Effect of Stem Diameter, Cutting Speed and Moisture Content on Cutting Torque for Green Gram Harvesting

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ABSTRACT

The study was conducted during November, 2021 at Department of FMPE, CAET, OUAT, Bhubaneswar, Odisha, India to investigate the torque requirement and ascertain optimum peripheral cutting velocity of rotary cutting disc based on varying stem diameter and moisture content of green gram . The cutting operation was simulated to find the cutting torque in the instrumented soil bin, which comprises of test trolley, processing trolley and vertical rotor assembly with vertical shaft having serrated cutting disc. Sample plant stems of green gram were firmly fixed in the plant stem holder, and buried beneath the soil to simulate the natural standing of the crop as in the actual field condition. The cutting torque required to cut the stem of green gram at different crop moisture content (39.2, 41.4 and 42.9% (wb)), peripheral cutting velocity (20, 25, 30, and 35 ms^{-1}) and plant stem diameter (2.95, 3.97 and 4.96 mm) was measured. It has been observed that peripheral cutting velocity of disc, stem diameter and moisture content of plant affected cutting torque at 1% level of significance. The cutting torque increased with decrease in moisture content and increase in diameter of plant stem of green gram. The cutting torque increased with an increase in peripheral cutting velocity up to the critical velocity of 30 ms^{-1}, but the value decreased after critical peripheral velocity.

KEYWORDS: Cutting torque, cutting velocity, gram mechanization, pulse harvesting

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

1. INTRODUCTION

Pulses are the important sources of proteins, vitamins and minerals and are popularly known as Poor man's meat and rich man's vegetable, contribute significantly to the nutritional security of the world. One of the most crucial components to increasing pulse yield and productivity is high-quality seed. In addition to reducing harvesting loss, mechanization of pulse harvesting can be crucial for obtaining high-quality seed while reducing labour, costs, and drudgery (Kumar et al., 2022). Only by using improved machinery, pulse harvesting can be enhanced, and to design such machinery, we must be aware of the necessary cutting torque. To understand how material will behave under various harvesting and threshing operating conditions, it is necessary to distinguish between the physical characteristics of plant stems and cutting resistance. When applying a system of forces to a material, failure in shear or impact is possible. Prior to shear failure, the material is effectively squeezed and bent, which increases the amount of work needed to do a cutting operation (Kepner et al., 1978). By comparing the cutting energy requirements, cutting force, and stress provided, cutting elements employed in harvester design can be evaluated (Chakraverty et al., 2003). Hence, it is necessary to determine the cutting energy requirements for suitable knife design and operational parameters. Researchers claimed that cutting energy and maximum cutting force were significantly influenced by moisture content and stem diameter (Yilmaz et al., 2008). As reported by Kathirvel et al. (2009), the peak cutting energy consumption was inversely proportional to cutter bar speed and directly proportional to stem diameter. According to Sushilendra et al. (2016), serrated blades cut more effectively than smooth edge blades at the same cutting velocity. They also observed a positive association between cutting force and energy with stalk area but a negative correlation with cutting force and energy with cutting speed. Green gram crop is typically harvested manually in India, either by uprooting the plant or by using a sickle (Singh and Singh, 1978; Kulkarni and Sirohi, 1985; Tiwari et al., 2017). Manual harvesting requires a lot of labour, takes a long time (200–240 man-hours per hectare), is expensive, and is drudgery prone (Sahni et al., 2018; Singh and Sahni, 2019, Tiwari et al., 2019). Harvesting is frequently delayed due to a labour shortage and inclement weather throughout the harvest season. The pulse crop must be harvested as soon as possible to reduce losses and to produce of high-quality seed. According to Tully (1984), manual harvesting with hand pulling accounted for 50–56% of the entire cost of lentil production. In line with reports, in some regions of Odisha, uprooting of crops like green gram is done on a contract basis and 50–60% of the crop is given as a wage for uprooting and transporting to the owner's threshing yard.

The only remaining method for the profitable production of green gram is adequate mechanized harvesting. In Odisha, pulses are ranked second, and their proportion has grown from 14.8 to 22.3% during the past ten years. In 2016–2017, green gram, black gram, and arhar, respectively, covered 826, 435, and 129 thousand hectares (Anonymous, 2021). With the aforementioned information in mind, the necessary cutting torque required for cutting the plant stem of green gram (variety: OUM-11-5) was investigated. The study's primary objective was to determine the effect of crop moisture content, rotary cutting disc peripheral velocity, and plant stem diameter on the cutting torque for cutting green gram plant stems.

2. MATERIALS AND METHODS

All the experiments were conducted during November, 2021 at the soil bin in the Department of FMPE, CAET, Odisha University of Agriculture & Technology (OUAT), Bhubaneswar, Odisha, India. The cutting torque required to cut the stem of green gram at different crop moisture content, cutting velocity and stem diameter was measured. A vertical rotor assembly, plant stem holder, test trolley, processing trolley and test rig all are situated inside the workshop (Figure 1). The vertical rotor assembly comprises vertical shaft having serrated cutting disc. The system allows for changes in forward speed, rotor speed, and cutting height. To determine the cutting torque required for cutting green gram, an experiment was designed using a 3-factors complete randomized design with three replications (Table 1), and the analysis was done using the statistical program MSTATC (version: Mstat 5.4).

Green gram plants (variety: OUM-11-5) were uprooted from the EB-2 field of OUAT, Bhubaneswar (20.26337° N 85.8094° E) and carried to the laboratory in wrapped bags of plastic and experiments were done on the same day. The experimental set-up of the test soil bin, as shown in figure 1, was utilized for conducting all the experiments. For providing simulating field conditions, the plants were fastened onto plant stem holders having holes of 3, 4, and 5 mm in diameter, and they were buried beneath the earth. Having adjusted the rotary cutting disc of vertical rotor assembly at proper cutting height, the required motor speed (5 hp, AC and rpm of 1400) and forward speed (0.3 ms^{-1}) of the processing trolley were adjusted and fixed.

The input shaft of the vertical rotor assembly received power from the motor via a V-belt (1:1 gear ratio), after which power was transferred by a belt and pulley to the shaft of the bevel gear arrangement (1.5:1 gear ratio) with a gear box (1:2 gear ratios). The vertical rotor assembly was then connected to the processing trolley by nuts and bolts, and the rotary cutting blade (3:1 gear ratio) was coupled by a V-belt and pulley arrangement that sent power to

Table 1: Experimental design for determining cutting torque for green gram crop

Independent variables		Reasons for selecting the levels	Dependent variables
Variables	Levels		
Crop moisture content, % (wb)	M_1=35−38	Green gram crop has moisture content between 35 and 45% (wb) during harvesting operation	Cutting torque, Nm
	M_2=38−42		
	M_3=42−45		
Peripheral cutting velocity of rotary cutting disc, V, ms^{-1} (rpm)	V_1=20 (1500)	Velocity of plant cutting should be higher than the critical velocity	
	V_2=25 (1881)		
	V_3=30 (2257)		
	V_4=35 (2633)		
Plant stem diameter, mm	D_1=3	Stem diameter influences the cutting torque requirement	
	D_2=4		
	D_3=5		

(a) Test trolley, processing trolley and vertical rotor

(b) Computer with datalogger

(c) Control panel

(d) Simulated samples in stem holder during cutting

(e) Simulated sample after cutting

(f) Measurement of stem diameter

Figure 1: Experimental set-up of test soil bin

the rotor shaft. Owing to this arrangement, vertical rotor assembly gets forward speed and rotary cutting disc gets rotary speed resulted in to cut the plant stem located under soil of stationary bin and diameter of plant stem was measured with vernier calliper (Aerospace; 300×0.02 mm).

The data collecting equipment (GTDL350, data logger with provision for 8 channels and multi-scan+multi-fold software; (Joo Shin Corporation and www.jooshin.kr) was used to measure the torque required for driving the motor's rotor shaft, and the results were recorded. Equation 1 was

used to compute the torque required to drive a rotary disc.

$$TR = T_M / V_R \qquad (1)$$

Where,

T_M = Motor torque, Nm
T_R = Rotor torque , Nm
V_R = Velocity ratio

3. RESULTS AND DISCUSSION

3.1. ANOVA results

The ANOVA for the effect of MC, PSD and PCV on torque requirement for cutting of green gram crop is given in Table 2. Table 2 shows that, at the 1% level of significance, plant stem diameter, moisture content, and peripheral cutting velocity of rotary disc all significantly influenced the torque required to cut a green gram crop. The combined effect of moisture content and plant stem diameter has been found to be non-significant at 1% level of significant, but significant at 5% level of significant. The combined effect of moisture content and plant stem diameter as well as plant stem diameter and peripheral cutting velocity was found to be non-significant. This may be due to the opposite effect of variables on torque required for cutting green gram crop.

3.2. Effect of crop moisture content, plant stem diameter and peripheral cutting velocity on torque

The effect of MC, PSD and PCV on torque required for

Table 2: Analysis of variance for cutting torque requirement for cutting green gram stems

S1. No.	Source	DF	SS	MS	F-value	p-value
	Dependent parameters					
	Cutting torque (Nm)					
1.	Factor A	2	5.987	2.994	37.4720	0.0000
2.	Factor B	2	303	151.673	1898.5728	0.0000
3.	AB	4	1.145	0.286	3.5836	0.0101
4.	Factor C	3	6.518	2.173	17.1980	0.0000
5.	AC	6	0.011	0.002	0.0233	
6.	BC	6	0.0342	0.057	0.7140	
7.	ABC	12	0.001	0.000	0.0014	
8.	Error	72	5.752	0.08		
9.	Total	107	323.104			

Independent parameters: Factor A: Moisture content of crop (39.2, 41.4 and 42.9%, (wb)); Factor B: plant stem diameter (2.95, 3.97 and 4.96 mm); Factor C: Peripheral cutting velocity (20, 25, 30, and 35, ms^{-1}); CV=4.46

cutting of green gram crop was measured. Figure 2 shows the effect of MC and PSD on cutting torque for harvesting green gram stem. At moisture content levels of 39.2, 41.4, and 42.9%, the average torque requirement for cutting was found to be 6.63±0.36 (mean±SD), 6.33±0.35, and 6.04±0.33 Nm, respectively. Similarly, the average torque required for cutting of green gram crop was observed to be 4.23±0.25, 6.43±0.34, and 8.33±0.45 Nm against diameters of 2.95, 3.97 and 4.96 mm, respectively. It was clear from figure 2 that irrespective of PCV of disc values, the torque required to cut a green gram increased with increase in plant stem diameter and decreased with increase in moisture content. It could be because of increased cross-sectional area with larger plant stem diameter and less rigid pith with higher moisture level than at lower moisture content.
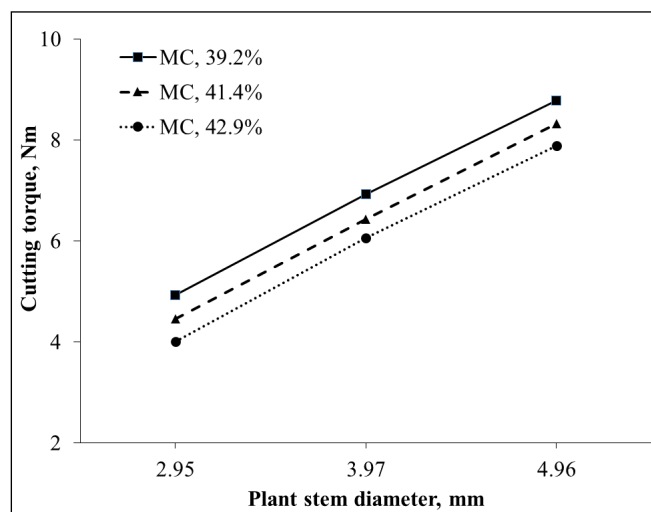

Figure 2: Effect of moisture content and plant stem diameter on cutting

Figure 3 shows the effect of PCV and MC on the torque required to cut a green gram crop. The average torque required for cutting green gram crop was found to be 6.05±1.73, 6.36±1.81 6.72±1.88 and 6.21±1.74 Nm for peripheral cutting velocities of 20, 25, 30 and 35 ms^{-1}, respectively. It is clear from figure 3, irrespective of the values of PSD, the torque required for cutting decreased with increase in crop moisture content and increased as PCV increased up to 30 ms^{-1}. With further increase in the PCV of the rotary cutting disc, the torque requirement to cut the green gram crop subsequently reduced. It suggests that 30 ms^{-1} is the critical PCV in soil bin condition for torque required for cutting. It could be because of cutting less hardened pith at higher moisture content than at lower moisture content and passing larger cross-sectional area by disc at bigger stem diameter of plant.

Figure 4 shows the effect of PSD and PCV of rotary cutting disc on torque requirement for cutting of green gram
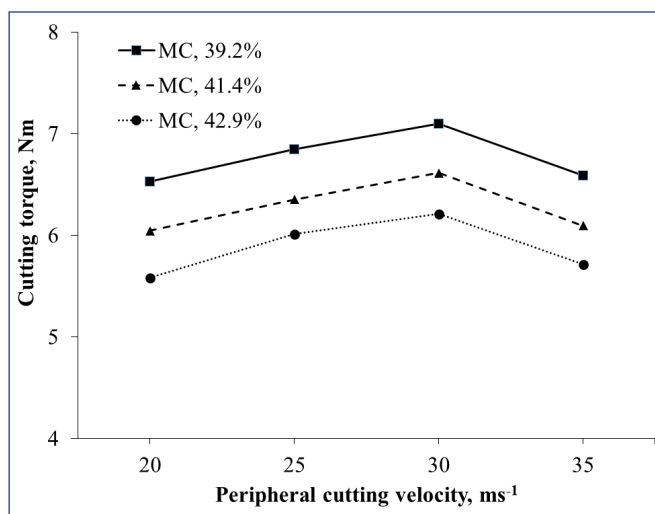
Figure 3: Effect of moisture content of crop and peripheral cutting velocity on cutting torque
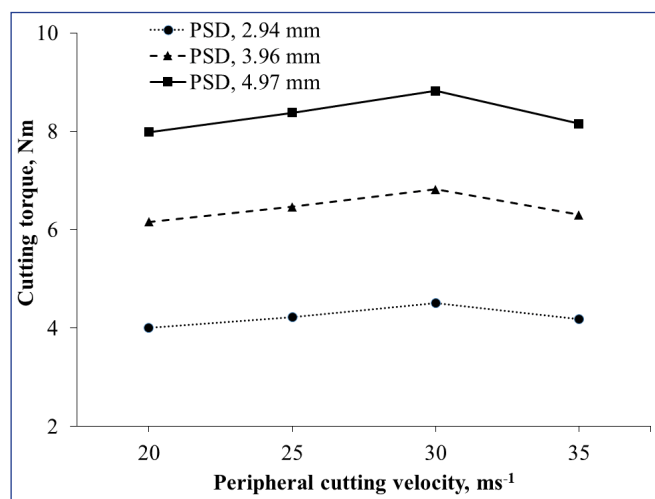

Figure 4: Effect of plant stem diameter and peripheral cutting velocity on cutting torque

crop. The average torque requirement was observed to be 4.23±0.2, 6.44±0.32, and 8.33±0.49 Nm against diameters of 2.95, 3.97 and 4.96 mm, respectively. Similarly, the average torque required for cutting was 6.05±0.33, 6.36±0.34 6.72±0.36 and 6.21±0.31 Nm at peripheral cutting velocities of 20, 25, 30, and 35 ms^{-1}, respectively. It is clear from Figure 4 that irrespective of the values of moisture content level, the torque requirement for cutting increased with increase of plant stem diameter whereas, the torque required for cutting increased with increasing peripheral cutting velocity up to critical peripheral cutting velocity (30 ms^{-1}) and after that the torque required for cutting decreased with increase of peripheral cutting velocity. Dauda et al. (2015) also found reduction in cutting torque from 1.95 to 1.49 Nm when rotational speed changes from 400 to 700 rpm. Furthermore, they found higher cutting torque when MC is less than 35%, beyond that torque reduced. O'Dogherty

and Gale (1986) and Kumar (2022) also found that torque required for cutting decreased with increasing moisture content and increased with increasing stem diameter of pulse crop. Similarly, Preethi et al. (2021) observed higher cutting force requirement with increase in stem diameter. They also observed reduced cutting force with increase in moisture content and cutter bar speed. All previous studies validate the findings of this research work.

4. CONCLUSION

The study estimated torque requirement for cutting green gram stems at different MC, PSD and PCV. The study found that, up to a critical PCV (30 ms^{-1}), the required cutting torque increased with PSD, but the value afterwards declined. Additionally, the torque required for cutting increased with PSD while decreased with an increase in MC. The torque required was considerably affected by the MC, PSD, and PCV at the 1% level of significance.

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