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RESEARCH ARTICLE
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Selection of a Cutting Mechanism and Optimization of Parameters for Coconut Harvesting Drone

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ABSTRACT

Background: Coconut *(Cocos nucifera* L.) palm is an important cash crop in India and third-largest producer of coconut in the world. In general, the skilled workers climb to harvest the coconuts from the tree without any safety device. The coconut trees are very tall and injuries associated with coconut tree climbing, particularly falling from coconut trees is common in coconut plantations. In order to rectify the problem, an appropriate cutting system needs to be developed. Hence the characterizing physical and mechanical properties *viz*., peduncle thickness, width, shape, size, moisture content, density and also the cutting blade characteristics, were studied.

Methods: The observed characteristics were used for the effective design of the cutting module. The cutting blades were selected for the investigation *viz*, circular saw blade and saw tooth blade. The parameters selected for the investigation are cutting speed (S) at three levels (500, 700 and 900 rpm), the inclination angle of the blade (θ) five levels (30, 45, 60, 75 and 90°), type of the blades (B) (regular tooth and ripped tooth pitch) and thickness of peduncle (T) three levels (30, 40 and 50 rpm). Similarly for chain saw, the velocity of cutting speed (S) at three levels (500, 700 and 900 rpm), the inclination angle of blade (θ) at three levels (45, 60 and 90°) and thickness of peduncle (T) three levels (30, 40 and 50 mm) were selected for the experiments.

Result: The optimization of the selected levels of variables was done to achieve best performance to select the cutting speed, cutting angle and type of blade. The results showed that circular saw blades with irregular tooth pitch have higher cutting efficiency than circular saw blades with regular tooth pitch. It was found that cutting time increases linearly with decreasing cutting speed. It was observed that chainsaw gives better cut quality with minimum cutting time than saw blades.

Key words: Chain saw, Coconut, Harvester, Peduncle, Saw blade.

INTRODUCTION

The coconut inflorescence is a compound spadix consisting of a peduncle, a number of rachillae on a rachis, sessile flowers on the rachillae and a spathe. Due to the height and lack of branches, it is very difficult to climb coconut trees. A professional climber with proper training only could be able to climb coconut tree. Because of the risk involved nowadays very less people are coming forward to climb on coconut trees. Thus, the development of the cutting mechanism adopted by drones has much impact on coconut cultivation. Here, the two types of cutting blades *viz*, circular saw and chain saw, was selected to study their performance and suitability. Circular saw blade cutting is the most widely spread way of wood sawing. Owing to the different design and construction of circular saw blades, it is possible to cut in different ways with respect to the wood fibers (Kminiak *et al*. 2016), (Strelkov, 2009) and (Naylor *et al*. 2012). For the quality of cutting and efficiency of machines, it is necessary to provide proper cutting conditions and cutting angles (Argay, 2014) and (Manzos, 1974). Inappropriate cutting angles can result in bad quality of a cutting, higher possibility of tool wear, a lower lifetime of a cutting blade and finally questionable reliability of the whole system (Kminiak *et al*., 2015) and (Nasir and Cool, 2019), (Zhao *et al*. 2020). The oblique angle of 45 degrees showed the least shearing stress. The selection of the knife's unique oblique angle

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decreases the peduncle's cutting force. The shearing stress was increased with increasing of cutting thickness. It is possible to decrease cutting power and cutting time with a suitable tool, geometry and conditions. The selection of blade type plays a significant role in cutting time requirements. In addition to the parameters, chainsaw construction, blade geometry (Maciak, 2000), (Maciak and Gendek 2007) and the feed force (Maciak, 2004), the initial tension of the saw chain has a considerable influence on the cutting efficiency.

MATERIALS AND METHODS

Measurement of basic dimensions

The study was conducted (2020-2021) at Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur- 621 712, India, located in (10°55′59.2″N 78°49′37.1″E). The measurement was carried out in all the selected varieties of coconut peduncles and the readings are tabulated in Table 1. The dimensions of peduncle samples were chosen based on harvesting parameters and cross-section of the peduncle.

Moisture content

Moisture content (MC) is the weight of water contained in the peduncle expressed in percent. Moisture content is one of the important property which can affect the strength and stiffness of the peduncle. This is because the presence of water affects the bonds between the fibres, making them more flexible. The moisture can be determined by the hot air oven method in the dry basis method. The peduncle specimens taken from the coconut field were weighed and dried at 103°C for 24 hours in the oven and then reweighed (Benaseer *et al*. 2018). The moisture content observed in the selected coconut varieties of peduncle are tabulated in Table 1.

$$\text{Moisture content (Dry Basis)} = \frac{m_i - m_f}{m_f} \times 100$$

Where

m_i - Initial weight of peduncle.

m_f - Final weight of peduncle.

Volume and density of peduncle

The number of samples selected based on different thicknesses and varieties is shown in Fig 1. The peduncles that are regular in shape, volume can be calculated on the basis of their dimensions. The volume of the peduncle was determined through geometric formula.

$$\text{Volume (V)} = \pi \times A \times B \times h$$

Where

A = Semi-major axis.

B = Semi-minor axis.

h = Height.

Density refers to the amount of wood in a unit per volume of wood. The ratio of dry weight and green volume of the given wood is the basic wood density. More wood content in a specific volume means it has a high density. The density of the peduncle is calculated by

$$\text{Density} = \text{Mass/Volume (kg/m}^3\text{)}$$

The volume and density observed in the selected coconut varieties of peduncle are tabulated in Table 2.

Cutting blades

The two types of circular saw blades were selected for the experiment. The first circular saw blade has a regular HSS saw and a full body. The second circular saw blade has a ripped tooth and its body has dilatation gaps for decreasing stress and vibrations in the process, as shown in Fig 2. The variable parameter was the ratio between the surface of teeth and the surface of teeth gap. The ripped tooth blade is sintered with carbide. The specifications of the cutting blades are tabulated in Table 3.

Chain saw

The chain saw is made up of a ¼ Picco Micro 3 was used to make smooth cuts with low vibration is shown in Fig 3. Left-handed and right-handed teeth are alternated in the chain. The chain consists of only link types 2 and 4 to get the drive link shape on both sides of the chain. This shape is convenient for the torque transfer. The 4-inch guide bar consists of an elongated bar with a round end of wear-resistant alloy steel typically 37 cm in length and 4 cm width at the middle of the bar. The tension of the cutting chain is adjustable, it neither binds on nor comes loose from the guide bar. Each segment in a chain features small, sharp, cutting teeth. Each tooth takes the form of a folded tab of chromium-plated steel with a sharp angular or curved corner and two beveled cutting edges, one on the top plate and

Fig 1: Measurement of dimensions of peduncle.

one on the side plate. The specifications of the chain saw is tabulated in Table 4.

Test rig for selection of blade and cutting speed

An experimental test rig was developed to investigate the influence of the selected levels of variables *viz*., cutting speed (S) at three levels (500, 700 and 900 rpm) and (500, 700 and 900 rpm for chain saw), the inclination angle of the blade (θ) five levels (30, 45, 60, 75 and 90°), type of blades (B) two levels (regular HSS tooth and ripped tooth pitch) and thickness of peduncle (T) three levels (30, 40 and 50 mm). The test rig consists of a base frame which is made of mild steel (60 × 60 cm) to support the entire setup is shown in Fig 4. The spring retraction was provided for the cutting arm mechanism which is fixed to the base firmly by welding. The cutting arm has the blade arrangement and it is given with a slot for fixing the different angles. Over the arm, the DC motor along with the blade setup are mounted. The motor used to operate the pulley is 12V DC, to run, the blade is geared 500-2500 rpm. The motor used for the blade has to rotate at the required speed and cut the bunch at a faster rate. The variable frequency drive (VFD) was provided to

Fig 2: Ripped tooth and regular HSS saw blades.

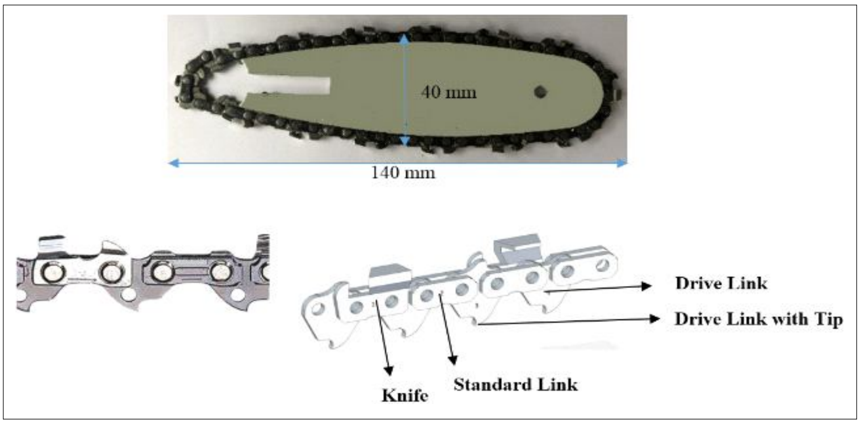


Fig 3: Chainsaw chain segment.

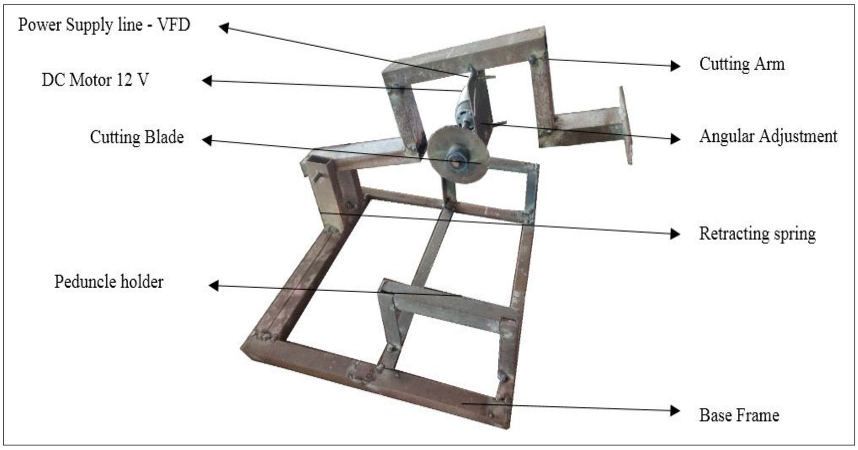


Fig 4: Experimental test rig.

vary the speed. The VFD controller is a solid-state power electronics conversion system consisting of three distinct sub-systems: a rectifier bridge converter, a direct current (DC) link and an inverter. Variable speed drives supply specific amperage and voltage to a motor at specified voltage and amperage. As the drive voltage changes, the motor's speed and torque varies.

RESULTS AND DISCUSSION

The experimental procedure was designed with a statistical Design of Experiments (DoE) approach with a full factorial Central Composite Design (CCD). A total number of 90 experiments were conducted using the experimental test rig with selected levels of variables, as shown in Fig 5 and 6. The time taken to cut the samples was recorded for all the treatments of the investigation. The experiments were done for three replications. The effects of selected levels of variables on the cutting time and quality of cut were analyzed. The moisture content, bulk density and volume of selected varieties of peduncle samples utilized for experiments were studied and their average values are tabulated in Table 1 and 2.

The cutting angle plays an important role in effective cutting of the peduncle. The minimum cutting time was

Table 1: Moisture content of coconut peduncle.

Variety	Moisture content								
	Initial				Final				Dry
	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	basis (%)
West coast tall	57	82	38	23	31	80.6	32	19	83.87
Coconut - ALR (CN) 1	51	66	35	22	29.5	66	31	20	72.88
Coconut - ALR (CN) 3	39	53	30	20	22.6	52	28	19	72.57
East coast tall	59	56	48	30	31	55	38	26	90.32
Chandrakalpa	42	58	32	22	21.6	56	28	20	94.44
Chowghat orange dwarf	53	68	36	19	25.5	66	33	18	107.84
Chowghat green dwarf	52	63	33	15	23.5	60	30	17	121.27
Malaysian yellow dwarf	51	64	32	18	27.5	61	31	15	85

Table 2: Density and volume of peduncle.

Variety	Height (m)	Semi major (A) half of the width (m)	Semi minor (B) Half of the thickness (m)	Volume (m^3)	Weight (kg)	Density (kg/m^3)
West coast tall	0.082	0.038	0.023	0.000225	0.057	253.29
Coconut - ALR (CN) 1	0.066	0.035	0.022	0.000160	0.051	319.60
Coconut - ALR (CN) 3	0.053	0.03	0.02	0.000100	0.039	390.58
East coast tall	0.056	0.048	0.03	0.000253	0.059	233.01
Chandrakalpa	0.058	0.032	0.022	0.000128	0.042	327.58
Chowghat orange dwarf	0.068	0.036	0.019	0.000146	0.053	362.90
Chowghat green dwarf	0.055	0.033	0.023	0.000131	0.041	312.97
Malaysian yellow dwarf	0.066	0.035	0.017	0.000123	0.050	406.50

Fig 5: Cutting of peduncle in experimental test rig.

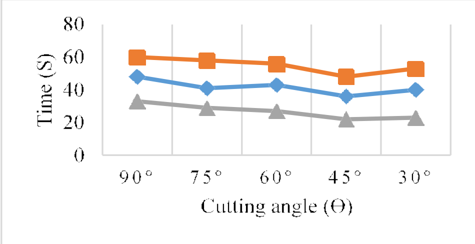
observed at (θ_4) 45° cutting angle for all three levels of cutting speed (S), two levels of blades (B) and three levels of peduncle thickness (T). The increase in inclination of blade angle from 90°(θ_1) to 30°(θ_5) effects the quality of cut and cutting time with respect to the thickness of the peduncle (T). The decrease of cutting speed from 900 to 500 rpm increases the cutting time from 90°(θ_1) to 60°(θ_3) and at (θ_4) 45°, it was recorded that decreasing the cutting speed increases the quality of cut for all the levels of variables. As the thickness of the peduncle (T) increases the cutting time also increases proportionally, as shown in Fig 7.

Effect of cutting speed on cutting time in the various cutting angle at different blades and thickness of peduncle

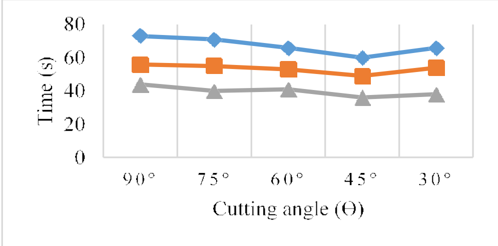
The cutting speed of the blade highly influences the effective cutting time of the peduncle and quality of cut. The minimum

Fig 6: Quality of cut (Peduncle)- regular HSS, ripped tooth blades and chain saw

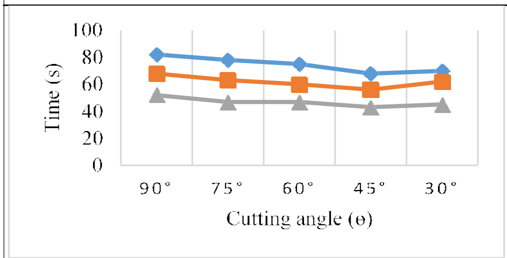
effect of cutting angle on cutting time in various cutting speeds at different blades and thickness of peduncle.



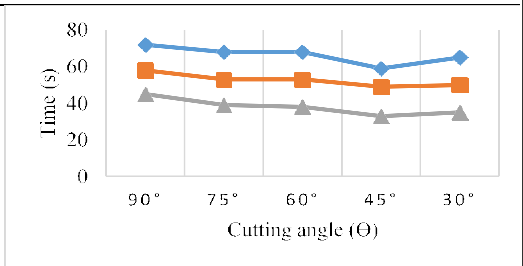
Regular HSS blade in 30 mm peduncle thickness



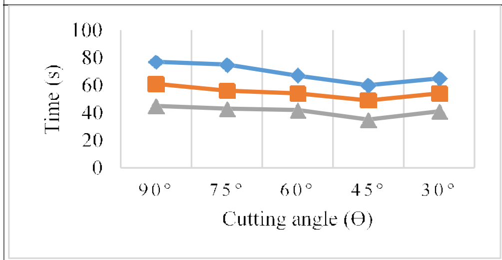
Regular HSS blade in 40 mm peduncle thickness



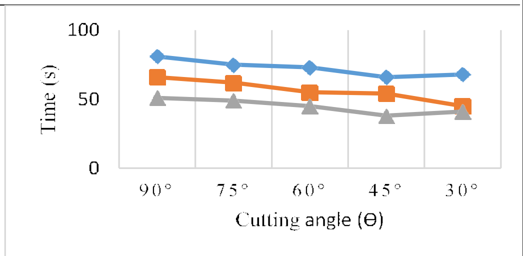
Regular HSS blade in 50 mm peduncle thickness



Ripping blade in 30 mm peduncle thickness



Ripping blade in 40 mm peduncle thickness



Ripping blade in 50 mm peduncle thickness

-------- (S_1) 500 rpm -------- (S_2) 700 rpm -------- (S_3) 900 rpm

Fig 7: Cutting angle on the various cutting speed at different blades and thickness of peduncle.

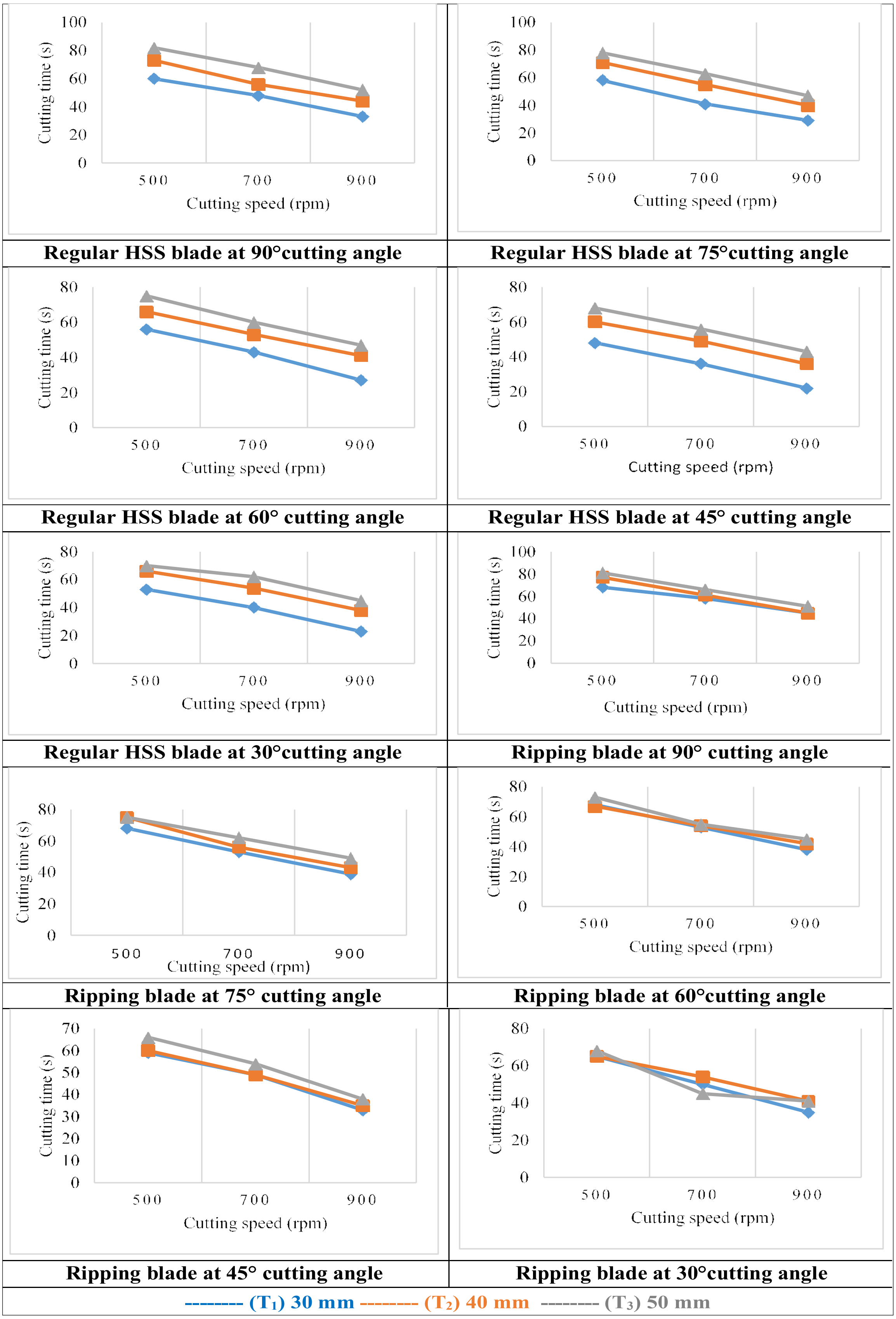


Fig 8: Cutting speed on the various cutting angle at different blades and thickness of peduncle.

Table 3: Specifications of cutting blades.

Ripped tooth blade		Regular HSS blade	
Outer diameter (mm)	125	Outer diameter (mm)	125
Width of cut (mm)	1.8	Width of cut (mm)	1.8
Number of teeth	40	Number of teeth	108
Thickness (mm)	2.4	Thickness (mm)	1.8
Tooth shape	ATB	Cutting Speed (RPM)	13500 (Maximum)
Hook angle°	18	Bore diameter (mm)	25.4
Relief angle°	17	Material	High-speed tool steel

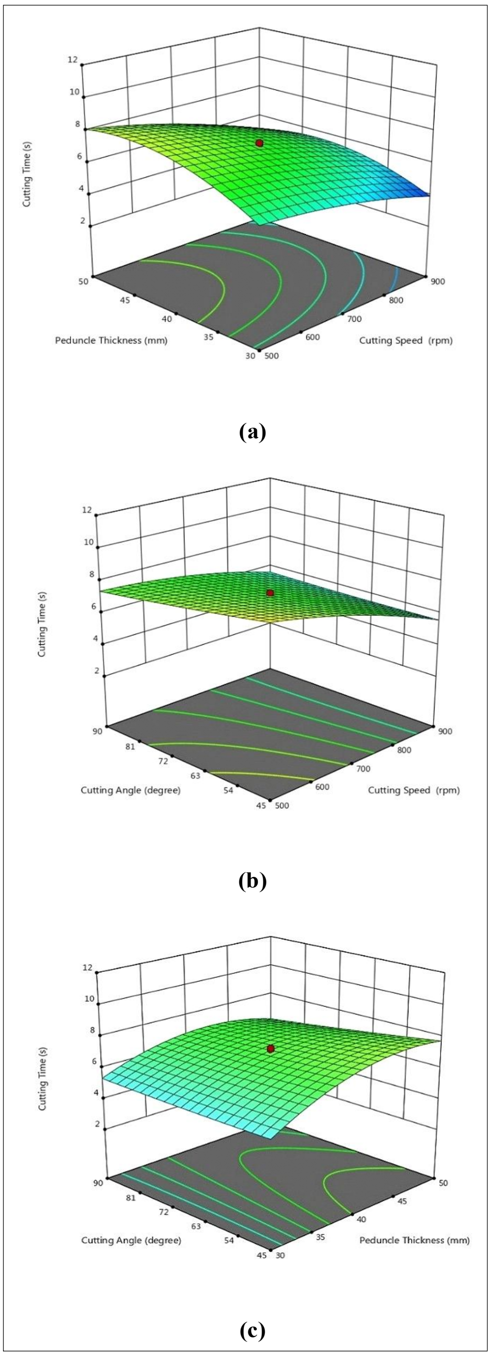


Fig 9: Interaction of selected variables in chain saw- 3D surface plot (a, b and c).

Table 4: Specifications of the chain saw.

Particulars	Values
Chain type	Picco micro 3
Chain pitch (mm)	6.35
Chain gauge (mm)	1.1
No. of drive links	28
Required bar length (mm)	254
Sharpening file size (mm)	3.2

cutting time was observed at (S_3) 900 rpm cutting speed for all five levels of cutting angle (θ), two levels of blades (B) and three levels of peduncle thickness (T). The increase in cutting speed from 500 rpm (S_1) to 900 rpm (S_3) decreases the cutting time with respect to the thickness of peduncle (T) from 30 mm (T_1) to 50 mm (T_3). The effect of cutting speed on cutting angle from 90°(θ_1) to 60° (θ_3) gives the bad quality of cut and it was recorded that at 45°(θ_4) cutting angle on 900 rpm (S_3) cutting speed decreases the cutting time and increases the quality of cut for all the levels of variables. As the blade (B_2) has ripping tips, it cuts comparatively well than the regular HSS blade (B_1), as shown in Fig 8.

Effect of cutting time on different cutting angles at various cutting speeds and different thickness of the peduncle in chain saw

The initial tension of the chainsaw is a decisive factor for more efficient and thus affects cutting time significantly. The cutting speed of the saw blade highly influences the effective cutting time of peduncle and the quality of cut. The minimum cutting time was observed at (S_3) 900 rpm cutting speed for all three levels of cutting angle (θ) and three levels of peduncle thickness (T). The increase in cutting speed from 500 rpm (S_1) to 900 rpm (S_3) decreases the cutting time with respect to the thickness of peduncle (T) from 30 mm (T_1) to 50 mm (T_3). The effect of cutting speed on cutting angle from 45°(θ_1) to 90°(θ_3) shows the gradual increase in quality of cut as shown in Fig 9 (a, b and c).

CONCLUSION

The physical and mechanical properties *viz.,* peduncle thickness, length, width, shape, size, moisture content, density and also the cutting blade characteristics were studied. The circular saw and chain saw were selected for the investigation along with parameters *viz.*, cutting speed (S), inclination angle of blade (θ), type of blades (B) (regular tooth and ripped tooth) and thickness of peduncle (T). Similarly for chain saw, the velocity of cutting blade speed (S), inclination angle of the blade (θ) and thickness of the peduncle (T) were selected for the experiments. The optimization of the selected levels of variables was done for achieving best performance by selecting the cutting speed, cutting angle and type of blade. The results showed that circular saw blades with ripped tooth pitch have higher cutting efficiency than circular saw blades with regular tooth pitch. The chainsaw has less cutting time and better quality of cut than circular blades. Hence, the chain saw was selected for the mechatronic cutting module in a drone for harvesting coconuts to reduce the drudgery and risk of tree climbers.

Conflict of interest: None.

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