# Development and validation of an automatic recording microcontroller-based pendulum impact cutter

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#### **ABSTRACT**

Knowledge of rice straw bunch in respect of cutting energy is the important factor for optimization of cutting elements in straw chopping system. A micro controller-based pendulum impact cutter was developed during 2019–21 at the ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh. The system was integrated with load cell, adjustable pendulum arm and adjustable shear and approach angle (0–30 degree) during the cutting experiment. In this study, straw bunch cutting energy at the lowest point of Node 3 was examined which is just above the ground surface. Three type of blades SMS serrated, cutter bar and SMS plain blade were used to determine cutting energy. In order to determine the cutting energy requirement of straw bunch, the mechanical and physical properties of straw were determined. The results represent that the cutting force was significantly affected by blade type, shear angle and approach angle. The minimum cutting energy for SMS serrated, cutter bar and SMS plain blade was registered as 120, 189 and 243 J, respectively among all combinations of shear and approach angle. Developed recording type pendulum impact cutter was compared with the traditional method at selected combination of shear and approach angle for all the three blades and the relative error was recorded between 4–6%. It was concluded that with increasing approach angle at constant shear angle the cutting force initially decreased up to 20 degree and rapid increase from 20 to 30 degree of approach angle. Consequently, the SMS serrated blade emerges as the preferred choice for the rotary impact cutter development, showcasing the potential of this research in advancing straw chopping technology.

**Keywords**: Approach angle, Micro controller, Mechanical property, Rice straw, Shear angle, SMS serrated blade

Rice (Oryza sativa L.) is one of the major staple foods consumed by more than 50% of population globally (Patel et al. 2023). Rice harvesting machineries such as reapers and combines are generally combined with reciprocating type cutting instrument. As the mechanized rice harvesting and the commercial utilization of rice straw continues to rise, the demand for engineering insights into stem and bunch properties has become more pronounced (Yore et al. 2002). The evaluation of cutting element performance for harvester design relies on factors like energy demands during cutting force applied stress on the cutting elements (Chakraverty et al. 2003). Consequently, there is a vital need to ascertain the energy in cutting, prerequisites for proper design of knife and operating parameters (Koloor and Kiani 2007, Yilmaz et al. 2008). The cutting energy of rice stalks were examined at different internode locations

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and its correlation with dimensional characteristics on different varieties (Alizadeh et al. 2011). Sushilendra et al. (2016) also evaluated the influence of blade type, blade cutting velocity, and cross-sectional area of blackgram stems on the cutting energy and force. Numerous researchers have explored the cutting strength of plant stems and the influencing parameters on cutting energy, as demonstrated in studies related to wheat by Hoseinzadeh et al. (2009) and Esehaghbeygi et al. (2009), barely (Tavakoli et al. 2009), and cassava Stem (Jyoti et al. 2022). Allameh and Alizadeh (2016) conducted research to investigate the fluctuations in cutting energy, considering various rice stem varieties and blade parameters. Another study explored the impact of moisture content and stalk diameter on determining the cutting force and cutting energy of chickpea stems (Telangi et al. 2023).

The traditional method for determining the cutting energy requires extensive calculations, which prompted the need to devise a sensor-based impact cutter. Hence the present study was carried out to i) develop an automated recording microcontroller-based pendulum impact cutter and assess its efficacy through a comparative analysis with

the conventional approach ii) selection of cutting blades at different shear and approach angle within three different blades.

### MATERIALS AND METHODS

A sample of rice straw (cultivar-Kranti) was gathered from the ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh field (26°36' N and 75°49' E). Subsequent to crop harvesting, various physical properties relevant to the harvesting process, such as the diameter of the straw bunch, height of straw remaining after harvest, and straw moisture content were assessed. The data were recorded during year 2019–21 and checked for mean difference and found non-significant. Therefore, the average values were taken for the analysis.

Conceptualization stem cutting energy measurement  $(E_c)$  by the traditional method: The cutting energy was assessed utilizing a pendulum impact cutter, which comprised a pendulum rod that exhibited angles before and after the straw bunch cutting. Various notations and formulas were employed (eq. 1 to 9) to calculate the cutting energy. The calculation process is elaborated in Fig 1A.

Whereas, the potential energy stored in the pendulum rod when elevated to an angle  $\theta$ , was given by:

$$E_{s} = MgL = MgR (1-Cos\theta)$$
 (1)

The energy lost due to friction and air resistance by the pendulum arm in absence of any cutting process through an angle  $\theta_0$  from the equilibrium position was given by

$$E_f = Mgr [MgR (1-Cos\theta) - 1 - Cos\theta_0]$$
 (2)

$$E_f = Mgr [MgR (1-Cos\theta_0 - Cos\theta)]$$
 (3)

When the straw bunch is placed in specimen holding unit or bench vice, the pendulum arm attached with the three different cutting blades was allowed to fall in and change over an angle,  $\theta_c$  on the upswing after the cutting. The energy required for straw bunch cutting  $E_c$  was calculated by deducting initial potential energy of pendulum arm  $E_s$  with potential energy lost due to the friction  $E_f$  and air resistance  $E_o. This was expressed as:$ 

$$E_c = E_s - (E_f + E_o)$$
 (4)

$$E_c = MgR(1-Cos\theta) - [MgR(Cos\theta_0 - Cos\theta) + MgR(Cos\theta_c)]$$
 (5)

$$E_c = MgR[(Cos\theta_c - Cos\theta_0)]$$
 (6)

The rotational velocity of the blade was obtained by equating potential energy with rotational kinetic energy of the pendulum arm, given by:

$$Mgh = \frac{2Mgh (1-Cos\theta)}{I}$$
 (7)

$$2\Omega = \frac{2Mgr (1-Cos\theta)}{I}$$
 (8)

Cutting force of straw bunch was determined by dividing the cutting energy to the diameter of straw bunch (eq. no 9) (Sushilendra *et al.* 2016)

$$F = \frac{E_c}{D} \tag{9}$$

where  $E_c$ : Energy required for cutting of straw bunch, Kj; M, pendulum rod mass with blade, kg; G, gravitational value = 9.8 m/s<sup>2</sup>;  $\theta_o$ , dropping angle of pendulum arm or rod;  $\theta$ , angle at without cutting of straw bunch;  $\theta_c$ , angle of rod after cutting a bunch;  $\Omega$ , angular velocity of the blade, radian/s; I, moment of inertia of rod, kg/m<sup>2</sup> rad<sup>2</sup>; F, cutting force, N; D, diameter (mm).

Experimental setup: An automated pendulum impact cutter test setup was constructed and comprised a main frame, a swinging arm blade with adjustable length, a bench

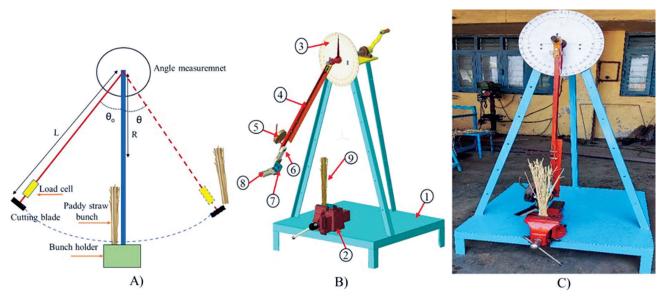


Fig 1 A) Schematic diagram of pendulum type impact cutter; B) CAD design- (1) Frame (2) Bench vise (3) Angle pointer (4) Adjustable pendulum arm (5) Dead weight (6) Load cell (7) Angle adjustment (8) Cutting blade (9) Straw bunch; C) Fabricated pendulum impact cut.

vice, an angular displacement indicator, a load cell (Make: Sun Robotics, Model: SYN–3603–1, Capacity–40 kg), and an Arduino Uno. Dead weights were affixed to the free end of the swinging arm, positioned just above the blade mounting platform, to modify the pendulum energy. The swing arm was secured in a fully upraised position (680 mm above the ground) through a locking mechanism. At the lower part of the main frame, a 150 mm bench vice was secured to grip the straw bunch. An angular displacement measuring system, consisting of a 420 mm diameter semi-circular dial with a needle, gauged the swing arm's angular movement.

a) Development of micro controller-based pendulum impact cutter: The constructed automatic recording pendulum impact cutter is depicted in Fig 1B and C, featuring an above said components. An arrangement for adding dead weight to the arm was implemented to overcome cutting resistance. The pendulum arm, measuring 1 meter in length and weighing 6.6 kg along with an additional 5 kg of dead weight, was employed for the experiments. The conventional practices of determining forces in the aforementioned impact cutter involve complex calculations. Therefore, the development of a microcontroller-based pendulum impact cutter becomes imperative for simplifying the determination of cutting forces. This setup includes a load cell, an Arduino Mega board, and an HX711 module, which were integrated into the system following an electrical circuit design. Additionally, a setup for load cell calibration was established under laboratory conditions.

Cutting energy experiments: Straw bunch was uprooted from the field with the determination of relevant parameters such as moisture content of the straw as 25±1.8%, average number of stems in single bunch was 23±2 and the diameter of the straw bunch was 50 mm, while the straw's length measured 300 mm. A complete factorial CRD (Completely Randomized Design) experiment was devised to evaluate the influence of blade parameters on cutting force of the straw bunch (Table 1).

Approach and shear angle setup: This angle adjustment setup contains two MS angles plates, one was fixed with load cell and other have to manage approach angle and shear

Table 1 Details of experimental design factors for measuring cutting force

Independent parameter	Levels	Unit	Details	Dependent				
Blade type	3		Blade 1 (SMS serrated)	Cutting force				
			Blade 2 (Cutter bar)					
			Blade 3 (SMS plain)					
Shear angle $(\beta)$	4	degree	0, 10, 20 and 30					
Approach angle $(\gamma)$	4	degree	0, 10, 20 and 30					
Experimental design Full factorial design								

angle. One plate was fixed to the load cell and other plate was in the L angle shape and free to rotate over the first plate. L angle have fixed holes at both adjacent surfaces according to the blade holes and made a slot of half circle, similarly slot was done on adjacent faces. Marking of required degrees was done on both sides of plate and adjustment was done.

Shear angle ( $\beta$ ): Shear angle is the angle made between the vertical plane and the cutting plane of stem. The shear angle depends on plant height. It was the most influencing angle for cutting of crop because it made the angle between the crop horizontal surface and cutting angle. Shear angle helps for better impact cutting to the crop.

Approach angle  $(\gamma)$ : It is the angle between central line of the blade and perpendicular to the direction of blades motion. Approach angle was the most important angle to cut the crop and angle made between the vertical plane and the blade. This adjustment was done to rotate the blade along the slot over the surface.

Blade type: Three different types of blades such as super straw management system (SMS) and crop harvesting blades were used for this study. All three blades were used for different purposes such as cutting, chopping and harvesting of crop. SMS serrated blade have large size of serration edge and SMS plain blade both have the cutting length of 100 mm, whereas the cutter bar having the cutting length of 80 mm. All three blades were made of heat-treated steel material as C80.

Calibration of load cell: A load cell having a maximum load-bearing capacity of 80 kg was selected for the measurement of straw bunch cutting force. It contains of strain gauges, which are secure onto a structural member that bends when weight is applied. The terminals from a load cell are coupled to the ADC (HX711 module), which alters the analog data to digital data (Selvan *et al.* 2022). Load cell, HX711 module, and Arduino Mega board (Fig 2) were linked to the system according to the electrical circuit for the calibration of load cell in laboratory conditions.

Validation of the developed sensor-based impact cutter: The validation of the newly developed impact cutter was performed through comparison with the traditional method, aiming to assess its accuracy in determining cutting force. Cutting energy values were ascertained using various combinations of independent variables and then compared between the two methods. The achieved results exhibited a notably lower relative error with the sensor-based impact cutter, signifying its capacity for actual determination of force.

## RESULTS AND DISCUSSION

Calibration curve of load cell: The load cell of 40 kg was connected to the Arduino Uno, and an initially known weight was placed on it to record the output. This procedure was repeated for various weights, and the output was recorded correspondingly along with the associated dead load. The calibration process, involving different loads and their corresponding outputs. The high coefficient of determination ( $\mathbb{R}^2 = 0.99$ ) observed during calibration

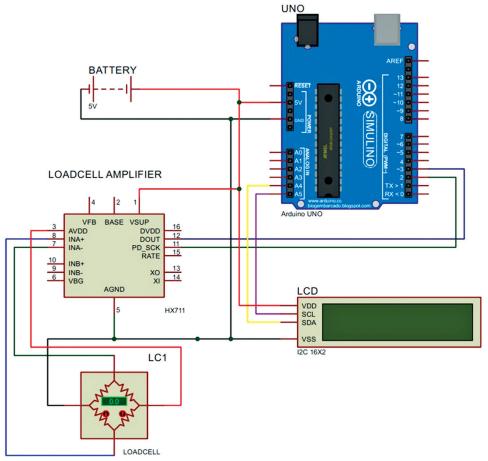


Fig 2 Circuit diagram of microcontroller unit.

signifies the load cell's linearity and suitability, ensuring an accurate fit.

The results of the ANOVA of the full factorial completely randomized design (FFCRD) experiment shows (Table 2), that models for all parameters were highly significant (P<0.01). It was found that the cubic model was the most appropriate model with the lack of fit as non-significant and good coefficient of determination (R<sup>2</sup> 0.93). Both parameters had a statistically significant effect (P<0.01) on cutting force. F-values denoted that blade type had comparatively greater impact on cutting force as compared to shear angle and approach angle. The linear interaction parameters have a significant effect at 5% level of significance.

Effect of shear and approach angle on the cutting force: The cutting force range displayed variations between 11.1 and 17.2 N, 13.4 and 19.5 N, and 20.0 and 25.8 N for SMS serrated, cutter bar, and SMS plain blade, respectively, with a shear angle of 0° and varying approach angles from 0° to 30° (Fig 3A). Initially, the cutting force decreased as the approach angle increased from 0° to 20°, after which it increased rapidly with further increments in the approach angle. Similar trends were observed by Jyoti *et al.* (2022). Among the blades, the minimum cutting force value was observed with the SMS serrated blade, measuring at 11.1 N.

Likewise, at a  $10^\circ$  shear angle, the cutting force exhibited a swift decline from  $0^\circ$  to  $20^\circ$ , followed

by a gradual increment as the approach angle further increased (Fig 3B) for all three blade types. Within this context, the cutting force range fluctuated between 7.9 and 14.6 N, 11.4 to 16.8 N, and 13.2 to 23.5 N for the SMS serrated, cutter bar, and SMS plain blade, respectively. These observations were made under a constant shear angle of 10° while varying the approach angle from 0° to 30°. The minimum cutting force for all the blades was observed at 20-degree approach angle i.e 7.9 N.

The graphical representation illustrates a distinct trend: as the approach angle increased from 0° to 10°, the cutting force experienced a rapid decrease, followed by a gradual increase and decrease as the approach angle varied from 10 to 20° (Fig 3C). Further cutting force slightly increase with increasing the approach angle

Table 2 ANOVA for the cutting force

			•	
Source	Sum of	df	Mean	F-value
	squares		square	
Model	3383.70	21	161.13	79.84**
A-Shear angle	47.20	1	47.20	23.39**
B-Approach angle	49.54	1	49.54	24.55**
C-Blade type	1495.39	2	747.69	370.49**
AB	9.35	1	9.35	4.63*
AC	17.93	2	8.97	4.44*
BC	70.73	2	35.36	17.52*
$A^2$	802.21	1	802.21	397.50*
$B^2$	666.16	1	666.16	330.08**
ABC	11.24	2	5.62	$2.78^{NS}$
$A^2B$	12.95	1	12.95	6.42*
A <sup>2</sup> C	15.11	2	7.56	3.74*
$AB^2$	6.20	1	6.20	$3.07  {}^{ m NS}$
B <sup>2</sup> C	7.45	2	3.72	$1.84  { m NS}$
$A^3$	93.54	1	93.54	46.35**
$B^3$	78.73	1	78.73	39.01**
Lack of Fit	71.66	26	2.76	1.52

<sup>\*\*</sup> Significant at 1 % level of significance; \* Significant at 5% level of significance; NS, non-significant.

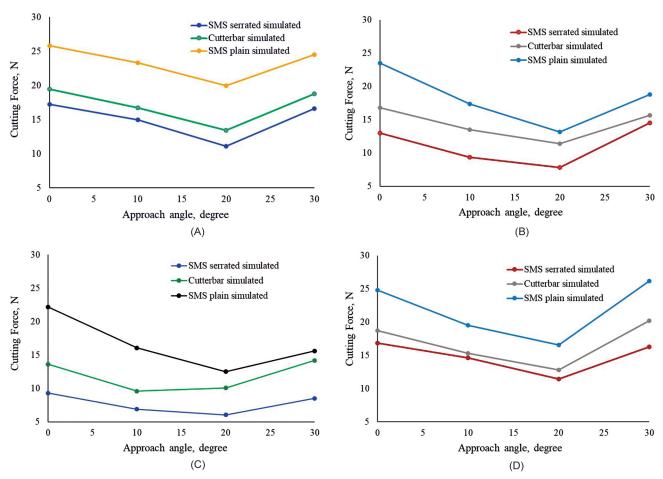


Fig 3 Cutting force observed at A) 0° shear angle; B) 10° shear angle; C) 20° shear angle; and D) 30° shear angle.

from 20 to 30°. This pattern was consistently observed across all three blade types, while maintaining a constant shear angle of 20°. Within this experimental configuration, the cutting force exhibited a range of variability. Specifically, it spanned from 6 to 9.3 N for the SMS serrated blade, from 9.6 to 14.2 N for the cutter bar, and from 12.5 to 22.5 N for the SMS plain blade.

Fig 3D illustrates a discernible pattern in which the cutting force exhibited a gradual decrease when the approach angle ranged from 0° to 20°, followed by a similar gradual increase as the approach angle continued to rise. This consistent behaviour was observed for all three blade types, while maintaining a fixed shear angle of 30°. Within this experimental configuration, the cutting force displayed a distinct range of values. Specifically, it spanned from 11.5 to 16.8 N for the SMS serrated blade, from 12.8 to 20.2 N for the cutter bar, and from 16.6 to 24.8 N for the SMS plain blade. These findings were derived under the condition of a constant shear angle of 30°, while systematically varying the approach angle from 0° to 30°. Similar trends were observed by Jyoti *et al.* (2022).

Contour plot for determination of cutting force at optimized shear and approach angle: Contour plot diagrams generated using Design Expert software depict the relationship between shear angle and approach angle, aiding in the determination of cutting force. The objective was to optimize the blade by minimizing the cutting force. The optimized value was found at a shear and approach angle of 20°, resulting in a minimum cutting force of 5.78 N for SMS serrated blade, 8.49 N for the cutter bar, and 11.82 N for SMS plain blade by the contour plot diagram. Allameh and Alizadeh (2016) observed 30° cutting angle and bevel angle as optimum values for paddy straw cutting.

Validation of automatic recording type pendulum impact cutter: Automatic recording type pendulum impact cutter validated by the traditional method which was calculated by the angle measured before and after dropping pendulum arm. Specific combinations (Table 3) were selected to determine cutting energy. Cutting energy varied from 180 to 512 J by the traditional method and 170 to 496 J by the newly developed automatic recording type method. The results indicate relative errors of 4.56 and 5.37%, 5.59 and 5.81%, and 5.13 and 5.70% for the SMS serrated, cutter bar, and SMS plain blades, respectively. This conclude that this procedure is the best for the determination of cutting force, cutting energy and specific cutting energy with less relative error.

The effect of blade configurations on cutting energy needs to be established to design an efficient straw chopping machine. In order to determine the blade parameters effect on energy required for cutting, an automatic recording type pendulum impact cutting test rig was fabricated with loadcell

Table 3 Comparison of cutting energy obtained by different blades

Blade type Shear Approach angle, angle, degree degree	Shear	Approach	Cutting 6	Relative	
	Traditional	Recording	error, %		
SMS serrated	0	0	361	345	4.56
	20	30	180	170	5.37
Cutter bar	10	20	242	228	5.59
	20	0	289	272	5.81
SMS plain	30	0	512	496	3.13
	10	30	398	375	5.70

and Arduino Uno. The energy required to cut straw bunch at varying blade type, approach ( $\gamma$ ) and shear angle ( $\beta$ ) was determined. The combination of 20° shear angle, 20° approach angle for SMS serrated blade yielded in minimum cutting energy of 120.6 J. Hence the treatment combination of  $\gamma$ 3 $\beta$ 3B1 can be best and optimized combination of the selected variables for design of tractor operated straw chopper cum mixer with counter rotating blades for chopping of straw. Patel *et al.* (2023) found SMS serrated blade as the optimum with minimum torque for cutting of paddy straw using rotary impact cutting principle.

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