Original Research Article

Development of Pendulum ImpactCutter for Measurement of CuttingForce and Energy of Plant Stalks

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ABSTRACT

A research study was conducted to examine how the blade type, cross-sectional area of stalks and moisture content of the crop isaffecting the cutting energy and cutting force needed for the harvesting of blackgram and greengram stalks. A pendulum impact cutter was developed for the measurement of cutting energy and force. The plant was positioned in the stalk holder to replicate the natural arrangement of stalks in a field. Three types of blades such as smooth edge, V-shaped and serrated type were used for the present study. The experimental findings indicated that an increase in the cross-sectional area of blackgram and greengram stalks resulted in higher cutting energy and cutting force requirements for all the three types of blades. The decrease in moisture content of greengramand blackgramcrops leads to increase in cutting energy and cutting force by all the three blades.The reason for increase of cutting energy and cutting force at low moisture content i.e., the both plant materials exhibits a fibrous property at low moisture content which holds a higher strength. So, more cutting energy and cutting force is required for cutting at low moisture contents.The serrated type blade exhibited lower cutting energy and cutting force requirements in comparison to the smooth edge and V-shaped types of blades across all stalk diameters.The following functional relationship is drawn form this research i.e., the cutting energy and cutting force is directly proportional to the cross-sectional area of stalks and inversely proportional to the moisture content of the crop.

Keywords: Pendulum impact cutter,Cutting force, Cutting energy, Diameter of stalk, Moisturecontent, Types of blades (Serrated, V-shape and Smooth), Crops (Greengramand Blackgram)

1. INTRODUCTION

To comprehend the material behavior under various harvesting conditions, it is essential to understand the variations in the physical properties of plant stalks and their cutting resistance. The efficacy of cutting elements utilized in a harvester can be assessed based on their requirements for cutting energy and cutting force. Therefore, it is essential to ascertain the cutting energy requirements for designing an appropriate knife. A study was conducted to examine how blade type and cross-sectional area of stalks impact the cutting energy and force needed for the harvesting of blackgram and greengram stalks. A pendulum impact cutter was created and developed for the measurement of cutting force and energy. The plant was placed in the stalk holder to simulate the natural arrangement of stalks in the field. The study employed three types of blades: smooth edge, V-shaped, and serrated. The experimental findings indicated an increase in cutting energy and cutting force requirements with the increasing cross-sectional area of blackgram and greengram stalks. The serrated blade exhibited lower requirements for cutting energy and force compared to both smooth-edge and V-shaped blades across all stalk diameters.

A Pendulum Impact Cutter was employed to measure the cutting energy and cutting force necessary for harvesting blackgram and greengram stalks. The study concluded that cutting force increased proportionally with the diameter of the stalks. Various researchers have documented the cutting strength of plant stems and the influential parameters affecting cutting energy in diverse crops. The outcomes revealed a notable impact of crop cross-sectional area and moisture content on both cutting energy and maximum cutting force. (Prasanthkumar and Saravanakumar 2017, Dara Rooha Blessy *et al*., 2019, Sushilendra*et al.,* 2020 andVeerammanavara *et al*., 2022). It was found that the peak cutting requirement directly correlated with the stalk diameter and inversely correlated with the moisture content of the stalk. Therefore, it is crucial to explore the impacts of blade type, on the cutting characteristics of blackgram and greengram crop stalks, specifically in terms of cutting energy and cutting force. A pendulum impact cutter was constructed to investigate the influence of blade velocity and blade type on the cutting energy and cutting force requirements for the selected varieties of blackgram and greengram crops, namely GBG-45 and LGG-630. Therefore, a study is conducted at Dr. N.T.R College of Agricultural Engineering, Bapatla with following objectives: To measure physical parameters of greengram and blackgram, To develop Pendulum Impact Cutter and To determine cutting force and energy of greengram and blackgram stalks.

2. MATERIAL AND METHODS

The present study was under taken in the Department of Farm Machinery and Power Engineering at Dr. NTR College of Agricultural Engineering, Bapatla. This chapter deals with materials and methods used to estimate physical parameters of greengram and blackgram, development and evaluation of Pendulum impact cutter apparatus for determination of cutting energy, cutting force, blade velocity at different moisture contents.

2.1 Physical parameters of greengram and blackgram plants

The Pendulum impact cutter was developed based on following parameters such as height, width, stalk girth, height of first pod, number of branches and number of plants per square meter area etc. The procedure adopted for measurement and characterization of these properties are discussed in the following sections.

2.1.1 Height of plant: The height of plant above the ground surface is an important factor in relation to height of cutting. The height of plants above the ground surface was measured at three different locations selected at random for greengram and blackgram using a steel rule and the mean value was calculated.

2.1.2 Width of plant: The width of plant was measured at three different locations selected at random for greengram and blackgram by using a steel rule and the mean value was calculated.

2.1.3 Stalk diameter: The stalk girth of plant near to the ground surface is an important factor in relation to width of cutting. The stalk girth of plants near to the ground surface was measured at three different locations selected at random for greengram and blackgram using a vernier caliper and the mean value was calculated.

2.1.4 Height of first pod: The height of first pod above the ground surfaces was measured at three different locations selected at random for greengram and blackgram by using a steel rule and mean values was calculated.

2.1.5 Number of branches per plant: The number of branches of each plant was counted at three different locations selected at random for greengram and blackgram after that mean value was calculated.

2.1.6 Number of plants: The numbers of plants were counted at three different locations selected at random for green gram and black gram after that mean value was calculated.

2.2 Development of Pendulum Impact Cutter

A pendulum impact cutter was initially drawn using SOLIDWORKS 3D and line diagram of 2D based on the physical parameters of greengram and blackgram. It consists of platform, dial gauge, blade holder, pendulum arm, pendulum shaft, main frame, stalk holder, and blades (serrated, plane and V-shape). The details of each component of pendulum impact cutterwere given briefly in the following sections.

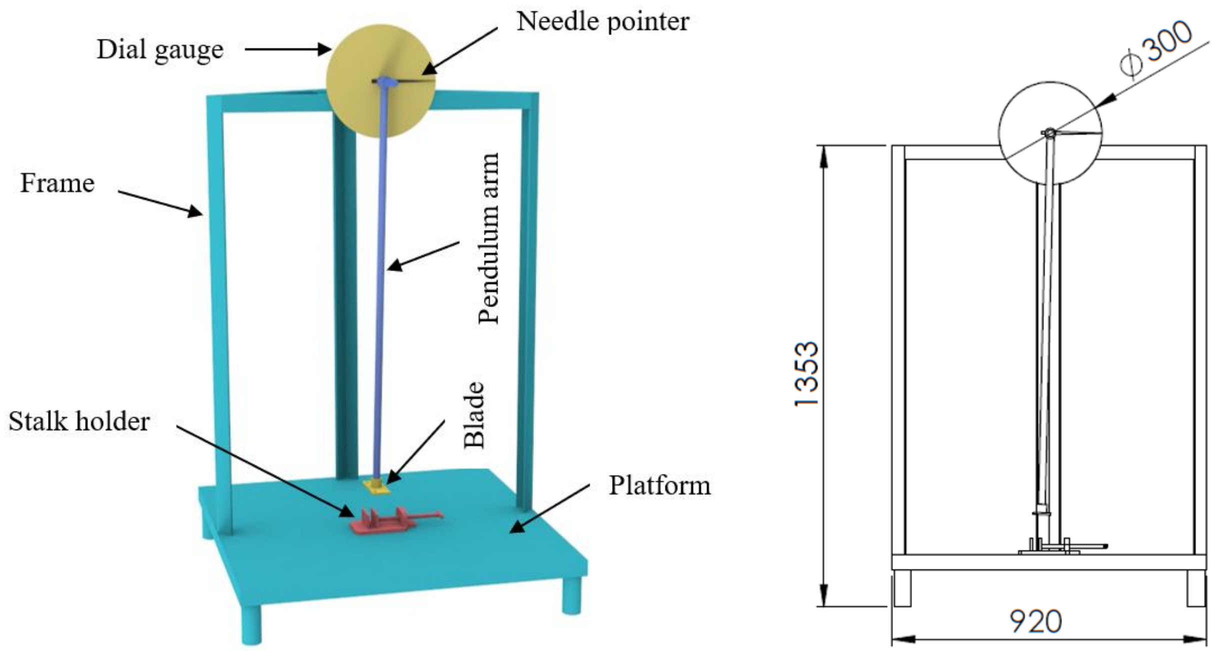
2.2.1 Platform:A support platform for the pendulum impact cutter was constructed by using a 2-inch L-angular bar to create a 920 mm square frame. This frame was then covered with a 3mm thick mild steel sheet measuring 920 x 920 mm. The platform surface was maintained horizontally, positioned 170 mm above ground level, and supported by 2-inch pipes of 15 cm length welded at each of the four corners on the bottom side of the frame.

2.2.2 Main frame: To offer support and structural stability to the elements of the pendulum impact cutter, a primary frame was constructed using 1.5-inch L-angular bar. The frame was triangular in shape, with a height of 1200 mm and side lengths measuring 630 mm, with a base length of 880 mm.

2.2.3 Pendulum arm:A pendulum arm was fashioned using a mild steel shaft with a diameter of 20 mm and a length of 1100 mm. At the top, a 40 mm bush with an internal diameter of 20 mm was welded. The overall weight of the pendulum arm was 3 kg.

2.2.4 Pendulum shaft: PendulumShaft was mounted on main frame with the help of two pillow block bearings and rotates freely. Pendulum arm was fixed to this pendulum shaft at one end. A mild steel shaft of 20 mm diameter and 660 mm in length was used as a pendulum shaft.

2.2.5 Dial gauge: The dial gauge is composed of two pointers and a graduated angular scale. The angular scale of the dial gauge was inscribed on a mild steel sheet with a diameter of 300 mm and affixed to the main frame of the pendulum. Two pointers, each 100



mm in length, were crafted and attached to a ratchet mechanism, enabling movement in only one direction. The dial gauge was employed to observe the displacement of the pendulum arm both before and after the cutting of the stalk.

Fig.1. CAD 3D and line diagram drawn in SOLIDWORKS Software

2.2.6 Stalk holder: The bench vice was securely fastened to the holder frame, which measured 150 mm in length and 70 mm in width. This frame was affixed to the platform, allowing the stalk holder to slide for the purpose of adjusting the cutting position.

2.2.7 Blade holder:A blade holder, crafted from mild steel sheet, was employed to secure the blade onto the pendulum arm. The holder measured approximately 100 mm in length and 25 mm in width. Bolts and nuts were incorporated to securely fasten the blades in place. In the middle of the sheet, a bush with an internal diameter of 20 mm was welded and equipped with a bolt to tighten the pendulum arm.

2.2.8 Blade: Three blade types-smooth edged, V-shaped, and serrated are utilized in the cutter bar of a combine harvester. These blades are employed to assess the cutting energy, blade velocity, and cutting force for selected varieties of greengram and blackgram.

2.3 Principle of operation of pendulum impact cutter

The operation of the pendulum impact cutter is based on the principle of the law of conservation of energy. A long arm, suspended from its top end and featuring a fixed knife at the bottom, is set in motion to oscillate within the vertical plane. At first, it undergoes an angular deflection θi, displacing it from the equilibrium position to one side. Following the principle of conservation of energy, upon release, the swinging arm is anticipated to oscillate to the opposite side of the equilibrium line, undergoing a deflection through an angle θf. Nonetheless, owing to frictional losses in the components and air resistance, θf typically proves to be less than θi. There was a continual transfer of energy in the swinging arm, transitioning from maximum potential energy at its extreme position during the upswing, as it was released to swing down. This transition involved a loss of potential energy and the acquisition of kinetic energy, reaching a peak kinetic energy when the arm reached the equilibrium line. The material designated for cutting was positioned at the location of maximum kinetic energy in the swinging arm and secured by the stalk holder. Upon release, the arm accelerated until it intersected and cut through the material in the path of the knife. The disparity between the angles before and after cutting is directly associated with the energy expended in cutting the stalk. By measuring the initial angle before the cut and the final angle after the cut of the oscillating pendulum, it became feasible to compute the energy absorbed by the knife to cut through the stalk.

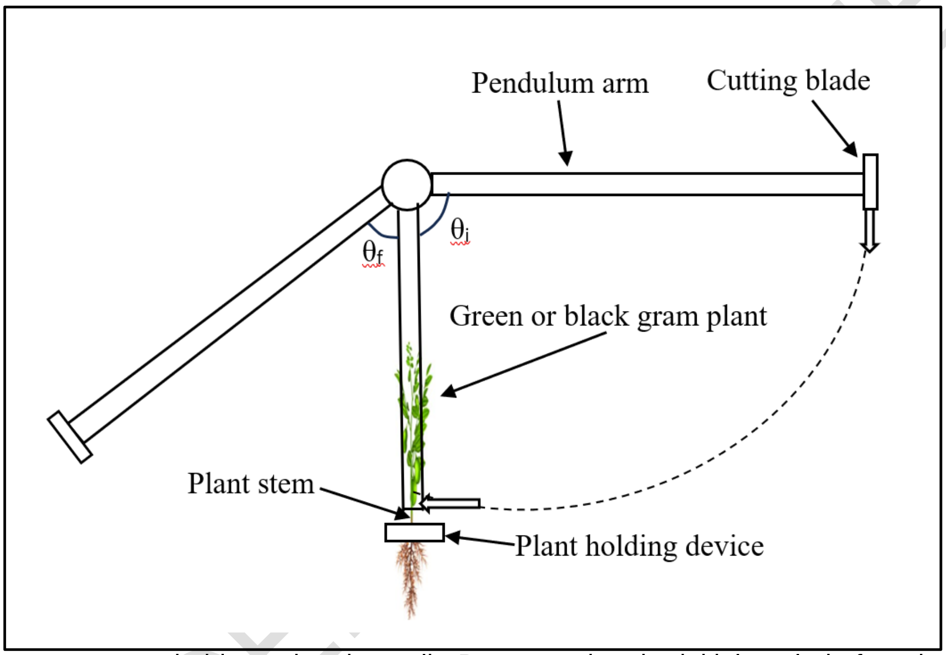


Fig.2. Position of pendulum arm before impact and after impact

2.4 Evaluation of developed pendulum impact cutter

2.4.1 Calculation of cutting energy

The term "cutting energy" refers to the energy necessary for severing a plant stem. The cutting energy depends on moisture content and stalks girth. It was determined by the following equation (Prasanthkumar and Saravanakumar 2017, Dara RoohaBlessy *et al*., 2019 and Sushilendra*et al*., 2020).

$$E = W \times R \times (COS\theta_f - COS\theta_i)$$

Where;

E=Cutting energy, J

W = Weight of the pendulum arm, N
R = Centre of gravity w.r.t rotation of pendulum, m
θ_f =Angular displacement of the pendulum after cut, degree
θ_i = Angular displacement of the pendulum before cut, degree

2.4.2 Calculation of cutting force

The cutting force was determined by measuring the cutting energy and dividing it by the length, which is equivalent to the diameter of the stalk. It was determined by the following equation (Sushilendra*et al*., 2020 and Veerammanavara *et al*., 2022).

$$F_C = \frac{E_C}{D} \times 10^3$$

Where,
F_C= Cutting force, N
Ec = Cutting energy, J
D = Diameter of the stem, mm

2.4.3 Determination of moisture content

The moisture content was assessed by drying samples in an oven at 110˚C for a duration of 24 hours. (Prasanthkumar and Saravanakumar 2017, Dara RoohaBlessy *et al*., 2019 and Sushilendra*et al*., 2020) and was expressed in wet basis. The reduction in sample weight was documented, and the moisture content was computed using the following equation.

$$M.C_{(wb)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where;

$M.C_{(wb)}$ = Moisture Content on wet basis, (%)
W_1 = Initial weight of the sample, (g)
W_2 = Final weight of the sample, (g)

2.5 Experimental procedure

The aim of the experiment was to find out the cutting energy, cutting force requirement for greengram and blackgram stems by using three types of blades and different stalk diameters at different cutting velocities. The greengram and blackgram plants having different stalk girth were chosen randomly in the field. A stalk holder was employed to secure the stalk for cutting purposes. A bench vice, constructed from cast iron, served as the stalk holder, ensuring the stability of the stalk during the experiment and preventing any undesired sliding. The stalks were positioned between the jaws of the bench vice. A lengthy pendulum arm, hanged at its upper end from a pivot point, featured a knife (blade) fixed at its lower end. The arm was allowed to oscillate freely within a vertical plane, facilitated by a support shaft passing through two pillow block bearings situated at either end, resting on the top section of the main frame. If a pendulum is displaced laterally from its initial equilibrium position, it experiences a restoring force induced by gravity, which accelerates it back toward the equilibrium position. Upon release, the restoring force, coupled with the mass of the pendulum, initiates oscillation around the equilibrium position, resulting in a back-and-forth swinging motion. In the pendulum impact cutter, a dial gauge was utilized to measure the deflection angle of the pendulum arm. The dial gauge comprises two pointers and a graduated angular scale. Pendulum arm was pulled to certain angle and made to release. So, that the cut will be made at the nearest distance to the ground. Due to weight of the pendulum, it will also make an angle in opposite to the equilibrium position. Note down the initial and final angle made by the pendulum arm for determination of cutting energy and blade velocity. After that measure the weight of the plant by using a weighing balance and keep it in the oven dryer at a temperature of 110^0 C for 24 hours. Measure the weight of the plant after the drying for determination of moisture content in the wet basis method. The

experiment was repeated numerous times under different moisture conditions, and the average cutting energy and force was computed.

Fig.3. Developed pendulum impact cutter

Table 1.Plan of experiments for pendulum impact cutter

Types of blades		
Smooth edged blade	V-shaped blade	Serrated blade
Diameter of stalks, D-1, D-2, D-3		
Moisture content, M-1, M-2, M-3		
Cutting energy and Cutting force		

3. RESULTS AND DISCUSSION

3.1 Effect of stem diameter on cutting energy and cutting force of black gram

From the graphical representations Fig.4 and Fig.5 represents the effect of stem diameter on cutting energy and force of black gram crop by three different blades such as serrated, V shape and smooth blades. It was observed that plant stem diameter increases, the cutting energy and force required to cut the plant stem increases by all the blades, However the lowest cutting energy and force required to cut the stem diameter was observed with serrated knife because of the serrations over the blade. The highest cutting energy and force was reported by smooth blades followed by V-shape blade. (Sushilendra et al., 2016) were also reported for similar trend of results for effect of stem diameter on cutting energy and cutting force of black gram crop.

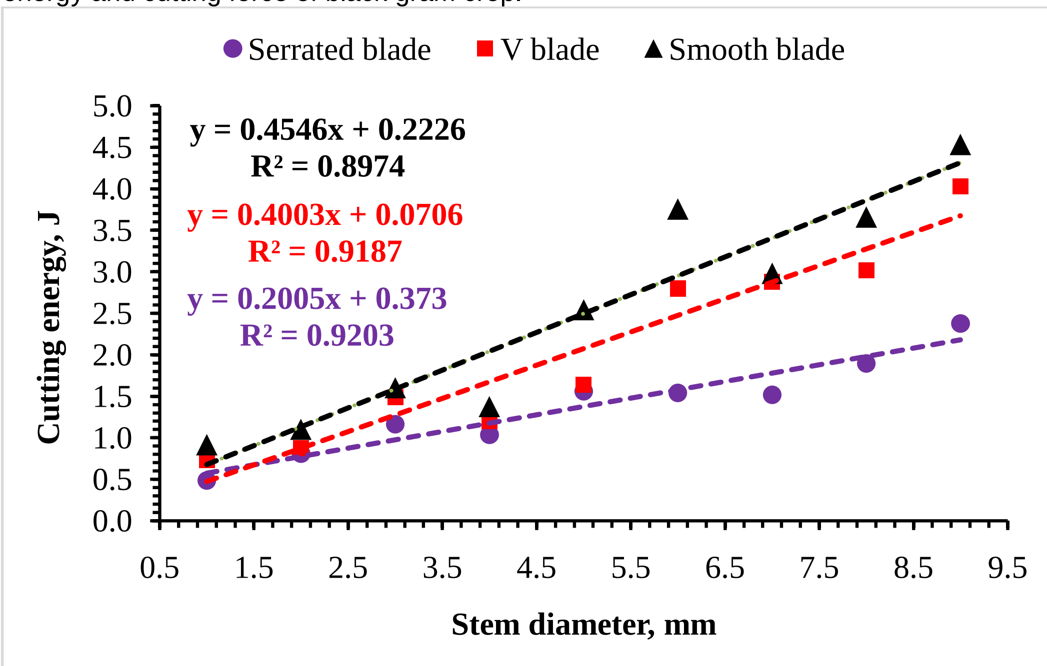


Fig.4. Effect of stem diameter on cutting energy using different blades of black gram

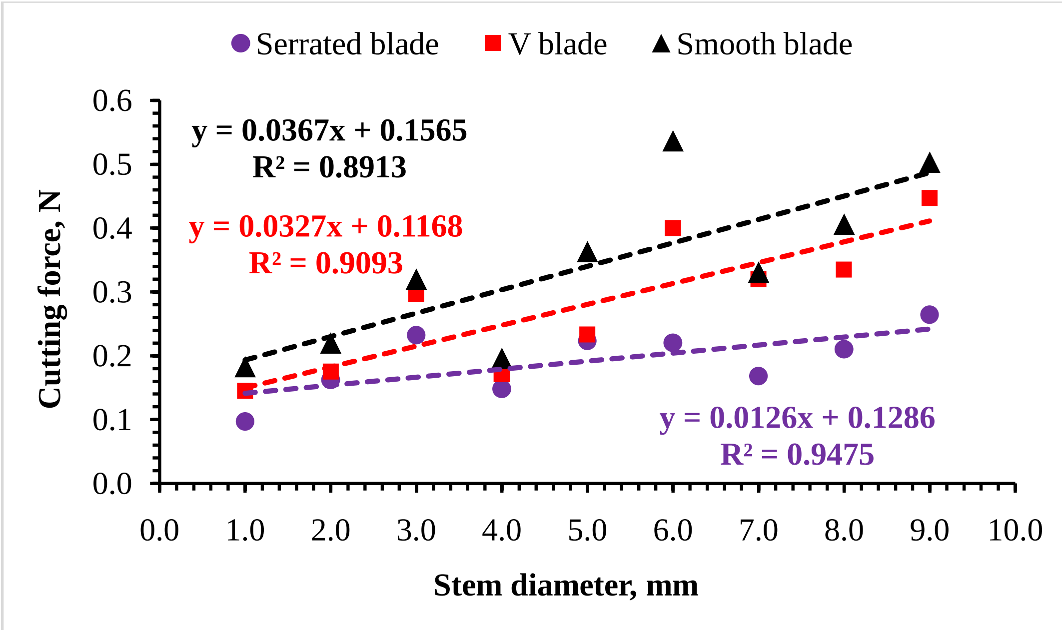


Fig.5. Effect of stem diameter on cutting force using different blades of black gram

3.2 Effect of moisture content on cutting energy and cutting force of black gram

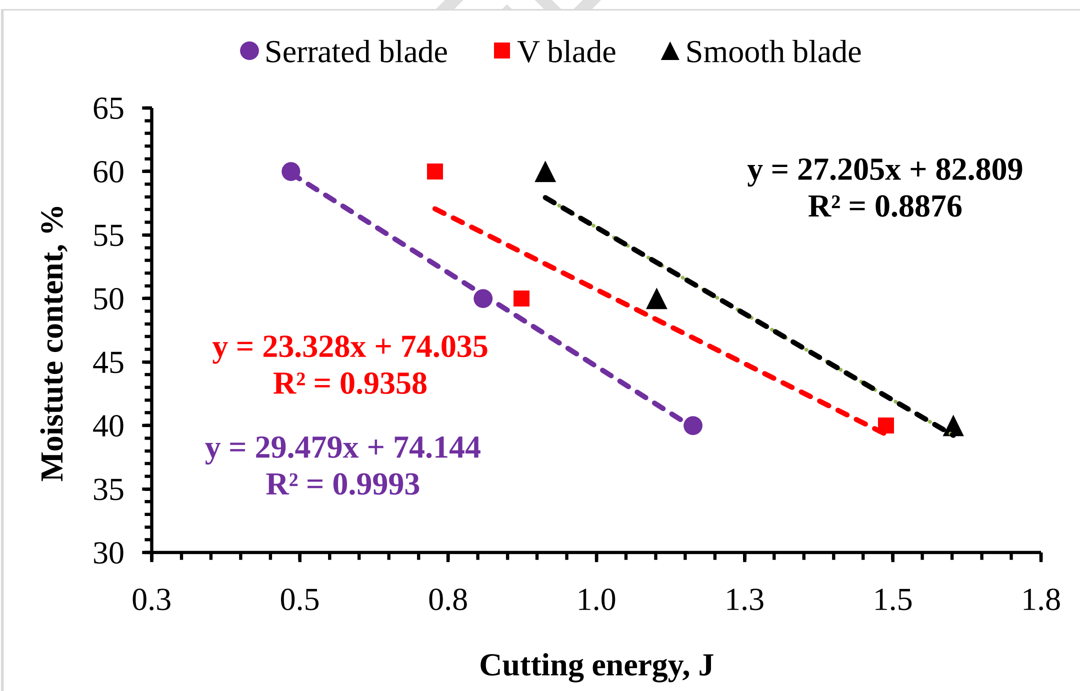


Fig.6. Effect of moisture content on cutting energy of black gram

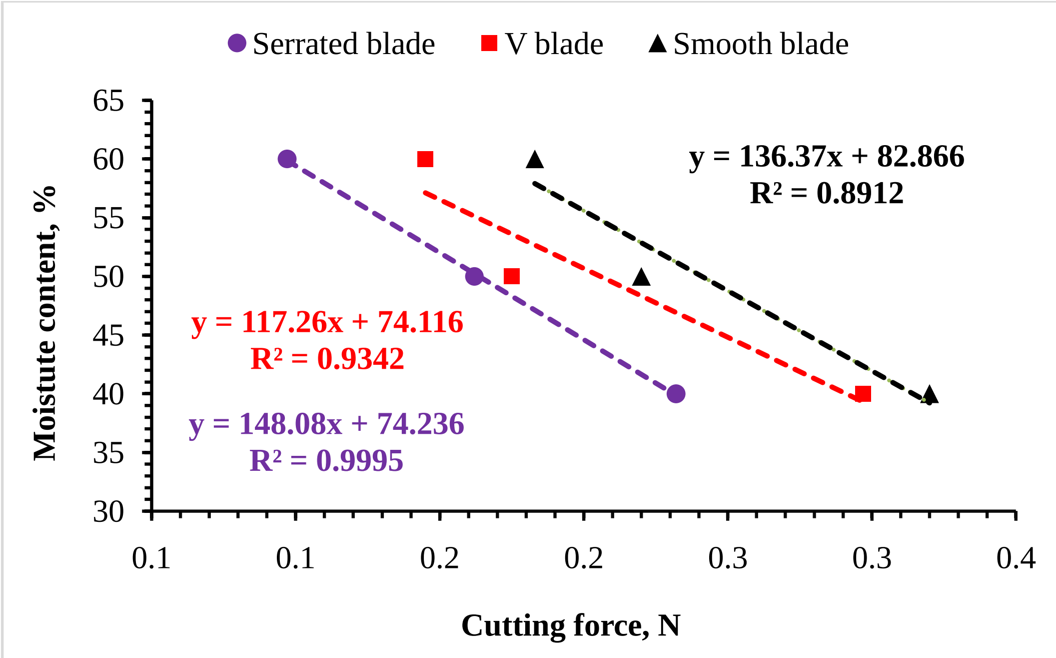


Fig.7. Effect of moisture content on cutting force of black gram

Fig.6 and Fig.7 depicts the effect of moisture content of stalk on cutting energy and force of green gram by three different blades such as serrated, V shape and smooth blades. The decrease in moisture content black gram crop leads to increasing of cutting energy and force by all the three blades. However, the lowest cutting energy and force was observed with serrated knife at higher moisture content because of the serrations over the blade. The highest cutting energy and force was reported at lower moisture contents by smooth blades followed by V-shape blade. The reason for increase of cutting energy and cutting force at low moisture content i.e., the both plant materials exhibits a fibrous property at low moisture content which holds a higher strength. The diameter of stalk increases the energy and force required to cut black gram stem also increases significantly but it decreases with moisture content of stem diameter. (Dange et al., 2016) was also reported similar trend of effect of moisture content on cutting energy and force of pigeon pea crop.

$$\text{Cutting energy} \propto \text{Cutting force} \propto \text{stem diameter} \propto \frac{1}{\text{Moisture content of stalk}}$$

3.3 Effect of stem diameter on cutting energy and cutting force of green gram

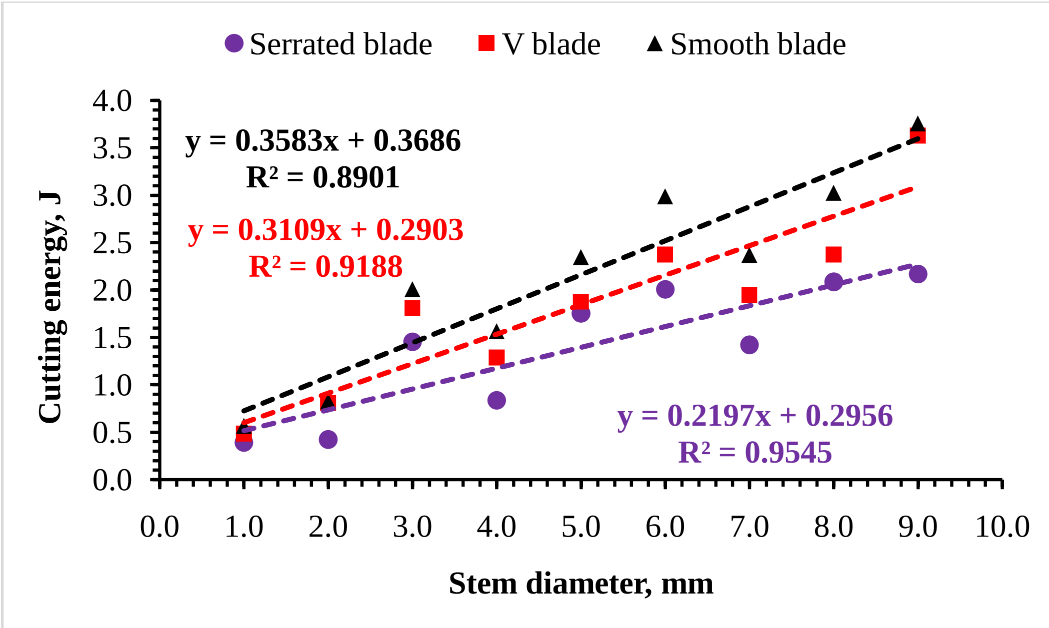


Fig.8. Effect of stem diameter on cutting energy using different blades of green gram

From the above graphical representations Fig.8 and Fig.9 represents the effect of stem diameter on cutting energy and force of green gram crop by three different blades such as serrated, V shape and smooth blades. It was observed that plant stem diameter increases, the cutting energy and force required to cut the plant stem increases by all the blades, However the lowest cutting energy and force required to cut the stem diameter was observed with serrated knife because of the serrations over the blade. The highest cutting energy and force was reported by smooth blades followed by V-shape blade. (Ramachandran and Asokan 2020) were also reported for similar trend of results for effect of stem diameter on cutting energy and cutting force of bengal gram crop.

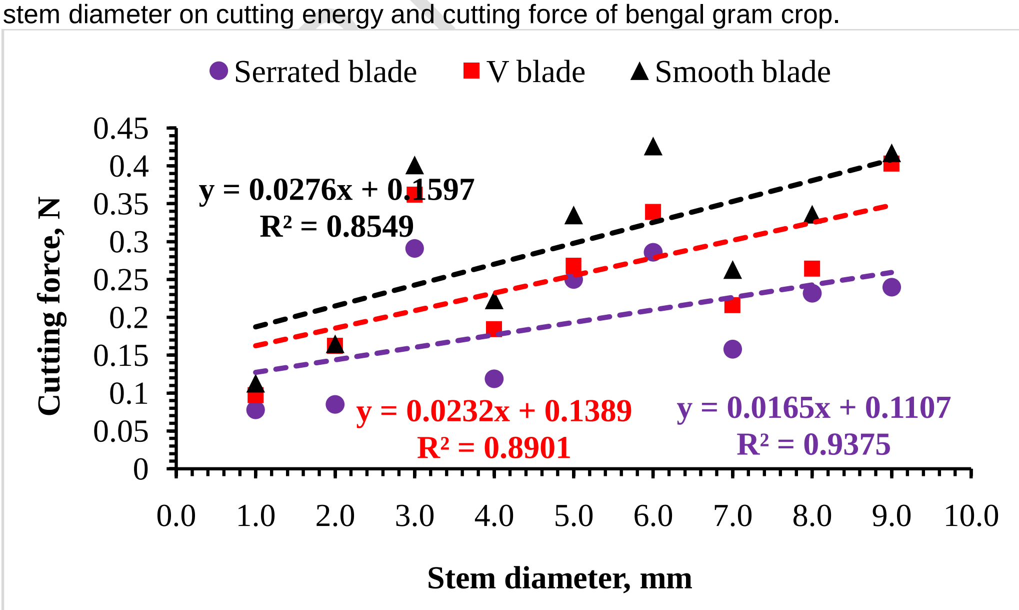


Fig.9. Effect of stem diameter on cutting force using different blades of green gram

3.4 Effect of moisture content on cutting energy and cutting force of green gram

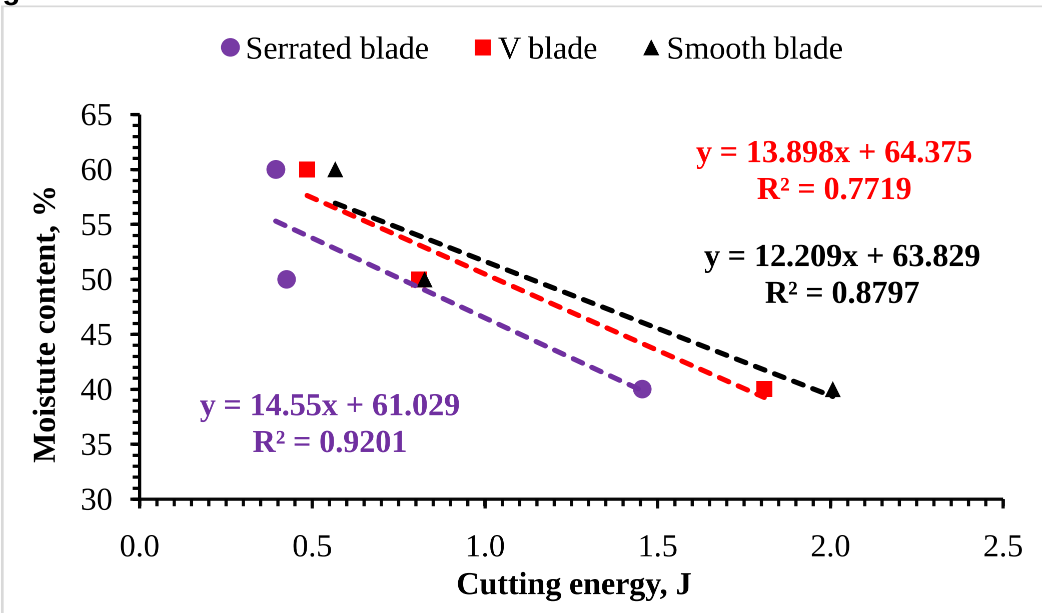


Fig.10. Effect of moisture content on cutting energy of green gram

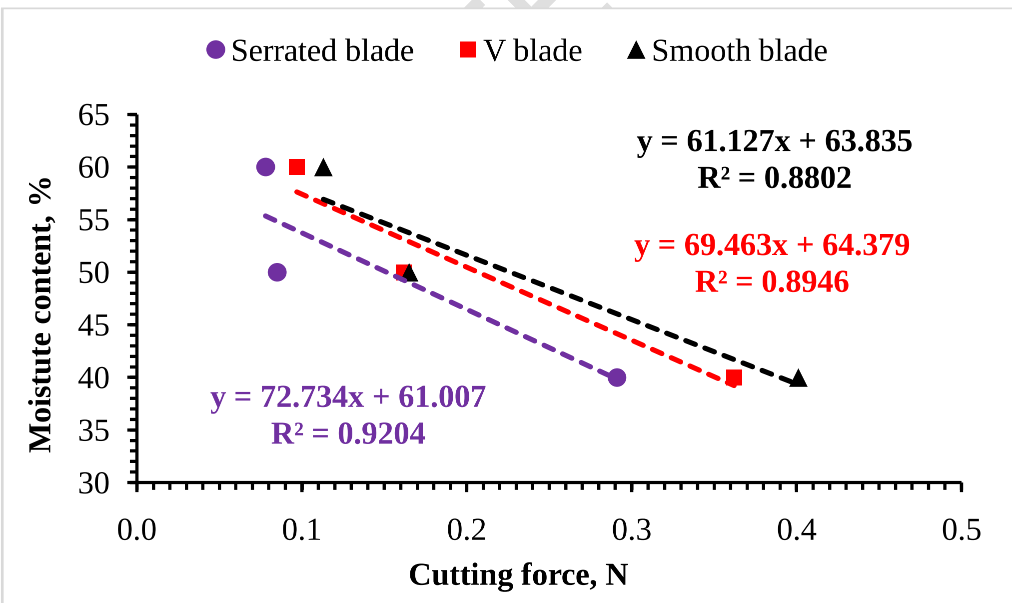


Fig.11. Effect of moisture content on cutting force of green gram

Fig.10 and Fig.11 depicts the effect of moisture content of stalk on cutting energy and force of green gram by three different blades such as serrated, V shape and smooth blades. The decrease in moisture content green gram crop leads to increasing of cutting energy and force by all the three blades. However, the lowest cutting energy and force was observed with serrated knife at higher moisture content because of the serrations over the blade. The highest cutting energy and force was reported at lower moisture contents by smooth blades followed by V-shape blade. The reason for increase of cutting energy and cutting force at low moisture content i.e., the both plant materials exhibits a fibrous property at low moisture content which holds a higher strength.The diameter of stalk increases the energy and force required to cut green gram stem also increases significantly but it decreases with moisture content of stem diameter. (Dange et al., 2016) was also reported similar trend of effect of moisture content on cutting energy and force of pigeon pea crop.

$$\text{Cutting energy} \propto \text{Cutting force} \propto \text{stem diameter} \propto \frac{1}{\text{Moisture content of stalk}}$$

4. CONCLUSION

The Pendulum Impact Cutter Apparatus was employed to quantify the cutting energy needed for both blackgram and greengram stalks. Understanding the energy requirements for cutting both types of stalks serves as the foundation for designing a harvesting machine for these crops. Hence, it is essential to determine the energy needed to cut blackgram and greengram stalks.The force required to cut or break plant stalks depends on the plant type, stem diameter, moisture content. This test was conducted at moisture contents as the moisture content increases cutting force and energy decreases. They are inversely proportional to each other; This is same for both blackgram and greengram crop. As we consider results and discussions, we can know that smooth edge blade requires more cutting force and cutting energy than serrated and v-shaped blade. Serrated blade requires less cutting force and cutting energy than smoothed edge blade and v-shape blade. This is same for both blackgram and greengram crops.This study contributes to identifying the cutting energy and cutting force needed for harvesting both black gram and green gram stalks. Determining cutting energy and cutting force supports the redesign of harvesters, leading to reduced fuel consumption. Consequently, it assists farmers in lowering the cost of harvesting black gram and green gram crops.

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