Sugar Tech
https://doi.org/10.1007/s12355-024-01483-0

RESEARCH ARTICLE

Design, Development and Evaluation of Foot-Operated Sugarcane Sett Cutter

T. Mohanaselvan[1] · S. P. Singh[2] · Adarsh Kumar[1] · H. L. Kushwaha[3] · Susheel Kumar Sarkar[4] · Pratibha Joshi[5]

Received: 2 March 2024 / Accepted: 24 August 2024

Abstract
One of the important unit operations in sugarcane cultivation is sett cutting. The number of setts of three buds for normal planting per ha is 37,000–40,000, but farmers use up to 75,000 with two buds at narrow row-row distance. The study conducted in the selected villages indicated *in-situ* sett cutting and hand operated knife (500 g) is being used for sett cutting. Ergonomically study predicted the use of heavy muscle power for hand operated knife (*Kathhi*) during continuous cutting through impact force. Minor injury was also reported during sett cutting with a hand cutter. The chemical composition of the traditional sett cutting tool (*Kathhi*) for carbon content was analysed and very low carbon steel (carbon content $<0.15\%$) was found. That showed the need to sharpen the blade frequently. Considering the ergonomics principle and mechanical aspects, a foot-operated sett cutter was designed and developed that can be used by male and female subjects. This foot-operated sett cutter consisted of a platform, cutter, and pedal assembly. The weight of the developed unit is 28 kg. The capacity of the cutter was 830 and 673 setts h^{-1} in standing posture and 700 and 620 setts h^{-1} in sitting postures with male and female workers, respectively. The number of setts cut per hour was 10.84% and 9.80% higher with developed sett cutters with male and female workers compared to the traditional sett cutting tool (Kathhi). The force required to be applied by the subject was only for less than one second in both postures, only after the foot pedal returned through the spring attached to its lever arm. The operating cost per 1000 setts was 8% less with the developed operated foot-operated sett-cutter as compared to *Kathhi*. The developed sett cutter has the potential for adoption by the marginal and small farmers of the country as well as developing countries.

Keywords Sett-cutter · Gender-friendly · Low carbon content · Operating posture · Sett cutting rate

✉ S. P. Singh
singhsp65@gmail.com

1 Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi, India

2 AICRP On Increased Utilization of Animal Energy With Enhanced System Efficiency, ICAR-Central Institute of Agricultural Engineering, Bhopal, M.P., India

3 Division of Agricultural Engineering and Renewable Energy, ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan, India

4 ICAR-Indian Agricultural Statistical Research Institute, New Delhi, India

5 CATAT, ICAR-Indian Agricultural Research Institute, New Delhi, India

Introduction

Sugarcane is the main source of sugar (80%) globally and is a prominent cash crop in the country (Shukla et al. 2017) which is grown on around 2.8% of the gross cropped area of the country. The total acreage under sugarcane in the country is estimated to be around 5.9 million ha in the sugar season of 2022–23 (ISMA 2023). Farm operations required for sugarcane cultivation included land preparation (ploughing and harrowing), planting of cane (sett cutting, furrow opening, dropping of setts, fertilizer, insecticide, covering of furrows and planking), intercultural (hoeing and weeding), top dressing of fertilizers, earthing-up, propping, stubble shaving and harvesting (Singh and Gupta 2015). Mohanselvan (2023) found overall mechanization indicator of 0.162 based on 18 unit operations (Tillage, FYM application, Furrow making, Irrigation channel making, Sett cutting, Loading of setts, Transportation of setts to field, Dropping of setts, Planting, Irrigation, Weeding, Spraying, Earthing up, Detrashing, Fertilizer application, Harvesting, Loading, and Transportation) in sugarcane cultivation. The mechanization indicator varied between 0 and 0.74 while farm power availability in the selected villages of Tamil Nadu state was 4.13 kW. Out of 18 unit farm operations in sugarcane cultivation, thirteen listed operations (FYM application, irrigation channel making, sett cutting, loading of setts, transportation of setts to field, dropping of setts, planting, weeding, earthing up, detrashing, fertilizer application, harvesting and loading to truck/ tractor trailers) were performed manually with traditional methods. Among these operations, the sett-cutting operation was identified as one of the hazardous operations from the field observation. The traditional sett-cutting methods followed by the farmers involve tools and postures, which are not ergonomically suitable as the long hour sett-cutting is needed for sowing of one ha land. The requirement of sugarcane sett of three buds for normal planting is 37,000–40,000 per ha (Singh et al. 2020 and https://kvk.icar.gov.in/API/Content/PPupload/k0331_39.pdf). Mohanaselvan (2023) found during the data collection that farmers were using sett with two buds. The requirement of these setts per hectare was normally 75,000 at narrow-row spacing in the selected villages of Tamil Nadu state. Kumar et al. (2017) reported a minimum cutting force required to cut the sugarcane stalk diameter in the range of 12.5–17.5 mm was 104.08 N, while the maximum cutting force was 380.61 N required to cut for sugarcane having a diameter in the range 32.5–37.5 mm by cylindrical type cutting mechanism. In the vertical rotary cutting mechanism, the minimum cutting force required to cut a stalk having diameter of 12.50–17.5 mm, the cutting force for these size of sugarcane was 43.51 N and the maximum cutting force was 281.86 N for cutting sugarcane having a diameter in the range 32.5–37.5 mm. Kamaraj and Tajuddin (2023) developed a 3.7 kW diesel engine operated sett cutter. The weight of the developed machine was 123 kg, which indicates its use for *ex-situ* sett cutting while farmers mostly prefer *in-situ* cutting at field.

Sugarcane sett consists of node (growth ring, root band, leaf scar, bud and root primordial), internode and vascular bundles. Power power-operated machine to cut sugarcane setts has been developed at ICAR-IISR Lucknow for planting sugarcane (Singh and Singh 2006). Fungicidal treatment of setts is also done simultaneously. Circular saw blades with sharp and finer teeth were used to cut setts. The developed sett cutter can be operated by electric motor or diesel engine or tractor. An electric motor operated sett cutting machine was developed at TNAU, Coimbatore. It is made up of a circular saw directly coupled to an electric motor of 0.5 hp. Through this cutter, 3600 sets can be prepared within an hour by employing 3 individuals (Rana et al. 2021). The developed electric operated sett cutter can be used in one place, i.e., stationary operation. Heavy weight available power operated sett cutters could not be easily transported to the site where farmers need them as farmers are practicing *in-situ* sett cutting. The movement of the farmer's hand at sitting posture during sett cutting with a traditional tool, i.e., *Kathhi,* goes above acromial height, which is not recommended ergonomically (ICAR 2013). Considering these points in mind and also to enhance human comforts with efficiency, a foot-operated sett cutter was designed and developed with the consideration of ergonomic parameters (anthropometric and strength) of the Indian farm workers.

Materials and Methods

The foot-operated sugarcane sett cutter was designed and fabricated in the Research Workshop of the Division of Agricultural Engineering, ICAR—Indian Agricultural Research Institute (IARI), New Delhi. Development of the sett cutter was based on the data related to the specific cutting resistance of sugarcane, the diameter of sugarcane, body parts that have maximum muscle power and material characteristics of manual cutting tools used by farmers. The design, development procedures and evaluating methods are narrated in different sub-headings.

Specific Cutting Resistance of Sugarcane

A Texture Analyser (Make: Stable Micro Systems Ltd, United Kingdom, Model: TA.HD plus C, Force capacity: 7.5 kN, Force resolution: 0.001 N, Speed range: 0.01–20 mm/s, Maximum aperture: 550 mm, Distance resolution: 0.001 mm and Data acquisition rate: 2000 pps) is a high force universal testing machine and used for a texture measurement system that moves up or down to compress or stretch a sample. The travelling arm is fitted with a 2.45 kN load cell and records the force response of the sample to the deformation that is imposed on it. Force, distance and time data were collected and presented as a curve on a graph, which, when analysed, indicated the texture of the sample. Fixtures were attached to the Texture Analyser base and arm. Depending upon the chosen probe/fixture, the texture analyser performs compression, extension, cutting, extruding, bending and shearing tests. The experiment was conducted in the Food Processing laboratory of the Division of Agricultural Engineering, ICAR-IARI, New Delhi. The sugarcane with a 30 mm diameter was selected as per availability of sugarcane and a cutting test was performed with three different speeds (10, 15 and 20 mm s^{-1}) of blades and specific cutting resistance (kN mm^{-2}) and the energy required (J) to cut 10 setts from sugarcane for each speed were calculated on the cane of 30 mm diameter only.

Throat Clearance and Cutting Angle

Throat clearance and cutting angle were the important parameters for the design of a proposed foot-operated sett cutter. Hence the diameter of sugarcane was studied for getting the required data. The sugarcanes were procured from the locally available market and farmers. A digital vernier caliper (Make: Mitutoyo, Least count: 0.01, Size: 150 mm) was used to measure the diameter of sugarcane used for the texture analyser and for developed foot-operated sett cutter.

Human strength

The foot-operated sett cutter is to be operated by human beings (men and women). Thus, the information on human strength was necessary input. Human strength measures an individual's physical capabilities, especially those that permit a person to exert force or sustain external loading without inflicting personal injury (Mital and Das 1987). It is very important to know the maximum strength capabilities of humans to design the different equipment and machines to match the worker's capabilities and to work safely without injury. Knowledge of worker strength is crucial in designing tools, equipment and machines to improve the human work interface. Singh et al. (2019) also focused on the need for ergonomic interventions that enable operators to increase their productivity with reduced drudgery. As the equipment is manually operated, the energy required to cut the sugarcane and the maximum force exerted by the body part must be considered. The force exerted by the foot (Right foot strength of 5th percentile Indian male and female in sitting—163 and 101 N, respectively) is greater than the force exerted by the hand (push and pull strength of male and female with a single hand in sitting—49 and 31 N, respectively), ICAR (2013). Though sugarcane sett cutting with a traditional tool (*Kathhi*) is by impact action of hand but ergonomically hand should not go above acromial height (ICAR 2013). Therefore, the mode of operation of the machine was foot operated. This also made hands free, which facilitated holding the sugarcane firmly and reduced the chance of injury.

Material Characteristics of Manual Cutting Tools Used by the Farmers

The cutting tool is another very important parameter for the design of this cutter. Hence, the tool (*Kathhi*—Fig. 1a) that the farmers of Tamil Nadu state use was procured. The length and width of knife were 310 mm and 50 mm, respectively. The thickness of the blade was 3 mm and the weight of *Kathhi* was 500 g. An analysis of the metallurgical composition of the material was determined. The sample from the procured tool was prepared in the workshop of the Division of Agricultural Engineering, ICAR-IARI New Delhi (Fig. 1b) and was tested for its chemical composition and mechanical properties through "ISO/IEC 17025: 2017 accredited laboratory by National Accreditation Board for Testing and Calibration Laboratories in New Delhi.

Design of Sett Cutter

Foot operated sett cutter was designed with various components, such as a platform, cutting blade, cutting section, groove, pivot joint, bearing holder shaft, ball bearing, foot pedal, *U*-type joint, ram-type guiding shaft, guiding shaft holder, cylinder-type guide, blade arm holder and compression springs.

Platform height was designed based on knee height sitting (416 mm for 5th percentile Indian female worker) plus elbow rest height (161 mm for 5th percentile Indian female worker), Gite et al. (2019). Considering the easy movement of the elbow, the height was fixed to 600 mm. Computer-aided design (CAD) diagram of a foot-operated sett cutter was made first on Solid works-2016 software. The rectangular shape of the platform was adopted due to the requirement of setts having two buds and holding lengthy sugarcane. The sett cutter plate form had four legs of 600 mm in height. Two cross members were welded to the legs to attach the bearing

Fig. 1 Manual cutting tool used by farmers for sett cutting

(a) Sett cutting knife (Kathi) **(b) Sample prepared for analysis**

holder shaft. The length of the cross member is 450 mm. The cross member for attaching the pedal assembly to the platform has a length of 550 mm. Thus, the platform has a dimension of 600 × 500 mm. All the legs and cross members were made from mild steel square pipe of 25 × 25 mm.

The specific cutting resistance of sugarcane was calculated as per a laboratory study conducted on a texture analyser in different blade speeds of 10 mm s^{-1}, 15 mm s^{-1} and 20 mm s^{-1}. Considering the maximum specific cutting resistance with the minimum blade speed of 10 mm s^{-1} of sugarcane (1.66 N mm^{-2}), the cutting blade thickness was selected as 3.5 mm, similar to that used by the farmers. The mild steel blade was adjusted according to the designed dimension of the sett cutter. The additional weight of 400 g was added for cutting smoothly. The cutting blade has a length of 150 mm and a width of 40 mm. The length of the cutting edge is 80 mm, the width of 5 mm and the thickness of 0.3 mm. The cutting arm had a length of 380 mm, inner diameter and outer diameter of 15 and 20 mm.

The shape of the cutting section is cuboid with length, width and height of 320 mm, 60 mm and 50 mm, respectively. The groove is provided in the cutting section for a complete cut of setts. The groove section was formed by attaching two rectangular flats of 95 mm in length, 25 mm in width and thickness of 5 mm. Thus, the total length of the cutting assembly is 500 mm and weighs 800 g. The wood was selected as a material for making the cutting section with the consideration of ease of attachment with the platform and to avoid damage to the setts.

The pivot joint was L-shaped with a semi-circular edge. The length and height of the L sections were 35 mm and 25 mm, respectively. The diameter of the semi-circular edge is 30 mm.

The heel breadth and foot breadth of Indian farm workers were considered for determining the dimensions of a foot pedal. 95th percentile of Indian male workers was considered as space criteria and values for heel breadth and foot breadth were 73 mm and 110 mm, respectively. The pedal width of 180 mm was adopted. The mild steel flat of 6 mm thickness was selected to fabricate the foot pedal. The overall dimension of the foot pedal is 560 mm × 180 mm.

The ball bearing with an inner diameter of 20 mm (number 6004) was provided to have a free movement of the pedal. Therefore, a bearing holder shaft of 20 mm in diameter and length of 560 mm was selected to hold the bearings. The shaft material was mild steel.

The compression springs were used to assist frequent up and down movement of the sett cutter during sett cutting. Dimensions were calculated as per Eq. (1).

$$\tau = K_S \frac{8PC}{\pi d^2} \quad (1)$$

where

τ is Shear strength = 400 N/mm^2,
G is Modulus of rigidity = 8×10^4 N/mm^2,
P = Load acting on the spring in N and
C = Spring constant = 5,
d = Wire diameter in mm.

Foot strength (right) sitting for 5th percentile of Indian female agricultural workers = 98 N (Gite et al. 2019).

Two springs are used so the load is equally acting on both of the springs;

The load acting on one spring = 49 N

$$\tau = K_S \frac{8PC}{\pi d^2}$$

$$K_S = \frac{4C - 1}{4C - 4} + \frac{0.615}{C}$$

$$K_S = \frac{4 \times 5 - 1}{4 \times 5 - 4} + \frac{0.615}{5}$$

$$K_S = 1.31$$

$$400 = 1.31 \frac{8 \times 49 \times 5}{3.14 \times d^2}$$

$$d^2 = 4.04$$

$$d = 2.00$$

A standard wire diameter of 2 mm was selected,

$$C = \frac{D}{d} (D = \text{ Coil diameter})$$

$$D = 5 \text{ x } 2 = 10 \text{ mm}$$

Wire diameter (d) and coil diameter (D) are 2 mm and 10 mm, respectively.

The number of turns in the spring is determined using Eq. (2).

$$\delta = \frac{8PC^3 n}{Gd} \quad (2)$$

where

δ = Deflection in mm,
G = Modulus of rigidity = 8×10^4 N/mm^2,
P = Load acting on the spring in N and
C = Spring constant = 5,
d = Wire diameter in mm,
n = Number of turns.

Assuming the deflection = 100 mm to blade touch the cutting section without clearance,

Thereby obtaining a complete cut

$$100 = \frac{8 \times 49 \times 5^3 n}{8 \times 10^4 \times 2}$$

$$100 = 0.3026 \times \text{ n}$$

$$n = 330 \text{ turns}$$

for the square and grounded end, total no of turns $(N) = n + 2$

$$N = 332 \text{ turns}$$

Free length is calculated as per Eq. (3)

$$L_F = \text{Nd} + \delta_{max} + 0.15\delta_{max} \quad (3)$$

The actual length of a spring when no force is being applied to it is known as free length (L_F).

$$L_F = 332 \times 2 + 100 + 0.15 \times 100$$

$$L_F = 779 \text{ mm}$$

The derived dimension was simulated through spring calculator software and various steps were followed to simulate the designed spring.

Step 1: Selection of spring type and end type of the spring.

Step 2: Enter the designed dimensions of the spring.

Step 3: Process of review was performed.

Step 4: Feedback for designed condition.

As per the simulation results, the spring dimensions were refined and finalized dimensions were obtained. A standard available mild steel shaft of 20 mm diameter was selected to place the springs on the shaft, so the spring coil diameter was adjusted according to the shaft diameter. The free length was reduced to minimize the buckling, considering the designed platform height. The final dimensions derived from the design procedures were 2 mm of wire diameter, 20 mm of coil diameter, 300 mm free length and 66 numbers of active turns.

The simulation was done with the final dimensions of spring. The spring was mounted over the shaft of 14 mm diameters and a 300 mm length, to minimize the buckling. Each side motion was restricted with a guiding shaft holder. From the load check, it was concluded that the required deflection of 100 mm can be obtained using the designed spring.

The *U*-type joint connects the spring assembly with the foot pedal. The *U* joint was made up of a 40 mm width mild steel plate having a thickness of 6 mm.

The ram-type guiding shaft of 14 mm diameter and 470 mm length was made to insert a spring. The main purpose of this guiding shaft is to prevent the springs from buckling. The guiding shaft holder and cylinder-type guide limit the motion of springs in the guiding shaft. The guiding shaft holder had a length of 100 mm, a width of 50 mm and a thickness of 5 mm.

The cylinder-type guide had a 14 mm inner diameter and a 30 mm outer diameter with a 40 mm guide height. The L-shaped blade arm holder was welded to the guiding shaft holder to connect the blade arm to the pedal assembly. The 20 mm × 20 mm mild steel angle of 135 mm length was used to fabricate the blade arm holder. A cylinder-type guide was selected to enable the sliding motion of the ram-type guiding shaft.

Patil and Patil (2013) reported Eq. (4) for getting a suitable cutting angle.

$$\text{Tan } \infty = \frac{\text{opp}}{\text{adj}} \quad (4)$$

$$\text{Tan } \infty = \frac{7.3\text{cm}}{15\text{cm}}$$

$$\infty = \text{Tan}^{-1}(0.486)$$

$$\text{Cutting angle } \infty = 25.9°$$

Therefore, the cutting angle was kept at 26°. Maximum sugarcane diameter was the criteria for deciding the throat clearance was kept at 40 mm.

Fabrication of Foot-Operated Sett Cutter

The different components were fabricated as per CAD drawings (Fig. 2) in the research workshop of the Division of Agricultural Engineering, ICAR-IARI, New Delhi. The sett cutter platform had four legs. Two cross members were welded to attach the bearing holder shaft to the legs. Another two cross members were also welded to the platform for attaching the pedal assembly to the platform. A mild steel plate was provided beneath the legs of the platform for its stability.

The arm of the cutting blade was welded to the cutting blade for the force application. The pivot joint was attached to the cutting section to connect the blade and cutting section. The pivot joint was attached to the wooden cutting section by wood screws. The cutting section made up of wood was connected to the plate form with the help of bolts and nuts. The groove sections were attached to the cutting section with wooden screws.

The bearing holder shaft was welded to the cross members attached to the legs. The ball bearing housing and bearing were inserted into the shaft. The foot pedal was attached to the bearing housing with the help of bolts and nuts. The *U*-type joint welded to the food pedal connects the spring assembly and foot pedal. The ram-type guiding shaft was made by machining operation (lathe) to insert a spring. The

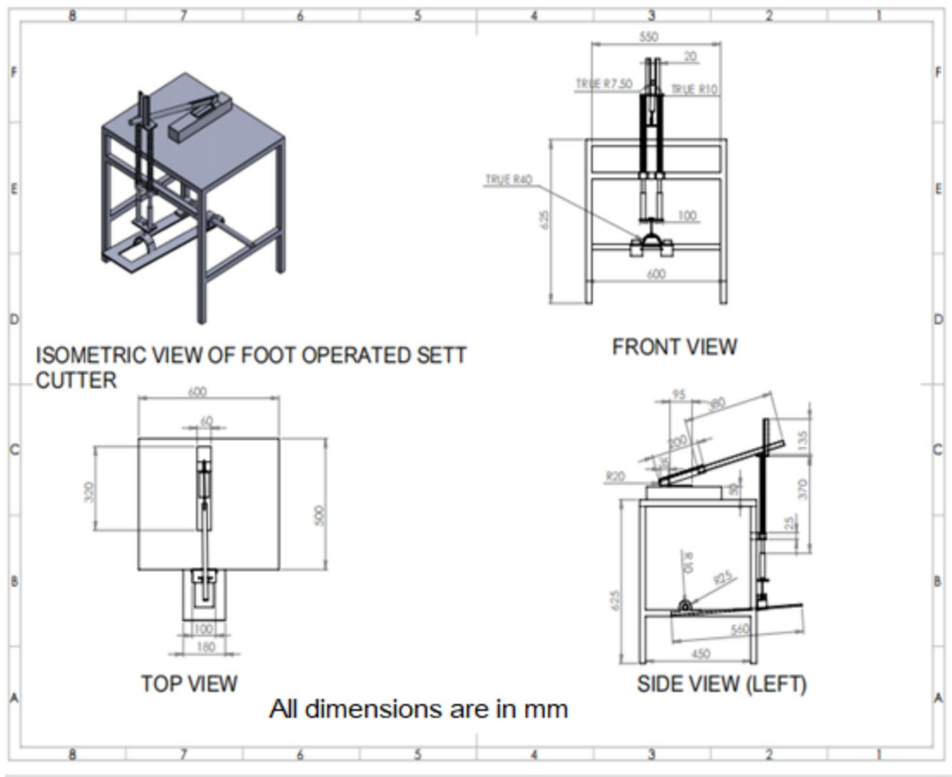

Fig. 2 Computer-aided design diagram with isometric, front, top and side views of designed foot-operated sett cutter

guiding shaft holder limits the motion of springs in the guiding shaft. The cylinder-type guide was welded to the sett cutter platform to enable the sliding motion of the guiding shaft with spring up and down while the pedal force was applied. The L-shaped blade arm holder was welded to the guiding shaft holder to transmit the force to the blade arm from the pedal assembly.

The developed foot-operated sett cutter had a platform, cutter, and pedal assembly (Fig. 3). The specification of the developed foot-operated sett cutter is given in Table 1.

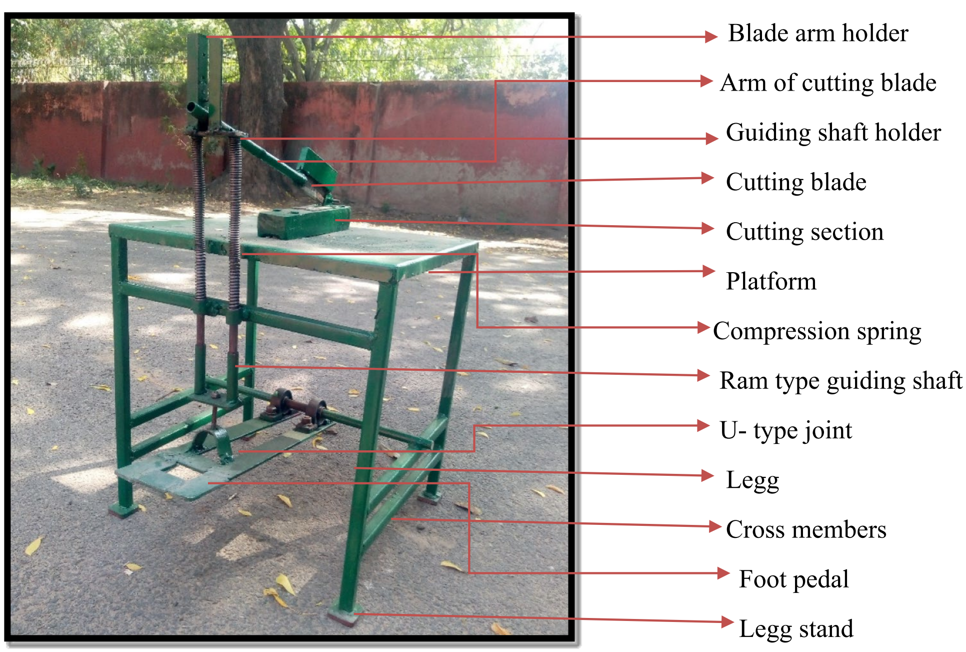

Fig. 3 Foot-operated sett cutter

Table 1 Specifications of developed foot-operated sugarcane sett cutter

Particular	Length (mm)	Width (mm)	Height (mm)	Diameter (mm)	Thickness (mm)	Shape
Cutter assembly						
Cutting blade	150	40	–	–	3.5	Rectangle
Cutting edge	80	5	–	–	0.3	Rectangle
Arm of cutting blade	380	–	–	15(ID) 20(OD)	–	Hollow cylinder
Pivot joint	35	–	25	25	3	L shape with semi-circular edge
Cutting section	320	60	50	–	–	Cuboid
Total length of cutting unit, mm	500					
Pedal assembly						
Foot pedal	560	180	–	–	6	Rectangle
Ram-type guiding shaft	470	–	–	14	–	Cylindrical shaft
Cylinder type guide	–	–	40	14(ID) 30(OD)	–	Hollow cylinder
Blade arm holder	135	20	20	–	5	L-angle
Sett cutter platform						
Platform	600	500	–	–	–	Rectangle
Legg stand	–	40×40	–	–	–	Square plates
Overall dimension	600	500	625	–	–	–
Compression springs	Coil dia—20 mm, Wire dia—2 mm, Length—300 mm Pitch—2.5 mm, Number of turns—66					
Overall dimension of sett cutter	600	500	940	–	–	–
Maximum throat clearance, mm	40					
Cutting blade angle, °	25.9					
Weight of machine, kg	28					
Pedal stroke length, mm	200					

Performance Evaluation of Developed Foot-Operated Sett Cutter

The performance evaluation of the developed foot-operated sett cutter was conducted in the Division of Agricultural Engineering, ICAR-IARI, New Delhi, India. The sett cutter was operated by male and female subjects (workers) in standing and sitting postures. The number of subjects in each category was two (i.e., male and female). The height and weight of the subjects of male subjects were 169–172 cm and 55–60 kg, respectively, while corresponding values for female workers were 157–160 cm and 46–49 kg.

The fresh sugarcanes from the nearby village were procured for performance evaluation. Procured sugarcane was segregated into three categories as per their diameters, i.e., 20, 25, and 30 mm for experimentation. The sugarcane diameter and machine parameters (number of setts per minute, time taken for single complete cut, number of incomplete setts) were measured during each experiment as per standard techniques/ methods. Weighing balance (Analogue type, GVC make, 130 kg capacity, Division: 1 kg), anthropometer (in-house developed using normal measuring tapes with least count of 1 mm) stopwatch (Make: Kardiff, L.C: 1/100 s) Vernier calliper and steel scale (300 mm, LC: 1 mm) were used during the performance evaluation. Sugarcane setts cutting was done with developed machine in standing and sitting postures by male and female workers and it was also cut using traditional knife for comparative study.

Statistical Analysis

The design of the experiment for conducting the experiment on texture analyser for cutting the cane was completely randomized design (CRD). The ANOVA between speed and force was analysed using the SAS system. The data obtained during the performance evaluation of the developed foot-operated sugarcane sett cutter was analysed statistically with a significance level of 5% using paired t-tests to compare the performance in standing and sitting posture with males and females.

Results and Discussion

Sugarcane-Specific Cutting Resistance

The relationship between cutting blade speed and force per sett cutting and energy required to cut a cane is shown in Fig. 4. It is evident from the figure that the maximum force was 1175.79 N at a speed of 10 mm s^{-1} and the minimum was 1105.15 N at 20 mm s^{-1}. Force per mm^2 cane followed a decreasing trend (1.66 N mm^{-2}) with blade speed from 10 m s^{-1} to 20 m s^{-1}. This may be due to an increase in cutting speed with a texture analyser. The energy required to cut a single cane of 30 mm diameter was also high (35.27 J) at 10 m s^{-1} and low energy was 33.15 J at 20 m s^{-1} (Fig. 4). This decreasing trend with an increase in speed may be due to an increase in force at high speed. The resistance force decreases with increase in linear speed of the cutting blade from 10 mm s^{-1} to 20 mm s^{-1}. Bastian and Shridar (2014) also found a specific cutting resistance of 1764.56 kN m^{-2} at the bottom side of cane, having a 40 mm diameter and 957.48 kN m^{-2} at the top side of the cane having 35 mm diameter between internodes. El-Nakib et al. (1996) also found the cane stalk hardness was 775 N for the average diameter of 2.3 cm of Egyptian sugar cane variety C-9.

To analyse and compare the means of blade cutting speed and force required to cut a set of sugarcane using a texture analyser was performed using ANOVA and no significant difference amongst speed and force was found. This may be due to the properties of selected cane.

Material Characteristics of Manual Cutting Tools Used by Farmers

From the chemical analysis, the carbon content of the blade material was $< 0.15\%$. So, the steel category falls under dead steel. Due to its low carbon content, the blade of the tool material needs to be sharpened frequently for efficient cutting operation. This also indicates the tendency to increase in muscular force requirement on worker's hand. From lab experiment on sugarcane-specific cutting resistance indicated the lesser force (1105.15 N) at 20 mm s^{-1}. Szabo et al. (2001) also reported an increase in cutting force by 30% after 13 and 21 cycles of the high- and low-force jobs, respectively. This way, the traditional knife with very low carbon steel used by the farmers for sett cutting may be harmful to them in the long run because of bluntness. Claudon and Marsot (2006) also reported that the use of a badly sharpened knife can increase upper limb biomechanical stresses.

The hardness value was 82 HRBW at 980.665 N load and strength was 515 N mm^{-2}. With this consideration, the blade material was selected as mild steel for the foot-operated sett cutter.

Performance Evaluation of Developed Sett Cutter

The developed foot-operated sett cutter was evaluated with male and female subjects. Sitting and standing postures were adopted during the performance evaluation of the sett cutter for both subjects to assess the ability of subjects to operate the developed cutter. Data obtained during the evaluation with male subjects are given in Table 2. It is clear from that output (number of setts cut per hour) with male workers in standing and sitting postures was 830 and 700, respectively. Corresponding values of the number of setts cut per h with female workers were 673 and 620 in standing and sitting postures. In contrast, the time taken for cutting single setts was the same (1.2 s and 1.7 s) for male and female

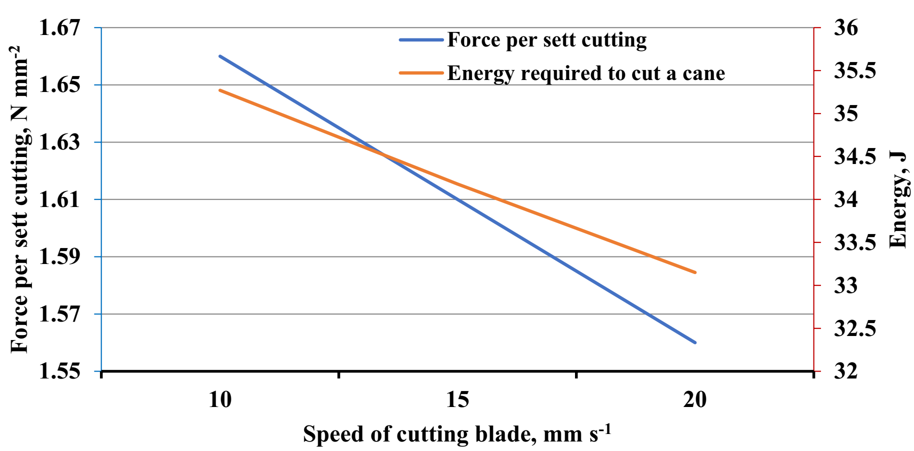

Fig. 4 Effect of speed of the cutting blade on force and energy required to cut a cane

Table 2 Performance in sett-cutting with developed foot-operated cutter in standing and sitting postures by male and female

Gender	Operational posture					
	Standing			Sitting		
	Setts cut per min, No	Time taken for single cut, s	Number of setts per h	Setts cut per minute, Number	Time taken for single cut, s	Number of setts per h
Male	13.8 (0.8)	1.2 (0.5)	830 (50)	11.7 (0.8)	1.7 (0.1)	700 (47)
Female	11.2 (0.9)	1.2 (0.5)	673 (54)	10.3 (0.7)	1.7 (0.1)	620 (40)

() = standard deviation

subjects in standing and sitting postures, respectively. It is also observed that the standard deviation was also same. The time taken to cut a set took 0.666–0.819 s and 0.666–1.033 s by male and female subjects in standing and sitting postures, respectively. It is also observed that the clear cut of cane is obtained at less than 1 s time. The lower output with female workers in both postures may be due to the additional time taken in lifting and arranging the cane for cutting than male workers. Data also indicates the operation of the developed machine is easier for male and female workers, which confirms the finding of Singh et al. (2012) that ergonomic consideration in the design of the machine helped the workers with ease in operation. The number of strokes in sett cutting per minute with male and female subjects was about 14 and 11, respectively, in standing posture, while the number of strokes was 12 and 10 in sitting posture for male and female subjects. The strokes in developed cutters were lower than the strokes required (68–86 per minute) by farm women in pedal threshers for threshing of paddy, as studied by Singh (2006) and Mohanty et al. (2008). This indicates towards lighter workload of subjects in the operation of developed foot-operated cutter than pedal operated paddy thresher. In the developed cutter, a person has to put compression force only for cutting that too for less than 1 s duration while the pedal returns with spring attached to its lever arm.

The paired t-test for the number of setts cut per hour with male subjects is significantly (18.6%) higher in standing posture than sitting posture at a t-stat value of 5.307228 for the confidence level of 95%. Similarly, it is also observed with female subjects that the number of setts cut per hour is significantly (8.55%) higher in standing posture than in sitting posture at a *t*-stat value of 2.604123. The time required to cut with male and female subjects was also significantly less in standing posture than in sitting posture (Table 2).

Comparative Analysis of Developed Cutter with the Traditional Method of Sett Cutting

The same male and female subjects also cut setts of sugarcane with traditional sett cutting tools, i.e., manual knife (*Kathhi*). The operation of sett cutting in the traditional method uses impact cutting that utilizes hand muscle power in traditional sett cutting operations. Data obtained during the operation with traditional tools is given in Table 3. It is clear from the table that the average number of setts cut per h was 740 with male subjects and 607 with female subjects.

Paired *t*-test analysis for the number of setts cut per hour with male subjects in traditional sett cutting (Table 3) and developed foot-operated sett cutter (Table 2) showed a significantly (10.84%) higher number of sett cut per h with the developed sett cutter than the traditional method at a confidence level of 95% and t-stat value of 4.36.

Results obtained from paired *t*-test for number of setts cut per hour with the female subject also showed significantly (9.80%) higher output number of setts cut per hour with the developed sett cutter than the traditional method at a confidence level of 95% and *t*-stat value of 2.3652. The observed data clearly inferred that the use of the foot for sett cutting is found better mode than using the hand. Dewangan et al. (2010) reported the highest muscular strength for the right leg (363.2 N) and the lowest for the left-hand push strength (112.4 N).

Human energy is generally applied through arms, hands, back and legs. Adaptations within the oxygen transport

Table 3 Performance data of male and female subjects in traditional sett cutting operation

Particular	Male			Female		
	Number of setts per min, Number	Time taken for single cut, s	Number of setts per hour	Number of setts per min, Number	Time taken for single cut, s	Number of setts per hour
Average value	12	1.44	740	10	1.53	607
S.D	0.50	0.05	30.00	0.93	0.09	55.68

Table 4 Cost of operation of the developed foot-operated sett cutter and traditional sett cutting knife

Cost of operation	Formulas	Foot-operated sett cutter	Traditional sett cutting knife (Kathhi)
Fixed cost (Rupees per hour)			
Cost (*C*), Rs	–	3500	300
Average cost (*A*), at 10% salvage value (*S*)	$A = \frac{C+S}{2}$	1925	165
Depreciation (D) at 10% salvage value (*S*)	$D = \frac{C-S}{L\times H}$	0.88	0.20
Interest (*I*) at 14%	$I = \frac{A\times i}{100\times H}$	0.60	0.05
Taxes, Insurance and housing @ 3%	$T, I \text{and} H = \frac{3\times A}{100\times H}$	0.13	0.01
Total fixed cost (*A*)		1.61	0.26
Variable cost (Rupees per hour)			
Repair and maintenance cost (*R* and *M*) (Assumed as 10% of the initial cost of the machine per year)	$R \text{ and } M = \frac{10\times C}{100\times H}$	0.78	0.06
Operator cost (As per Tamil Nadu state government norms)	Rs. 400/8	50	50
Total variable cost (*B*)		50.78	50.06
Total cost of operation (Rupees per hour)	$A+B$	52.39	50.32
Operating cost per 1000 setts (Rupees per 1000 setts)		62.87	67.93

system generally limit the maximal power produced by legs. On the other hand, the capacity for arm exercise is dependent upon the amount of muscle mass engaged (Shephard 1967). Owing to these limitations, a person can generate four times more power (up to 200 W) by pedalling than by hand cranking (Wilson 1986). Pedal power enables a person to drive devices at the same rate as that achieved by hand cranking but with far less effort and fatigue. Pedal power also enables to drive of devices at a required rate depending on the need of power. Potedar et al. (2011) reported that leg muscles are better suited to provide manual power on a sustainable basis in cycling and dual foot pedal mode, as leg muscles were primarily used.

The cut setts obtained with a cutter were clear and sharp without bruising (Fig. 4), as observed cut setts with a manual knife (*Kathhi*). Another advantage of a foot-operated sett cutter was also avoiding static muscle loading as in the case of manual cutting due to holding of 500 g *Kathhi*.

Cost Economics of Developed Foot-Operated Sett Cutter

The cost of a developed foot-operated sett cutter was found to be Rs. 3500 and the cost of a traditional sett cutting knife (*Kathhi*) is Rs. 300. Working hour of the developed sett cutter was assessed based on planting seasons. Three planting seasons, namely Autumn (October), Spring (February–March) and Summer (April–May), are followed in a year in Tamil Nadu. The total number of days per annum for sett cutting is 90 days and sett cutting operation is done for five hours in a day. So, total working hours are 450 h per annum. The life of the fabricated machine is assumed as 8 years and the life of a traditional sett cutting knife is 3 years as per farmers' data. The cost of operation with both methods is shown in Table 4.

It is found from the table that the cost of operation per hour of a developed foot-operated sett cutter was Rs. 52.39, while it was Rs. 50.32 with a traditional sett cutting knife. The operating cost per 1000 setts was 8% less with the developed foot-operated sett-cutter. Developed foot-operated sett cutters can be successfully operated by male and female workers, while only male workers perform the traditional cutting. Cutting with the machine also avoided any injury to a worker because fingers/hands are far away from the cutting unit and hands are free to hold the cane firmly while cutting. Therefore, the developed sett cutter is farmer-friendly and has potential to be adopted by the farmers of marginal and small categories in addition to developing countries.

Conclusion

The sugarcane-specific cutting resistance was measured using a texture analyser and the relationship of force per sett cutting and energy required with the speed of the cutting blade was developed. The force and energy requirement was high (1.56 N mm^{-2} and 33.15 J) at low blade speed (10 mm s^{-1}) and vice versa. The chemical composition of the traditional sett cutting tool was analysed and it was identified as low carbon steel (carbon content $< 0.15\%$). So, mild steel was selected as a blade material. The foot-operated sett cutter was developed as per the consideration of anthropometric data and strength data of agricultural workers for providing a portable tool for sett cutting. This equipment consisted of a platform section, pedal assembly and cutter assembly. The weight of the equipment was 28 kg. The overall dimensions (l × w × h) of the cutter were 600 × 500 × 940 mm, respectively. The performance of the developed foot-operated sett cutter was assessed with male and female subjects (workers) in sitting and standing postures to enable the workers to adopt any posture while cutting with the machine. The parameters assessed during its performance evaluation were the number of setts per minute and time to single cut. Visual observations were also made for a clear cut of setts by developed cutter. Comparative analysis also had been done to compare the performance in different postures and further, it was also compared with the traditional method of sett cutting. The capacity of the cutter was 830 and 673 and 700 and 620 setts per h in standing and sitting postures with male and female workers, respectively. The number of setts cut per hour was 10.84% and 9.80% higher with developed sett cutters with male and female workers compared to the traditional sett cutting method. The force required by the subject was only for less than a second in both postures after that foot pedal returned through spring attached to its lever arm. The operating cost per 1000 setts was 8% less with the developed operated foot-operated sett-cutter. The developed sett cutter has potential for adoption by the marginal and small farmers of the country.

Author Contributions 1. Primary data collection, analysis and writing of manuscript. 2, 3, 4. Analysis of data, interpretation of results and writing of manuscript. 5 and 6. Statitistical analysis of data and social aspects for the paper.

Funding Institute funded ie., ICAR-Indian Agricultural Research Institute, New Delhi.

Data Availability Data are available with Mr. Mohanaselvan T.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Bastian, J., and B. Shridar. 2014. Investigation on mechanical properties of sugarcane stalks for the development of a whole cane combine harvester. *Indian Journal of Applied Research* 4 (9): 1–3.

Claudon, L., and J. Marsot. 2006. Effect of knife sharpness on upper limb biomechanical stresses—a laboratory study. *International Journal of Industrial Ergnomics* 36: 239–246. https://doi.org/10.1016/j.ergon.2005.11.007.

Dewangan, K.N., G. Gogoi, C. Owary, and D.U. Gorate. 2010. Isometric muscle strength of male agricultural workers of India and the design of tractor controls. *International Journal of Industrial Ergonomics* 40 (5): 484–491. https://doi.org/10.1016/j.ergon.2010.05.008.

El-Nakib, A.A., F. El-Sahrigi, and H.A. El-Mawla. 1996. Physical properties of sugar cane: Their relation to mechanization. MSAE exploration of modem tech. *4th Conference of MISR Society of Agricultural Engineering* 13 (4): 63–78.

Gite, L.P., K.N. Agarwal, C.R. Mehta, R.R. Potdar, and B.S. Narwariya. 2019. Handbook of ergonomic design of agricultural tools. In *Equipment and workplaces*, 218. New Delhi: Jain Brothers.

ICAR. 2013. *Handbook of agricultural engineering*, 774. New Delhi: Directorate of Knowledge Management in Agriculture Indian Council of Agricultural Research.

ISMA. 2023. Indian Sugar Mills Association 2022–2023. https://www.indiansugar.com/NewsDetails.aspx?nid=57133#:~:text=India%20is%20the%20world's%20second,the%20preceding%202021%2D2022%20season.

Kumar, S., S. Pal, S. Khandai, M. Kumar, and A. Tripathi. 2017. Performance evaluation of sugar cane cutter planter using different parameters. *International Journal of Agricultural Engineering* 10 (2): 367–373. https://doi.org/10.15740/HAS/IJAE/10.2/367-373.

Mital, A., and B. Das. 1987. Human strengths and occupational safety. *Clinical Biomechanics* 2 (2): 97–106.

Mohanaselvan, T. 2023. *Study of Sugarcane Mechanization and Health Hazards in Erode District*. Unpublished M Tech Thesis. Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi.

Mohanty, S. K., B. K. Behera, and G. C. Satapathy. 2008. Ergonomics of farm women in manual paddy threshing. *Agricultural Engineering International: the CIGR Ejournal* X (June), Manuscript MES 08 002, 1–8.

Patil, M., and P.D. Patil. 2013. Optimization of blade angle for cutting system of sugarcane harvester. *International Indexed and Refereed Research Journal* 42 (4): 49–52.

Potedar, R.R., R. Ramchandra, A. Kumar, and J.K. Singh. 2011. Ergonomic evaluation of rotary power input by hand and leg muscles to operate farm equipment. *Journal of Agricultural Engineering (ISAE)* 48 (3): 8–16.

Rana, Lalita, Navnit Kumar, Anil Kumar, Meena, Sunita Kumari and Manish Kumar. 2021. Mechanization in sugarcane: Need of the hour. *Just Agriculture* 1 (8): https://justagriculture.in/files/newsletter/2021/april/63.%20Mechanization%20in%20Sugarcane%20Need%20Of%20The%20Hour.pdf.

Shephard, R.J. 1967. Physiological determinants of cardiorespiratory fitness. *Journal of Sports Medicine Physics Fitness* 7: 111–134.

Shukla, S. K., L. Sharma, S. K. Awasthi, and A. D. Pathak. 2017. Sugarcane in India: Package of practices for different agro-climatic zones. Technical Bulletin No. 1. AICRP on Sugarcane, ICAR-IISR Lucknow, 1–64.

Singh, P.R., and R. Gupta. 2015. Role of women in mechanized sugarcane cultivation. *Agricultural Engineering Today* 39 (3): 22–29.

Singh, S.P., Surendra Singh, and Pratap Singh. 2012. Ergonomics in developing hand operated maize dehusker-sheller for farm women. *Applied Ergonomics* 43: 792–798. https://doi.org/10.1016/j.apergo.2011.11.014.

Singh, S.P., M.K. Singh, Mukesh K. Singh, and U. Ekka. 2019. Ergonomics for gender friendly farm equipment to enhance better human-machine interaction. *RASSA Journal of Science for Society* 1 (1&2): 54–59.

Singh, S.N., A.D. Pathak, T.K. Srivastava, A.K. Shah, and C. Gupta. 2020. *Can node technology for sugarcane planting for higher yield with reduced cost. Technical bulletin 1/2020*, 2. Lucknow: ICAR—Indian Institute of Sugarcane Research.

Singh, J., and A. K. Singh. 2006. Catalogue of tools and machinery developed at IISR for mechanization of sugarcane. ICAR—Indian Institute of Sugarcane Research, Lucknow, p32.

Singh, S. P. 2006. Final Report on Ergonomic Evaluation of Manually-operated Rice Farming Equipment with Women Workers. Project

No. 532. ICAR-Central Institute of Agricultural Engineering, Bhopal, p29.

Szabo, Richard L., Robert G. Radwin, and Chris J. Henderson. 2001. The influence of knife sullness on poultry processing operator exertions and the effectiveness of periodic knife steeling. *American Industrial Hygiene Association* 62: 428–433.

Tajuddin, A., and P. Kamaraj. 2023. Development and evaluation of power operated sugarcane sett cutter. *Madras Agricultural Journal* 110(4-6) https://doi.org/10.29321/MAJ.10.200264.

Wilson David Gordon. 1986. *Understanding Pedal Power*. Volunteers in Technical Assistance, Virginia, USA. https://pdf.usaid.gov/pdf_docs/pnabc976.pdf.