Development of a Stem Cutting Unit for a Cassava Planter

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ABSTRACT

A cassava stem cutting unit was developed to generate the design data for its use on a prototype of a cassava planter. It consisted of a 25.5 cm circular saw blade, cam mechanism, bottom plate, electric motor (0.75 kW) to operate saw blade and a motor (0.37 kW). The cassava stems were fed manually into a feeding chute for free fall on to the bottom plate, and then these were cut by the circular saw operated by an electric motor. The cam mechanism operated by the cam motor, controlled the number of cuts by the circular saw. The cutting length could be adjusted between 15 and 30 cm by altering the position of the bottom plate. Test results indicated that the highest cutting quality of this unit at more than 60 number of circular saw teeth when operated at faster than 1,200 rpm cutting shaft speed and slower than 50 rpm cam shaft speed. Cutting capacity depended on cam shaft speed. At 50 rpm cam shaft speed, minimum cutting capacity was found to be 5,034 stakes per hour (40,272 stakes per day of 8 h) with 83.91% cutting efficiency. The stems were undamaged when operated at these conditions and showed satisfactory germination performance.

Keywords: Cassava planter, cutting unit, stake, cutting speed, cutting capacity, cutting efficiency

1. INTRODUCTION

The world fresh cassava roots production has reached 167 - 190 million metric tones each year (FAO, 2005). Africa, Asia and Latin America/Caribbean are the largest cassava producing regions. Nigeria, Brazil, Thailand, Indonesia and Congo are among the top five producers of cassava roots. These five countries comprise more than 60% of the world cassava production. Nigeria, Brazil and Thailand possess around 18%, 12% and 10% of the total production respectively (FAO, 2005). Thailand has cassava plantations totaling approximately 1.072 million ha in 48 out of 76 provinces of the country (OAE, 2003; 2004). Each year, Thailand processes and exports various cassava products e.g. cassava chips, cassava pellets and cassava starch to domestic and international customers. Presently, the status of Thailand as the largest exporter of cassava products reflects the acceptance by clients around the world. The cassava industry exports more than 25,000 million baht (US $625 million) a year (OAE, 2004). Therefore, cassava is one of the major crops for Thai economy. It is second only to rice and rubber.

The price of cassava roots in Thailand increased in 2005 due to the higher demand of cassava for industrial production of cassava starch, bio-ethanol, etc. and also due to increased export to China (OAE, 2004). The price hike encouraged Thai farmers to increase growing areas and switch from other crops to cassava. Due to existing labor shortage for agricultural work, most of the cassava cultivation operations on medium to large farm are mechanized excluding planting. Planting is done manually, which is often delayed due to shortage of labor as well as non-existence of mechanical planters. The need to mechanize the planting of cassava in Thai conditions has long been recognized but previous attempts to design a cassava planter have not yielded a serviceable machine. Therefore, it is considered appropriate to design and develop a mechanical cassava planter suitable for Thai conditions to overcome the current labor shortage problem. A stem cutting is first process of cassava planting that affects the germination and yield. In Thailand, it is done manually, but in some other countries, the stems are cut by cutting machine for use as the planting material of the planter. They then studied the cutting unit to obtain the design data for developing the prototype of the cassava planter that can accomplish stake cutting and planting in one machine.

2. MATERIAL AND METHODS

2.1 Factors Affecting Cutting Design

Cutting is defined as the process of mechanically cutting a solid body along a predetermined line using a cutting tool. In most cases, the original body is divided into two parts that creates new surfaces. The basic cutting concept and the line of cut are explained by Persson, (1987). Cutting has been given other names, in many special cases describing the special kind of cutting device or cutting procedure, such as chopping, mowing, sawing, splitting, slicing, dicing, chipping etc. Chancellor (1987) indicated that the cutting energy for wood by sawing (0.068 J/mm^2) was less than chipping (0.280 J/mm^2).

In Thailand, cassava can be planted at any time of the year, except during heavy rains or in dry season. Planting materials (cassava stems or stakes) are usually taken from 8-12 month - old plants from the previous crop, which is usually harvested in twelfth month. At harvest, whole stalks are bundled and stacked upright or piled horizontally in the field under shade or in open until they are required for planting. The period of storage of planting material depends on rains for land preparation and ranges from 15 to 90 days. Usually storage of no longer than 30 days is recommended to secure more than 80% survival rate. The quality of stakes depends on age of stem, thickness, number of nodes and health of stems.

When the stakes are to be planted, they are cut in 150-300 mm length with 5-7 nodes (Fig. 1). Immature herbaceous parts at top and too woody at the base of the stalk are removed because it reduces survival. Cutting is at an angle, which makes it easy to insert the stake into the soil, but the Centro Internacional de Agricultura Tropical (CIAT) recommends horizontal cutting because a slanted cut increases tissue exposure and dehydration (Sinthuprama, 1980).

Normally, for planting diameter of cassava stems vary between 10 and 50 mm. The stems are woody with large pith, and particularly the presence of node all over the stem surface. From these physical properties, it is desired to designed a cutter blade which should not damage the nodes or stake and should be able to cut the stalks of various diameters.

Helio (1980) explained the cassava stems preparation for planting in Brazil. They used a circular saw powered by an electric, gasoline or diesel motor, to cut the stems into 200 mm length, and placed them in plastic boxes for use as the planting material for a Sans planter. Akhir and Sukra (2002) reported about the cassava stems cutting machine in Malaysia. The stems are cut by seven circular saws attached on the horizontal cutting shaft which was operated by an electric motor. The conveyer chain with pegs was used to convey the cassava stems to the cutting unit. It can cut up to 3,300 stakes per hour. However, information on circular saw and exact test conditions are missing. The Research and Development of Thai Tapioca Institute (RDTTI, 2005) developed a cassava planter prototype. This machine is in the experimental stage. The cutting component was modified from the cutter of sugarcane planter. Knives are fixed on the twin counter rotating rollers which are driven by ground wheel. The stems are cut into 250-300 mm length and carried to the furrow formed by the ridger bottoms. Guzel and Zeren (1990) studied the theory of free cutting and its application for cotton stalk cutting. They used a rotary cutter operated by the tractor PTO. The cutting system consisted of four blades with a clearance of 90 degrees. The results indicated that when cutting height was 100 or 150 mm and diameter of stalk ranged between 10 and 25 mm, energy consumption of blades were from 240 to 289 kg-m. Also, maximum and minimum velocities for blade varied from 46.97 to 51.87 and 33.67 to 36.52 m/s respectively.

a) b)

Figure 1. Cutting and planting of stakes; a) traditional cutting method, b) vertical or angled planting

2.2 Design and Fabrication

The cassava stem cutting unit was designed to meet the currently known cultural practices. The length of cutting could be adjusted between 150-300 mm and it can horizontally cut various diameters of cassava stems. This unit will be combined with planting unit of the cassava planter. It should be cutting continuously and can deliver the stakes into the delivery tube of the planting unit. Then cam mechanism and bottom plate were designed to achieve these functions. Circular saw was selected as a cutting blade because its ability to cut various materials especially wood and its available in local market. The knowledge and technology used for fabrication of its components was very simple so that the local shop could manufacture without difficulty.

The cutting unit consisted primarily the main frame, cam mechanism, feeding chute, bottom plate, cam motor (0.37 kW), saw electric motor (0.75 kW), and circular saw blade. The dotted arrows present the directions of each device of the power transmission set are shown in Fig. 2. The operator manually feed the cassava stems into feeding chute for free fall on to the bottom plate, and then the stems were cut by the circular saw operated by an electric motor. The cam mechanism operated by the cam motor, controlled the number of cuts by the circular saw. The cutting length could be adjusted by altering the position of the bottom plate. This unit plays an important role in the quality and capacity of the cassava planter. Therefore, detailed experiments were conducted to determine the performance of this unit.

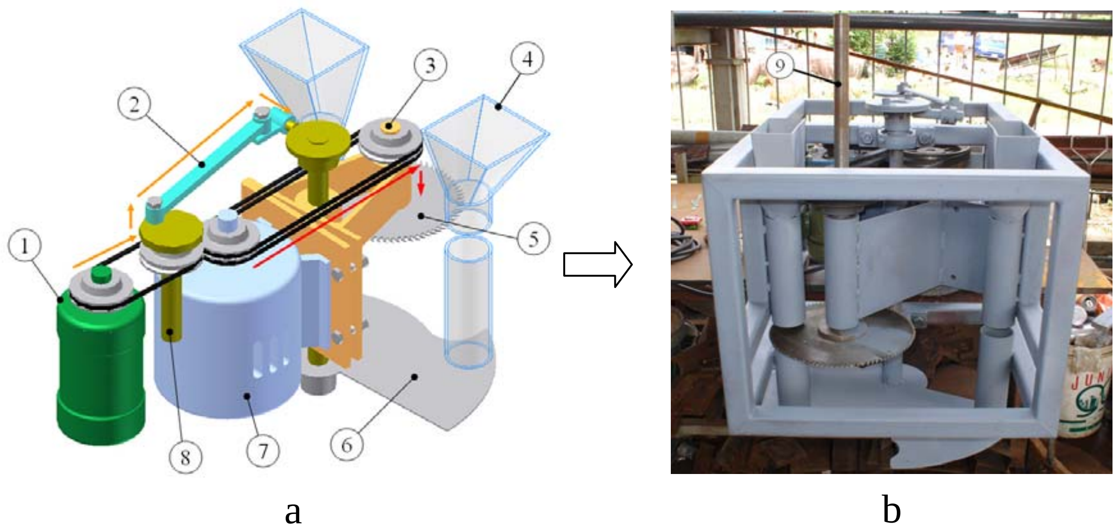


Figure 2. The power transmission (a) and the prototype of cassava stem cutting unit (b): 1-cam motor ; 2-cam mechanism; 3-cutting shaft; 4-feeding chute; 5-circular saw blade; 6-bottom plate; 7-saw electric motor; 8-cam shaft; 9-position of torque transducer

2.3 Experimental Parameters

The important factor for germination of cassava stems is its quality after cutting. This study was conducted to investigate the optimum teeth of circular saw, cutting speed and maximum number of stalks cut of desired length. The circular saws available in local market (different numbers of teeth), and possible cam shaft speeds and cutting shaft speeds were used for testing. Three types of 255 mm tungsten carbide tipped circular saws (40, 60 and 100 teeth as shown in Fig. 3) were used in laboratory testing. Each saw had 3 mm kerfs, 25.4 mm arbor and 10-15 degrees alternate top bevel (ATB) hook angle. The number of teeth per centimeter of circular saw 40, 60 and 100 teeth were 0.5, 0.75 and 1.25 respectively.

Four cam shaft speeds, 20, 30, 40 and 50 rpm equivalent to peripheral velocities of 0.08, 0.13, 0.17 and 0.21 m/s respectively were used. The cam was operated by 0.37 kW motor and the speed was controlled by inverter.

Four speeds of the circular saw, 1,200, 1,400, 1,600 and 1,800 rpm equivalent to peripheral velocities of 16.02, 18.69, 21.36 and 24.03 m/s respectively were used. The cutting shaft was powered by 0.75 kW electric motor and the speed was set by the inverter.

100 teeth 60 teeth 40 teeth

Figure 3. Circular saws used in this study

2.4 Instrumentation and Measurement

The instrumentation used in the laboratory testing consisted of strain gauges installed on the cutting shaft for measuring torque. The strain gauges were connected to slip ring. Output signals from the strain gauges were received by the slip ring. A dynamic strain amplifier (Spiders-8; Hottinger Baldwin Messtechnik Gmbh, Germany) amplified the output signals and these were sent to computer. The Catman (version 4; Hottinger Baldwin Messtechnik Gmbh, Germany) software was used to control, analyze, record and display the output signals. The cam shaft speed and cutting shaft speed were measured by a proximity switch. The output signal was measured by a tachometer indicator.

The torque transducer was calibrated in static load condition before using it for testing. The calibration equation was:

$$T\ (N.m) = 124.41 \times \text{strain gauge output (mV/V)} \quad \ldots(1)$$
$$R^2 = 0.9999$$

The power requirement was calculated by using the formula given by Hunt (1995)

$$P = 2\pi TN / 60{,}000 \quad \ldots(2)$$

Where,

P = Power at cutting shaft, kW
T = Torque requirement, N-m
N = Shaft speed, rpm

2.5 Performance Evaluation

The following indicators were used to evaluate the performance of the developed cutting unit: cutting capacity, cutting efficiency, stem damage, power requirement, specific energy consumption and percentage of germination. Their details are as follows:

a) Cutting capacity (stakes/h)

$$C_p = \frac{s}{t} \qquad \text{…(3)}$$

Where, *s* = number of stakes
t = time (h)

b) Cutting efficiency (%)

$$E_f = \frac{Cp}{Theoretical\ cutting\ capacity} x100 \qquad \text{…(4)}$$

The theoretical cutting capacity was estimated to be twice the cam shaft speed.

c) Percentage of damaged strakes (%)

$$= \frac{D}{s} x100 \qquad \text{...(5)}$$

Where, D = Number of damaged stakes after cutting

All kinds of broken stakes (excluding rough cut-face) were considered to be damaged stakes.

d) Power requirement = Determined from the net power …(6)

e) Specific energy consumption = Power requirement per output capacity

(W-h/stakes) or (kW –h/stakes) ...(7)

f) Percentage of germination (%)

$$= \frac{A}{B} x100 \qquad \text{…(8)}$$

Where, A = Survived plants one month after planting (stakes)
B = Total planted (stakes)

The performance of stem cutting unit was analyzed with different circular saws, cam shaft speeds and cutting shaft speeds by using a randomized complete block design (RCBD) of a 3x4x4 factorial experiment (Fig. 4) with three replications in each treatment and comparison between treatments means were done by least significant difference (LSD) at the $P < 0.05$.

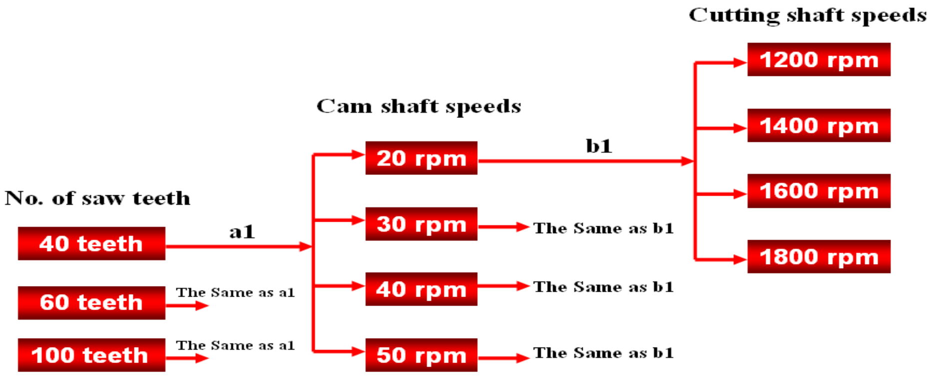


Figure 4. Schematic of a 3x4x4 factorial experimental design

3. RESULTS AND DISCUSSION

The laboratory test results to determine the effect of number of circular saw teeth, cam shaft speed and cutting shaft speed on cutting performance are reported under following heads.

3.1 Cutting Capacity and Cutting Efficiency

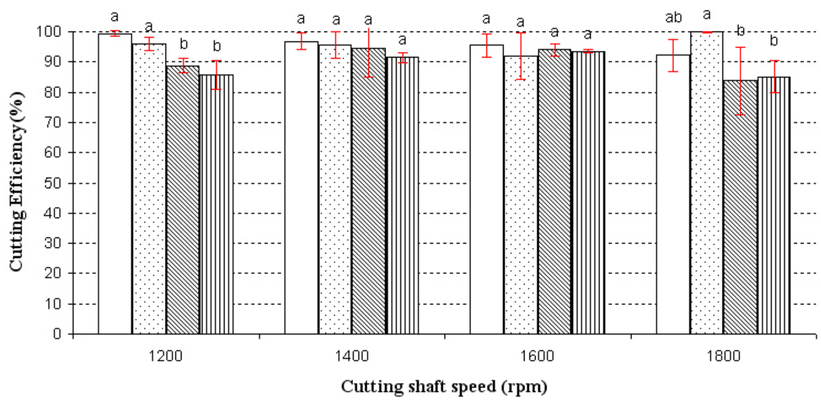
The statistical analysis indicated that the number of circular saw teeth (A) and cutting shaft speed (C) did not significantly affect cutting capacity and efficiency within the range of speeds tested. However, cam shaft speed (B) showed a significant effect. Among the first order interactions of number of circular saw teeth and cutting shaft speed (AC); and among the second order interactions of number of circular saw teeth, cam shaft speed and cutting shaft speed (ABC) were significantly different at 5 % levels

The results (Table 1), show that, the cutting capacity of all types of circular saws depends on cam shaft speed. It increased with increase in the cam shaft speed. This unit controlled cutting length by bottom plate. When the feeders feed whole cassava stem into the feeding chute, the circular saw that is operated by cam mechanism, swings to cut the stems after freely falling to the bottom plate. The tests indicated that with higher cam shaft speed, the circular saw swings faster and affects the cutting length, because the saw cuts the stems before letting them fall on to the bottom plate. Thus, the cam shaft speed used for design of the cutting unit of the planter was selected less than 50 rpm. The cutting efficiency details are given in Fig. 5.

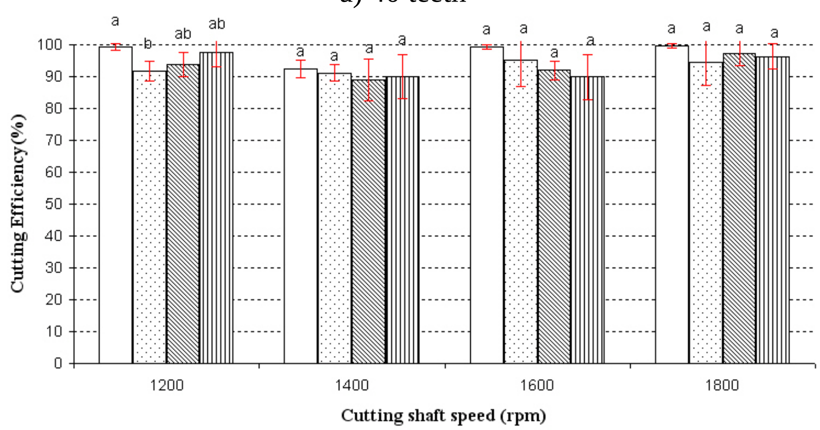
Table 1. Cutting capacity at different number of circular saws, cam shaft speeds and cutting shaft speeds

Cam Shaft speeds (rpm)	Cutting shaft speeds (rpm)	Cuttings Capacity (stakes/h)		
		Circular saw 40 teeth	Circular saw 60 teeth	Circular saw 100 teeth
20	1200	2386	2383	2356
	1400	2323	2219	2286
	1600	2291	2381	2308
	1800	2214	2391	2340

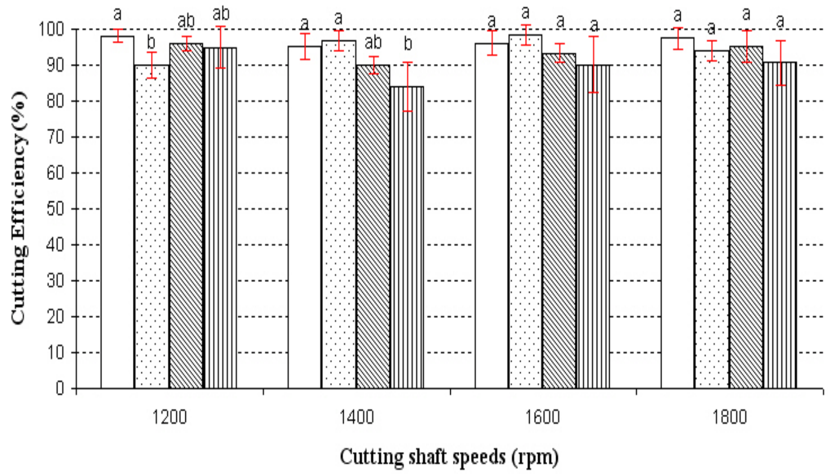
30	1200	3455	3305	3242
	1400	3440	3280	3484
	1600	3309	3429	3542
	1800	3597	3407	3382
40	1200	4262	4507	4601
	1400	4533	4273	4317
	1600	4515	4416	4483
	1800	4018	4674	4576
50	1200	5142	5846	5698
	1400	5485	5399	5034
	1600	5613	5395	5406
	1800	5110	5779	5438



a) 40 teeth



b) 60 teeth



c) 100 teeth

Cam shaft speeds : □ 20 rpm ⊡ 30 rpm ▧ 40 rpm ▥ 50 rpm

Figure 5. Effect of cam shaft speed and cutting shaft speed on cutting efficiency for different circular saws. **ab:** letters indicate differences among each treatment ($P < 0.05$)

Fig. 5 indicates that the efficiency depends on cam shaft speed. The minimum cutting efficiency of all circular saws was found at high cam shaft speed. It was observed during the tests that feeding rate maintained by the operator at low cam shaft speed was more uniform than at higher speed. Therefore, the operators have to be careful in feeding the stems to achieve higher capacity and efficiency. The cam shaft speed was limited to 50 rpm to match manual feeding. At cam shaft speed of 50 rpm, the minimum average cutting capacity was found to be 5,034 stakes/h (40,272 stakes/day of 8 h) with cutting efficiency 83.91%, which can supply enough planting material for planting more than 3.2 ha/day.

3.2 Stake Damage

Statistical analysis indicated that the number of circular saw teeth (A) and cutting shaft speed (C) showed significant effects on stake damage. Among the first order interactions number of circular saw teeth and cutting shaft speed (AC) showed similar results. The test results are presented in Figs. 6 and 7, which revealed that the stake damage was significant for 40 teeth circular saw, while 60 and 100 teeth saws did not cause stake damage. The number of damaged stake at 40 teeth can be reduced by increasing the cutting shaft speed. Fig. 8 shows the cut-faces by using 60 and 100 teeth saws, which are smoother than 40 teeth saw and traditional cutting. Thus, the teeth of circular saw should be more than 60 and should be operated at speed over 1,200 rpm.

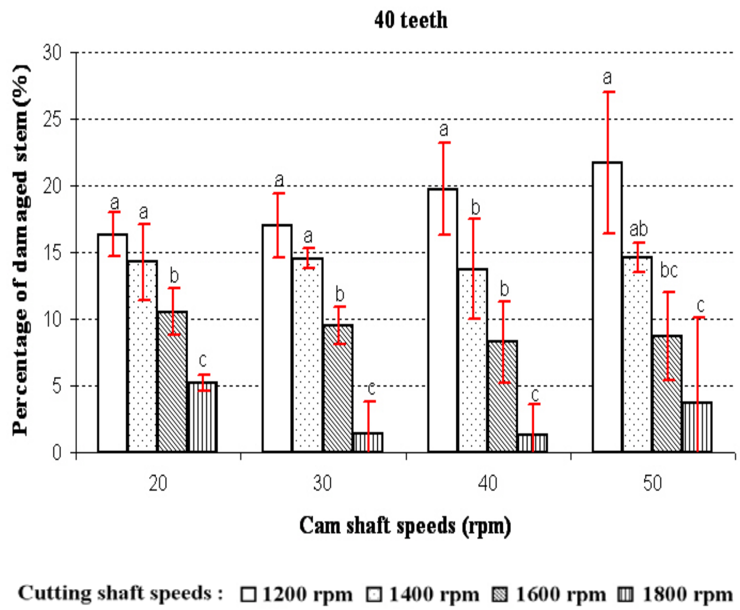


Figure 6. Effect of cam shaft speed and cutting shaft speed on stake damage for 40 teeth circular saw. **abc:** letters indicate differences among each treatment ($P < 0.05$)

Figure 7. Stake damage by 40 teeth saw

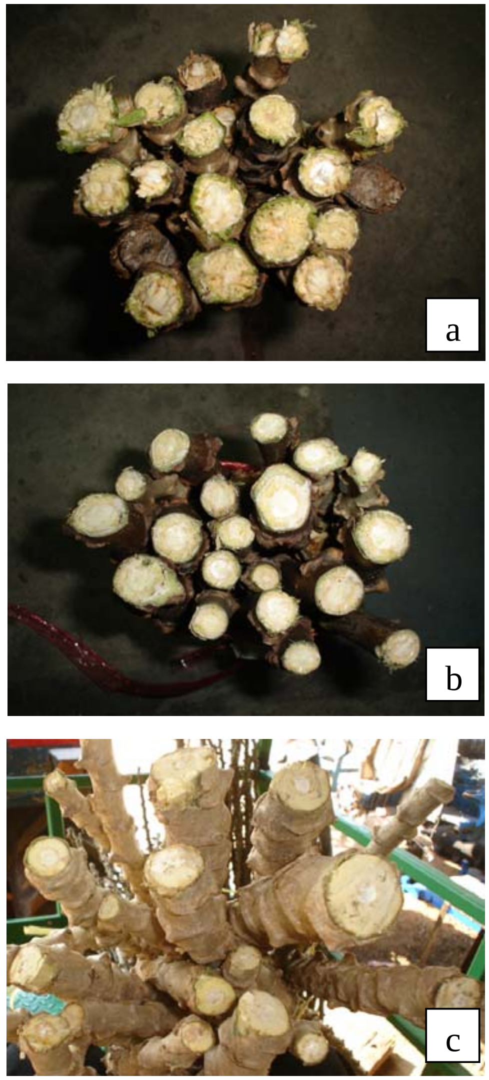


Figure 8. Smoothness of cut obtained with circular saws and traditional method method: a) 40 teeth saw; b) 60-100 teeth saw; c) Cutting by machete

3.3 Torque, Power Requirement and Specific Energy Consumption

The number of circular saw teeth had a little effect on torque and power requirement. The results in Fig. 9 show that the torque requirement at no-load and loaded conditions of all circular saws was similar to the theoretical expectations. It decreased when the cutting shaft speed increased. The maximum torque at load for all blades was less than 1 N-m. Statistical analysis revealed that the effect of cutting shaft speed was the most significant on torque and power requirement, followed by cam shaft speed.

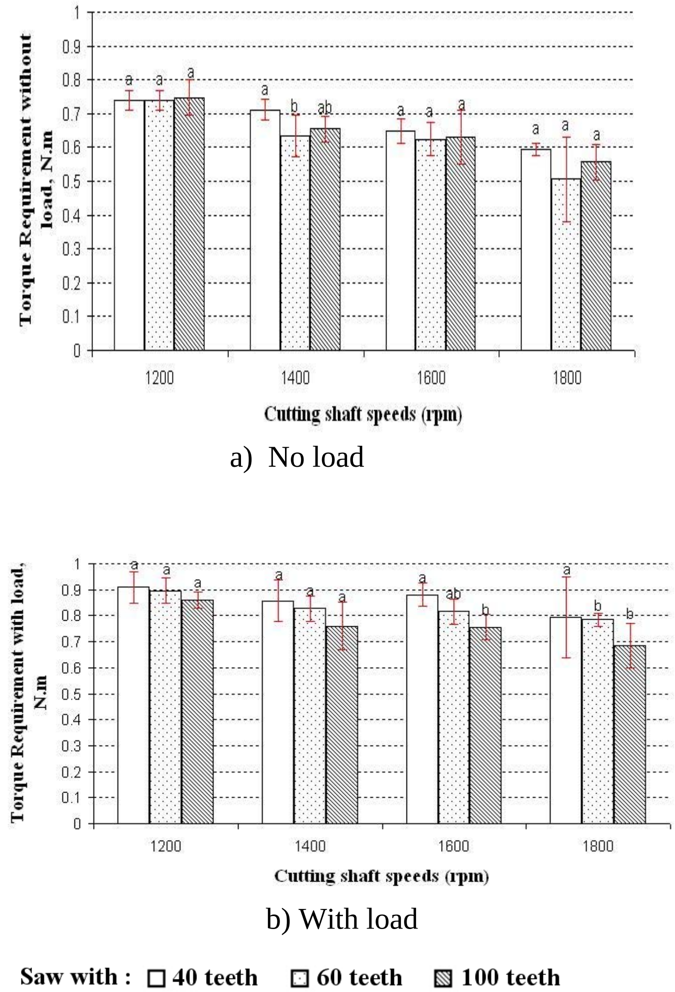
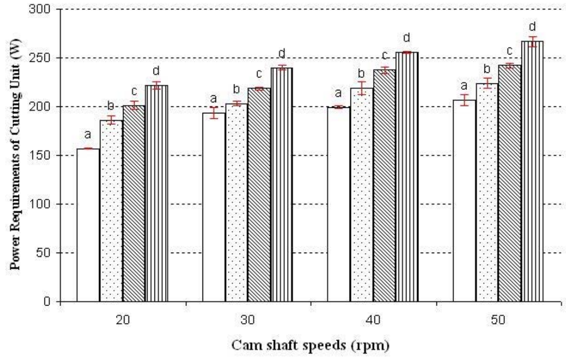
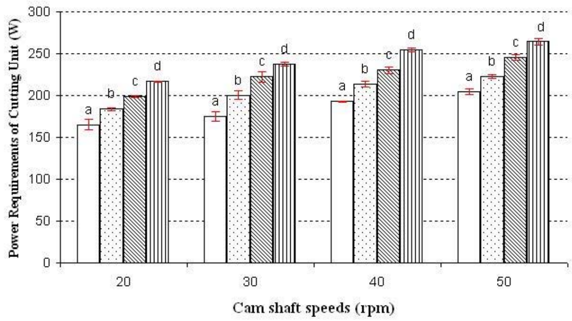


Figure 9. Effect of number of teeth of circular saw on torque at different cutting shaft speed. **ab:** letters indicate differences among each treatment ($P < 0.05$)

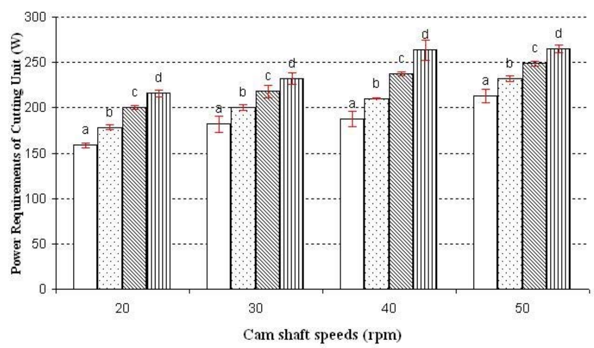
The effects of cutting shaft speed and cam shaft speed on power requirement are presented in Fig. 10. It was observed that the power requirement of all blades increased as the speed of cutting shaft and cam shaft speed increased, this was due to the additional energy requirement for increasing speed of the motor.



a) 40 teeth



b) 60 teeth

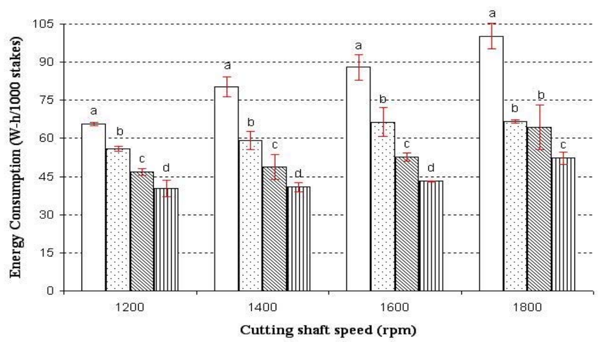


c) 100 teeth

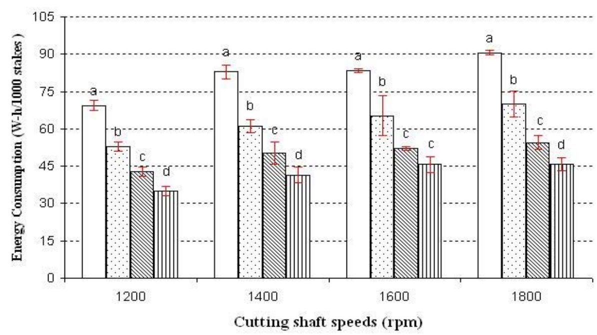
Cutting shaft speeds : □ **1200 rpm** □ **1400 rpm** ▧ **1600 rpm** ▥ **1800 rpm**

Figure 10. Effect of number of teeth of circular saw and cutting shaft speed on power requirement at different cam shaft speeds. [abcd]**:** letters indicate differences among each treatment ($P < 0.05$)

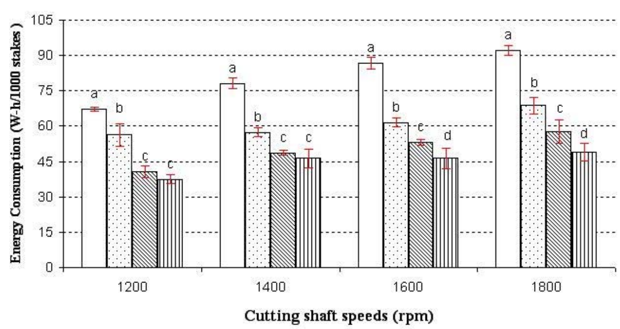
The circular saw teeth did not show significant effect on specific energy consumption. The relationship between specific energy consumption, cam shaft speed and cutting shaft speed is shown in Fig. 11. It was observed that the specific energy consumption decreased when the cam shaft speed increased (the capacity increased when cam shaft speed increased), and it increased with the speed of cutting shaft. Statistical analysis indicated that the cam shaft speed most significantly affected the specific energy consumption, followed by cutting shaft speed.



a) 40 teeth



b) 60 teeth



c) 100 teeth

Cam shaft speeds : □ 20 rpm □ 30 rpm ▧ 40 rpm ▥ 50 rpm

Figure 11. Effect of cam shaft speed and cutting shaft speed on energy consumption for different circular saws. **abcd:** letters indicate differences among each treatment ($P < 0.05$).

3.4 Percentage Germination

Germination is the importance factor for accepting the design concept of the machine. Thus, after testing, stakes were randomly selected from each treatment to study the germination rate and then germination rate was compared for stakes from traditional method. The stakes, one month after planting, were inspected (Table 2). Comparison indicated that the percentage germination of cassava did not depend on the number of circular saw teeth, cam shaft speed and cutting shaft speed. The recorded germination performance was considered satisfactory.

Table 2. The results of percentage germination one month after planting

Conditions		Number of plants (Stakes)	Plants' survival one month after planting (Stakes)	Percentage of germination (%)
Traditional Method (cut by knife)		20	20	100
Different Number of	40	20	19	95
teeth of circular saw	60	20	20	100
(teeth) at cutting speed 1800 rpm	100	20	20	100
60 teeth of circular saw	1,200	20	20	100
at different cutting shaft	1,400	20	20	100
speeds (rpm)	1,600	20	20	100
	1,800	20	20	100
60 teeth of circular saw	20	20	20	100
at different cam shaft	30	20	20	100
speeds (rpm)	40	20	20	100
	50	20	19	95

The performance of stem cutting unit was satisfactory. The design data obtained will be used for the development of a prototype and its components.

4. CONCLUSIONS

The stem cutting unit was designed and tested for collecting data for the design of a cassava planter. It consisted of circular saw blade, cam mechanism, bottom plate, electric motor and motor gear. They were installed on the main frame. It can cut all diameters and varieties of cassava stems in horizontal plane with minimum power. The length of cutting can be adjusted from 150 to 300 mm by changing the position of bottom plate.

Test results indicated that the best cutting quality was obtained when a 60 teeth circular saw was operated at more than 1,200 rpm cutting speed and less than 50 rpm cam shaft speed.

The designed unit exhibited higher capacity and efficiency upon uniform feeding rate. At cam shaft speed of 50 rpm, the minimum cutting capacity was found to be 5,034 stakes/h with cutting efficiency of 83.91%. The stems were not damaged when operated at these conditions and the germination was satisfactory.

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