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EFFECT OF MILLING RICE STRAW ON HAMMER MILL MACHINE EFFICIENCY AND MILLING QUALITY

Radwan M. E. I.

Central Laboratory for Aquaculture Research, Agriculture Research Center, Ministry of Agriculture, Egypt

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Abstract

In many countries, massive amounts of post-harvest rice residues are eliminated through open air field burning, which presents a threat to public health and poses an environmental pollution problem. So, the overall goal of the present study is to study the effect of grinding rice straw on machine efficiency and bio- product quality using a hammer mill machine to produce a high quality of rice straw and high machine efficiency with optimum cost. The hammer mill machine was evaluated under three levels of different drum speeds of 2400, 3200 and 4000 rpm, four different sieves of holes diameter 3, 6, 12 and 18 mm and three different knives number of 16, 24 and 32 with constant pyramidal knives shape. The evaluation included machine productivity, machine efficiency, specific energy consumption, fineness degree of rice straw and economical costs of rice straw mass. The obtained data showed that, the highest values of machine productivity of 158.6 kg/h, lowest specific energy consumption of 43.72 kW.h/Mg and the lowest cost per mass unit of 71.29 L.E/Mg were recorded in the case of sieves hole diameter 18 mm, knives number of 24 and drum speeds of 4000 rpm, the highest values of fineness degree of rice straw 83.74 % was recorded in the case of sieves holes diameter 3 mm, knives number of 24 and drum speed of 4000 rpm and a hammer mill machine efficiency of 91.9 % was recorded in the case of sieves hole diameter 6 mm, knives number of 24 and drum speeds of 3200 rpm.

Keywords: Hammer mill machine, rice straw, holes diameter of sieves, drum speeds, knives number, specific energy, economical costs.

INTRODUCTION

Rice cultivation produces large quantities of straw waste, ranging from 2 to about 9 tons ha^{-1} globally (Abdulla and El-Shatoury 2007).Millions of tones of agricultural residues are wasted every year in Egypt. It comes from cereal production and foliage residues such as rice straw. These materials are of low digestibility to ruminants and have low nitrogen content. Consequently, they have a low animal production potential. Straw is a poor livestock feed. Rice straw is no exception; it contains about 80% potentially digestible substances and is therefore a source of energy. However, its actual digestibility by ruminants is only 45 to 50%. Furthermore, the amount animal can eat is limited to less than 2% of body weight because of the slow rate at which it is fermented in the rumen and methods for chemically treating straw have been known for a long time (Jackson, 1987). One of the chemicals used is sodium hydroxide which is neither cheap nor easy to obtain in Egypt. El- Zahaby (1996) mentioned that there is a large amount of residues all over the Egyptian farms. He made complete survey of field crop residues in Egypt and suggested to use these residues to produce thermal energy, unconventional bricks, and unconventional cattle feed. Dobermann and Fairhurst (2000) mentioned that the burning of rice straw is environmentally unacceptable as it leads to (1) release of soot particles and smoke causing human health problems such as asthma or other respiratory problems, (2) emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide (N_2O) causing global warming and (3) loss of plant nutrients such as N,P,K and S. Almost entire amounts of C and N, 25% of P, 50% of S and 20% of K present in straw are lost due to burning. There are many factors affecting rice straw milling. Galy (1973) found that the feed rate is directly proportional to the hole diameter of concave, when the cylinder speed is kept constant. Kadder (1997) studied the effect of different speeds cutting some field crop residues such as cotton, maize stalks and rice straw on the power requirement and cutting length. It was found that the cutting length decrease by increasing knives number and cutter head drum speed. Younis *et al.* (2002) developed chopping machine and used it for cutting residues of rice, cotton and maize. They found that the feeding roll speed to cutting rotor speed ratio of 1: 15 gave the best results in favor of cutting lengths, but the productivity was very low due to decreasing feeding roll speed. The feeding roll speed to the cutting rotor speed ratio of 1: 10 gave the best results in productivity due to the high speed of feeding roll. While mean, the sympathetic of cutting lengths was very low, the optimum feeding roll speed to the cutting rotor speed ratio of 1: 12.5 and cutting rotor speed of 2000 rpm (50 m/s), gave a satisfied productivity and sympathetic cutting lengths, the minimum values of required power and consumed energy, 1.94 kW and 5.1 kW/ton, were found at rotor speed of 1000 rpm (25 m/s). Kamel *et al.* (2003) made study to maximize utilization of forage chopper and to reduce its hourly operating cost during chopping rice straw residues. They used the forage chopper for chopping and spreading rice straw into the soil under different forward speeds, different number of knives on the chopper cutter and different straw moisture contents. They recommended to use the forage chopper with 12 knives at two forward speeds (1^{st} and 2^{nd} low gear of tractor) after harvesting directly (moisture content ranged from 39.69 to 28.01%) and decreasing the number of knives to 3 knives at lower levels of straw moisture content (up to 13.49%) to obtain high percentage of small pieces (less than 2 cm) and high productivity. Hegazy (2006) developed and evaluated a grain crusher of local made. The results revealed that optimum operating conditions were obtained at 44.21 m/s hammer speed, 22.5 degrees of hammer edge angle and 7.94 mm size. At these levels maximum productivity of 0.228 ton/h, the lowest power requirement of 3.521 kW and energy consumption of 2.447 kW.h/ton were obtained. El-Khateeb (2007) mentioned that increasing the cutter head speed from (22.1 to 35.3 m/s) tend to increase percentage of chopping length (0.5 to 2cm) from (50% to 60%), machine productivity from (1.32 to 2.81Mg/h), useful power from (2.19 to 3.86 KW) and with decrease the unit energy required from (1.87 to1.37 kW.h/Mg) and machine cost from (16.33 to 7.22L.E/ Mg) at knives number 2 and moisture content 65%. The objectives of the present study are to:

1. Evaluate a local made hammer mill during milling rice straw.
2. Optimize some operating parameters (drum speed, number of knives, and sieve holes diameters) affecting the performance of hammer mill for rice straw.
3. Evaluate the hammer mill from the economic point of view.

MATERIALS AND METHODS

The main experiments were carried out at the Central Laboratory for Aquaculture Research (CLAR) in Abbassa village at Abu Hammad district, Sharkia Governorate during 2010-2011 seasons to test and evaluate the performance of the modified hammer mill during milling rice straw under local conditions.

Materials:

Rice straw:

Rice straw (variety Sakha 101) at an average moisture content of 5.5%, stem diameter 3-4 mm, and lengh of 900-1230 mm was used throughout all experiment.

Hammer mill:

Fig.1 is schematic view of the hammer mill machine.

Knives and Sieve;

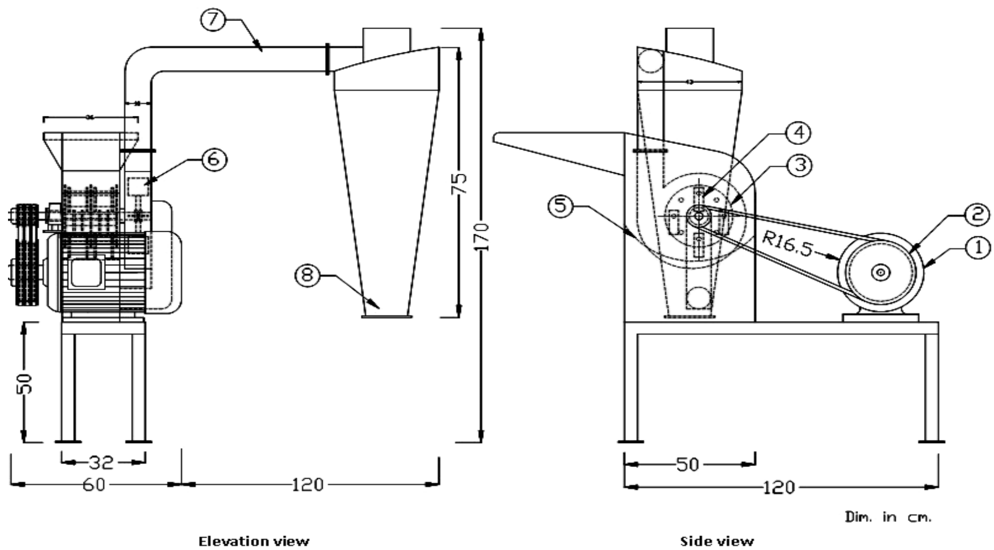
The specifications of knife and screens are displayed in Table 1.

Hammer mill drum, Sieve and pulleys:

The specifications of hammers, Screens and pulley are shown in fig. 2.

Table 1. The specifications of the used knife and screens.

Knives		Screens	
Type	swinging hammers	Hole Diameter, mm	3-6-12-18
Material	Steel iron.	Width, mm	210
Length (A), mm	120	Roll outside , mm	480
Width (B), mm	35	Length over the back, mm	900
Thickness (c), mm	5	Gauge, mm	2
Swinging length (D), mm	90		
Diameter to fit rode size (E),mm	16		
Shape	Pyramidal.		



No.	Part name	No.	Part name	No.	Part name
1	motor	4	knives	7	Outlet tube
2	pulley	5	sieve	8	seclon
3	drum	6	fan		

Fig. 1. Schematic view of the tested hammer mill

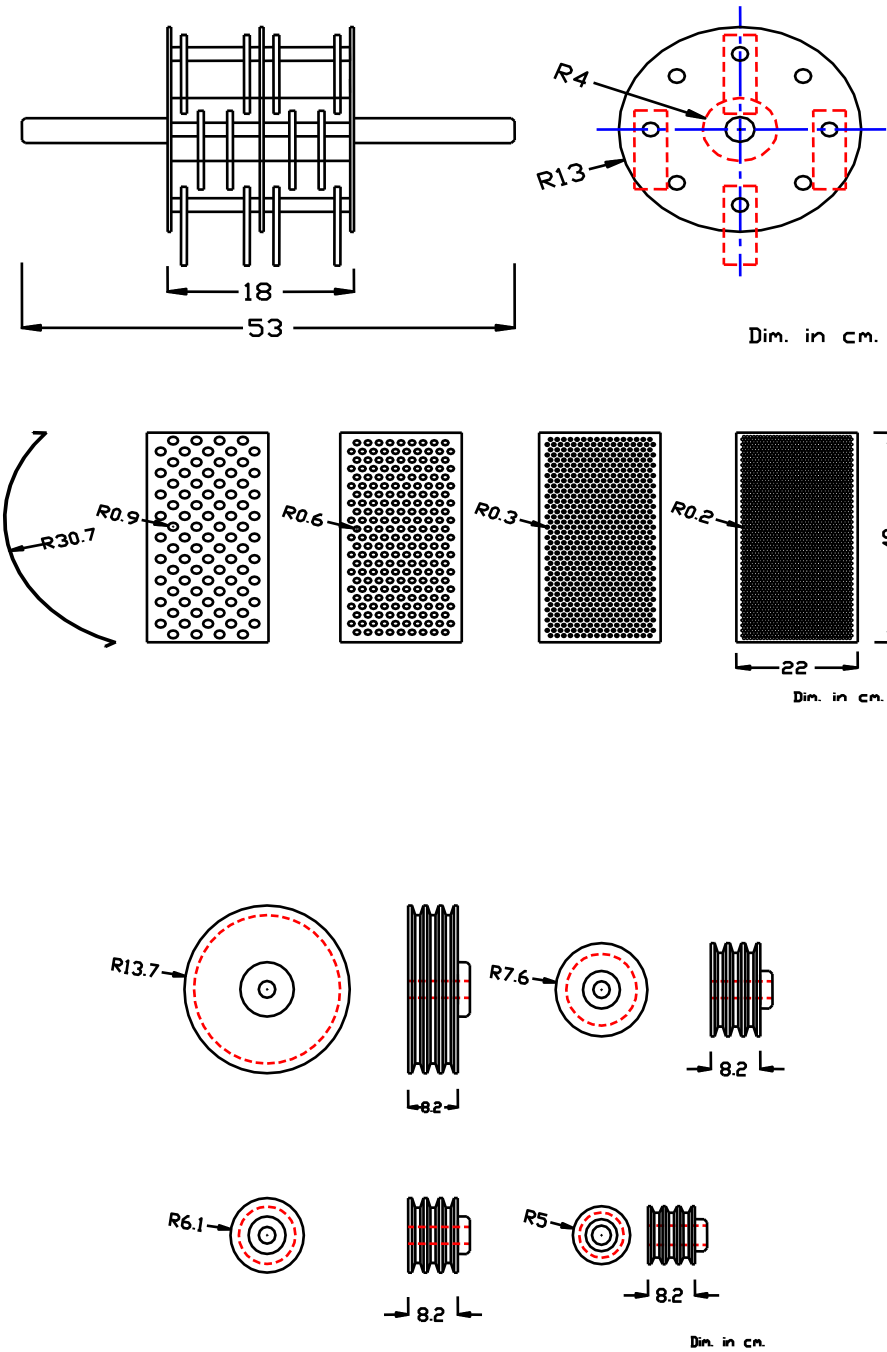


Fig (2): Views of hammers mill drum, sieves and pulleys.

Measuring instruments:

The following instrumentations with desirable accuracy were used for different measurements during the execution of experiments: stop watch, electronic balance, caliper, digital tachometer, watt meter and Stander testing sieve.

Methods:

The resizing experiments were conducted to determine the operating parameters affecting the performance of hammer mill. These parameters are:

1. Three drum rotating speeds of 2400, 3200 and 4000 r.p.m. corresponding to drum liner speeds of (32.67, 43.56 and 54.45 m/s) respectively.
2. Four sieve holes diameters of 3, 6, 12 and 18 mm.
3. Three number of knives 16, 24 and 32.

Procedures

A given quantity of 1 kg mass of rice straw was dropped in the machine hopper after adapting the knives number, sieve hole diameter, and drum speed. The elapsed time to complete the sample processing is measured and recorded and total consumed power (kW) under working load was determined by using a wattmeter (700–k type). The processed sample was received in a special container to measure its mass and separate it to different particle size categories. The process is repeated 3 times for each combination of different study parameters.

Measurements

Evaluation of the hammer mill was performed taking into consideration the following indicators:

Machine productivity and milling Efficiency:

Productivity of the hammer mill

It is the rate of machine productivity in a time unit (Mg/h).

Milling efficiency:

$$\text{milling efficiency} = \frac{Wm}{Win} \times 100$$

Where Wm = output (milling yield mass, g)

Win = input (sample mass, g).

Fineness Degree (particle size distribution):

The ground rice straw samples were classified into four grades on the basis of modulus of fineness as follows: Fine (samples < 2 mm), Fine Medium two Π (2 < samples < 5 mm), Coarse Medium one I (5 < samples < 10 mm), and Coarse (samples > 10 mm). Source: Shii *et al.* (2009).

Milling power and specific energy:

The required milling power was estimated by using the following equation (Kurt, l979)

Total consumed power = load (kW) $= \frac{\sqrt{3} I . V \eta \cos\Theta}{1000}$ (kW)

Where: I = line current strength in Amperes, V = Potential strength (voltage) equal to 380 V, $\cos\Theta$ = power factor (equal to 0.84), and η = Mechanical efficiency.

The specific energy (kW.h/Mg) was calculated by using the following equation:

Specific Energy = The consumed power (kW)/ machine productivity (Mg/h).

Operational cost:

$$\text{Operational cost (L.E./Mg)} = \frac{\text{Machine hourly cost (L.E. /h)}}{\text{Machine productivity (Mg/h).}}$$

The machine hourly cost was determined by using the following formula (Awady, 1978):

$$C = \frac{P}{h}\left(\frac{1}{a} + \frac{i}{2} + t + r\right) + (W \times e) + \frac{m}{144}$$

Where: C: Machine hourly cost, L.E./h; P: Price of machine, L.E; h: Yearly working hours; a: Life expectancy of the machine, h; i: Interest rate/year; t: Taxes and over heads ratio %; r: Repairs and maintenance ratio %; W: Power of motor in, kW; e: Electricity cost, L.E./kW.h; m: The monthly average wage, L.E.; and 144: The monthly average working hours.

RESULTS AND DISCUSSION

The discussion will cover the obtained results under the following headings:

Effect of drum rotational speed on machine productivity and milling Efficiency:

Figs. 3 and 4 show that the general trend of the mill is that the productivity increased by increasing the drum speed but the contrarily was occurred with the milling efficiency when the other effective parameters (sieve holes diameter, and number of knives) are kept constant. Results showed that the highest machine productivity was achieved at the highest drum rotational speedof4000 rpm (54.45 m/s), but the highest value of machine efficiency was recorded at the drum rotational speed of 3200 rpm (43.56 m/s) with the different values of the other parameters. As the milling productivity increases, the loss in refilling time for refilling the hammer hopper increases consequently, the milling efficiency decreases. Hence, the milling efficiency took the opposite trend of the milling productivity with drum speed.

Effect of knives number on machine productivity and efficiency:

Figs. 3 and 4 illustrate the milling productivity as it affected by knives number. It is obvious that it rapidly decreased productivity by increasing the knives number, while, the milling efficiency decreased as knives number

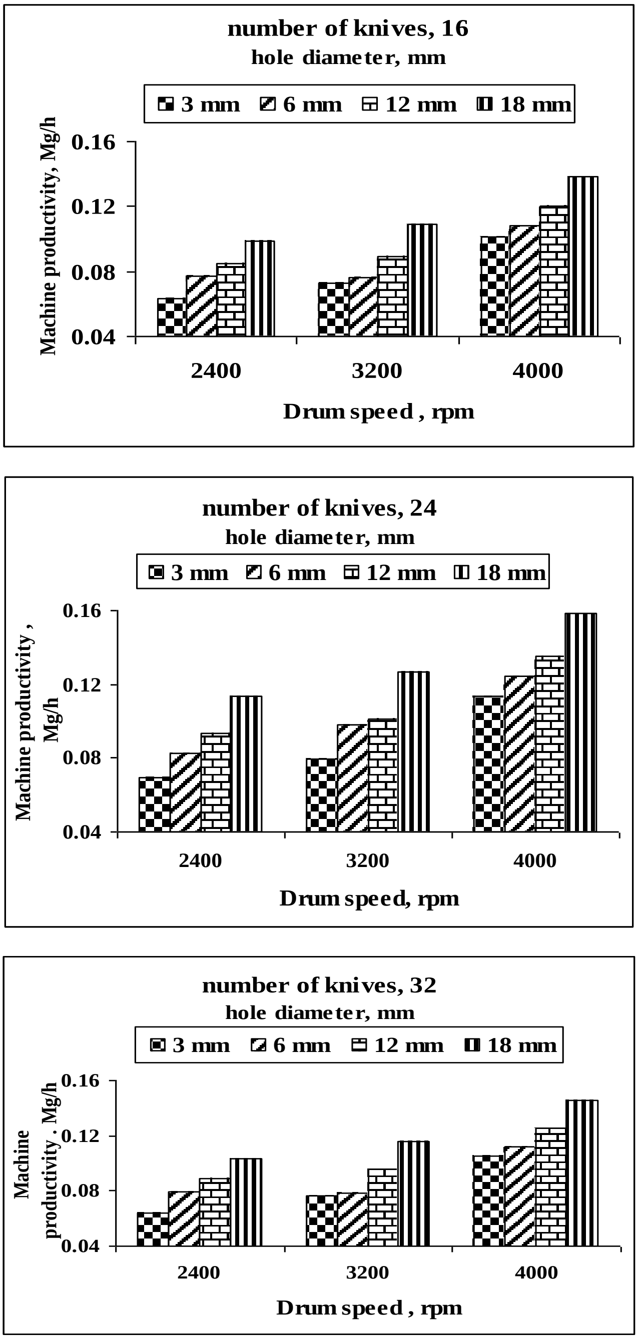


Fig. 3. Effect of drum speed, sieve holes diameter and number of knives on machine productivity.

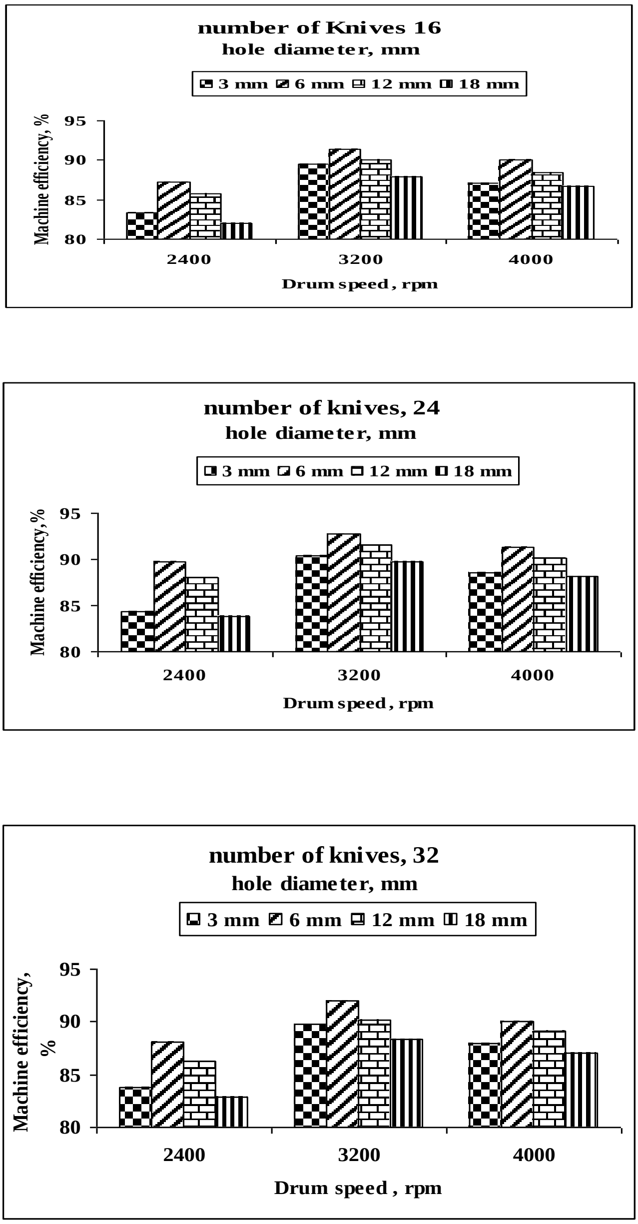


Fig. 4. Effect of drum speed, sieve holes diameter and number of knives on machine efficiency.

increased as long as values of other parameters including drum rotational speed and sieve holes diameter are constant. The obtained results revealed that the highest machine productivities and efficiencies were obtained at 24 knives number at any value of drum speed and sieve holes diameter. The increase in machine productivity by increasing the number of knives from 16 to 24 can be attributed to the increase in number of cutting edges that ease the process of cutting in a shorter time period straw. It is also noticeable that increasing the number of knives from 24 to 32decreased the machine productivity. This could be attributed to the small space left between knives caused the straw pieces to be squeezed between the knives and hinder the straw flow due to the increase of friction forces between straw and the concave.

Effect of sieve holes diameter on machine productivity and efficiency:

Figs. 3 and 4 indicate a clear increase in the values of milling productivity as the sieve holes diameter was increased. On the other side, the milling efficiency was decreased by increasing the sieve holes diameter. Hence, From the previous results it is clear that the maximum machine productivity of 0.158 Mg/h was recorded at sieve holes diameter of 18 mm, drum rotational speed of 4000 rpm (54.45m/s), with number of knives of 24, while the maximum milling efficiency of 91.9% was achieved at sieve holes diameter of 6 mm, number of knives of 24 and 3200 rpm (43.56 m/s) of drum speed. The increase in machine productivity by increasing the sieve holes diameter is obviously due to the ease of straw exiting through the concave.

Fineness degree (particle size distribution):

Fig. 5 illustrate the fineness degree percentage of milled rice straw using different values of drum rotational speed, sieve holes diameter and number of knives. The data of milled rice straw show that drum rotational speed of 4000 rpm (54.45 m/s), sieve hole diameter of 3 mm and knives number of 24 gave the highest percentage of fineness degree of 83.74%.

While, the hammer mill can produce the highest degree of coarse milling of (40.74%) by using drum rotational speed of 2400 rpm (32.67 m/s), sieve holes diameter of 18 mm and knives number of 32, the highest degree of medium I milled rice straw of 42.19% can be achieved by using drum rotational speed of 2400 rpm (32.67 m/s), knives, sieve holes diameter of 6 mm and knives number of 32 and finally the highest degree of Medium Π milled rice straw of 31.98% can be achieved by using drum rotational speed of 2400 rpm (32.67 m/s), sieve holes diameter of 3 mm and knives number of 32.

Specific Energy:

Fig. 6 illustrate that specific energy values are greatly affected by drum rotational speed. The obtained results show that increasing drum rotational speed lead to increase the consumed power and the contrarily was noticed with the required energy. According to the obtained data it appears that the lowest specific energy (43.72 Kw.h/Mg) was obtained at drum rotational speed of 4000 rpm (54.45 m/s) while the highest specific energy (80.83 Kw.h/Mg) was recorded at drum rotational speed of 2400 rpm (32.67 m/s), meanwhile the other parameter remained constant. The decrease in specific energy by increasing drum speed can be attributed to the increase of the machine productivity. The recorded results show that the specific energy decreases with using pyramidal knives. While, the required energy increases by both decreasing the sieve holes diameter and knives number. The results indicate that the lowest values of specific energy were (60.86 – 55.9 – 51.3 and 43.72) kW.h/Mg for sieve holes diameter (3, 6, 12 and 18 mm) respectively at drum speed of 4000 rpm and using number of knives 24. It was recommended to use the hammer mill at drum rotational speed of 4000 r.p.m (54.45 m/s), 24 knives count, and sieve holes diameter 18 mm to reduce the consumed energy for milling rice straw.

The Operational Cost:

Fig. 7 represent the total operational cost for hammer mill (L.E. /Mg). Results show that the operational cost for the used mill decreases as the drum rotational speed increases, while the total operational cost production decreases by increasing both the sieve holes diameter from 3 to 18 mm and knives number. This decrease may be due to the great increase occurred in machine productivity. The lowest values of total operational cost of (118.5 – 103.42 – 90.66 and 71.290 L.E./Mg) at drum speed of 4000 rpm and using number of knives 24, and sieve holes diameters (3, 6, 12 and 18 mm) respectively. Hence, the previous results reveal that, a remarkable reduction in total operational cost can be achieved by using drum rotational speed of 4000 rpm (54.45 m/s), knives number (24) and sieve holes diameter of 18 mm.

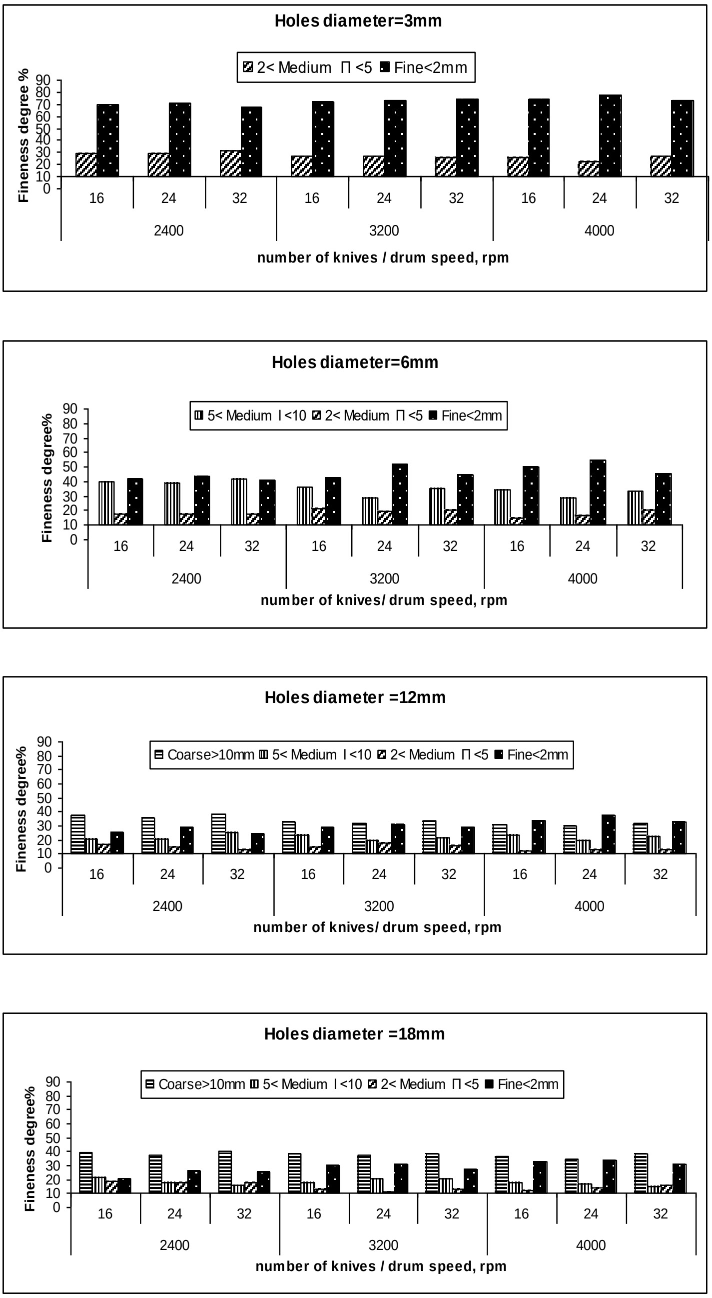


Fig. 5. Effect of drum speed rpm and number of knives at sieve holes diameter 3, 6, 12 and 18 mm on fineness degree

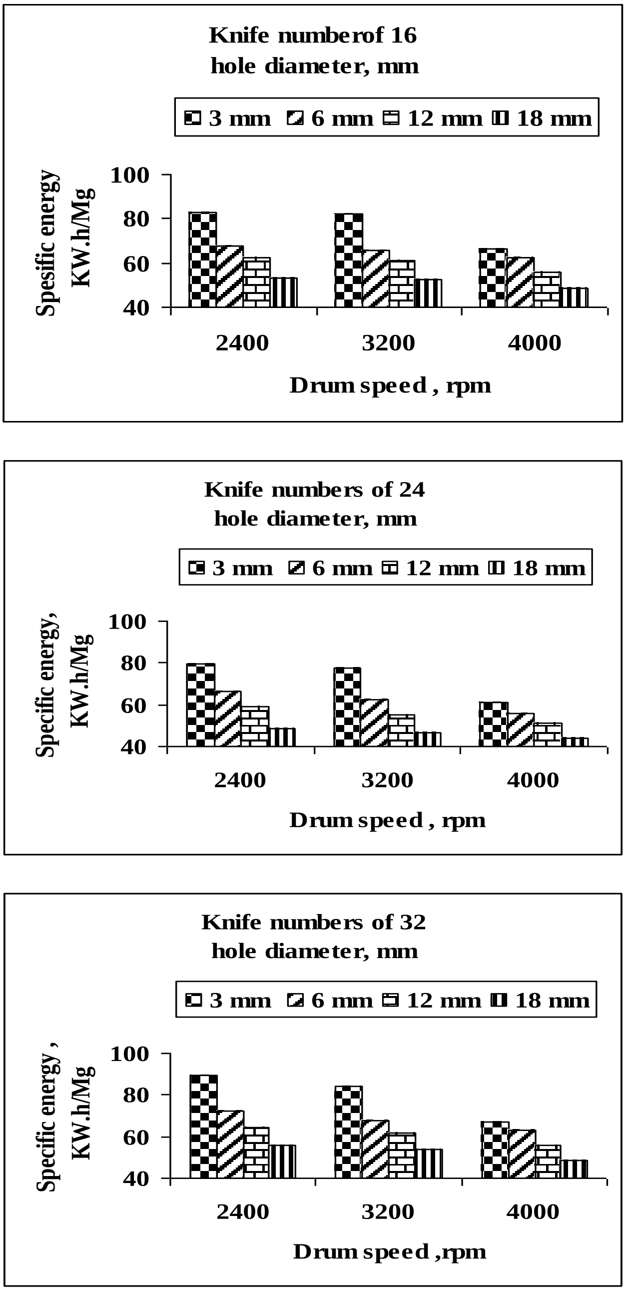


Fig. 6. Effect of drum speed, different sieve holes diameter and number of knives shapes on specific energy.

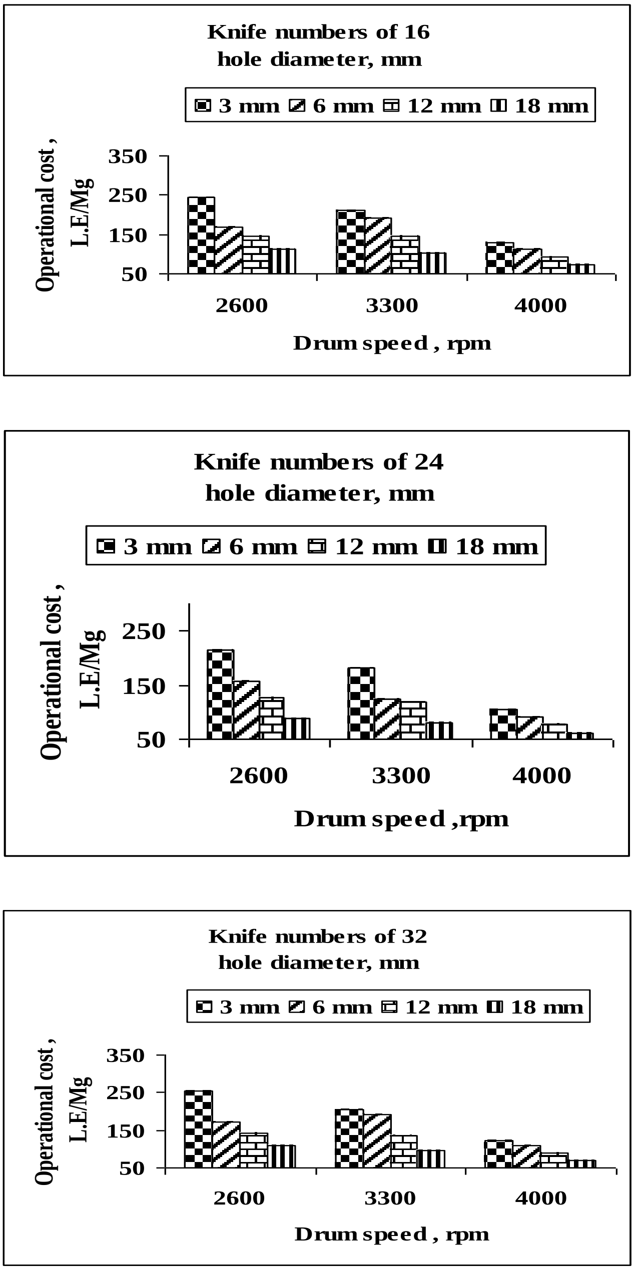


Fig. 7. Effect of drum speed, different sieve holes diameter and number of knives shapes on operational cost.

REFERENCES

Abdulla, H.M.; S.A. El-Shatoury. 2007. Actinomycetes in rice straw decomposition. Waste Manag, 27: 850–853

Awady, M.N. 1978. Tractor and farm machinery. Text Book, Fac. Of Agric., Ain-shams University, 164-167.

Dobermann, A. and T. Fairhurst. 2000. Rice Nutrient disorders and nutrient management. Potash and Phosphate Institute (Singapore) and International Rice Research Institute (Philippines), pp: 191.

El-Khateeb, H.A. 2007. Effect of engineering parameters of residues chopper on chopper quality. j. Ag. Res., Kafr El-Sheikh Univ., 33 (1): 1-15

El-Zahaby, A.M. 1996. Techno-economic study on utilization of some field crop residues, Ph.D. Thesis, Fac. of Agric., Cairo Univ.

Galy, A.M. 1973. Some factor affecting performance of locally made threshing machine. M.Sc. Thesis, Fac. of Agric., Alex. Univ.

Hegazy, K.E. 2006. Development and evaluation a locally made grain crusher to suit production of livestock feeds from date pits. J.Agric. Sci. Mansoura Univ., 31-40.

Jackson, M.C. 1987. Rice straw as livestock feed. Ruminant nutrition, World Animal Review, 34-40. FAO, Rome.

Kadder, S.S.B. (1997). Development of a simple cutting system using the field wastes in small farms. Ph.D. Thesis, Fac. Agric., Zagazig Univ.

Kamel, O.M.; M.E. El-Iraqi and M.I. Egela, 2003. Maximizing utilization of forage chopper for chopping rice straw residues. Misr, J. Ag. Eng., 20 (3): 751-766.

Kurt, G. l979. Engineering formulas. 3rd. Ed. Mc Graw – Hill book Co.

Shii, C.; H.L. Sheau and C. Wen. 2009. Preparation and characterization of solid biomass fuel made from rice straw. Fuel Processing Technology, 90: 1041–1046.

Younis, S.M.; M.I. Ghonig; M.A. Boyomi and T.H. Mohamed. 2002. Techno-Economic Evaluation of a developed field crop residues chopper. The 10th Annual conference of Misr Society of Agr. Eng., 16-17: 63- 80.

تأثير طحن قش الأرز على كفاءة الالـة المطرقيـة وجودة الطحن

محمد السيد اسماعيل رضوان

المعمل المركزى لبحوث الثروة السمكية ، مركز البحوث الزراعية ، وزارة الزراعة ، مصر.

الملخـص العربـى

أجريت الدراسةعلى طحن قش الارز عام ٢٠١٠-٢٠١١بالمعمل المركزى لبحوث الثروة السمكية بقرية العباسة بمحافظة الشرقية- جمهورية مصر العربية حيث كان الهدف الرئيسي من هذه الدراسة هو تقييم أداء آلة الطحن المطرقية لأنتاج قش علي درجة عالية من الجودة باقل تكاليف من خلال دراسة بعض عوامل التشغيل التي تؤثر علي اداء الآلة وصفات الجودة للمنتج المطحون. وتم تقييم الآلة من خلال دراسة تأثير المعاملات الآتية:

١- ثلاث سرعات دورانية للدرفيل(٢٤٠٠- ٣٢٠٠- ٤٠٠٠ لفة/الدقيقة) سرعة خطية (٣٥.٣٩- ٤٤.٩٢-٥٤.٤٥ م/ث) على الترتيب.

٢- اربع اقطار مختلفة لثقوب الغربال (٣مم – ٦مم – ١٢مم –١٨مم).

٣- ثلاث اعداد مختلفة من السكاكين (١٦ – ٢٤ – ٣٢) سكينة.

وذلك لمعرفة تأثير العوامل السابقة على قياسات أداء الآلة وجودة المنتج (القش المطحون) وتشمل الآتى:

١- إنتاجية الآلة. ٢- كفاءة الآلة. ٣- درجة النعومة .

٤- الطاقة المستهلكة. ٥- تكاليف التشغيل .

ومن أهم النتائج المتحصل عليها: لاستخدام الآلة المطرقية لطحن قش الارز والحصول على أعلى إنتاجية (١٥٨.٦ كجم/ ساعة) وأقل تكاليف (٧١.٢٩ جنيه/ ميجاجرام) وأقل استهلاك للطاقة (٤٣.٧٢ كيلووات. ساعة/ ميجاجرام) يوصى باستخدامها تحت العوامل الآتية: السرعة الدورانية للدرفيل (٤٠٠٠ لفة/الدقيقة)، أقطار ثقوب الغربال تكون ١٨مم، عدد السكاكين يكون ٢٤ سكينة. ولاستخدام الآلة المطرقية لطحن قش الأرز والحصول على أعلى درجات نعومة (٨٣.٧٤%) يوصى باستخدامها تحت العوامل الآتية: السرعة الدورانية للدرفيل (٤٠٠٠ لفة/الدقيقة)، أقطار ثقوب الغربال تكون٣مم وعدد السكاكين يكون ٢٤ سكينة. وللحصول على اعلى كفاءة للالة (٩١.٩%) يوصى باستخدامها تحت العوامل الاتية: السرعة الدورانية للدرفيل (٣٢٠٠ لفة/ الدقيقة)، أقطار ثقوب الغربال تكون٦مم وعدد السكاكين يكون ٢٤ سكينة.