Modification of a machine for chopping rice straw using circular saw

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Abstract: Crop residues are considered the most critical problem facing the Egyptian farmers. The harmful resulting emissions give a significant contribution to air pollution called the “Black Cloud”. A suitable technology for the use of agriculture residues to give renewable energy and reduce air pollution is required in Egypt. While, with cutting this crop residues are taken advantage of them in animal feed, composting, biogas production, or other industries friendly to the environment. This quantity presents a sizable problem to the farmers, government and the environment. The objective of this study is to develop a machine for chopping plant residues by using the circular saw. The cutting process of agriculture plants is more complicated than the cutting of engineering materials (as steel, copper …etc.) this is due to that most of the engineering materials are homogeneous and isotropic, whereas the plants are non-homogeneous and non-isotropic materials. The usage of computer aided design (CAD) has changed the overlook of the industries and developed healthy & standard competition, as could achieve target in lean time and ultimately the product reaches market in estimated time with better quality and consistency. In general view, it has led to fast approach and creative thinking. The idea of development of the original machine which applies the theory of hammer knives is supplying a new pre-cutting device to reduce the required time to chop the residues to the suitable cutting length. Therefore, this device would increase the performance and capacity of the original machine. The experimental work was carried out during rice harvesting season of 2020 on a variety (Sakha 101) (average 4 mm stem diameter) at a special farm in Gharbia Governorate, Egypt. An Egyptian made hammer mill machine had been developed for chopping rice straw residues. The machine was modified by installing two types of knives i.e. sharp free knives and serrated discs to the original knives. The cutting power requirement and machine production are raised by rising cutting drum speed and reducing moisture content. By using the disk mill and flail knives reduced the energy requirement for chopping and raised fine degree of the chopped materials and solve the clogging problem. It can be commended that, throw out the addition of the circular disc and the other flail knives supports the process to the cutting force.

Keywords: Modification, chopping, rice straw, circular saw and chopping drum

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1 Introduction

EEAA (2021) stated that in Egypt the quantity of agriculture residues is about 50 million ton in 2021 which rice straw represent about 5.2 million ton. El-Hanfy and Shalby (2009) noted that in order to perform the cutting operation in this mechanism, moving knives (rotary knives) and other resting knives (fixed knives) are participated in the cutting process. To provide the resistance against the cutting force, the cutting rotor knives are responsible for

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cutting operation and the other fixed knives supports the material during the cutting process. During the straw cutting process the cutting edge of rotor knives penetrates into the stalks of straw, overcoming its strength to cut it and also mentioned that the modified mechanism was provided by one horizontal hexagonal cutter rotor mounted on two ball bearings.

The spaces were kipped stable by using spacer between serrated knives. Gopal and Kumar (2014) noted that hammer mills crushers operate with close tolerances between the cutting hammers and the screen bars. They reduce the material size by combining with shear and impact reduction methods. The fine materials particles of biomass improve the quality and density of briquettes. A briquetting plant, used to produce the briquettes from farm crop residues essentially have hammer mill consists of a rotating shaft with free- swinging hammers, which reduce the size of particle to a predetermined size through a perforated screen. Xuan et al. (2012) stated that hammer mills are widely used in food and feed industries as its advantages of high productivity and flexibility of more variety of products. After the material being ground is fed into the chamber, it is initially struck by the rotating hammers and then thrown against grid plates. Therefore, the material is crushed or shattered by the repeated hammer impacts, collisions with the grid plates and walls of grinding chamber as well as particle on particle impacts.

El-Fatih et al. (2010) mentioned that a desired blade cutting angle ranging from 20 °to 30 °gives an optimum cutting energy requirement for residues materials and also mentioned that cutting drum speed and concave holes diameter have affected the chopper productivity, cutting efficiency, power requirement, energy consumption and composting period. Evaluation is the final proof of a successful design. Bijagare et al. (2012) and Liu et al. (2011) said that the hammer mill had hammers like projection mounted on a shaft. The hammer revolves at high speeds and cuts the materials fed into pieces. Kumar (2013) said that hammer mill features are as following, material is reduced by impact from free-swinging bar hammers, finished product size controlled by grates or crusher sizes, materials can be reduced to granular powder at high rate, heavy-duty cast-iron or carbon steel construction, right-hand or left-hand machine available, easy access for maintenance and crusher/grate change. Omran (2008) stated that at higher cutting speeds the percentage of small cutting length rises as a result of higher number of affecting cutting knives. The category > 7 cm for rice straw had the highest cutting percentage this might be attributed to sticking of rice straw around the cutting rotating shaft. Saharkar and Dhote (2015) mentioned that computer-aided design system is a computer interactive graphics system equipped with software to accomplish certain tasks in design and manufacturing functions. Kamboj et al. (2012) said that, CAD software's help in future expansion of model by providing facilities to modify the designed work later. As there is wide scope of CAD in agricultural field, therefore an attempt to design the machine was made by using CAD. Dwivedi and Dwivedi (2013) stated that most CAD programs now permit creation of three-dimensional models, which may be viewed from any angle. State-of-the-art solid modeling CAD programs are a virtual reality for machine design that helps designers in design activities.

2 Material and methods

Figure 1 shows the modified machine. The selected machine (Egyptian made thresher) is functioning according to the theory of impact for cutting residues by using swimming hammer knives.

The evaluation of modified machine performance with rice straw at three moisture contents (9% –16.5% –59.3%) at three levels of feeding capacity (W1=180, W2=240 and W3=300 kg h^{-1}) on the three operating speeds 450, 1000 and

1200 rpm (6, 13 and 16 m s^{-1}) with the different modification stages as the following (as shown in Figure 2):

(1) Before the modification stage.

(2) The first modification stage of cutting rotate drum in which, knives with sharp edge have been set on the rotating drum with a distance (3 cm).

(3) The second modification stage of cutting rotate drum in which, knives with sharp edge beside (35 cm) saw disk mill have been set on the rotating drum with a distance (1.5 cm).

(4) The third modification stage of cutting rotate drum in which, knives with sharp edge beside (35, 30 and 22.5 cm) saw disk mills have been set on the rotating drum with a distance (0.7 cm).

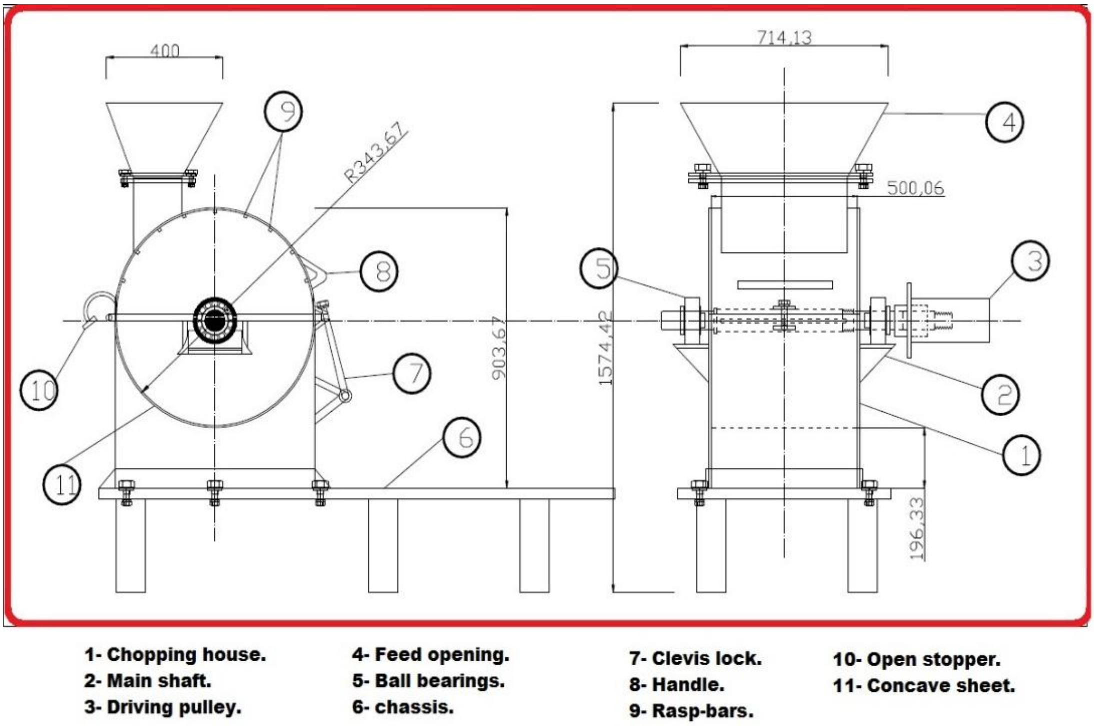
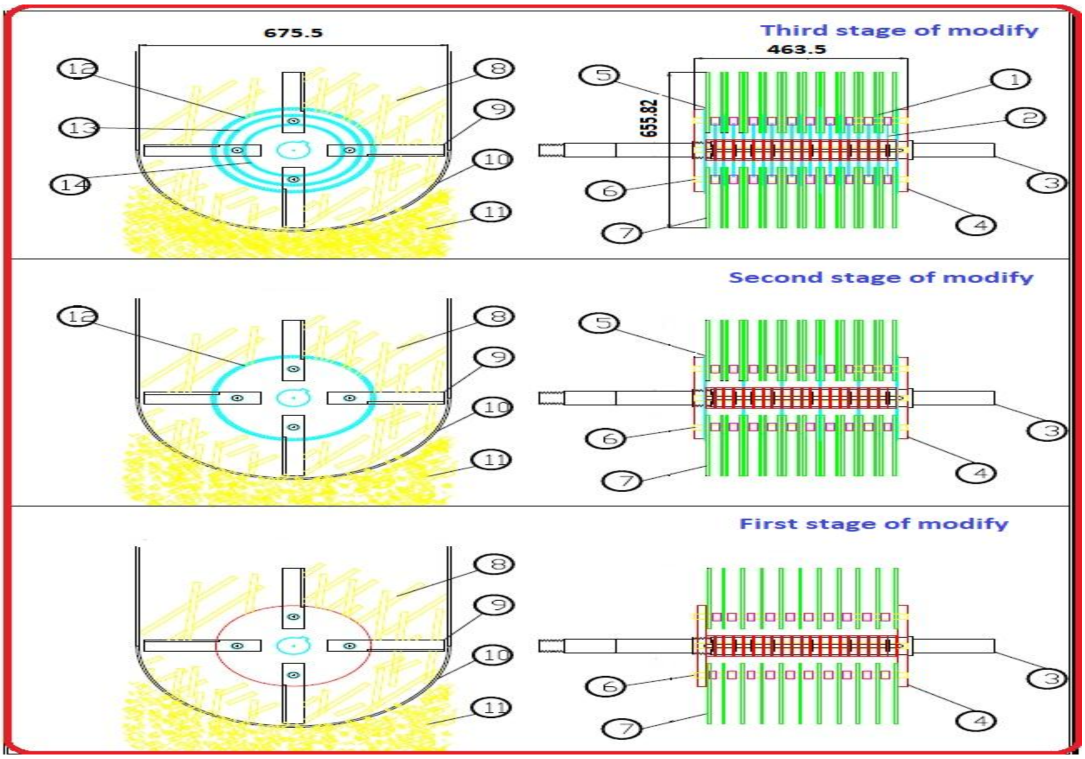


Figure 1 Elevation and side view of machine under study



1	Swing knives	6	Steel pipes	11	Chopping residues
2	Spacer	7	Free knives	12	Saw disk dim 14 inch
3	Main drum	8	Residues	13	Saw disk dim 12 inch
4	Flange	9	Bars	14	Saw disk dim 9 inch
5	Corals	10	Concave		

Figure 2 The different stages of drum for modified machine.

2.1 Cutting drum

Certain principles were considered during the design and fabrication of the modified machine. Such principles were in designing the chopping action. The main aim of this research is to modify the old threshing drum to the new one as shown in Figure 3 to be more suitable for chopping rice straw residues.

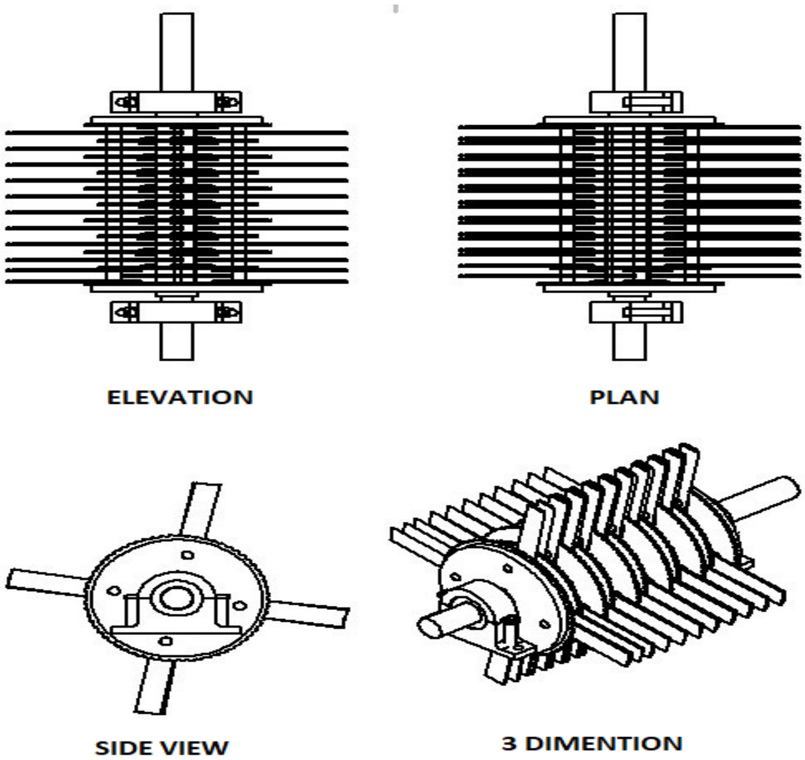


Figure 3 Drum of the machine under study

2.2 Swinging knives

All free ends of the hammers were made with a graduated spike surface to rise the sheer force on the raw materials. Each knife is fastened by four bars and rotates with high speed corresponding to a lower speed of feeding drums. The swinging knifes were fitted to the flange by four bars and bolts. The knives were static and dynamic balance has been done for the chopping drum at 4500 rpm.

2.3 Saw disk mills

Saw Disk knives made of steel with 9, 12 and 14 inch in diameter were fixed in the threshing drum. The action of these knives interacted between themselves actions to help in cut the crop materials easily, reduce the impact force by the beaters and prevent the straw around the drum. All disks with different diameters rotate with the main shaft at the same high speed.

2.4 Theoretical design consideration

The mechanism applied here is of impact loading where the time of application of force is less than the natural frequency of vibration of the body. Since the hammers are rotating at high speed, the time for which the particles come in contact with the hammers is very small, so here impact loading is applied. This design was carried out on the basic safety of the operator. The deflection of the hammers while in operation was also considered in the design. Swinging instead of hammers was used to avoid the hammers from getting stocked in case a hammer comes in contact with a material it cannot break at first impact. The machine is modified with the help of CATIA (Computer Aided Three Dimensional Interactive Analysis) software. A solid model is the complete type of geometric model used in CAD systems. It contains all the wireframe and surface geometry necessary to fully describe the edges and faces of the model.

2.5 Using of CAD software (SolidWorks)

Computer aided design of the machine was made by using "SolidWorks" software. This design helps to find out the typical dimensions of components of machine with great accuracy in small time. Typical dimensions of the machine such as blade size, distance etc. and their 3D models can be easily made in small time with the help of software as shown in Figure 4. Input commands are provided for cutting tool features such as tool diameter, length of cut.

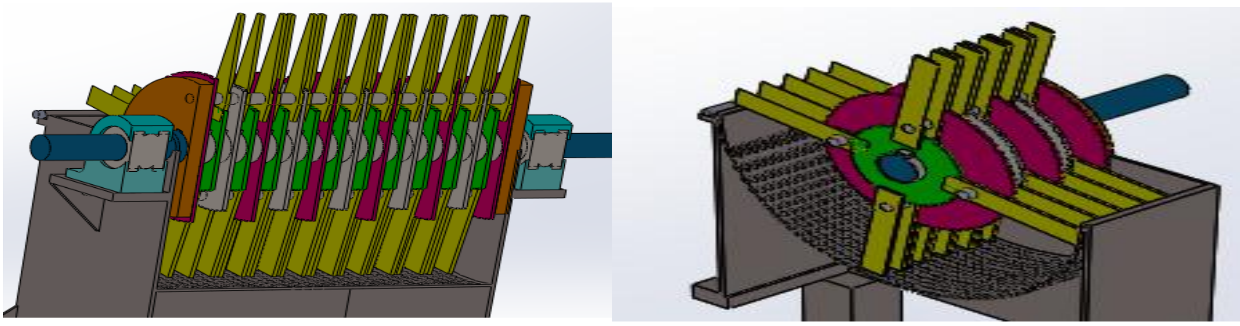


Figure 4 The chopping house cross sections

2.6 Finite element modeling

A numerical model of chopping machine is created by using three-dimensional software. Deformation under static analysis is found as shown in Figure 5. Maximum strain value is obtained. The static results are analyzed and verified by simulation. The core of the FEA method is an idealization of the object or continuum by a finite number of discrete variables. For this purpose, the object is first divided into a grid of elements that forms a model of the real object. Each element is a simple shape such as a knife, circular saw, or flanges. Program has information to write the governing equations in the form of model analysis of the knife deformation, disk deformation and flange deformation.

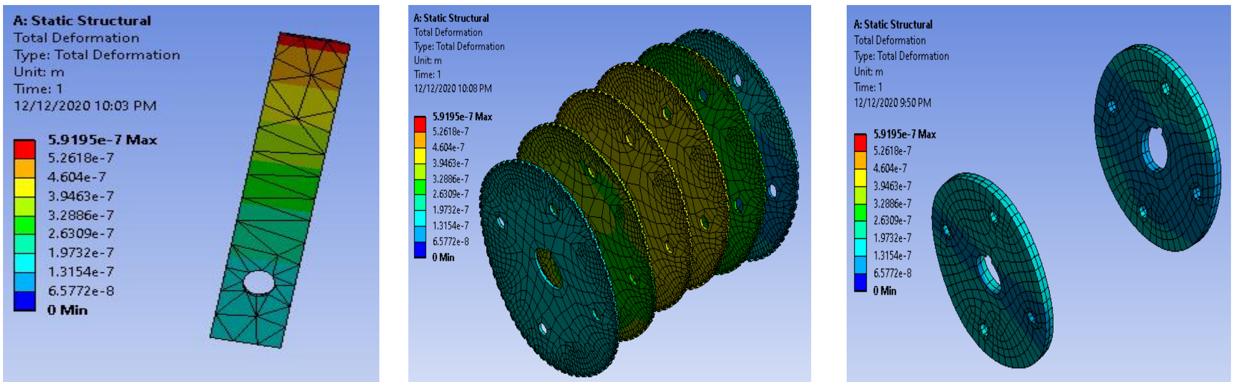


Figure 5 Model analysis of the knife deformation, disk deformation and flange deformation in Ansys pro

The shaft is considered to be subjected to torsion and bending as shown in Figure 6. The model is considered for the horizontal shaft impact chopping so as to find out the relation between the feed, the crusher parameters and the output parameters. Attrition method has the material scrubbed between the hammers and the screen bars. Attrition consumes more power and causes heavier wear on hammers and screen bars.

The prediction of model analysis of the cutting drum deformation, drum shear stress and drum principal stress during cutting operations is very important for the designers and agricultural machinery manufacturers, which will allow them to manufacture optimized machinery by using predicted knowledge.

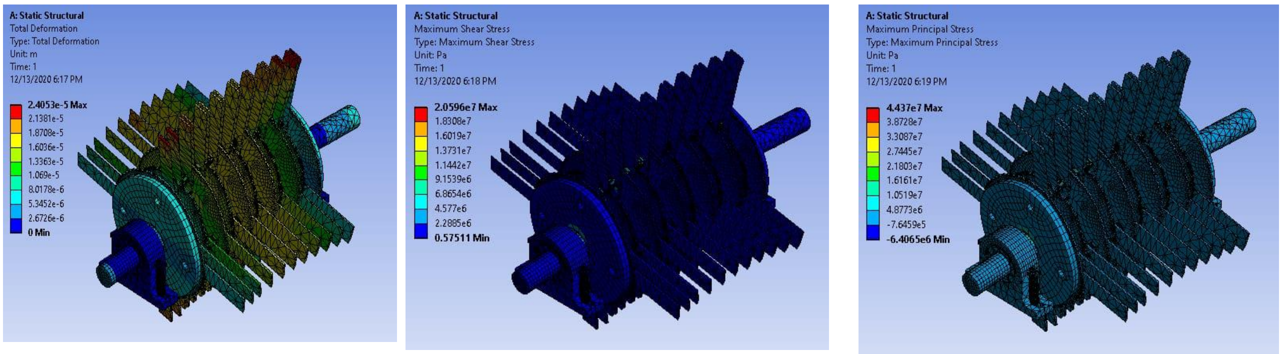


Figure 6 Model analysis of the cutting drum deformation, cutting drum shear stress and cutting drum principal stress in Ansys pro

3 Factors under study

The general design was based on allowing a durable and strong metallic object inform of hammers to beat any material which obstructs its way during the operation, thereby resulting into breakage of the material which can also be referred to as size reduction in commination operation. This occurs in an enclosed chamber called (the crushing chamber). Take into consideration the following:

(1) Cutting drum speeds were of 450, 1000, and 1200 rpm.

(2) Moisture content percentage for rice straw residues (9%, 16.5% and 59.3%) on wet base.

(3) Distance between flail knives themselves were (0.7, 1.5 and 3 cm) where the third distance is the machine's standard one.

(4) Three levels of feeding capacity (W1: 180, W2: 240 and W3: 300 kg h^{-1})

3.1 Moisture content (M.C)

The samples were taken periodically from the machine outlet and placed in polyethylene bags. The samples were oven dried at 70̊ for 48 h on wet base (cited by Nwaigwe et al. (2012)) by using the electrical oven:

$$M.C. = \frac{SB - SA}{SB} \times 100 \quad (1)$$

Where, SB is the sample weight before drying (g) and SA is the sample weight after drying (g).

3.2 Cutting drum speed

Speedometer was used to measure the rotation speed with three ranges available (450 – 1000 - 1200) rpm.

3.3 Evaluation parameter

3.3.1 Cutting efficiency

Nwaigwe et al. (2012) noted that, the efficiency (μ, %) of the modified chopping materials mill is given by using the following equation:

$$\mu = (\text{Amount passing sieve / total weight of sample}) \times 100 \quad (2)$$

3.3.2 Chopper productivity (P)

El-Shal et al. (2010) mentioned that, actual machine capacity (AMC) is the actual rate of productivity by the amount of actual time consumed in operation (lost + productive time). Machine productivity was calculated by using the following formula by Mady (1999):

$$P = W / T \quad (3)$$

Where, P is productivity (t h^{-1}), W is the mass of the sample (ton), and T is the time(h).

3.3.3 Required power (*RP*)

Arfa (2007) mentioned that, consumed fuel during chopping operation was determined by measuring the volume of diesel fuel required and refueling the machine tank after finishing the operation time. El-Fatih et al. (2010) and Arafa (1991) stated that, the power consumption was calculated by using the following formula:

$$RP = (FC \times \rho f \times LCV \times 427 \times \eta_m \times \eta_{th}) / (367200) \quad (4)$$

where, RP is the required power (kW), FC is the fuel consumption (L h^{-1}), ρf is the fuel density

(Diesel 0.85 kg L^{-1}), LCV is the lower calorific value of fuel (11000 kcal kg^{-1}), thermo- mechanical equivalent (427 kg m $kcal^{-1}$), η_m is the engine mechanical efficiency (85% engine), and η_{th} is the engine thermal efficiency (30% Diesel engine).

3.3.4 Consumed energy (CE)

The machine applies the principle of shear and impact in the reduction of size. The energy required to produce the small change in the size of the chopping materials was obtained by using the following of El-Fatih et al. (2010):

CE (kW h ton^{-1}) = (Required Power, kW) / (machine productivity, kg h^{-1}) × 1000 (5)

4 Results and discussion

4.1 Machine productivity

The data in Figures 7, 8 and 9 show that the cutting productivity raised with rising cutting drum speed and with reducing the distance between flail knives and using saw disks this is shown in as example productivity increase from 150 kg h^{-1} at speed 450 rpm in feeding capacity (W3) before modification to 270 kg h^{-1} at speed 450 rpm in feeding capacity (W3) with the third stage of modification at 59.3% rice straw moisture content. These results agree with El-Hanfy and Shalby (2009) stated that, the average of cutting length reduced and the distribution percentage of short pieces raised by rising cutting speeds and overlapping between fixed and rotary knives. The results also show that the cutting productivity raised with reducing the straw moisture content and rising feeding capacity.

4.2 Required power

The data in Figures 10, 11 and 12 show that the power requirements reduced with rising cutting drum speed and with reducing the distance between flail knives this is shown in as example power requirements reduce from 34 kW at speed 1200 rpm in feeding capacity (W3) before modification to 22 kW at speed 1200 rpm in feeding capacity (W3) with the third stage of modification at 59.3% rice straw moisture content. These results agree with Arfa (2007) mentioned that, the power requirement for cutting different residues was raised with rising drum speed, feed rate and moisture content but the power consumption and energy requirement were reduced by rising oval slots area and concave clearance.

The results also show that the required power raised with reducing the straw moisture content and rising feeding capacity.

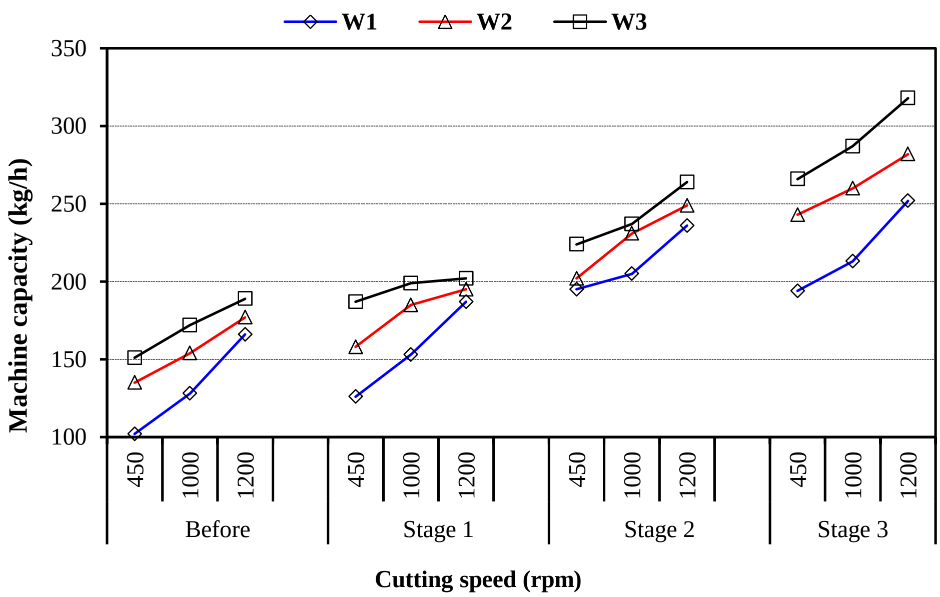


Figure 7 The relationship between cutting drum speed and productivity at different levels of feeding capacity for 59.3% rice straw moisture content

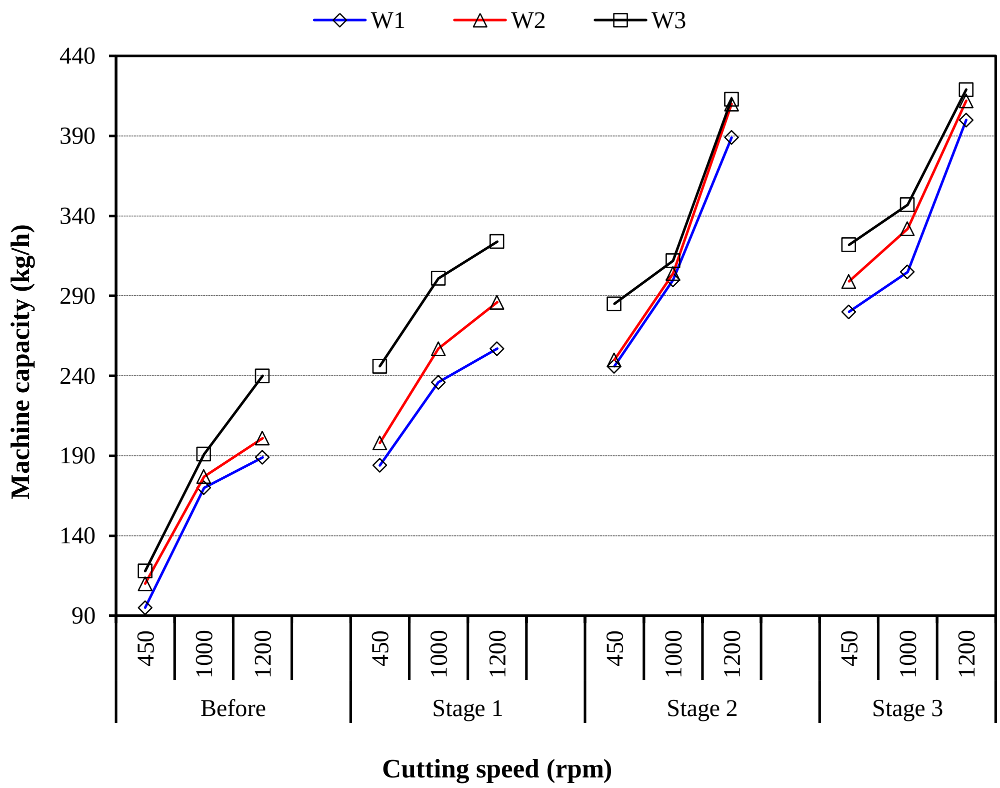


Figure 8 The relationship between cutting drum speed and productivity at different levels of feeding capacity for 16.5% rice straw moisture content

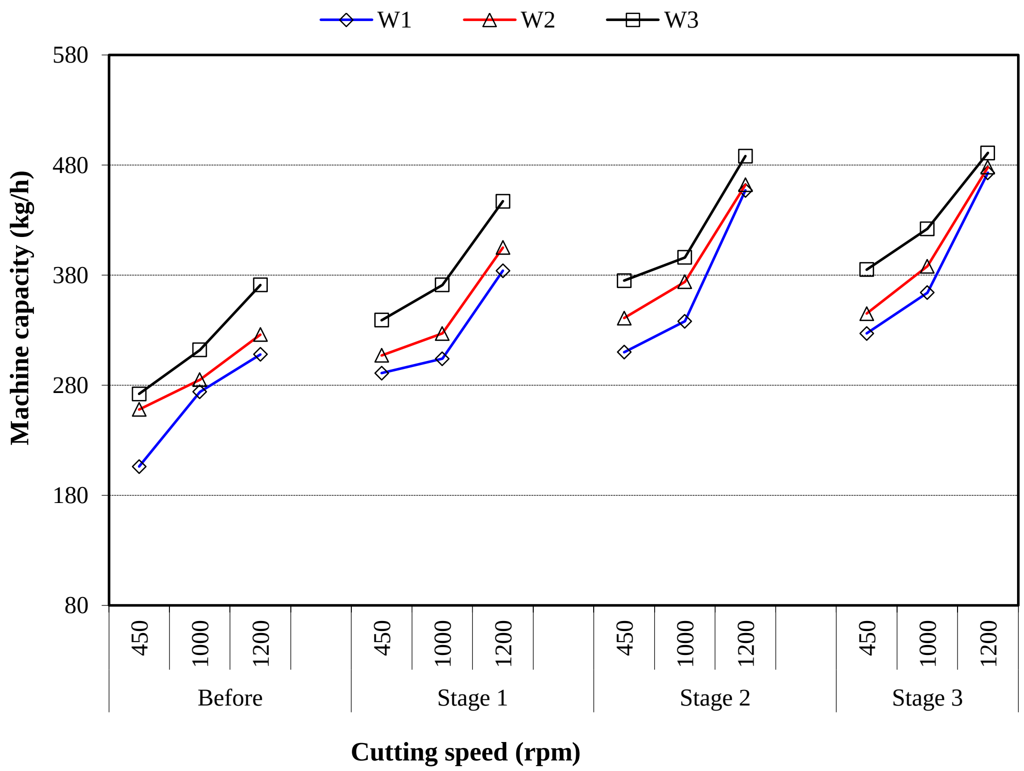


Figure 9 The relationship between cutting drum speed and productivity at different levels of feeding capacity for 9% rice straw moisture content

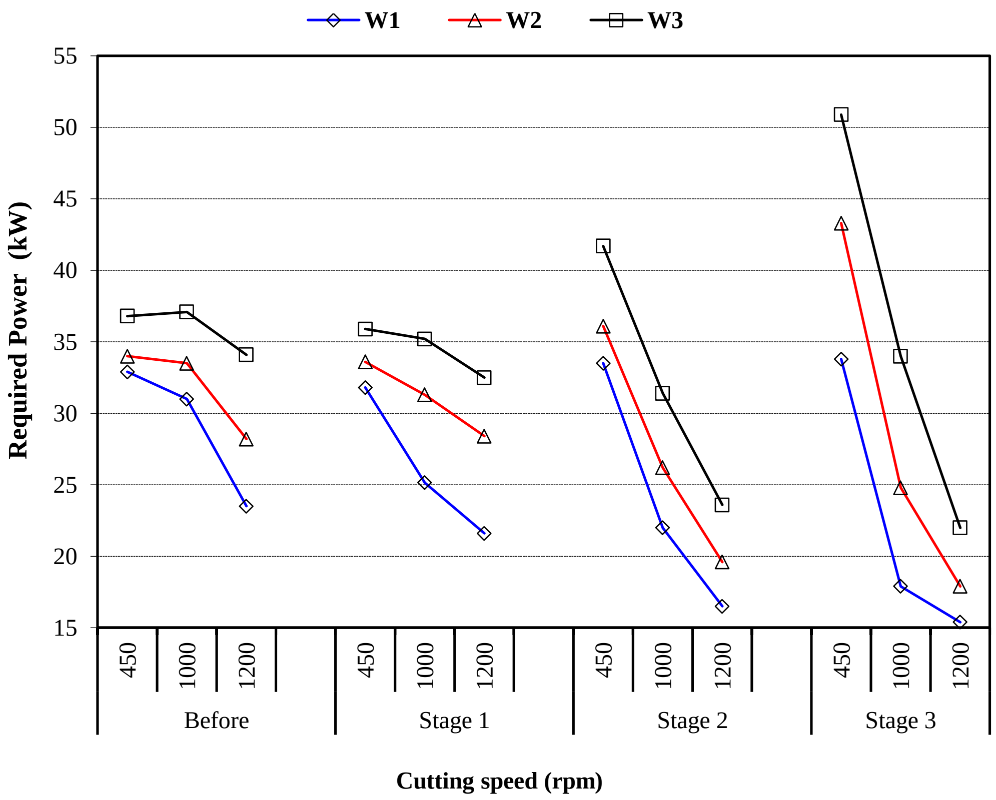


Figure 10 The relationship between cutting drum speed and power requirements at different levels of feeding capacity for 59.3% rice straw moisture content

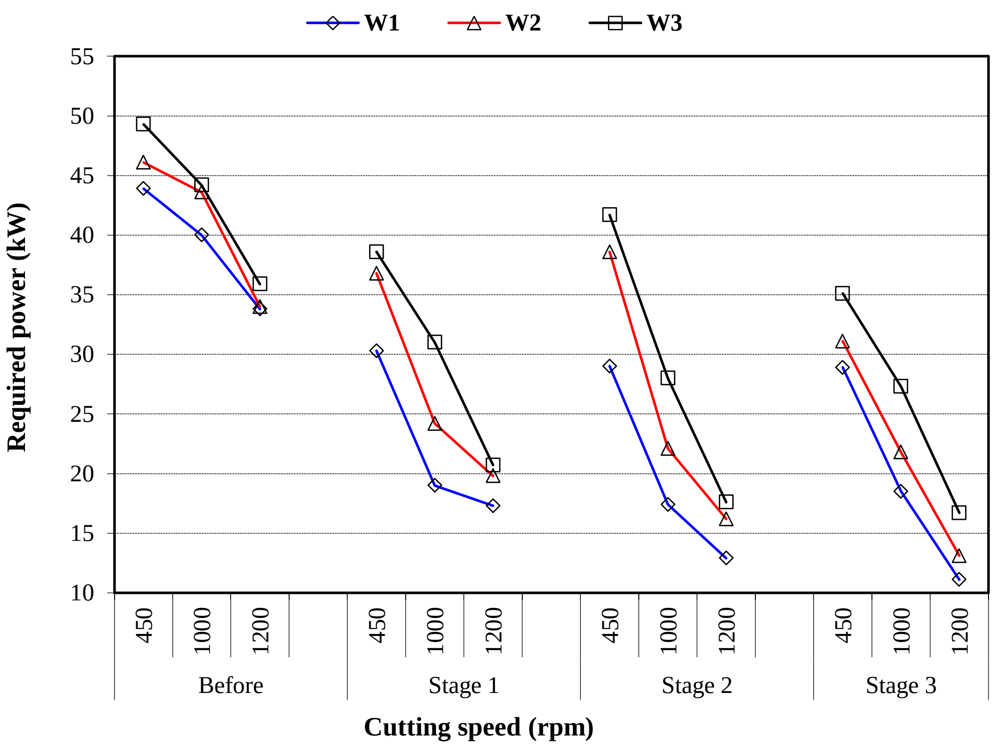


Figure 11 The relationship between cutting drum speed and power requirements at different levels of feeding capacity for 16.5% rice straw moisture content

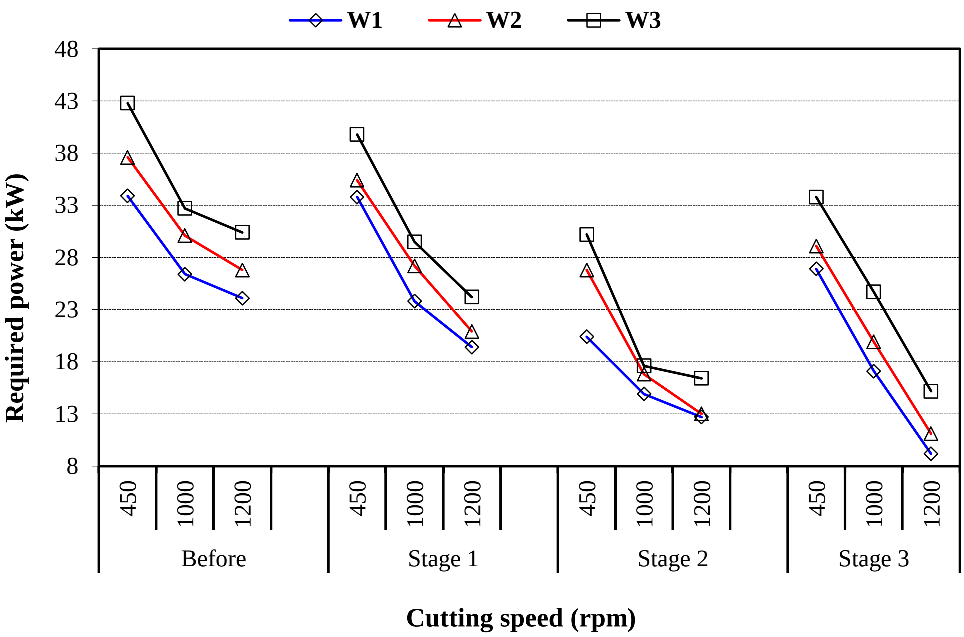


Figure 12 The relationship between cutting drum speed and power requirements at different levels of feeding capacity for 9% rice straw moisture content

4.3 Energy consumption

The data in Figures 13, 14 and 15 show that the energy consumption reduced with rising cutting drum speed and with reducing the distance between flail knives this is shown in as example Energy consumption reduce from 180 kw h ton^{-1} at speed 1200 rpm in feeding capacity (W3) before modification to 75 kw h ton^{-1} at speed 1200 rpm in feeding capacity (W3) with the third stage of modification at 59.3% rice straw moisture content. These results agree with Kepner et al. (1993) mentioned that, dull knives and excessive clearance lead to rise cutting energy this due to the crop residues tern rather than sheared and also accelerates wear because wedging between the knives and shear bar. The results also show that the energy consumption raised with rising the straw moisture content and rising feeding capacity.

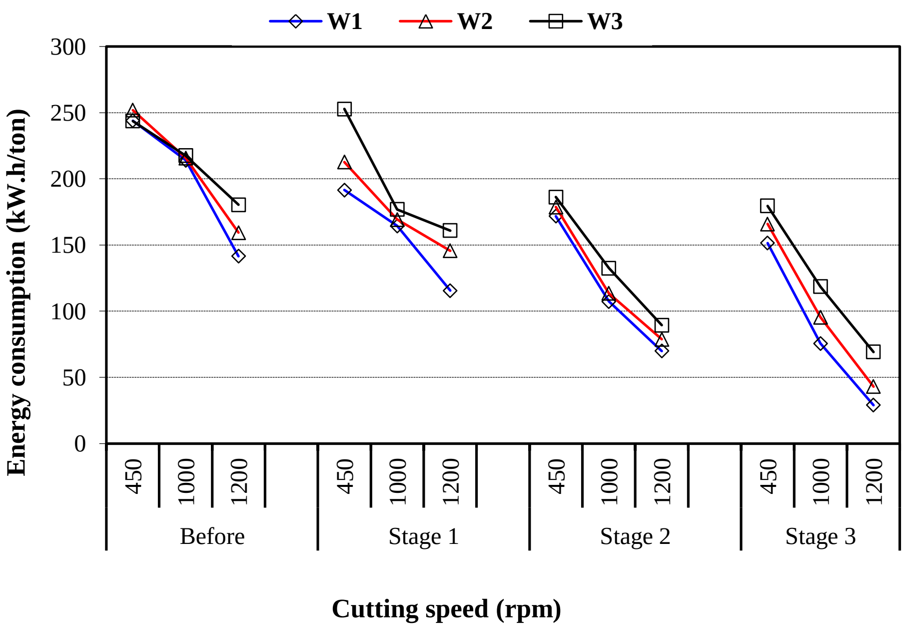


Figure 13 The relationship between cutting drum speed and energy consumption at different levels of feeding capacity for 59.3% rice straw moisture content

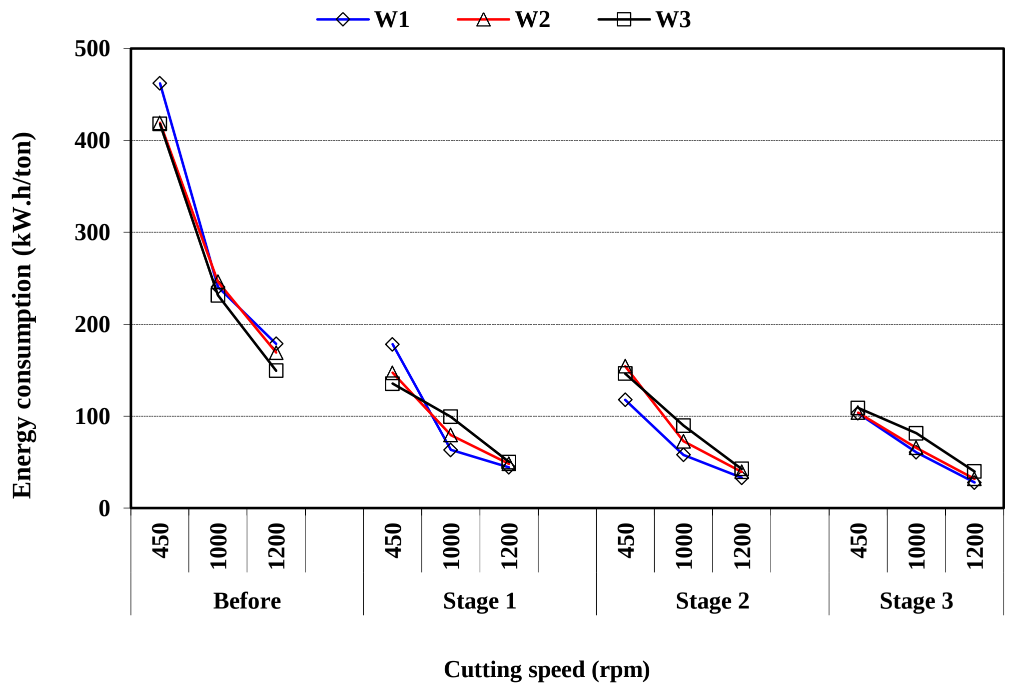


Figure 14 The relationship between cutting drum speed and energy consumption at different levels of feeding capacity for 16.5% rice straw moisture content

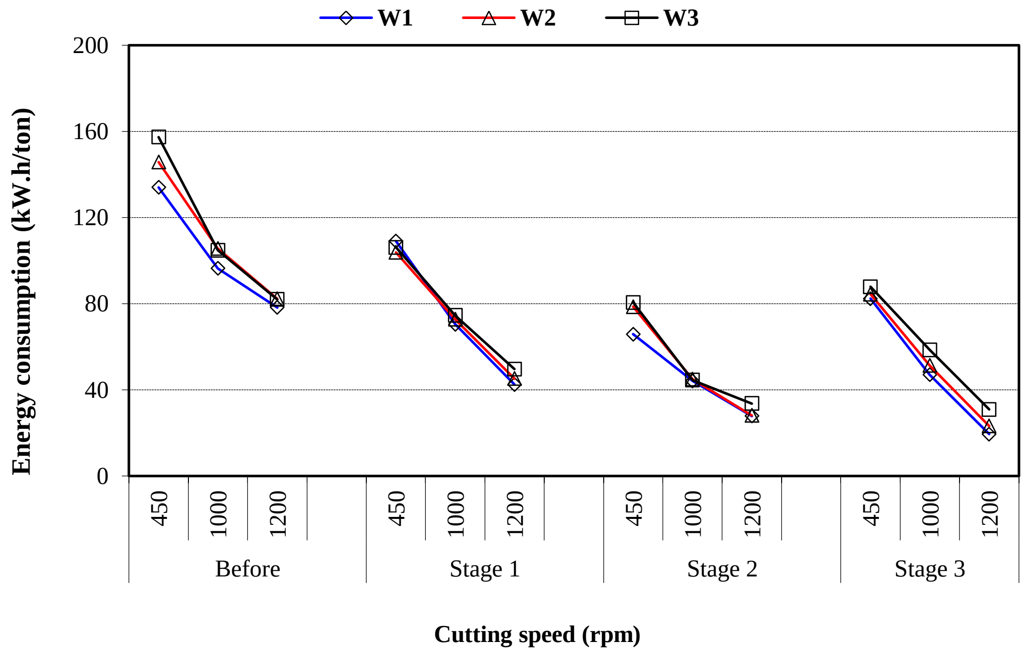


Figure 15 The relationship between cutting drum speed and energy consumption at different levels of feeding capacity for 9% rice straw moisture content

4.4 Cutting efficiency

The data in Figures 16, 17 and 18 show that the cutting efficiency raised with rising cutting drum speed and with reducing the distance between flail knives this is shown in as example Cutting efficiency reduce from 60% at speed 450 rpm in feeding capacity (W3) before modification to 78% at speed 450 rpm in feeding capacity (W3) with the third stage of modification at 59.3% rice straw moisture content. These results agree with Omran (2008) recommended that chopping farm in pieces less than 3cm improves its efficiency to use in feeding livestock.

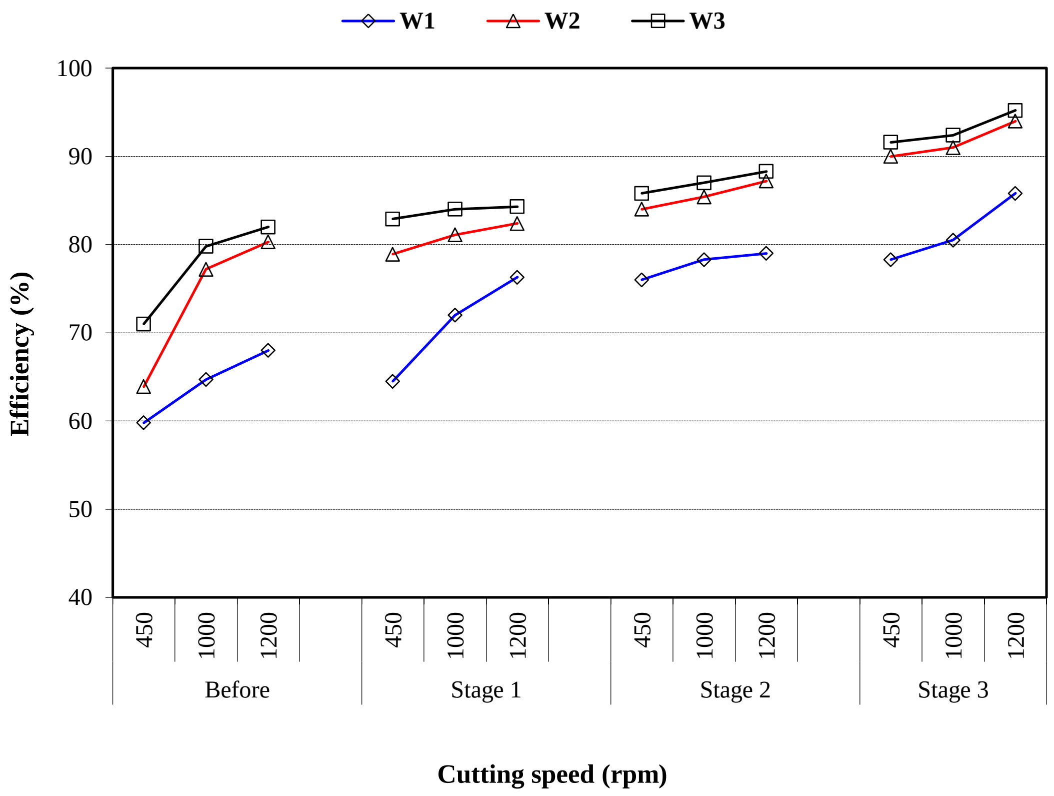


Figure 16 The relationship between cutting drum speed and efficiency at different levels of feeding capacity for 59.3% rice straw moisture content

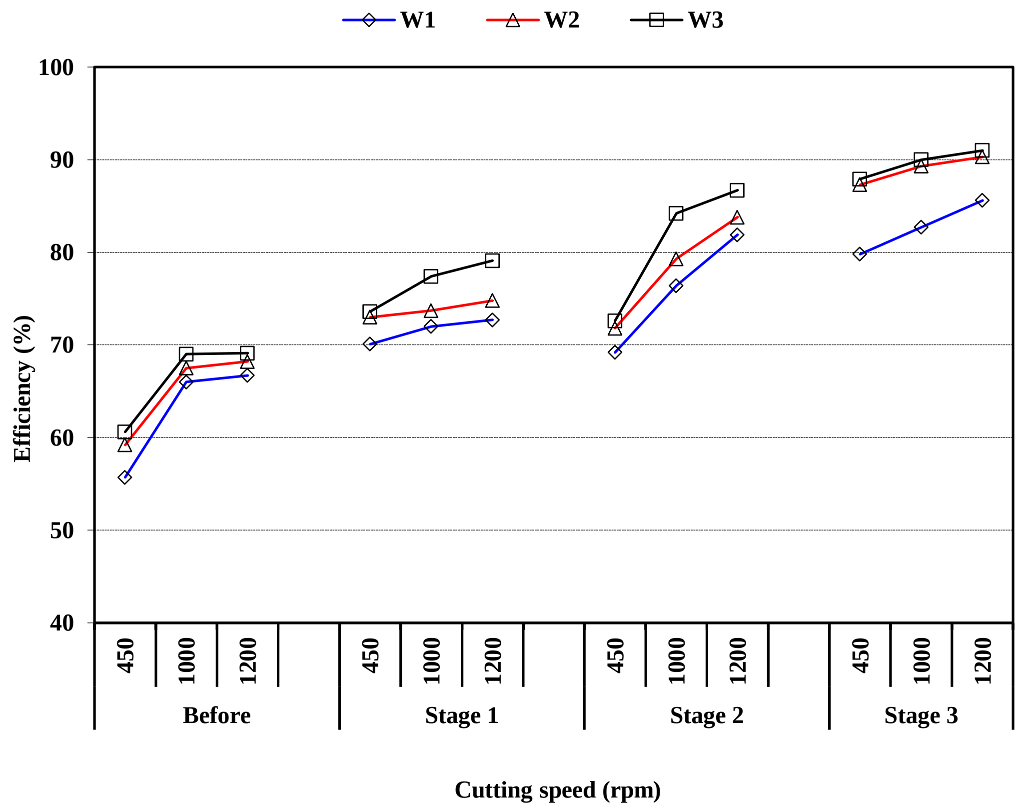
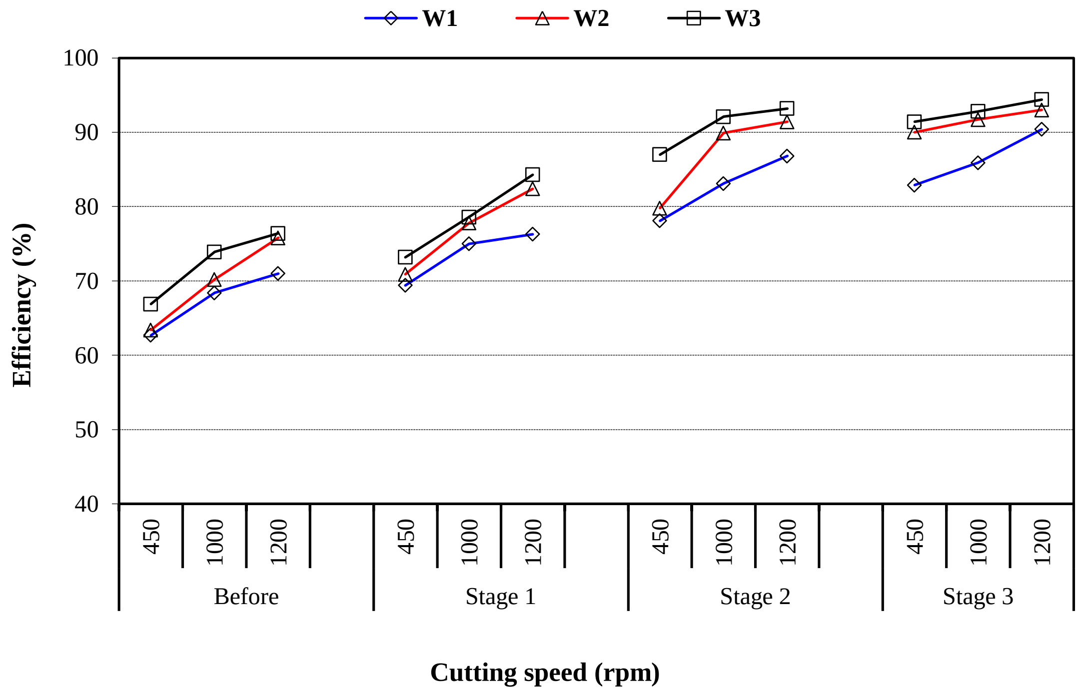


Figure 17 The relationship between cutting drum speed and efficiency at different levels of feeding capacity for 16.5% rice straw moisture content



Figure% 18 The relationship between cutting drum speed and efficiency at different levels of feeding capacity for 9% rice straw moisture content

5 Conclusion

The cutting power requirement and machine production raised by rising cutting drum speed and reducing moisture content. By using the disk mill and flail knives reduced the energy requirement for chopping and raised fine degree of the chopped materials and solve the clogging problem.

It can be commended that, throw out the addition of the circular disc and the other flail knives supports the process to the cutting force.

Developing was operated by the addition of two types of knives (sharp free knives + serrated discs) to the original cutting drum existing already in the machine. This machine is evaluated in terms of production capacity and operating efficiency rotation of the machine on the three operating speeds (450 - 1000 - 1200 rpm) and at different moisture content ratios (9%, 16.5% and 59.3%) for rice straw residues, Distance between flail knives themselves were (0.7, 1.5 and 3 cm) where the third distance is the machine's standard one at three levels of feeding capacity ($W1_{=}180$, $W2_{=}240$ and $W3_{=}300$ kg h^{-1}).

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