressions for determining cutting energy requirement and peripheral knife speed were given as stated by Prasad and Gupta (1975).
The energy dissipated in cutting a specimen in given formula

$E = W L (\cos \theta_2 – \cos \theta_1)$ ....(1)
Where,
E = Energy dissipated, (kgm)
W = Weight of the swinging part, (kg)
L = Distance of centre of gravity of the swinging part from the pivot point of the pendulum, (metre)
θ_2= Maximum angle of deflection on the pendulum frame from vertical after cutting the specimen, (deg)
θ_1= Maximum angle of deflection of the pendulum from vertical at the end of free swing, (deg)

Blade velocity

The maximum blade velocity at impact can be determined by nothing the angle of swing between the vertical and rest position. When the pendulum weight W is released through an angle θ,

$V = \sqrt{2gL (1\text{-}\cos \theta_s)}$ ……… (2)

Moisture content

The moisture content of the pigeon pea stem was measured according to standard method. About 500 gm sample of stem was kept in an oven for 24 hours at 105^0 C. the loss in weight of the sample was recorded and the moisture content in percent was determined as in equation.

$$MC = \frac{Wi \times Wd}{Wi} \times 100$$

Where,

MC = Moisture content, per cent

W_i = Initial weight, kg

W_d = Dried weight of sample, kg

Results and discussion

The three replications were taken for different cross sectional area of pigeon pea stem. The dial showed the indicated angle for cutting pigeon pea stem and corresponding cutting energy and force were calculated using formula. In the experiment, with cutting blade (bevel angle 30^0) energy required to cut the stem of the pigeon pea was minimum for 8 mm diameter 17.38 Nm and maximum for 30 mm diameter 141.96 Nm, whereas cutting force for the stem diameter 8 mm was 232.5 N and for stem 30 mm diameter, it was found 747.25 N (Table 1).

Table 1. Cutting energy and force required for pigeon pea stem with 30^0 bevel angle blade

Pendulum dropped at an angle, degree	Stem diameter, mm	Indicated angle (degree)		Cutting energy, Nm	Cutting force, N
		Swing of arm from pivot with cutting angle, degree	Swing of arm from pivot without cutting angle, degree		
30	8	8	24	17.38	232.50
40	12	12	32	29.48	296.80
55	18	8	41	47.86	337.75
70	24	5	58	100.72	709.00
90	30	6	69	141.96	747.25

With cutting blade (bevel angle 45^0) energy required to cut the stem of the pigeon pea was minimum for 8 mm diameter 16.21 Nm and maximum for 30 mm diameter 188.16 Nm, whereas cutting force for the stem diameter 8 mm was 249.11 N and for stem 30 mm diameter, it was found 890.13 N (Table 2).

Table 2. Cutting energy and force required for pigeon pea stem with 45^0 bevel angle blade

Pendulum dropped at an angle, degree	Stem diameter, mm	Indicated angle (degree)		Cutting energy, Nm	Cutting force, N
		Swing of arm from pivot with cutting angle, degree	Swing of arm from pivot without cutting angle, degree		
35	8	6	25	16.21	249.11
50	12	10	34	35.82	340.28
65	18	6	43	58.25	491.86
80	24	5	62	126.45	758.34
100	30	5	75	188.16	890.13

Effect of moisture content on cutting energy and force

It was observed that the cutting energy and force for pigeon pea stems decreases with increases in moisture content irrespective of cutting blade bevel angles (Fig. 3 and 4). The moisture content has expressed a increasing effect on cutting energy and force. Increasing moisture content leads to decreased cutting energy and force of pigeon pea stem up to 45 % moisture content, after that it was gradually showed reverse effect as moisture content increased. Unlike phenomena in maize, wheat and paddy, cutting energy increases with increasing moisture content of stem (Prasad and Gupta, 1975 and Esehaghbeygi *et al.,* 2009), in case of pigeon pea the relation is inverse as the pigeon pea stem has vascular bundles of the stem are collateral and arranged in a ring (Shahanara *et al.*, 2007).

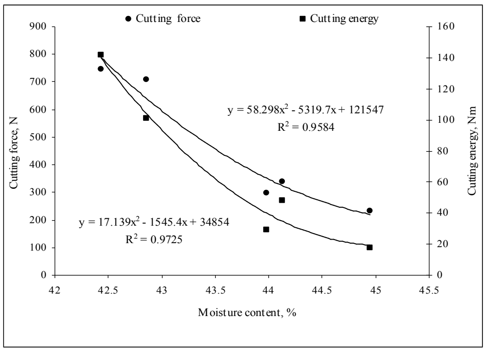

Fig 3. Cutting force and energy against moisture content of pigeon pea crop with 30^0 bevel angle blade

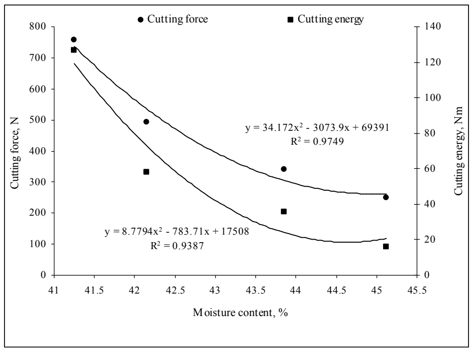

Fig 4. Cutting force and energy against moisture content of pigeon pea crop with 45^0 bevel angle blade

Effect of stem diameter on cutting energy and force

It showed that the cutting energy and force required for cutting pigeon pea stems increased gradually as the diameter of the stem increases from 8 mm to 18 mm. But energy and force suddenly increases from stem diameter 18 mm to 24 mm (Fig.5 and 6). It may due to full maturity of plants. Full mature plants cellulose became compact and hard so the force required to cut was increased as diameter increased.

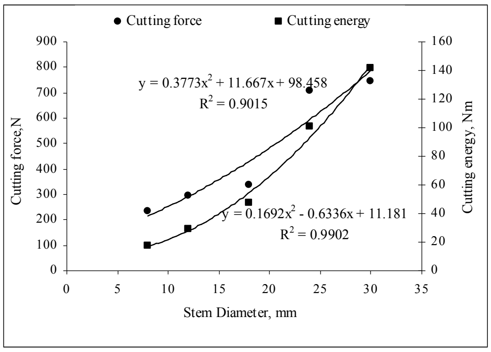

Fig 5. Cutting energy and force against stem diameter of pigeon pea crop with 30^0 bevel angle blade

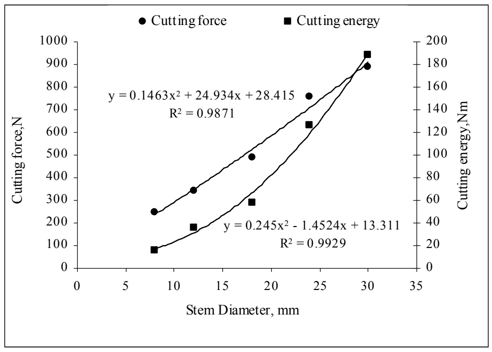

Fig 6. Cutting energy and force against stem diameter of pigeon pea crop with 45^0 bevel angle blade

Effect of blade speed and bevel angle on cutting energy

Cutting energy was a minimum at velocities of about 2.28 and 2.91 m/s^{-1} for 30^0 and 45^0 bevel angles of cutting blades respectively. It increased sharply when the velocity was increased of 3.98 m/s^{-1} as also reported by Yiliep *et al.* (2005) and Prasad and Gupta (1975). This may happen due to the fact that at lower velocity, impact is too less to sufficiently fail the stem and hence energy requirement is increased. At higher velocities, the increase in the cutting energy may be owing to the kinetic energy imparted by the pendulum to the separated parts of the stem after cutting.

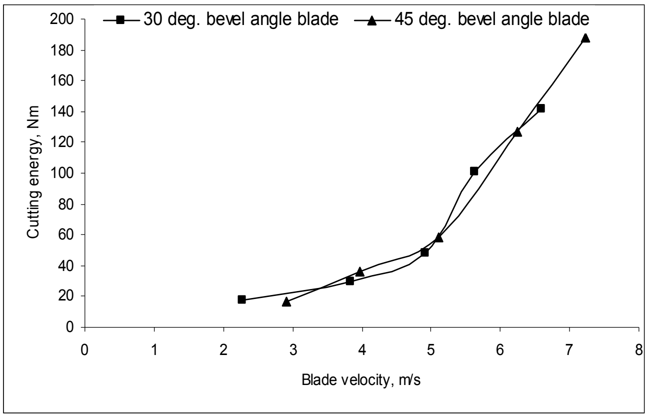

Fig 7. Effect of blade velocity on cutting energy for pigeon pea stems

Conclusions

The investigation of force and energy required for the pigeon pea stem with different treatment has been carried out and the conclusions have been drawn form the experiment mentioned below. Cutting speed, blade bevel angle, moisture content, stem diameter are the main constraints affecting cutting energy and force of pigeon pea stem. Blade velocities ranging between 2.28 m/s to 7.23 m/s for cutting the pigeon pea stems of diameter ranging from 8 mm to 30 mm. Effect of blade velocity indicated that the cutting energy was a minimum at 2.28 m/s for 30^0 blade bevel angle. The dynamic cutting force is observed to increase with an increase in the cross-sectional area in respect of samples tested. Cutting energy and force decreased with increase in moisture content of the stem. The energy and force required to cut the pigeon pea with 30^0 bevel angle blade performed better than 45^0 bevel angle blade.

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