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DEVELOPMENT AND PERFORMANCE EVALUATION OF HAMMER MILL FOR SIZING RICE STRAW TO BE USED AS BIOMASS

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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 develop knife shape and, to investigate the effect of a set of parameters during grinding rice straw on machine efficiency and bio-product quality using a hammer mill machine to produce a high quality ground rice straw and high machine efficiency with optimum cost. The hammer mill machine was evaluated under three levels of different drum speeds of 2600, 3300 and 4000 rpm, four different sieve hole diameters of 3, 6, 12 and 18 mm, three different number of knives (16, 24 and 32), with two knives shape (rectangle - pyramidal). The evaluation included machine production rate, machine efficiency, specific energy consumption, fineness degree of rice straw and economical costs of rice straw grinding. The obtained data showed that the highest value of machine productivity (158.6 kg/h), the lowest specific energy consumption (43.72 kW.h/Mg) and the lowest cost per mass unit (71.29 L.E/Mg) were recorded in the case of sieve hole diameter of 18 mm, number of knives 24 and drum speed of 4000 rpm with pyramidal knives, the highest value of fineness degree of rice straw 83.74% was recorded in the case of sieve hole diameter of 3 mm, number of knives 24 and drum speed of 4000 rpm with rectangle knives. Hammer mill machine efficiency of 92.7 % was recorded in the case of sieve holes diameter 6 mm, number of knives 24 and drum speed of 3300 rpm with pyramidal knives.

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

INTRODUCTION

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 (Jackson, 1987). 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

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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 different speeds of 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 and lowest power requirement of 3.521 kW and consumption 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. Develop of hammer mill for milling and chopping rice straw to suit the small farms.
2. Evaluate a local made hammer mill during milling rice straw.
3. Optimize some operating parameters (drum speed, shape and number of knives, and sieve holes diameters) affecting the performance of hammer mill for rice straw.
4. Evaluate the hammer mill from 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 of 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

Table 1 summarizes the specifications of the used hammer mill before and after modifications.

Figs. 1 and 2 are schematic views of the modified hammer mill machine.

Knives and Sieve

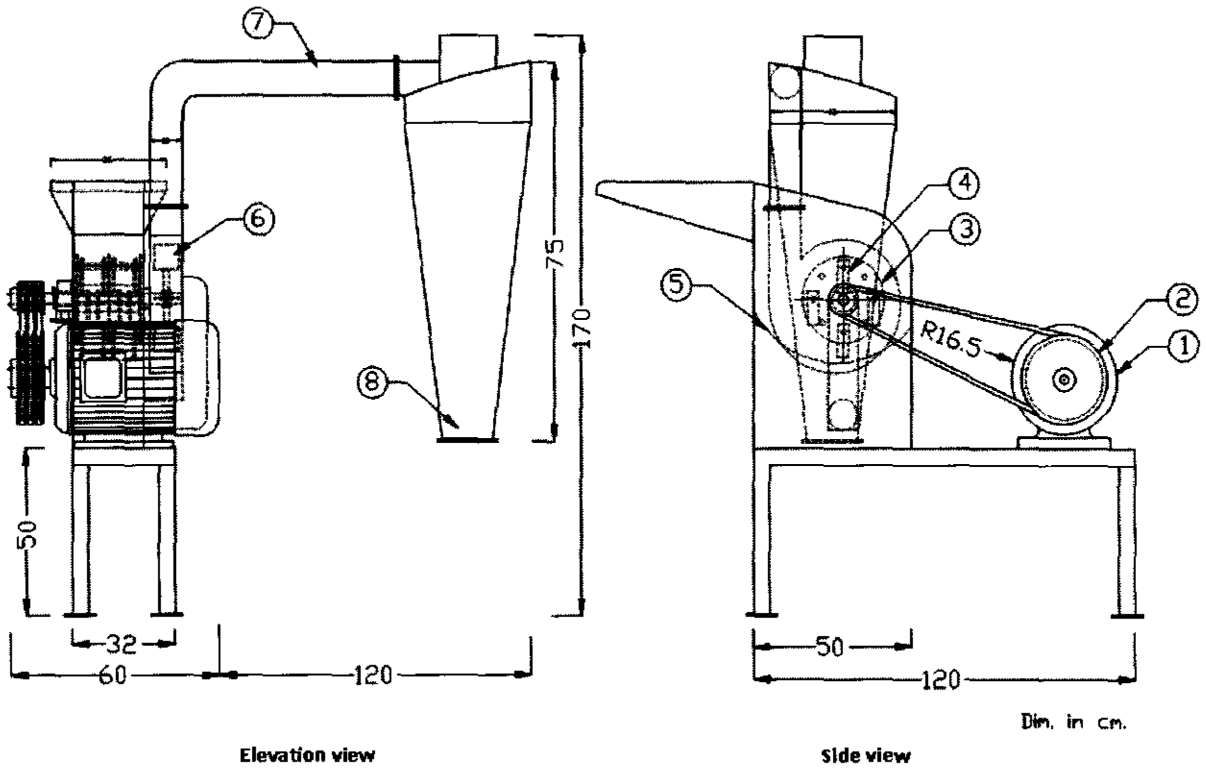
The specifications of hammers and screens are displayed in Table 2.

Table 1. Specifications of hammer mill before and after modifications

Item	Specifications of device	
	Before modification	After modification
Model	Local made	Local made
Type	Swinging hammer mill	Swinging hammer mill
Overall length, cm	170	170
Overall width, cm	32	32
Overall height, cm	170	170
Rotor Diameter, cm	33	33
Rotor Width, cm	60	60
Source of power, kW	AC Motor (12.682)	AC Motor (12.682)
Knives shape	Rectangular	Rectangular and pyramidal
Knives Number	16	16-24-32
Screen Hole Diameter, mm	1	(3-6-12-18)
Total Screen Area, cm^2	1890 (90 * 21 cm)	1890 (90 * 21 cm)

Table 2. The specifications of the used knives 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	Rectangular and 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

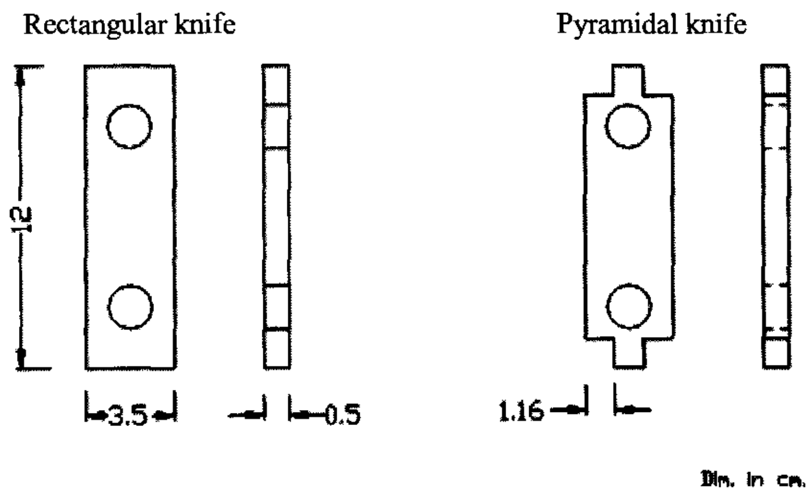


Fig. 2. Schematic view of the modified knives

Measuring instrument

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 2600, 3300 and 4000 r.p.m. corresponding to drum liner speeds of (35.39, 44.92 and 54.45 m/s) respectively.
2. Four sieve holes diameter of 3, 6, 12 and 18 mm.
3. Three counts of knives 16, 24 and 32.
4. Two knives' shapes, rectangular and pyramidal.

Procedures

A given quantity of 1 kg mass of rice straw was dropped in the machine hopper after adapting the knives number and shape, sieve hole diameter, and drum speed. The elapsed time to complete the sample processing is measured and recorded and total consumed (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:

Crushing Capacity and Efficiency

Capacity of the hammer mill

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

Crushing and milling efficiency

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

Where Wm = output (milling yield mass, g) and 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 П (2 < samples < 5 mm), Coarse Medium one I (5 < samples < 10 mm), and Coarse (samples > 10 mm). Source: Shii *et al*. (2009).

Crushing power and energy requirement:

The require crushing power was estimated by using the following equation (Kurt, 1979)

Total consumed power = load (kW)

$$= \frac{\sqrt{3}\, I.V\, \eta \cos \Theta}{1000} \text{ (kW)}$$

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

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

Energy requirements = the consumed power (kW)/ crushing capacity (Mg/h).

Machine unit operating cost

$$\text{Machine unit operating cost (L.E./Mg)} = \frac{\text{Machine cost (L.E. /h)}}{\text{Miller capacity (Mg/h).}}$$

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

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

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 Milling Capacity and Efficiency

Figs. 3 and 4 show that the general trend of the mill is that the capacity increased by increasing the drum speed but the contrarily was occurred with the milling efficiency when the other effective parameters (sieve holes diameter, number of knives and knife shape) are kept constant. Results showed that the highest machine capacity was achieved at the highest

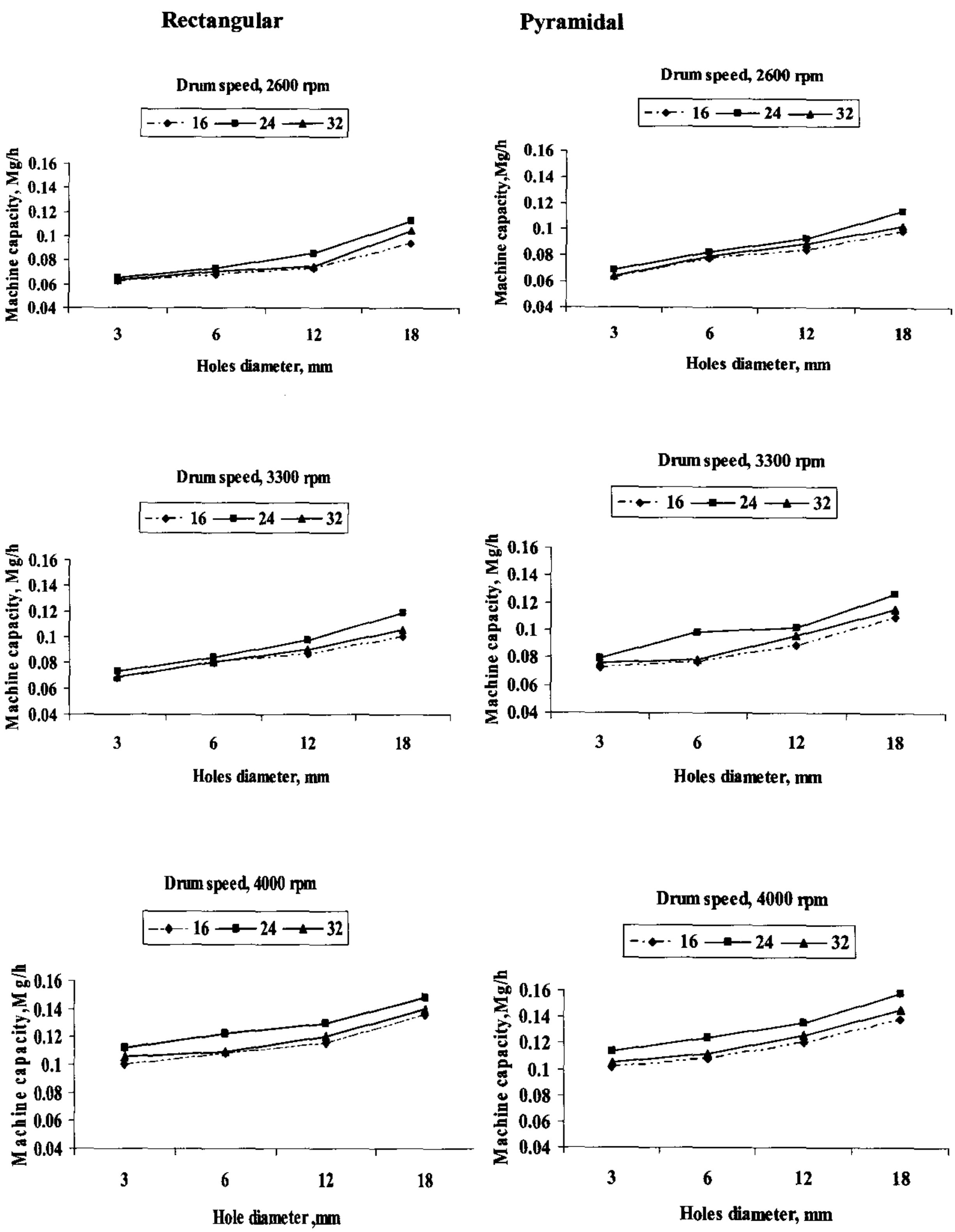


Fig. 3. Effect of drum speed, different sieve holes diameter, and number of knives using two different knife shapes on machine capacity

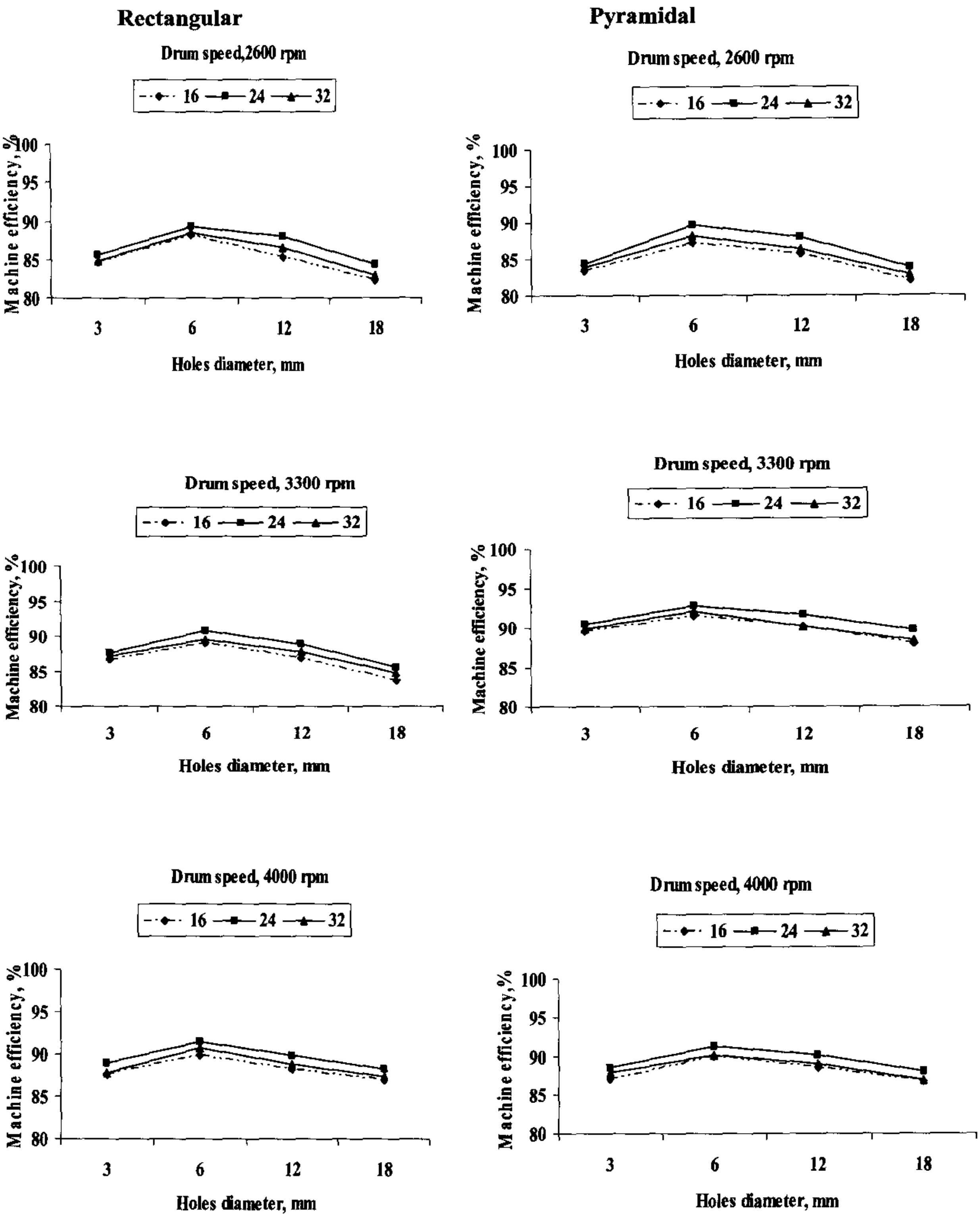


Fig. 4. Effect of drum speed, different sieve holes diameter, and number of knives using two different knife shapes on machine efficiency

drum rotational speed of 4000 rpm (54.45 m/s), but the highest value of machine efficiency was recorded at the drum rotational speed of 3300 rpm (44.92 m/s) with the different values of the other parameters. As the milling capacity increases, the loss in refilling time for refilling the hammer hopper increases consequently, the milling efficiency decreases. Hence, the crushing efficiency took the opposite trend of the crushing capacity with drum speed.

Effect of Knives Shape on Machine Capacity and Efficiency

Figs. 3 and 4 display the relation between knife shape and machine capacity and efficiency. Hence, it appears that the machine capacity and efficiency increased by changing the knife shape from rectangular to pyramidal knives. Results showed that the maximum machine capacity was achieved at the pyramidal knives and drum rotational speed of 4000 rpm (54.45m/s) with sieve hole diameter of 18 mm, when using number of knives 24, while the maximum milling efficiency was recorded at the pyramidal knives and drum rotational speed of 3300 rpm (44.92 m/s) with sieve hole diameter of 6 mm, when using number of knives 24. It is obvious that the machine production rate increased by changing the knife shape (rectangular to pyramidal). This is could be due to the increase of the cutting edge area that facilitate the cutting effect of the knives and push the cut straw rapidly to exit the machine chamber in less time.

Effect of Knives Number on Machine Capacity and Efficiency

Figs. 3 and 4 illustrate the milling capacity as it affected by knives number. It is obvious that it rapidly decreased capacity by increasing the knives number, while, the milling efficiency decreased as knives number increased as long as values of other parameters including drum rotational speed, knives shape and sieve holes diameter are stable. The obtained results revealed that the highest machine capacities and efficiencies were obtained at 24 knives number at any value of drum speed, knives shape 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 Capacity and Efficiency

Figs. 3 and 4 indicate a clear increase in the values of milling capacity 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 capacity of 0.159 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 machine efficiency of 92.7% was achieved at sieve holes diameter of 6 mm, number of knives of 24 and 3300 rpm (44.92 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 the concave.

Fineness Degree (Particle Size Distribution)

Figs. 5 to 8 illustrate the fineness degree percentage of milled rice straw using different values of drum rotational speed, knives shape, sieve holes diameter and number of knives. The obtained results indicate that, the fineness fine percentage. The data of milled rice straw show that drum rotational speed of 4000 rpm (54.45 m/s), pyramidal knives, 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 (39.94%) by using drum rotational speed of 2600 rpm (35.39 m/s), pyramidal knives, sieve holes diameter of 18 mm and knives number of 32, the highest degree of medium I milled rice straw of 41.59% can be achieved by using drum rotational speed of 2600 rpm (35.39 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 31.97% can be achieved by using drum rotational speed of 2600 rpm (35.39 m/s), pyramidal knives, sieve holes diameter of 3 mm and knives number of 32.

Specific Energy

Fig. 9 illustrate that specific energy are greatly affected by drum rotational speed. The obtained

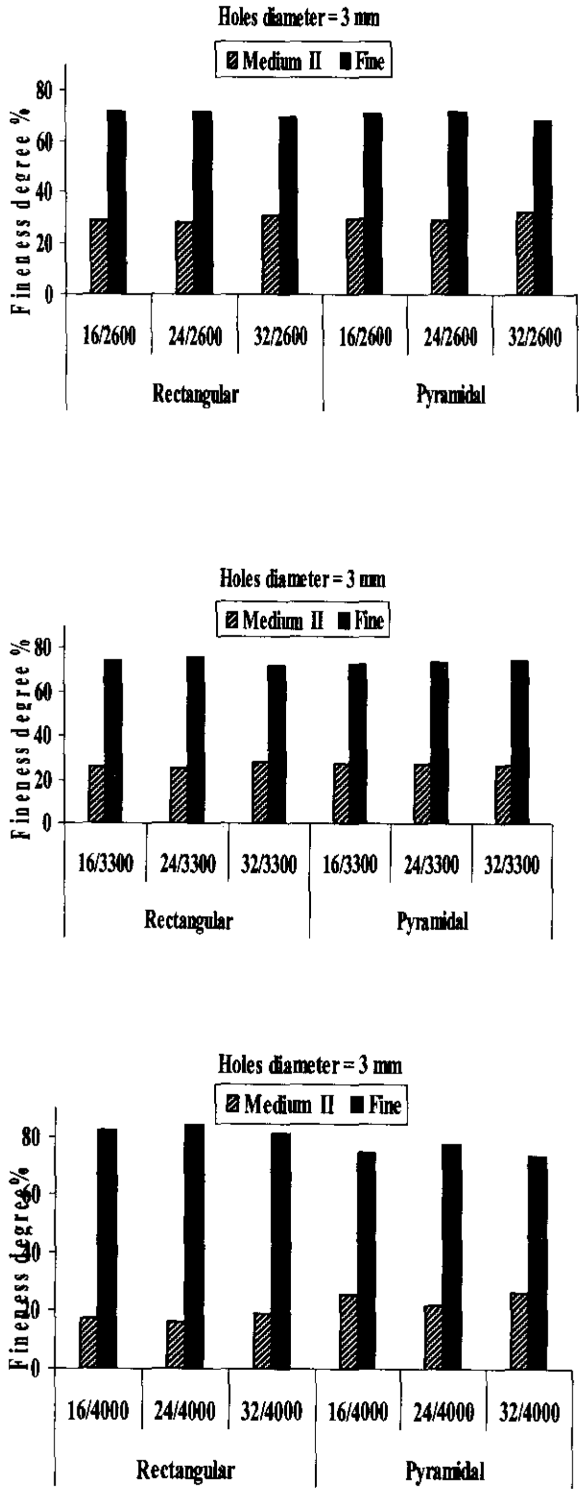


Fig. 5. Effect of drum speed, number of knives and different knives shape at sieve holes diameter 3 mm on fineness degree

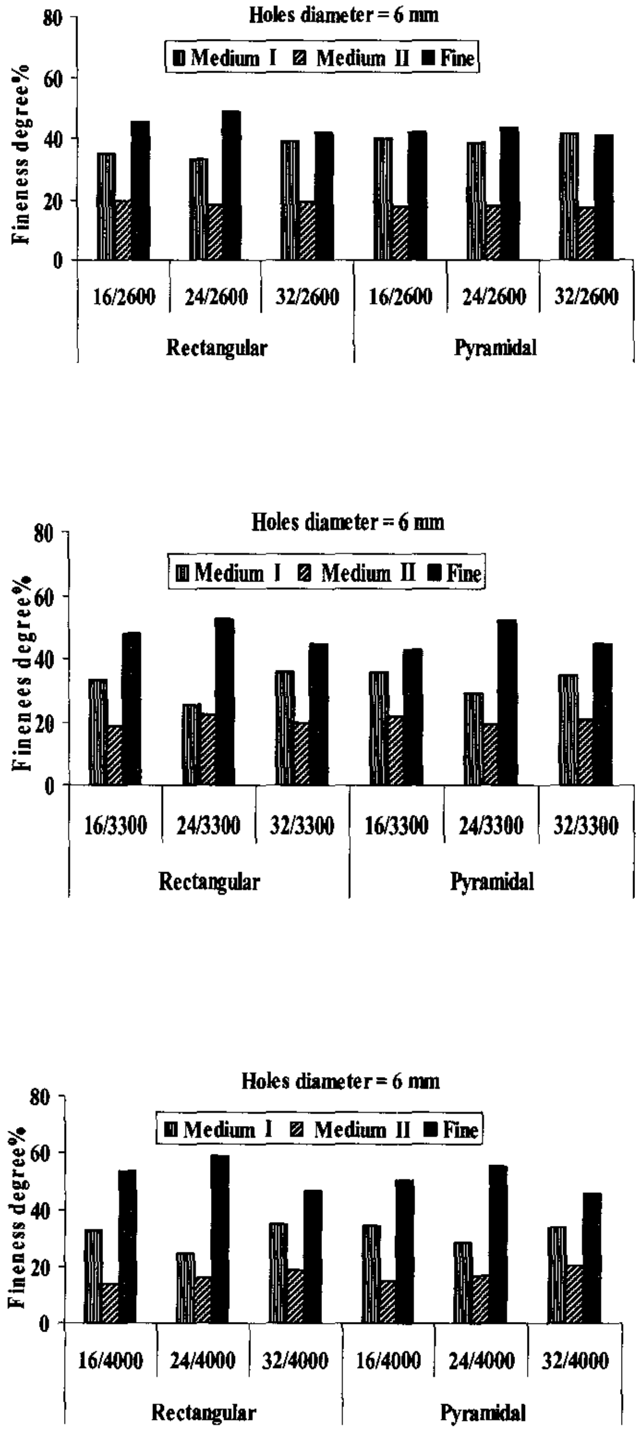


Fig. 6. Effect of drum speed, number of knives and different knives shape at sieve holes diameter 6 mm on fineness degree

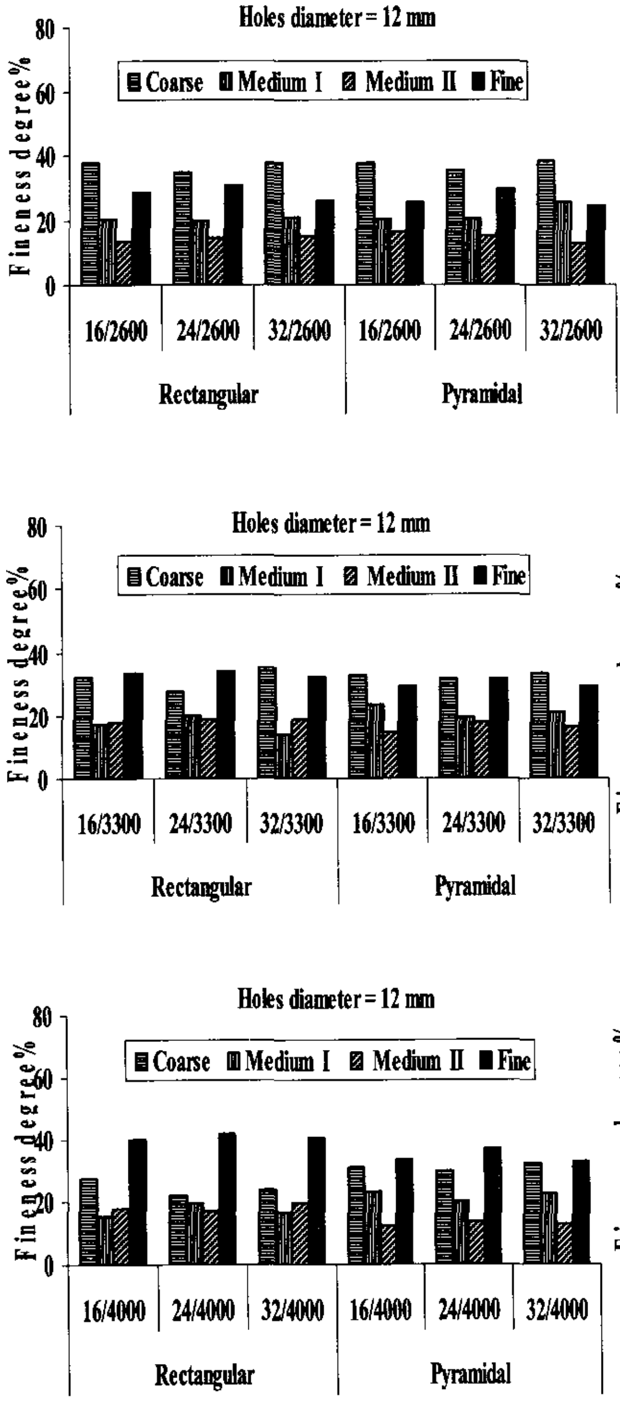


Fig. 7. Effect of drum speed, number of knives and different knives shape at sieve holes diameter 12 mm on fineness degree

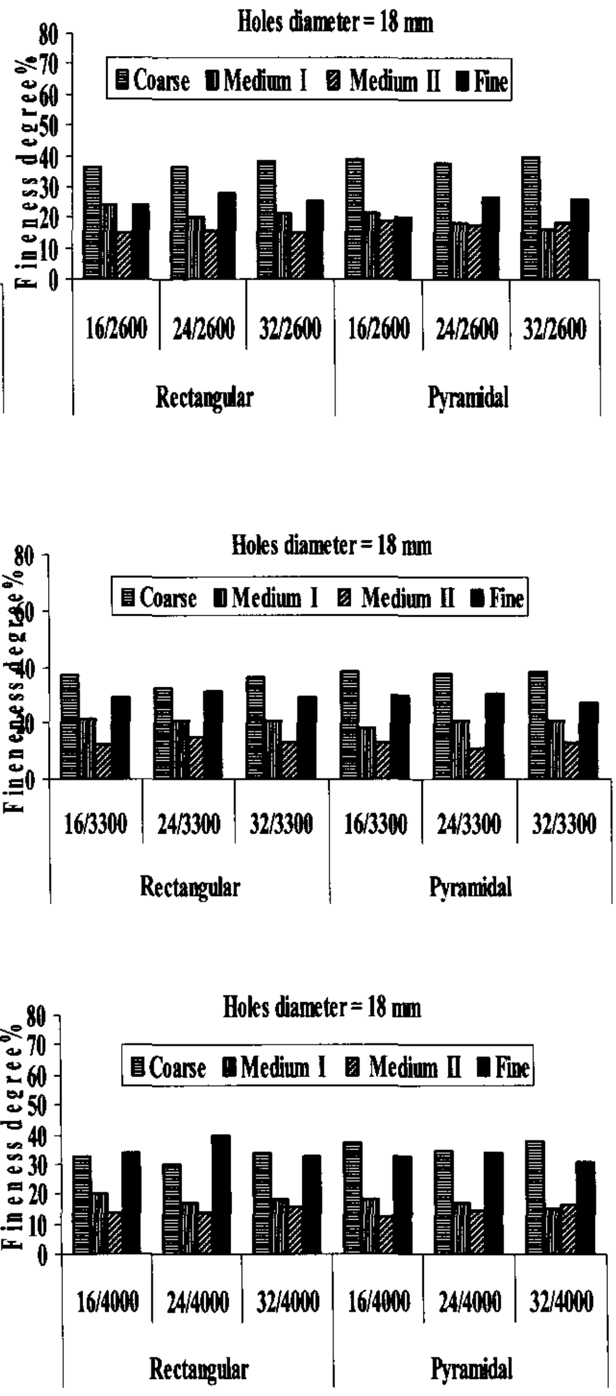


Fig. 8. Effect of drum speed, number of knives and different knive shapes at sieve holes diameter 18 mm on fineness degree

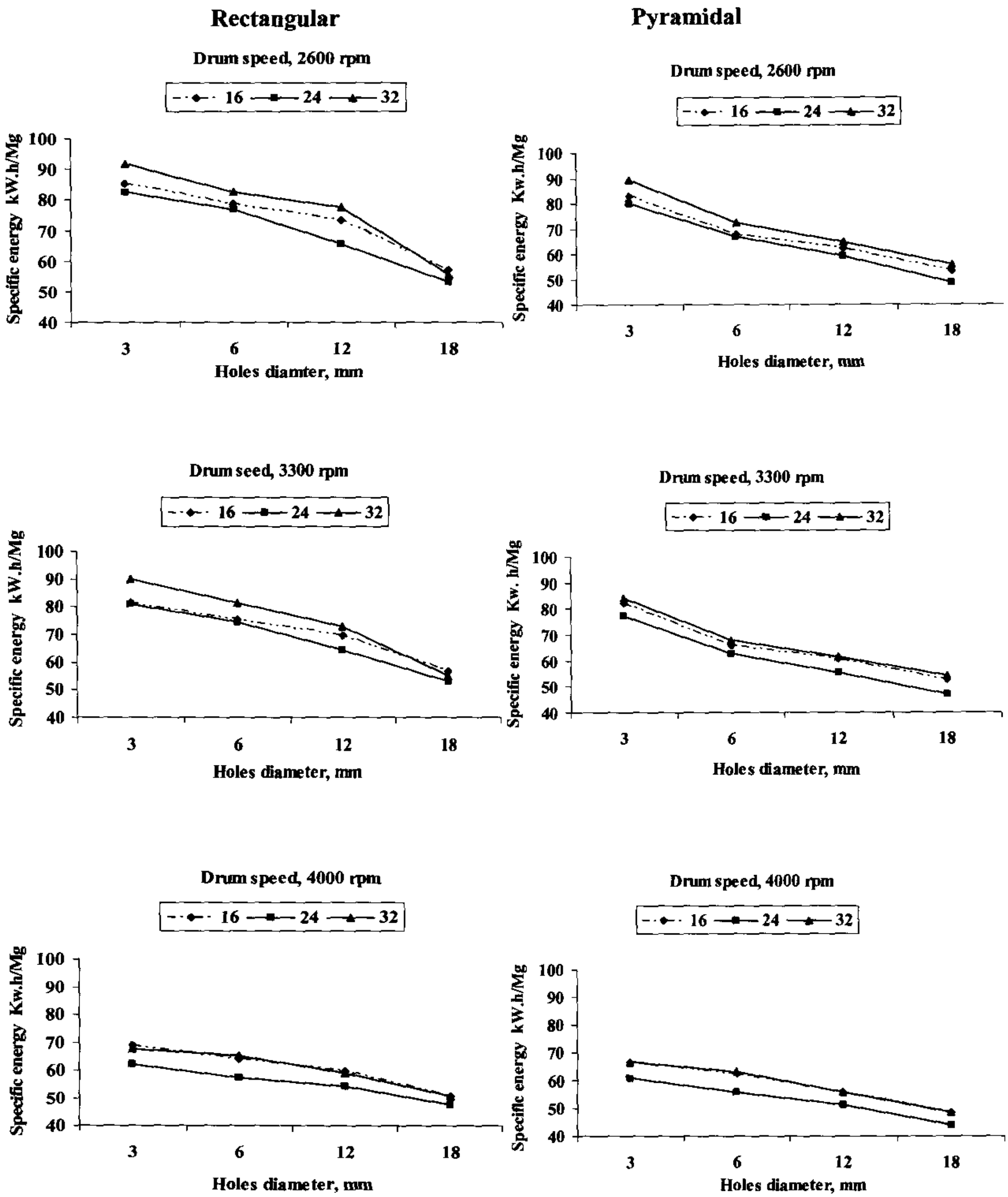


Fig. 9.Effect of drum speed, different sieve holes diameter, and number of knives using two different knife shapes on specific energy

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 were obtained at drum rotational speed of 4000 rpm (54.45 m/s) but the highest specific energy were recorded at drum rotational speed of 2600 rpm (35.39 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, pyramidal knife 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), pyramidal knife, 24 knives count, and sieve holes diameter 18 mm to reduce the consumed energy for milling rice straw.

The Operational Cost

Fig. 10 represent the total production cost for hammer mill (L.E. /Mg). Results show that the cost per unit of production for the used mill decreases as the drum rotational speed increases and the same trend was observed with cost production by using pyramidal knives, while the total 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 cost production of (118.5 – 103.42 – 90.66 and 71.290 L.E./Mg) at drum speed of 4000 rpm, pyramidal knife 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 production cost can be achieved by using drum rotational speed of 4000 r.p.m (54.45 m/s), pyramidal knives, knives number (24) and sieve holes diameter of 18 mm.

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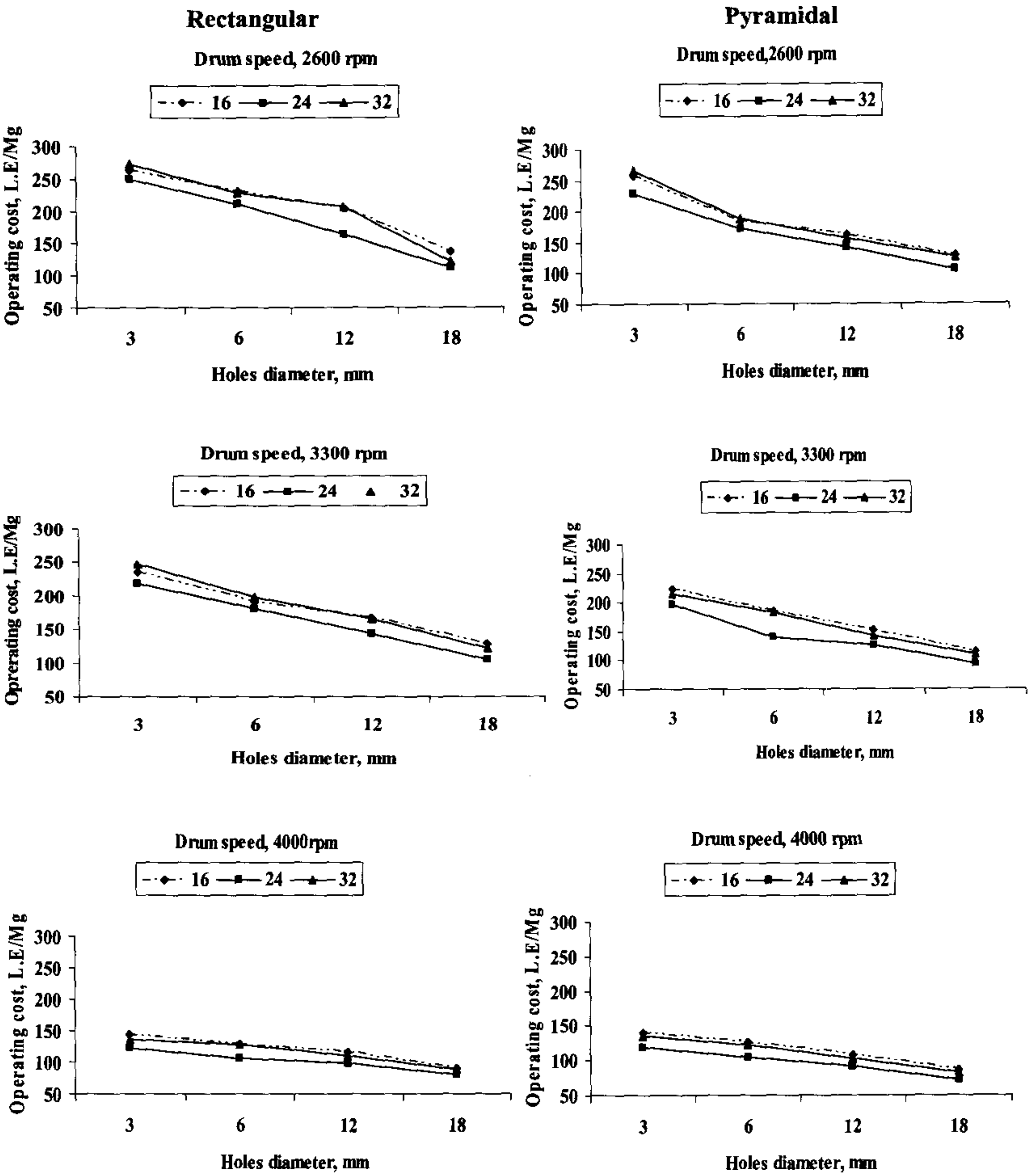

Fig. 10. Effect of drum speed, different sieve holes diameter, and number of knives using two different knife shapes on operational cost

تطويــر وتقييــم آداء آلـــة مطـــرقيــة لطحــن قـــش الأرز لاســـتخدامـه ككتلـة حيـــويـــة

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أجريت الدراسة على محصول قش الأرز عام ٢٠١٠-٢٠١١م بالمعمل المركزى لبحوث الثروة السمكية بقرية العباسة بمحافظة الشرقية- جمهورية مصر العربية. الهدف الرئيسي من هذه الدراسة هو تقييم أداء آلة الطحن المطرقية لإنتاج قش علي درجة عالية من الجودة بأقل تكاليف ممكنة من خلال دراسة بعض عوامل التشغيل التي تؤثر علي أداء الآلة وصفات الجودة للمنتج المطحون. وتم تقييم الآلة من خلال دراسة تأثير المتغيرات الآتية: ثلاث سرعات دورانية للدرفيل (٢٦٠٠-٣٣٠٠- ٤٠٠٠ لفة/دقيقة) سرعة خطية (٣٥,٣٩- ٤٤,٩٢- ٥٤,٤٥ م/ث) على الترتيب. أربع أقطار مختلفة لثقوب الغربال (٣ مم – ٦ مم – ١٢ مم -١٨ مم). نوعين من أشكال السكاكين وهما المستطيلة والمتدرجة الشكل. ثلاث أعداد مختلفة من السكاكين (١٦ – ٢٤ – ٣٢) سكينة. وذلك لمعرفة تأثير العوامل السابقة على قياسات أداء الآلة وجودة المنتج (القش المطحون) وتشمل الآتي: إنتاجية الآلة، كفاءة الآلة، درجة النعومة (توزيع الحبيبات)، القدرة والطاقة المستهلكة وتكاليف التشغيل. ومن أهم النتائج المتحصل عليها: لاستخدام الآلة المطرقية لطحن قش الارز والحصول على أعلى إنتاجية وأقل تكاليف وأقل استهلاك للطاقة يوصى باستخدامها تحت العوامل الآتية: السرعة الدورانية للدرفيل (٤٠٠٠ لفة/الدقيقة)، سكاكين هرمية الشكل، أقطار ثقوب الغربال تكون ١٨مم، عدد السكاكين يكون ٢٤ سكينة. ولاستخدام الآلة المطرقية لطحن قش الأرز والحصول على أعلى كفاءة للمكينة يوصى باستخدامها تحت العوامل الآتية: السرعة الدورانية للدرفيل (٣٣٠٠ لفة/الدقيقة)، سكاكين هرمية الشكل، أقطار ثقوب الغربال تكون٦مم وعدد السكاكين يكون ٢٤ سكينة.