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Effect of Blade Angles and Thickness on Specific Cutting Energy and Cutting Index of Cassava Stem

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ABSTRACT

Cassava harvesting is highly labour intensive and a partially mechanized operation. Development of a separate cassava stem harvester and incorporation with available cassava digger enhance then harvesting efficiency. To optimize the stem harvester design, this study investigated the effect of blade thickness, approach angle and shear angle on specific cutting energy and cutting index. The treatment with 20°shear angle, 30° approach angle and 6mm thickness yielded the minimum specific cutting energy and best quality of cut cassava stem respectively.

Keywords: approach angle, shear angle, specific cutting energy, harvesting efficiency

INTRODUCTION

Cassava (*Manihot esculenta crantz*) also commonly known as Tapioca, is an important crop for food security and income generation for tropics mainly in the developing countries. India ranks first in the world for the productivity of cassava with 27.92 t/ha as against the world average 10.76 t/ha (Edison *et. al.* 2013). In India, 0.23 million ha area is under cassava cultivation with 8.06million tonnes of annual production (FAOSTAT, 2010).Althoughcassava is cultivated in 13 states ofIndia, major production is from the southern states of Kerala, Tamil Nadu and Andhra Pradesh (Edison *et. al.* 2013).Itis consumed as cooked/baked tubers in cooking preparations and in making pappads. Cassava starch has wide industrial applications. It is used in textile industries as a sizing agent, in pharmaceutical industries, making adhesives, dextrin manufacturing, paper industry, laundry and in many fast food preparations.

Harvesting of cassava is a highly labor-intensive operation. In India, the conventional practice is to cut the stem upon maturity and then slightly wet the field. Tractor operated cassava diggers have been successfully developed for uprooting the tubers from the soil. But the stem harvesting operation is yet to be mechanized. Therefore, complete mechanization of cassava harvesting requires a tractor front mounted stem cutter followed by a digger at its rear end.

Design of cassava stem cutter and its cutter mechanism needs engineering data on cutting properties of cassava stem. Specific cutting energy and cutting index are considered important criterion to assess the efficiency of any cutting system. The harvester blade material is an important design parameter. The knife should be made from a material that is harder than what it is cutting. Steel or a steel alloy was favoured due to its hardness and high tensile strength investigated by Neves *et al.* (2001). Various studies have been performed to optimize the cutter thickness, cutting angle, shear angle, approach angle etc. to minimize the cutting energy of stem for various crops like soybean (Koloor and Ghaffar 2007), Miscanthus (Maughan *et al.* 2014), maize and sorghum stalk (Prakash 2003 and Yiljep and Mohammed 2005).

MATERIAL AND METHODS

The experiments were conducted in the workshop of Department of Farm Power and Machinery, Agricultural Engineering College & Research Institute in Coimbatore, India. Freshly harvested cassava stems of CO-4 variety were collected from farmer's field. The moisture content of the collected cassava stems was found out by hot air oven method on dry basis. The moisture content of the stems was maintained almost at a constant level by keeping the stems under shade till the completion of the investigation.

Experimental Design

The bevel angle of 25° for cutter blade was selected for the investigation. The bevel angle is the angle of the bevel edge of the cutter blade. The bevel angle of cutter blade decides the sharpness of the blade and the ease with which it enters the stem during harvest(Rider *et al*, 1993). The minimum cutting force and cutting energy occurred at a bevel angle of 25° (Prasad and Gupta, 1975).

Four levels of approach angle of cutter blade (0°, 15°, 30° and 40°) were selected for the initial laboratory investigation (Table 1). Approach angle is the angle between the central line of the blade and normal to the direction of motion of the blade. The approach angle decides the effect of blade parameters and stem configuration on the dynamics of cutting cassava stem (Prasad and Gupta, 1975).

Four levels of shear angle 0°, 15°, 20° and 25° were selected for the initial laboratory investigation. Shear angle is the angle made between the vertical plane and the cutting plane of the stem. The shear angle depends on plant height.

The thickness of the blade affects the cutting energy at the entry point into the stem required for harvesting cassava stem. Hence two levels of thickness of cutter blade *viz.*, 3 mm and 6

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mm were selected for the investigation.

Table 1. Experimental design

Sl No.	Independent parameters	Levels (Values)	Dependent parameters
1.	Approach angles	4 (0^o, 15^o, 30^o and 40^o)	1.Cutting energy
2.	Shear angle	4 (0^o, 15^o, 20^o and 25^o)	2. cutting index
3.	Blade thickness	2 (3 and 6 mm)	

Fabrication of Test Rig

The impact type pendulum test rig was fabricated and is used in this study(Fig 1). A dead weight of 5 kg was added at the lower end of the swing arm so that the centre of gravity is shifted 5 cm towards the right of the swing arm. The cassava stem was firmly clamped vertically in the vice directly below the pendulum hinge point. The diameter of the cassava stem at the place of the cut was measured for each treatment of the investigation with a vernier calliper. A total number of 96 randomly replicated treatments were conducted with selected levels of cutter blade thickness, shear angle and approach angle.

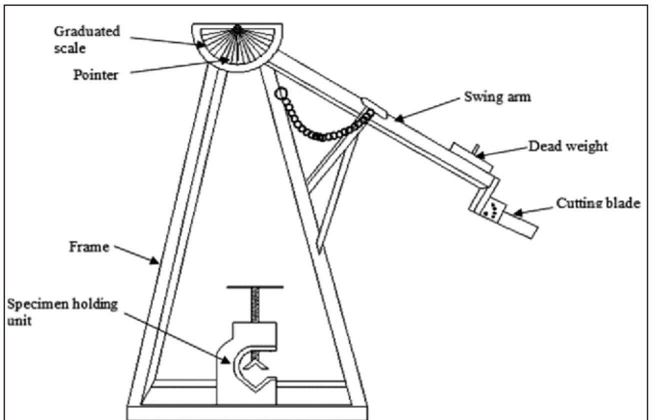

Fig.1. Schematic diagram of Pendulum type impact test rig

Before conducting trails with each treatment, the swing arm was lowered slowly to check the alignment of the blade with cassava stem. When the swing arm is at extreme upswing position, the angular displacement indicator makes an angle 'θ' with the dial gauge. Then the pendulum was released from the extreme upswing position by releasing the lock. The pendulum swings down to cut the cassava stem positioned in the vice. After cutting the cassava stem the pendulum swung to the other end reaching an angle of θc which was noted from the dial indicator. Each experiment was replicated thrice and the swing arm angles θ and θc were recorded. The experiment was repeated for all combination levels of shear angle, approach angle and thickness of cutter blade.

Energy Required for Cutting Cassava Stem

From the measured values of θ and θ_o, the energy expenditure for cutting cassava stem was determined as detailed below, Fig 2.

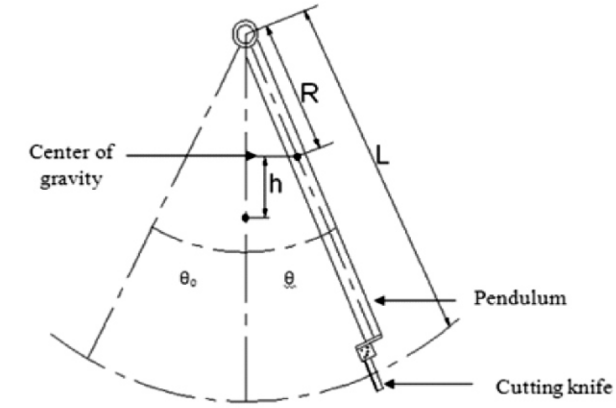

Fig. 2. Force measurement of pendulum type impact test rig

When the pendulum arm is in the equilibrium position, the potential energy stored is zero. But when it rose to an angle θ, the potential energy stored is given by Eq. [1].

$$E_s = Mgh = MgR\,(1\text{-}\cos\theta) \quad (1)$$

Where

M = Mass of the pendulum arm, kg

R = Distance between the centre of rotation and the centre of gravity of the pendulum arm, m

E_S = Energy stored in the pendulum when raised to θ˚, J

If the pendulum arm is released from θ, in the absence of cutting, and moves through an angle θ0 on the other side of the equilibrium position, then the energy lost due to friction and air resistance by the pendulum will be

$$E_{f=} MgR\,[(1\text{-}\cos\theta) - (1\text{-}\cos\theta_o)] \quad (2)$$

$$E_{f=} MgR\,(\cos\theta_o - \cos\theta) \quad (3)$$

When a sharp knife is attached to the pendulum arm it will cut the cassava stem, placed at equilibrium position during its downswing and move through an angle, θc on upswing after cutting. The energy utilized in cutting the stem, Ec is the difference between the initial potential energy, Es, 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

Where,

E_c = Energy utilized for cutting the peduncle,

E_f = Energy lost in friction and air resistance by the Pendulum arm, J

E_0 = Energy available in the pendulum arm after cutting, J

The energy expenditure incurred for cutting cassava stem with different selected levels of blade thickness, approach angle and shear angle were determined using the above equation.

The specific cutting energy for cutting cassava stem was computed to nullify the effect of diameter of cassava stem on cutting energy. The specific cutting energy for cutting cassava stem was arrived by dividing the cutting energy required by the exposed cross-sectional area of cassava stem (The shape of cassava stem was cylindrical) after completion of cutting for all the treatments of the investigation (Persson, 1987). All the replication was replicated thrice and the averages of specific cutting energy reported.

Cutting Index

The quality of cut of cassava stem is an important factor in the cassava harvesting process. A clean cut without shattering or peeling is desirable since it is reused for planting also reduces the exposed area available for the microorganism to act. If the stem is cut at an improper combination of shear angle, approach angle and thickness of the blade, there is a possibility of splitting along the axial direction that causes losses. For the assessment of damage caused during cutting of cassava stem, a 8 - point damage rating scale (1 - stem with a clean cut and no surface damage, 8 – shattered stem) was used which is an adoption of the damage classification in sugarcane cutting process (Kroes,1997).

Hence after completion of cutting of cassava stem with a selected level of thickness, shear angle and approach angle of cutter blade in impact type pendulum test rig, the cutting index in terms of the extent of damage caused to the cassava stem was observed and recorded for all the treatments of the investigation.

RESULTS AND DISCUSSIONS

To calculate Specific cutting energy, the energy required was divided with the exposed area of cassava stem. The mass, effective length and moment of inertia of the cutting arm were recorded. The results of this study are applicable for the selected variety; however, they could also serve as a reference for other varieties.

Effect of approach angle on specific cutting energy of cassava stem

The results showed that increase in approach angle from 0 ($_1$) to 15° ($_2$)has led to an appreciable reduction of 14.5 to 29.7 and 11.3 to 27.2 percent in specific cutting energy respectively for 3 and 6 mm thickness of cutter blade, Fig 3. The effect of thickness of cutter blade on specific cutting energy was not predominant at all selected levels of shear and approach angle. The cutter blade with 30° ($_3$) approach angle yielded minimum specific cutting energy for selected levels of 3 and 6 mm thickness of cutter blades.

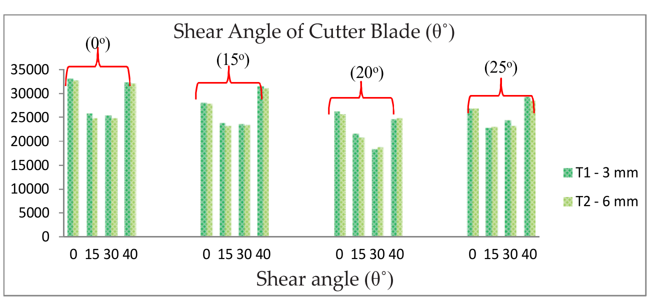

Fig 3. Effect of Approach Angle (θ˚) of cutter blade on specific cutting energy for cassava stem cutting in impact type pendulum test rig

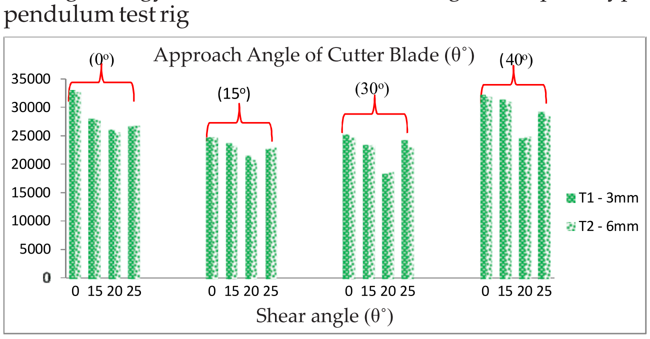

Fig 4. Effect of shear angle (δo) of cutter blade on specific cutting energy for cassava stem cutting in impact type pendulum test rig

Effect of approach angle on cutting index of cassava stem

It is inferred from results that with an increase in approach angle from 0˚ ($_1$) to 30° ($_3$) of cutter blade, the value of cutting index decreased indicating the enhanced quality of cut of cassava stem for 3 and 6 mm thickness of cutter blade respectively. Further increase in approach angle from 30˚ ($_3$) to 40° ($_4$) resulted in an increase of cutting index value indicating deterioration in cutting quality of cassava stem, Fig 5. The decrease in cutting index for small approach angles of cutter blade (up to 30°) might be due to the greater wedging action of the knife edge. With greater wedging action, the bevel edge of the cutter blade penetrates very easily into the stem surface with minimum resistance improving the quality of cut with minimum damage. The vice provided in the pendulum test rig to hold the stem tightly might have offered greater counter resistance to the blade and hence improved quality of cut. At all selected levels of approach angle of cutter blade, there was no appreciable variation in cutting index for 3 and 6 mm thickness of the blade.

It is inferred that the cutter blade with the shear angle of 20°(δ_3) yielded the minimum value of cutting index indicating the highest quality of cut of cassava stem at all selected levels of approach angle () and thickness of the blade. Comparison of thickness of blade, 6 mm (T_2) thickness produced the better quality of cut of cassava stem at 20˚(δ_3) shear angle.

The best quality of cut of cassava stem with the lowest cutting index of 1.3 was obtained for the combination level of 6 mm thickness, 20shear angle (δ_3) and 30 approach angle ($_3$) of the cutter blade.

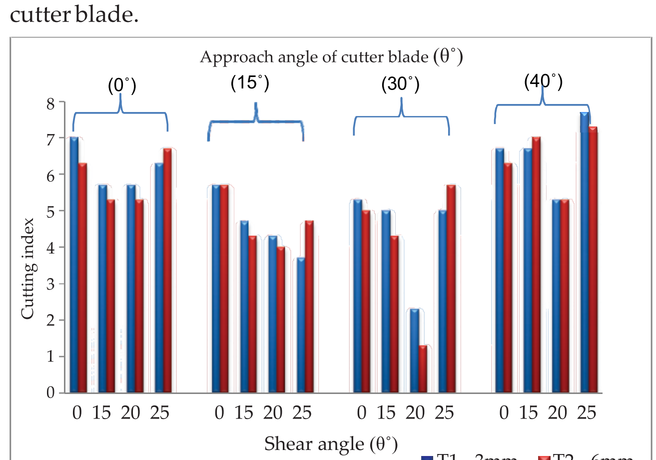

Fig 5. Effect of shear angle (θ˚) on cutting index at selected levels of shear angle (θ˚) of cutter blade in impact type pendulum test rig

Effect of approach angle on cutting index of cassava stem:

It is inferred that with an increase in shear angle from 0˚ (δ_1) to 20˚ (δ_3) of cutter blade, the value of cutting index decreased indicating the enhanced quality of cut of cassava stem. Further increase in shear angle from 20˚ (δ_3) to 25˚(δ_4) resulted in an increase of cutting index value indicating deterioration in cutting quality of cassava stem. Similarly with an increase in approach angle from 0˚ ($_1$) to 30˚ ($_3$) resulted in improved quality of cut for 3 and 6 mm thickness of cutter blade respectively, Fig 6. Further increase of approach angle up to 40˚ ($_4$) resulted in deterioration of the quality of cassava stem cut. At all selected levels of the shear angle of cutter blade, there was no appreciable variation in cutting index for 3 and 6 mm thickness of the blade. In general, the cutting index was maximum at 0˚ shear angle (δ_1) of cutter blade due to maximum frictional force.

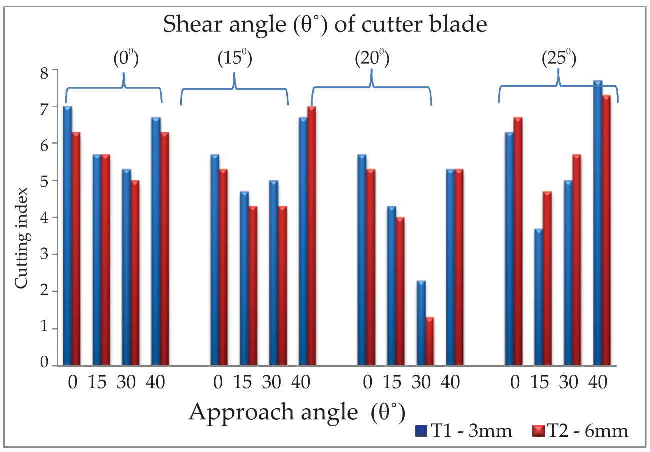

Fig 6. Effect of shear angle (θ˚) on cutting index at selected levels of approach angle of cutter blade in impact type pendulum test rig

At a higher shear angle of 20˚ (δ_3) of cutter blade, the lesser resistance offered by the cutting plane of cassava stem resulted in lower impact cutting energy improving the quality of cut. At a higher shear angle of 25˚ (δ_4) of cutter blade, the edge of the cutter blade is away from the plane of least resistance resulting in poor quality of cut.

CONCLUSION

Before designing tractor operated cassava stem cutter following design criteria should be used for its optimum operation:

The studies on the effect of blade thickness indicated that the specific cutting energy was a minimum at blade thickness of 6mm. A blade approach of 30° was observed to be optimum corresponding to the minimum value of specific cutting energy. Optimum shearangle was reported to be about 20°. Using impact type test rig the lowest specific cutting energy of 18622.2 Jm-2 and cutting index of 1.3 was obtained for optimised values above mentioned parameters. Hence, a blade of 6 mm thickness should be used in cassava stem cutter with approach and shear angle of 30° and 20° respectively.

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