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Ergonomically Evaluating and Modifying Fodder Cutter by Increasing Number of Blades and Varying Throat Geometry

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ABSTRACT: Chaff cutter is one of the agricultural equipment used to chop all kinds of green and dry fodder into small pieces to feed animals. Due to less cost and ease of operation, it is available in every household owning cattle. It is most common and widely available machines used twice a day to chopped the fodder. The operation on existing chaff cutters is physically demanding because of the high energy requirement and continuous adoption of awkward work postures. Size reduction operation is considered to be one of the most energy-intensive or energy inefficient operations. The force exerted while cutting the chaff in the static position pose work related musculoskeletal disorders in performing the activity. The power required to cut the fodder by existing chaff cutter was very high than power applied by the operator for cutting. Which leads to high physiological demand and more energy expenditures throughout the degree of rotation flywheel. Interventions or design modification for reducing the occupational stress involved in chaff cutting will be most successful for reducing the human power requirement in chopping the fodder. Therefore, the manually-operated chaff cutter has a scope for modification based on human power and energy requirement for cutting different fodders. The modification in the chaff cutter were done by increasing number of blades for cutting i.e. single, double, three and four blade and reducing throat area by A, A/2, A/3 and A/4. The power required for cutting the fodder reduces with increase in number of blades and reduction in throat geometry. The power required to cut the fodder was minimum for four and three blades and maximum for single blade chaff cutter. The ergonomic evaluation of the manual chaff cutter in terms physiological parameters (oxygen consumption, heart rate and energy expenditure) during the chopping operation of was also carried with all the four types of chaff cutter. The energy expenditure for single and four blade chaff cutters were maximum. Chaff cutter with three blade and reduce throat area by A/3 from existing chaff cutter has minimum energy consumption while operating chaff cutter. From the study it was observed that the power required to chopped the fodder is less for three blade chaff cutter and it is ergonomically compatible for the operation. From the study it can be concluded that chaff cutter with three cutting blade and one-third reduction in trough area from existing the human energy expenditure reduces and there is drop in muscles fatigue. The modified hand operated manual chaff cutter is ergonomically compatible for farmers while chopping operation.

Keywords: Manual fodder cutter, Livestock, Ergonomics, India.

INTRODUCTION

India has largest livestock population in the world about 540 million and contributes 12% of world share of livestock (Livestock Census, 2019). Livestock contributes 32% of total agricultural GDP and support livelihood of about two-third rural population. According to livestock census, 2019 about 85% of farmers in India are small and marginal farmers having land holding less than 2 ha. These 85% of small and marginal farmers have about 45% of total operated area under cultivation and owner of 75% of animal husbandry. Since, maximum share of livestock in the country owned by small and marginal farmers and they have maximum 2-3 cattle to support their livelihood. They contribute additional income to the livelihood. Livestock helps on food supply, family nutrition, family income, asset savings, soil productivity, livelihoods, transport, agricultural traction, agricultural diversification and sustainable agricultural production, family and community employment, ritual purposes and social status (Moyo and Swanepoel 2010). Growing human population, rising per capital income and increasing urbanization are fueling rapid growth in demand for food and animal. It contributes manifold to the growth and development of agricultural sector. The households having less than 2ha of land possess a larger share of livestock. The landless, marginal and small categories of farmers own 84% of total livestock (Shantanu *et al.,* 2008). Presently women contribute 69% of workforce in livestock and most of the job done manually. In present scenario most of the livestock work like washing, rearing, milking, bathing feeding are done by female farmers. Animal feeding is very important aspect of livestock husbandry. It is very necessary to have effective utilization of available feed sources. Chaff is hay cut into small pieces for feeding to livestock (Mohan and Kumar, 2004); it is a good fodder, and it is clean and evenly cut, free of dust, of good color and with a fresh aroma. Chopped fodder aids the animal's digestion and prevents animals from rejecting any part of their food. To chopped the animal feed chaff cutter is only equipment owned by them to chopped the fodder. In India manually operated chaff cutter is most available agricultural equipment in India and being used twice a day every day to feed the cattle. Manually energized chaff cutter machines are environment-friendly i.e., non-pollutants and available with almost all small land marginal farmers having cattle. It is easy to operate even unskilled men and women can also operate. Manually operated chaff cutter is the only agricultural equipment, which is used every day throughout the year by a large number of farming families (Kumar *et al*., 2010). Chaff cutter is one of the agricultural equipment, used for chopping all kinds of green and dry fodder into small pieces to feed to the animals. Cutting of crop into small pieces (crushing) then feeding to the livestock, increases the consumption and palatability of feed, hence reducing the wastage. Chaff and hay play a vital role in most agricultural production as it is used for feeding of livestock. Chaff is hay cut into small pieces for feeding to livestock (Mohan *et al.,* 2004). It is a good fodder, and at its best is cleanly and evenly cut, free of dust, of good color and with a fresh aroma. In this machine, the hay is cut into small pieces for feeding cattle (approx. 10mm to 25mm) (Patil *et al*., 2019). But the existing equipment available are most drudgery prone, operated at very awkward postures and required large amount of extraneous energy. Chopping of fodder by operator is done manually which is physically demanding through its energy and postural requirements and is commonly regarded as source of drudgery (Kumar *et al.,* 2004); many farmers associated with this task reported back, shoulder and wrist discomfort (Kalaiselvan *et al*., 2016). It may also cause clinical or anatomical disorders and may affect worker's health. But traditional chaff cutters owned by the farmer for a long time without any modification. It is done manually which is physically demanding though its energy requirement and odd postures (Kumar *et al*., 2013). Thus, there is a necessity to modified the existing machines for fodder cutting with least energy consumption but also will be easily available to small farmers at a cheaper cost running at a better efficiency. There is need to modify machine which are easy to operate, reduction in manual efforts due to machine, decreasing dependency on manpower, Compact and portable design, multipurpose and economic, thus delivering improvement in productivity and affordable to small farmers due to low cost. Traditionally for the operator it is done manually which is physically demanding through its energy and postural requirements and is commonly regarded as source of drudgery. Many farmers associated with this task reported back, shoulder and wrist discomfort. These work conditions impact the quality of work, productivity, and occupational health and safety of the workers, increasing their risk of developing WMSDs. Joshi *et al.,* (2018) study found that there are ergonomic risk factors in manual chaff cutting, which may lead to the development of WMSDs and in turn may affect productivity and quality of work. The risk factors are predominantly related to awkward postures and repetitive movement of the limbs. From the previous studies it was observed chaff cutter is only equipment available for fodder cutting for animal husbandry. Since maximum share of livestock owned by small and marginal farmers, hand operated manual chaff cutters are frequently used by them (Livestock Census, 2019). But, the existing machine which was developed year back had not changed significantly in design during its existence in past although the machine is drudgery prone and adversely affects the farmers health. The chaff cutter needs to be redesigned to incorporate input from ergonomics and advances in engineering design. Therefore, the available human energized chaff cutter has a scope for modification based on human power and energy requirement for cutting different fodders. The chaff cutter needs to be redesigned to incorporate input from ergonomics and advances in engineering design.

By considering this, the present study was intended to modify the existing chaff cutter using a different number of fodders cutting blades (one, two, three and four) and reduction in throat area by, full, half, One - third and One- fourth from the existing throat area of chaff cutter. The study was carried out with the following objectives:

1. To study the engineering properties of selected fodder and machine parameters of existing chaff cutter.
2. To study the power required and power applied by human, to cut the fodder for the existing and modified chaff cutter
3. To ergonomically evaluate the physiological parameter for the existing and modified chaff cutter

MATERIAL AND METHODOLOGY

The traditional manually operated chaff cutter was used for the study. It is most widely used machine for the chopping of fodder. The machine chopped the fodder into various length which can be palatable for animal. Manually operated chaff cutter have different components of chaff cutter are, flywheel, throat, feeding chute, main shaft, worm Gear, feed rolls, stand and handle. Most of the parts of chaff cutter are made up of cast iron and blade mounted on the flywheel are of high carbon steel. To operate the chaff cutter two person is required, one to operate the flywheel for cutting the fodder and another put the feed into the feeding trough.

To conduct the experiment the laboratory work was carried out in farm machinery and ergonomics lab, and field work was conducted in the field of Division of Agricultural Engineering. The most common and widely used fodder namely, maize, jowar and bajra were selected for experiment and they were grown division field. All the three types of fodder were grown according to agronomical parameters of cultivation and harvested after recommended days of maturity of crop for feeding cattle.

A. Determination of Engineering characteristics of the fodder

The physio-mechanical characteristics of selected fodder were calculated after cutting of fodder. The length and diameter of cut stalk were measured through vernier's calliper. The cross-sectional area was determined by measuring radius of stalk. To determine the moisture content of cut fodder the chopped stalk sample were weighted initially by weighing balance and the weighted sample were kept in oven to dry for 24 h at 104°C. The sample reweighted after drying. The reduction in weight of stalk after drying give the percentage moisture content of fodder.

The moisture content of fodder was calculated by given formula:

Percent Moisture Content

$$= \frac{\text{Weight of water in product}}{\text{Weight of dry matter in product sample}} \times 100 \quad ..(1)$$

The force applied, shearing strength and energy required to cut the fodder were determined through texture analyser in the Division of Post-harvest and technology. For the determination of shearing strength an experimental set up was fabricated to hold the stalk while cutting the fodder in the texture analyser. The cutting blade of texture analyser have bevel angle of 15^o similar to the chaff cutter cutting blade bevel angle. The force required to cut the stalk of fodder were depicted directly by graph through texture analyser software. The Shearing Strength (N/cm^2), Specific Energy(N-cm), Specific Energy(J/cm^2) were calculated by formula given:

Shearing Strength (N/cm^2)

$$= \frac{Force\ required\ to\ cut\ the\ fodder(Fs)}{Cross\ sectional\ area\ of\ stalk(A)} \quad ..(2)$$

Energy, E_c (N-cm)

$$= \frac{Force\ required\ to\ cut\ the\ fodder(Fs)}{diameter\ of\ stem\ (d)} \quad ..(3)$$

Specific Energy, E_s (J/cm^2) =

$$\frac{Force\ required\ to\ cut\ the\ fodder(Fs)}{Cross\ sectional\ area\ of\ stalk(A)} \quad ..(4)$$

Where,

F_s = Shearing force (N),

A = Cross-sectional area of the stalk at shearing plane in mm^2.

E_c = Specific cutting energy, J/mm^2

E_c = Cutting energy, J

D = Diameter of the stem, mm

Chaff cutter modification: The chaff cutter was modified and evaluated by reducing the throat area of chaff cutter and increasing the number of cutting blades. Four different number of blades; single, two, three and four were taken for cutting the chaff. Consequently, with increase in number of blades of chaff cutter the throat area was reduced i.e., for four blade throat area reduced to A/4, for three blade throat area reduced to A/3, for two blade throat area reduced to A/2 and for single blade throat area kept A, where A is throat area of existing chaff cutter. This was done to reduce the force requirement for cutting chaff by reducing the cutting front length. As the force applied to cut the chaff depend directly on cutting front length of blade, the higher the cutting front length more the force required to cut the chaff. Therefore, reduction in throat area reduces the cutting front length. Secondly, with the increase in number of blades the idle degree of rotation of flywheel reduces. As chaff cutter work on the principle of flywheel, where force is applied during the cutting and rest of the degree of rotation flywheel rotate ideally. Therefore, by increasing number of blades the force applied can be minimized by reducing cutting front and evenly distributing the force applied throughout the degree of rotation without reducing the through output of chaff.

B. Determination of mechanical power required to cut fodder using different number of blades

The torque meter, data logger and sensor were attached to manual chaff cutter to measure the mechanical power applied by the operator to cut the fodder. An instrumental set up were designed: sensor to measure the number of rotations of flywheel, torquemeter to measure the average torque and instantaneous torque applied during the cutting operation and data logger to store and save data. The sensor was attached at one end of flywheel shaft on the trough side of chaff cutter concentric with the shaft. On the other end of shaft torquemeter was attached to measure the torque applied by operator to cut the fodder. Computer connected to data logger displayed real time data of torque applied at each degree of rotation of flywheel through software. The force and power applied by operator to cut the fodder calculated by formula.

$$P = 2\Pi NT \quad ..(5)$$

$$T = F \times R \quad ..(6)$$

Where,

P = Power ,Watt

N = Number of rotation per minute, rpm

T = Torque Applied

R = Perpendicular distance from axis of rotation, m

F= Force Applied, N

Measurement of Physiological Energy Required: The ergonomics evaluation of operator was done in terms of physiological parameters Heart rate, oxygen consumption and energy expenditure to assess the quantum of physical work load. The human energy required to cut the fodder through chaff cutter was determined by portable heart rate monitor and k_4b_2. Six healthy male experimental subjects were selected for this study. The subjects were physically and medically fit for carrying out the experiments. Subjects were farm workers having working experienced in the farm and in the age group of 30-40 years were selected to perform experiment. The cardiorespiratory response of all the selected subjects was observed in the laboratory. Calibration of selected six subjects were taken. The oxygen consumption was measured by sub-maximal testing on a treadmill and K_4B_2. Naughton protocol (Naughton *et al.,* 1963) were followed to determine aerobic capacity. In this method, the straight line on the calibration chart was extended up to an estimated maximum heart rate of the subject which is equal to "220-age of the subject". The heart rate during the operation were recorded and oxygen consumption were obtained from calibration graph. A portable heart rate monitor was used to measure the heart rate during the chaff cutter operation by using different number of blades. The energy expenditure during the experiments was computed by multiplying the oxygen consumption values with the calorific value of oxygen, which is 20.88 kJ $^{-1}$ (Nag *et al.*, 1980) for all six subjects operating four different chaff cutter.

Performance Parameters of Chaff Cutter Evaluation

The capacity of the chaff cutter calculated in terms of volume of the fodder as it passes through the throat of machine using formula given:

Capacity of Chaff Cutter

The theoretical capacity C, in kg h^{-1}, was calculated using Duffees formula:

$$C = 60 \times 10^{-3}\, D\, L\, W\, H\, n\, N \quad ...(7)$$

Where,

C = capacity of machine, t/h

W = width of throat, m

H = height of throat, m

L = length of cut, m

N = number of knives on the flywheel

n = speed, rpm

D = bulk density, kg/m^3

Length of cut of chaff can be determined by

$$L = 2\, p\, R\, \tan a / N \quad ...(8)$$

Where,

R = radial distance between centre of rotation of flywheel and inner edge of throat

a = clearance angle between the knife and plane of rotation

RESULT AND DISCUSSION

A. Engineering Characteristics of Fodder

The crop parameters like moisture content, length of stalk, diameter of stalk, area of cross section for fodder crop: Maize, sorghum and pearl millet were measured. The average length, diameter, average cross-sectional area and length of stalk range for different fodder given in Table 1.

The mechanical properties of fodder calculated through texture analyser. The force required to cut the fodder directly obtained from graph plotted by texture analyser. The cutting strength, energy required to cut the stalk and specific energy required for fodder chopping calculated by given equation (2, 3 and 4). The physio-mechanical properties are tabulated in Table 2. From the table the moisture content needed during harvesting and chopping the fodder to make it suitable for livestock feed lies between 75-88%. The force required for cutting the fodder stalk reduces with increase in the moisture content. From the experiment it was observed that lower portion of fodder along the root side has higher cutting strength in comparison to middle and top portion. The cutting strength reduced as it moves from root to top side of stalk. This is due to physiological structure of the plant (McRandal & McNulty, 1980) determined that, for field grasses of unit stem mass of 2.35 mg/mm, the shear strength was 16.0MPa and shear energy was 12.0 mJ/mm^2. The same has been reported by (Taieb and Imbabi, 1995). The chopping energy and force requirements increased with increasing stem diameter. This is due to hardening of plant with the age. Prasad & Gupta, (1975) studied the mechanical properties of maize stalk in relation to cutting under quasi-static deformation. The cross-sectional area and moisture content of the crop had significant influence on cutting energy and maximum cutting force. The shearing energy and maximum shearing force were found to be directly proportional to the cross-sectional area and inversely proportional to the moisture content of the stalk. Eissa (2008), obtained similar results from measuring the mechanical properties (average tensile and compressive strength) for maize stalks at different moisture content (10.10, 46.8 and 65.6%) was (4.27, 2.25 and 1.18MPa) and (2.95, 2.03 and 1.28MPa) respectively.

Table 1: Crop physical parameters of different fodder.

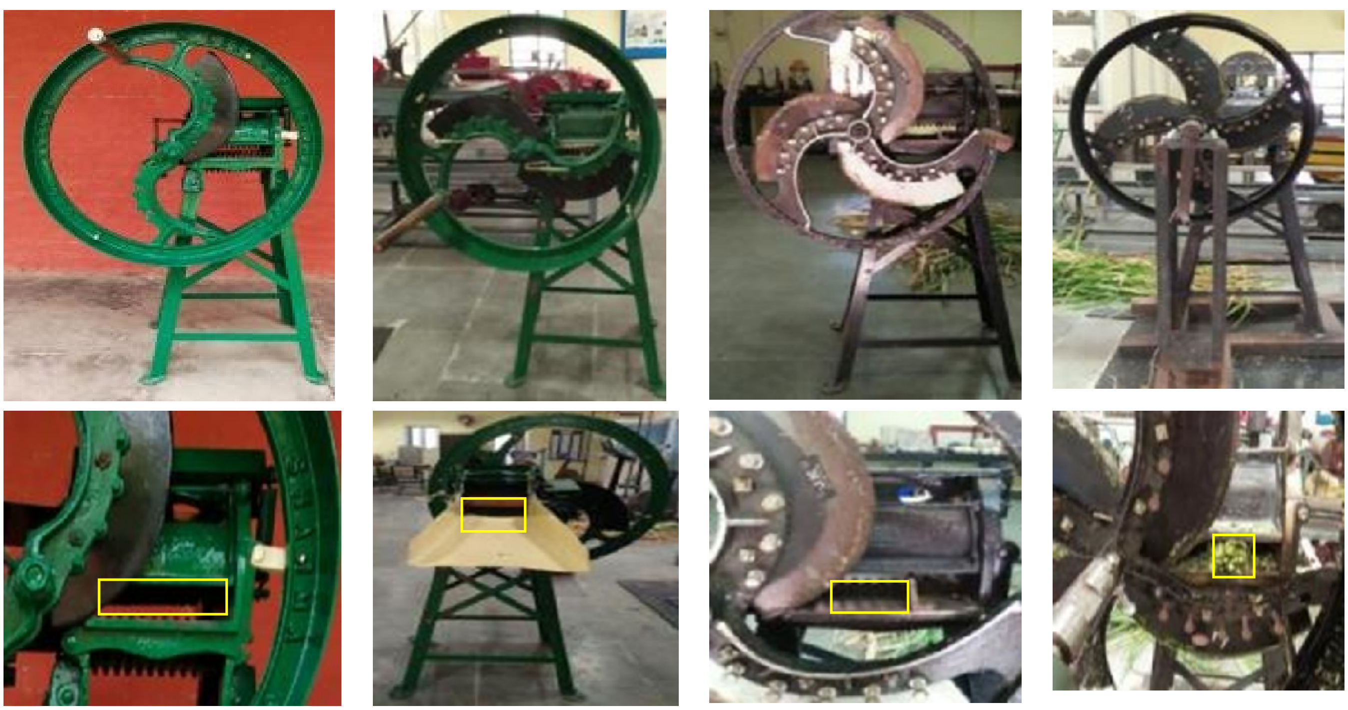
Sr. No.	Parameters	Maize	Jowar (Sorghum)	Bajra (Pearl Millet)
1.	Average Length of stalk(cm)	256	288	279
2.	Diameter of stalk(mm)	18.5	11.65	10.22
3.	Range in the length of stalk(cm)	150-265	245-280	250-288
4.	Cross Sectional area of stalk(cm^2)	1.67	1.23	1.21
5.	Moisture Content (%)	75-80	72-88	76-86

Table 2: Mechanical parameters of different fodder.

Sample	Moisture Content (%)	Force(N)	Area(cm^2)	Cutting Strength (N/cm^2)	Cutting Energy(N-cm)	Specific Energy(J/cm^2)
Bajra(Pearl Millet)	82.5	339.19	1.66	212.56	170.53	0.99
	84.6	427.62	1.67	250.35	224.99	1.33
	79.8	357.35	0.85	175.04	71.65	0.79
Maize	81.6	373.33	2.35	76.74	171.87	0.75
	83.7	345.85	2.35	151.64	200.63	0.88
	85.5	386.29	1.38	60.75	69.04	0.48
Jowar (Sorghum)	82.2	342.89	1.21	283.38	143.2	118.34
	85.6	320.78	1.34	239.38	126.4	94.33
	88.7	367.31	0.97	378.73	141.9	146.28

Sakharov *et al.*, (1984) reported that the required force to cut the stretched stalks was 50% less than that of unbent stalks. Chattopadhyay & Pandey (1999) determined the bending stress for sorghum stalk between 40-53 and 45- 65MPa at the seed stage and forage stage, respectively. Information on plant properties and the power or energy requirement of equipment has been very valuable for selecting design and operational parameters of the equipment.

B. Determination of cutting front length and area of cut required to cut fodder using different number of blades
The existing chaff cutter was modified by increasing number of blades and reducing throat area. The diagram depicting change in throat area and different number of blades of chaff cutter in Fig. 1. With the reduction in the throat size and increase in number of blades on flywheel, the cutting front of blade reduces. From the experiment it was observed that force applied to cut the fodder directly proportional to cutting front of blades. Therefore, less the cutting front length less will be force applied and ultimately power required to cut the fodder reduces. It was observed that cutting of the fodder takes place in three stages. In first stage the length of cutting front increases with increase in degree of rotation, in second stage the cutting front remain constant and finally in third stage the cutting front length reduces. All the three stages of cutting take place at 360 degree of rotation of flywheel for different number of blades depicted in the Fig. 2. For single cutting blade chaff cutter first stage lies between flywheel rotation between 0°-50°, where length of cut increases in second stage cutting front remain constant for 50°-90° of flywheel rotation. Lastly in third stage cutting front decreases from 95°-105° degree of rotation. For two cutting blade chaff cutter first stage lies between flywheel rotation between 0°-40°, length of cut increases in second stage cutting front remain constant for 40°-75° of flywheel rotation. Lastly in third stage cutting front decreases from 75° to 90° degree of rotation. For three blade first stage lies between flywheel rotation between 0°-35° length of cut increases in second stage cutting front remain constant for 35°-65° of flywheel rotation. Lastly in third stage cutting front decreases from 65° to 75° degree of rotation. For four blade first stage lies between flywheel rotation between 0°-20°, where length of cut increases in degree of rotation and in second stage cutting front remain constant for 20°-24° of flywheel rotation. Lastly in third stage cutting front decreases from 24° to 38° degree of rotation. Kumar *et al.*, (2010) observed similar study of different phase of cutting operation.



Number of blade:One
Throat Area:A

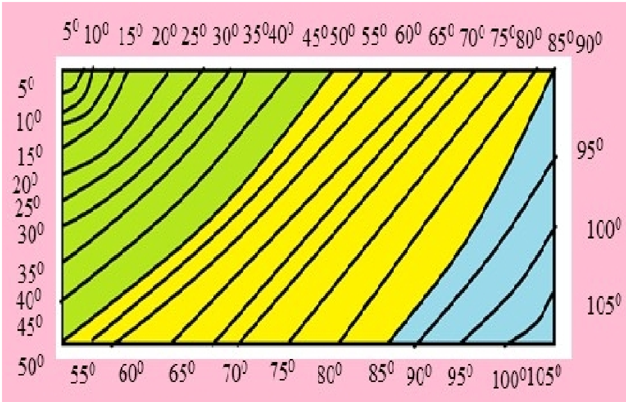
Number of blade:Two
Throat Area:A/2

Number of blade:Three
Throat Area:A/3

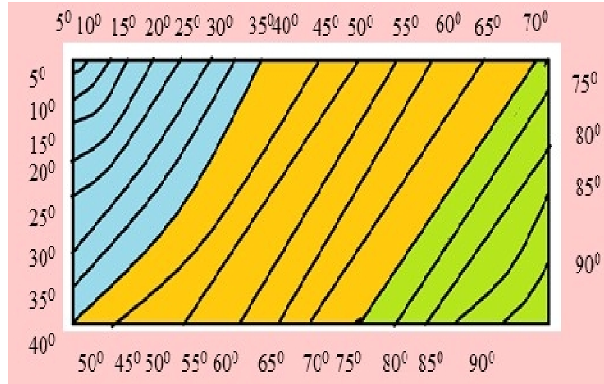
Number of blade:Four
Throat Area:A/4

Where, A= Throat Area of Existing Chaff Cutter 147cm^2

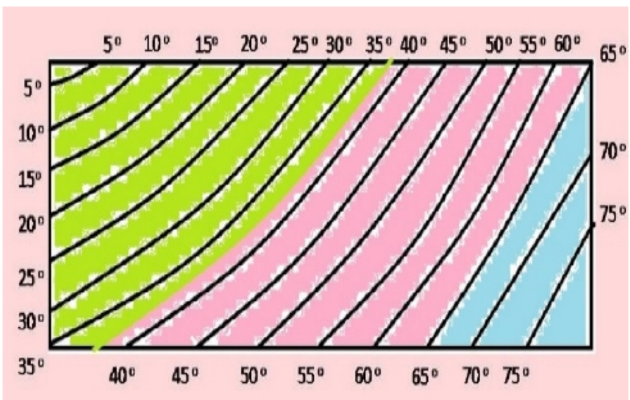
Fig. 1. Chaff cutter with different number of blades and varying throat area.



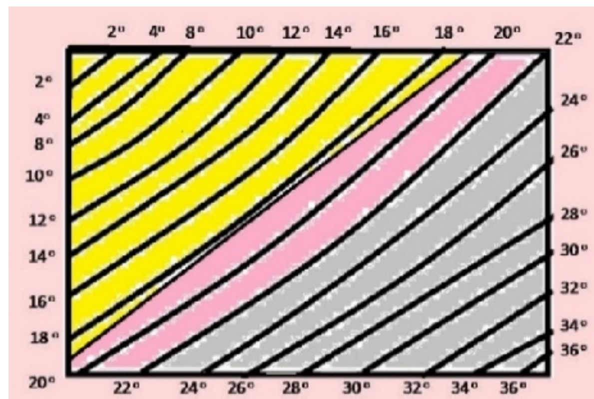
Fodder in cutting trough for one blade flywheel



Fodder in cutting trough for two blades flywheel



Fodder in cutting trough for three blades flywheel

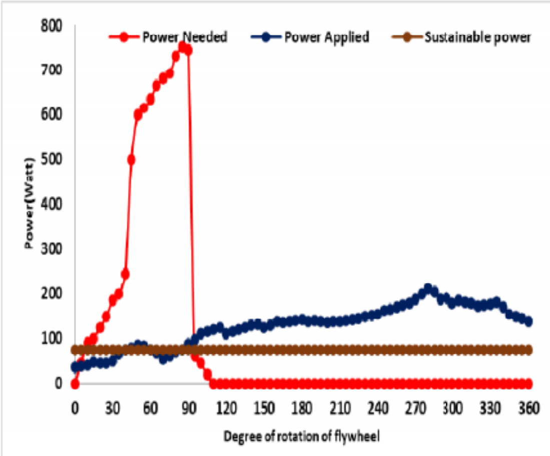


Fodder in cutting trough for four blades flywheel

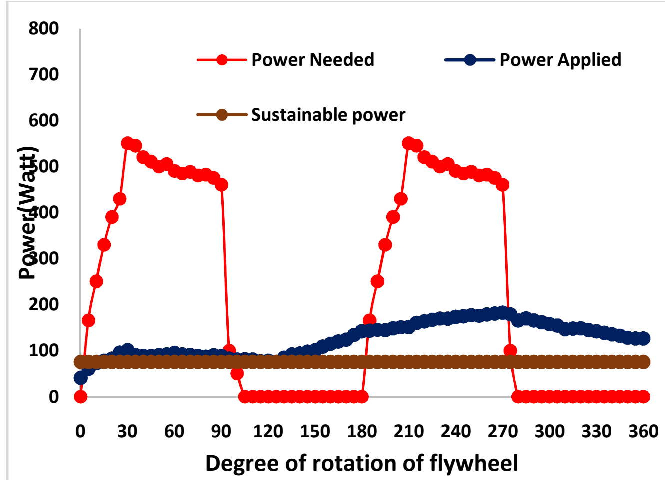
Fig. 2. Chaff cutter with varying cutting front length at three different stages of chopping.

B. Determination of mechanical power required to cut fodder using different number of blades

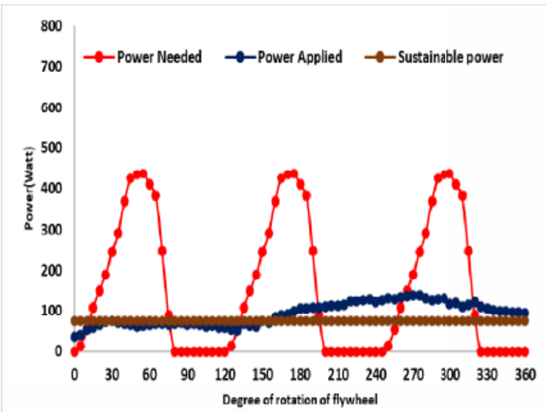
From the experiment with existing chaff cutter, it was found that there is a mismatch between the power applied by an operator and the power requirement for cutting material. At a full-filled cutting trough, the peak power requirement is about 600W, which is more than five-six times the available sustainable power by an operator. With an increase in the number of blades and downsizing trough area, the power required can be evenly distributed throughout the degree of rotation and ultimately reduces the power requirement for cutting. This concept will reduce the gap between the power applied by an operator and the power requirement for cutting material and make it compatible for operator. Experiment was conducted to measure the power consumption for cutting by different number of blades. The power required to cut the crop calculated by the average cutting energy required with the cutting front area. Fig. 3 depicts the power required to cut the fodder at different flywheel rotational angles in cutting trough. The peak power requirement exceeds 750W for single blade and 550W for two blades. The power availability to cut the fodder for single and two number blades is maximum and there is huge gap between power required and power available. The sustainable power of normal human being is 75W for which further creates a vast gap. In three and four blade this mismatch is reduced due to evenly distribution of power through out the degree of rotation and reduction in cutting front length of blade. In four blade the gap between the power required and available power is minimum or they almost overlap each other.



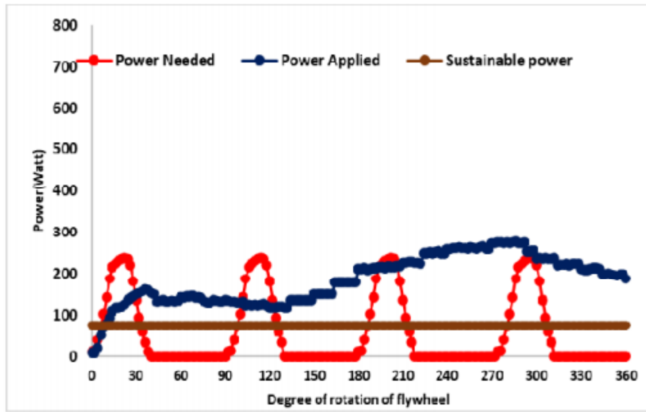
Power requirement in cutting fodder through single blade chaff cutter



Power requirement in cutting fodder through doble blades chaff cutter



Power requirement in cutting fodder through three blades chaff cutter



Power requirement in cutting fodder through four blades chaff cutter

Fig. 3. Power requirement in cutting fodder through different number of blades.

D. Evaluation of physiological parameter of operator in cutting of fodder

Selection of subjects and maximum aerobic capacity. Table 3 shows the mean value of age, calibration equation, VO_2 max and maximum heart rate of the sample subjects. The maximum heart rate was calculated by formula HR=220- age of the subjects.

Physiological parameters. The Heart rate was recorded by the portable heart rate monitor for one hour of continuous fodder cutting operation using four different number of blades of flywheel. The corresponding oxygen consumption was obtained from the calibration chart of different subject. From the Table 4 it can be observed that heart rate and oxygen consumption was lowest for the worker operating single blade fodder cutter and full trough area, followed by two and three blade fodder cutters. Correspondingly the oxygen consumption was minimum for single blade and highest for four blades. It was found that HR and OC do not increases at greater rate for single, double and three blades, while four blades fodder cutter have maximum change in heart rate. This is due to continuous operation of cutting through out four blades without having idle period. It was found that the oxygen consumption varied from 27-71% of VO_2 max (maximum aerobic capacity) for cutting fodder, whereas the limit for sustainable activity is 35% (Nag *et al.*, 1980; Nag and Chatterjee 1981).

Table 3: Calibration equation of different subjects.

Subject	Age	Calibration Equation	R^2	VO_2 max	Maximum Heart Rate
A	33	Y = 0.0165X-0.748	0.946	2.31	187
B	45	Y = 0.0216X-1.406	0.926	2.35	175
C	35	Y = 0.0138X-0.391	0.902	2.16	185
D	36	Y = 0.0173X-1.036	0.888	2.33	184
E	32	Y = 0.0271X-1.132	0.955	2.06	188
F	28	Y = 0.0169X-0.996	0.895	2.02	192

*X=Heart rate of subjects Y= oxygen consumption of the subjects

Table 4: Physiological parameters of different subjects on during fodders through different number of blades.

Subjects	Average Heart Rate(beats per minute)				VO_2 (l/min)				Energy Capacity(j/min)				Power Consumption(watt)			
	Single Blade	Two Blade	Three Blade	Four Blade	Single Blade	Two Blade	Three Blade	Four Blade	Single Blade	Two Blade	Three Blade	Four Blade	Single Blade	Two Blade	Three Blade	Four Blade
Sub A	144	138	137	147	1.33	1.21	1.1	1.36	27.7	25.2	22.9	28.3	462.6	382.6	420.9	473.1
Sub B	128	127	125	134	1.47	1.13	1.12	1.62	30.6	23.5	23.3	33.8	511.3	389.6	393.1	563.5
Sub C	132	129	128	137	1.43	1.26	1.17	1.51	29.8	26.3	24.4	31.5	497.4	406.9	438.3	525.2
Sub D	136	134	133	140	1.3	1.1	1.08	1.33	27.1	22.9	22.5	27.7	452.2	375.6	382.6	462.6
Sub E	133	131	126	135	1.39	1.29	1.09	1.41	29.0	26.9	22.7	29.4	483.5	379.2	448.7	490.4
Sub F	130	128	127	131	1.15	1.13	1.14	1.17	24.0	23.5	23.8	24.4	400.1	396.5	393.1	406.9

The energy expenditure was calculated by multiplying oxygen consumption values with the calorific values of oxygen 20.88 j/min. From the graphical representation it was observed that energy expenditure for single blade is lowest which falls in "moderate "work load and four blades is highest falling in "heavy" category of work. These results indicates that fodder cutting is an energy extensive operation and fell under the category of "heavy work" (Nag *et al.*, 1980). Nag and Chatterjee (1981) and with increasing the number of blades and reducing the trough area the energy expenditure reduces to "heavy" to "moderate". The power required by human in cutting fodder was also calculated shown in Fig. 4. From the graph it is observed that power requirement for cutting is much less by using three and four blades. With reduction in power required for cutting the gap between power for cutting and sustainable power of human reduces, giving more comfort and less fatigue for the operation. Particularly vulnerable postures such as forward flexion and upper arm abduction adopted while performing the activity can increase the chances of WMSDs.

Forward flexion and abduction of the upper arm stresses the glenohumeral capsule and renders it vulnerable to injury (Mukhopadhyay *et al.*, 2007). This is mainly due to static muscular load and postures deviating from the neutral position for long durations. Such findings have been reported in similar field studies on manual brick workers and also in a controlled environment (Sen and Chakraborty 1984). Previous studies have found that these work conditions impact the quality of work, productivity, and occupational health and safety of the workers, increasing their risk of developing WMSDs. The results are supported by Zakiuddin and Modak (2011) who conducted a study on Kadwa cutter. The graph in Fig. 4 and 5 show human energy expenditure and physiological power consumption in operating all type of chaff cutter having different number of blades.

Performance Parameters of Chaff Cutter. The output capacity of fodder and the length of cut of fodder was calculated using the formula given in equation. The size chopped fodder have minimum length of 5-8mm four blade. The smaller size of fodder and very large size is not preferable and palatable for cattle feed.

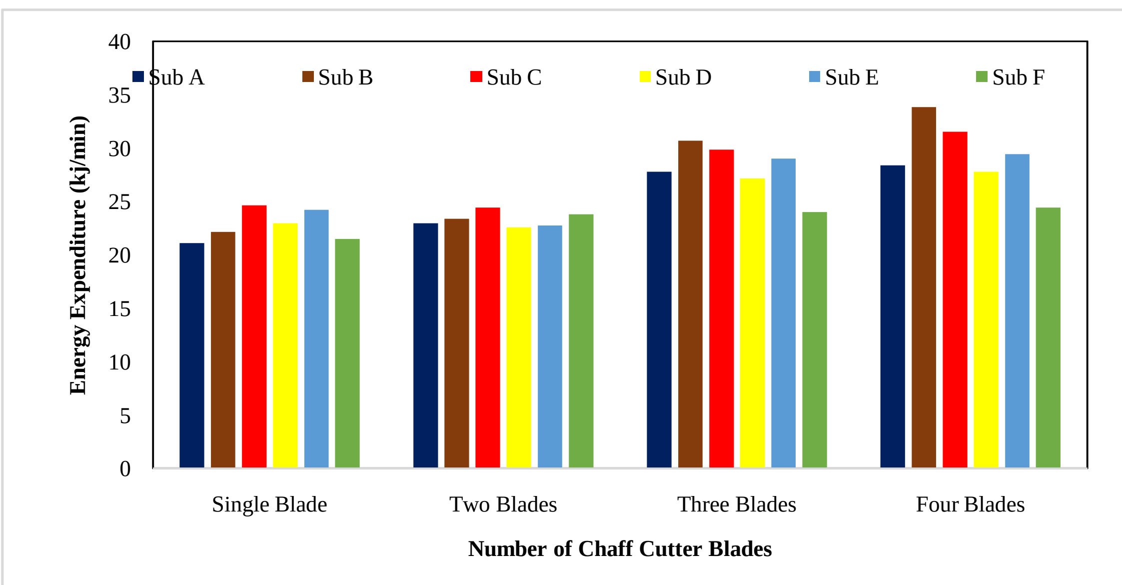


Fig. 4. Graph showing energy expenditure of different subjects.

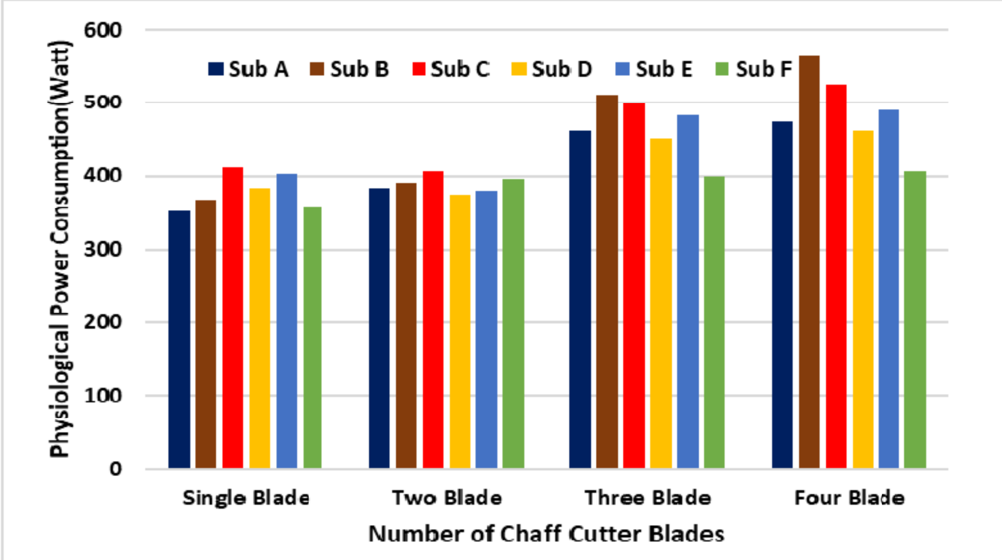


Fig. 5. Graph showing physiological power consumption of different subjects.

Table 5: Average through output capacity and Average Length of cut of chopped fodder for different chaff cutter.

Chaff Cutter Type	Average Through Output capacity	Average Length of cut
Single Blade	150kg/h	30-35mm
Two Blades	169kg/h	28-32mm
Three Blades	172kg/h	12-16mm
Four Blades	162kg/h	4-6mm

The chopped fodder length range between 25-35mm is required for cattle feed which are obtained from two and three blade. The through output capacity of all four types of chaff cutter for three different types of fodder namely: Sorghum, Pearl Millet and Maize were almost same. With increase in number of blades, cutting trough area is reduced which maintained the output capacity of chopped fodder. But the length of cut of fodder reduces with increase in number of blades. The productivity of the chopping machine with a sharpener unit was 5.74 t h^{-1}, the chopping length was 15 mm and the chopping efficiency was 79.37 % (Shal *et al.*, 2018). The output capacity and length of cut of fodder mentioned in the Table 5.

CONCLUSIONS

The existing manual chaff cutter was evaluated in terms of power required in cutting different types of fodder and power available by human for cutting. The experiment was conducted by varying number of blades on flywheel i.e., one, two, three and four and respectively reducing the throat area by full, half, one third and one fourth from throat area of existing chaff cutter.

It was observed that power required in cutting fodder reduces with increase in number of blade and reduction in throat area. The huge gap between power available and power required in cutting is minimum for four blade cutter and maximum for single blade cutter. The through output has no effect with increase in blade number but length of cut reduces with increase in number of blades.

The ergonomic assessment of operator were also done in terms of heart rate and energy expenditure. The energy expenditure for three blade was minimum and lie in "moderate work load". Therefore, according to experiment three blade chaff cutter with reduced throat area required less power in cutting and ergonomically compatible for the operator.

FUTURE SCOPE

Present research paper highlights the importance of livestock mechanization in Indian agriculture. The study evaluates the ergonomics and mechanical parameters in operating the fodder cutting machine and its impacts on farmer health. Further according to experiment, it was concluded that existing fodder cutter need to modified to make it compatible for operation

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