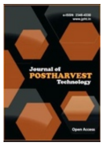

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RESEARCH ARTICLE

Effect of blade's constructional and operational features on cutting torque requirement in context of henna harvesting

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ABSTRACT

The present study was focused on the investigation of effect of various blade and operational parameters for selection of efficient cutting system for henna harvester. The effect of blade type, cutting speed and diameter of henna stem were observed on the cutting torque and specific cutting energy at constant moisture content. The experimental was conducted with three parameters i.e., blade type, cutting speed and henna stem diameter to find the effect on cutting torque. The three-carbide tipped circular saw blades was selected under study were showed good torque characteristics and demanded lesser torque compared to the regular brush cutter blade. The average cutting torque values for three carbide tipped blades lies between 3.12- 4.18 N.m, while average cutting torque for regular brush cutter blade was 18.82 N.m. The cutting torque was having inverse relation with the rotational cutting speed. The average cutting torque at lowest rotational cutting speed i.e., at 600 rpm was 9.18 N.m while at highest rotational speed i.e., 1200 rpm it was 6.31 N.m. It was observed that at higher rotational speed i.e., at 1000 and 1200 rpm cutting operation was somewhat noisy due to speed induced vibrations. The cutting torque showed a linearly proportional relationship with diameter of stalk. The specific power requirement for regular brush cutter blade was highest compared to carbide tipped blades. Finally, based on the results the carbide tipped blade with 120 teeth at 600-800 rpm was recommended for the henna harvester.

Keywords: Carbide tipped blade, shear cutting, harvester, specific cutting energy, blade, woody crop, cutting force

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INTRODUCTION

Henna (*Lawsonia inermis* L.) is a perennial plant that has cosmetic, medicinal and industrial uses with an economic life cycle of 25 years. It is native of North Africa and also cultivated in India, Middle East, Arabian Peninsula and other Asian countries on a commercial scale. It is generally referred to as Mehndi in India and used during different socio-cultural events such as marriage, festivals, etc. (Saksena, 1979). It is a branched glabrous shrub-like tree with a height of 2 to 6 meters (Shukla et al., 2012). To grow henna, rich, fine sandy or medium-textured, well-drained soil is considered best. Henna cultivation involves

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various unit operations from its propagation up to the harvesting. There are mainly two methods of henna propagation one is by stem cutting and another one is by seedling transplanting. After three years of plantation, the henna crop becomes matured for harvesting. It is harvested twice a year i.e., firstly in the month of October-November and subsequently in April-May. In harvesting operation, branches having leaves are cut near the ground. The cross-sectional diameter at the height of cut is around 10 to 30 cm depending upon maturity of plant. The reviewed literature suggested that there is no or very little mechanization in the field of henna harvesting. Therefore, there is limited information available related to the power demand involved in the henna harvesting. Although, numerous studies are available on the other woody crops like kenaf, mulberry etc. Wang and Zhang (2010) found that rotational speed has significant influence on the mechanical properties such as equivalent stress, critical frequency and vibration amplitude of the circular saw blade. The influence of cutting speeds on the cutting force and power demand involved in kenaf stem cutting was studied by Dauda et al. (2015) and revealed that basic cutting strength is directly proportional to the cutting speed, whilst the cutting torque varies inversely with the moisture content. Singh et al. (2019) studied influence of stem diameter, moisture content and age of plant on cutting strength and found that henna stem is having highest cutting strength at 30 percent moisture content and decreases as moisture content decreases or increases above or below given moisture content. While the cutting strength of henna decreases as age increases. In order to develop efficient harvester for henna, the main focus should be on the durability and stability of cutting element (Meng et al., 2019). The type of cutting element used in the harvester has an influence on the quality and efficiency of harvester (Sun et al., 2011). Since henna stem is known for its greater strengths, it is very difficult to harvest it using conventional cutting arrangements like cutter bar, chain saw etc. The circular saw blade as a cutting element for harvesting of smaller diameter woody crops is relatively stable, effective and convenient compared to chain sawing and reciprocating cutter (Meng et al., 2019). Estimation of the energy demand is sufficient criterion for checking the functional effectiveness of circular saw blade (Dauda et al., 2015).

MATERIALS AND METHODS

The manually harvested henna stems harvested at a height of 15 to 20 cm from the ground were used for experimentation. The diameter of stem was measured at cutting plane by using digital Vernier Caliper having least count of 0.001 mm. The moisture content of henna stem was determined by keeping samples in the air oven for 24 h at 110°C. The stems were grouped into four groups according to their diameters (Fig. 1). Since the diameters of all stem samples were not equal, the torque required to cut the stem was presented as torque per unit cross sectional area (specific torque) of stem.

Figure 1: Grouping of Henna Stem

Three circular saw carbide tipped blades and one regular brush cutter blade were selected for experimentation. They differentiated from each other according to the number of teeth they have. The blades are named as C_1, C_2, C_3 and C_4 for identification purpose. The blades named C_1, C_2 and C_3 were carbide tipped blades while blade C_4 was regular brush cutter blade. The specifications provided by the manufacturer for each of the four blades are presented in table 1.

Table 1. Circular saw blade specifications

Blade	Number of Teeth	Outer Diameter (mm)	Bore Diameter (mm)	Blade Thickness (mm)
C_1	40	254	25.4	3.5
C_2	80	254	25.4	3.5
C_3	120	254	25.4	3.5
C_4	100	254	25.4	3.5

Experimental setup

The setup for experimentation is shown in Fig 2. The experimental setup consists of Crompton Greave 7.5 kW, 415 V AC electric motor to provide drive to the blades. The motor was having capability of running at variable rotational speeds by controlling input frequency. Cutting torque was measured by installing torque sensor (Make: Sushma torque sensor, Model: SA-101, Capacity: 1kN-m) between the motor and circular saw blade. During cutting the stem was held by holder provided with bolting arrangement. The double acting hydraulic cylinder was provided to feed the stem held by holder to the blade during its forward stroke and return back to its original position after cutting was over. The hydraulic cylinder was powered with 7.5 HP orchard tractor's hydraulic system and operated with separate hydraulic control lever arrangement. The hydraulic cylinder was used to maintain constant feeding speed during entire experiment. The motor, torque sensor etc. were mounted on frame in such way that it does not become unstable during cutting process. The torque data was recorded by HBM data logger and stored into computer memory using catmaneasy 4.2 software.

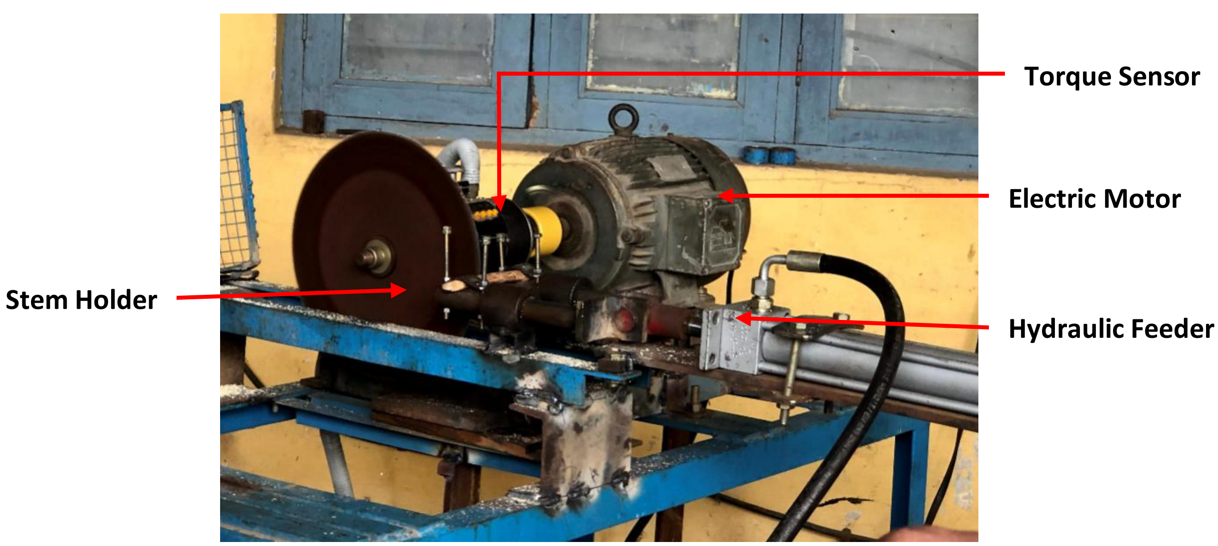

Figure. 2 Experimental Setup

Experimental plan

The detailed plan for the experiment is presented in Table 2. There are three independent parameters namely blade type, blade rotational speed and diameter of stem. The effect of these three independent parameters was observed on the one dependent parameter i.e., Cutting torque. The blade type and blade rotational speed had three levels, while diameter of stem had five levels.

Table 2: Experimental plan

Independent Parameters	Levels	Dependent Parameter
Blade Type	4 (C_1, C_2, C_3, C_4)	
Blade rotational speed (rpm)	4 (600, 800, 1000, 1200)	Cutting Torque
Diameter of Stem (mm)	5 (10±1, 15±1, 20±1, 25±1, 30±1)	

The data obtained from the experiments were configured in full factorial RBD design. Further, the analysis of variance was performed to know the statistical significance of independent parameters. To check the which level of the independent parameter made a difference the Duncan multiple range test of significant independent parameters was conducted. All statistical tests were conducted at 5 percent level of significance.

RESULTS AND DISCUSSION

Torque for cutting of Henna stem

The effect of henna stems and different circular saw blade speed is shown from figure. 3-5 It is seen that cutting torque increased with increase in diameter of stem, while decreased with increase in blades rotational speed. The ANOVA performed using SAS for testing significance of the independent parameters on the cutting torque is shown in Table 3.

Table 3: Analysis of Variance for Cutting Torque

Source	DF	SS	MS	F Value
Model	12	13182.04352	1098.50363	83.39*
Blade Type	3	10362.74034	3454.24678	262.22*
Blade Rotational Speed	3	297.16784	99.05595	7.52*
Diameter	4	2518.32705	629.58176	47.79*
Error	227	2990.29107	13.17309	
Corrected Total	239	16172.33459		

DF = Degrees of freedom, SS = Sum square, MS = Mean square; *Significant at 5% level

It is evident from Table 3 that the model is highly significant at 95 per cent confidence interval of ($p \leq 0.001$). Also, the individual parameters; blade type, blade speed and diameter of henna stem showing highly significant effect ($p \leq 0.001$) on cutting torque. The effect of the blade type highest has highest influence on the cutting torque followed by diameter of henna stem and blade rotational speed

Effect of blade type on cutting torque

The effect of blade type on the cutting torque is represented in fig. 3 The result of experiment shows that blade C_4 produced significantly higher torque than blade C_1, C_2 and C_3. The average cutting torques for all rotational speeds and stem diameters were 4.18, 3.71, 3.12, and 18.82 N-m for the blades C_1, C_2, C_3 and C_4, respectively. It was seen that cutting torques for all types of blades were increasing trend of cutting torques with increase in blade rotational speed. The results of Duncan multiple range test (DMRT) conducted to detect the difference between the levels of independent parameters revealed that there was no significant difference among the cutting torques due to the circular blades C_1, C_2, and C_3 but blade C_4 had significantly higher torque values compared to the remaining three blades. The carbide tipped circular saw blades showing the better performance than regular brush cutter blades in terms of cutting torque requirement.

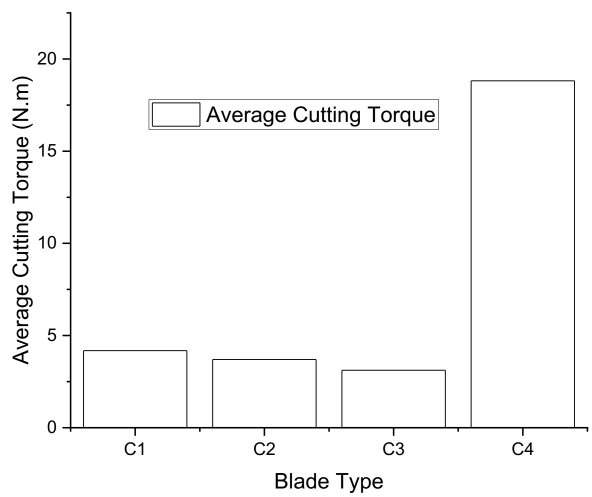

Figure. 3. Cutting torques for different blade types

Effect of blade rotational speed on the cutting torque

The effect of the blade rotational speed on the cutting torque is shown in figure 4. The experimental results showed that rotational cutting speed bears strong negative correlation (r = -0.9669) with cutting torque. The average cutting torque decreased linearly from 9.18 N tom to 6.31 N tom with increase in blade rotational speed from 600 rpm to 1200 rpm. During the experiment it was observed that at some instances for lowest rotational speed i.e., 600 rpm the henna stems having diameters of 10 ± 1 mm and 15 ± 1mm tend to break the stem rather than cut it smoothly. This phenomenon particularly observed for the blade C_1. The reason behind this phenomenon was because of a smaller number of teeth i.e., 40 carbide tipped teeth on c1, having greater pitch between the teeth therefore, at lower rotational speed the small diameter henna stems stuck between two teeth and getting broken rather than cutting. It was also observed that at higher rotational speeds i.e., 1000 and 1200 rpm blades tend to vibrate and cutting was appeared to be noisy. The greater vibrations and noisy cutting may reduce the life expectancy of the blade.

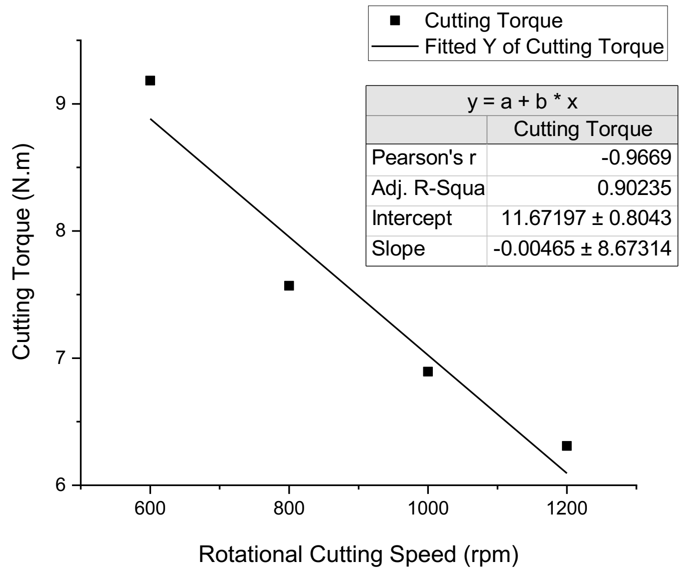

Figure 4: Cutting torques relationship blade speed

Effect of stem diameter on cutting torque

The effect of stem diameter on cutting torque is presented graphically in figure 5. the diameter of stem has significant effect on the cutting torque. There exists strong positive correlation (r = 0.98478) between diameter of stem and cutting torque. From the results it was seen that increase in diameter of stem increased the cutting torque, linearly. The average cutting torque increased from 2.18 to 11.68 N-m for stem diameter of 10±1 to 30±1 mm, respectively.

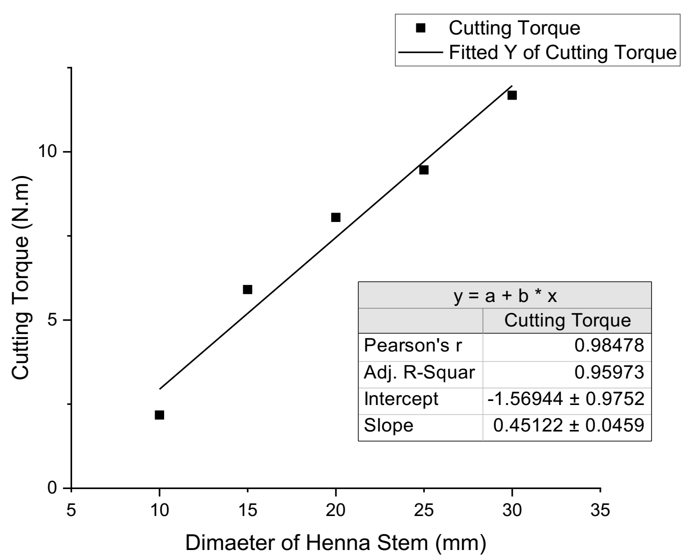

Figure 5: Cutting torque requirement for different diameter of henna stem

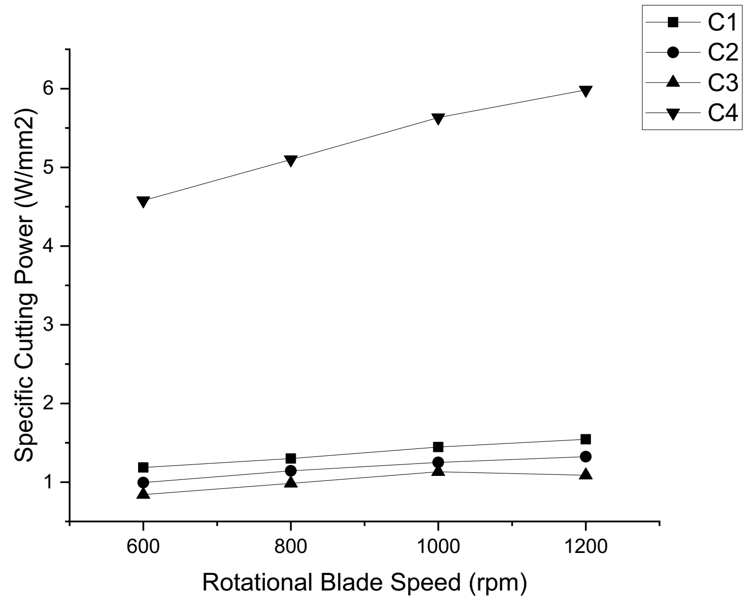

Figure 6: Specific Cutting Power on rational blade speed

Effect of blade type and blade rotational speed on specific cutting power

The power requirement per unit cross sectional area of stem is the important characteristic that need to be considered while selecting blade. The results of the experiment showed that specific power requirement of the blades increased with increase in the rotational blade speed, irrespective of the blade type (Fig. 6). But blade C_4 showing more aggressive increase in cutting torque compared to the remaining three blades i.e., $C_{1,}$ C_2 and $C_{3.}$ The reason may be the blade $C_{1,}$ C_2 and C_3 are carbide tipped blades and they are more stable at higher rotational speeds causing no additional speed induced vibrations thus they were having less aggressive increase in specific cutting power compared to the blade C_4. The average specific cutting power for blade $C_{1,}$ $C_{2,}$ C_3 and C_4 were 1.37, 1.18, 1.01 and 5.32 W/mm,^{2} respectively.

CONCLUSION

The study was conducted to observe the effect of blade type, blade rotational speed and diameter of henna stalk on the cutting torque and specific cutting power for selection of efficient cutting system to be fitted on the henna harvester. All parameters under study showed significant effect on the cutting torque. The carbide tipped blade with 120 teeth had lowest torque while, regular brush cutter blade had highest torque among all blades. The rotational blade speed showed strong negative correlation with the cutting torque. The cutting torque decreased from 9.18 to 6.31 Ntom for increase in rotational blade speed from 600 to 1200 rpm. At higher rotational blade speeds i.e. 1000 and 1200 rpm cutting blade experienced some vibrations which caused noisy cutting process. The diameter of blade also showed significant effect on cutting torque. The specific cutting power was highest for regular brush cutter blade while it was lowest for 120 teeth carbide tipped blade. Based on the results of the experiment it is concluded that the carbide tipped blade with 100 teeth with rotational blade speed between 600-800 rpm is recommended for henna harvester cutting system.

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