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PERFORMANCE EVALUATION OF TWO DIFFERENT HAMMER MILLS FOR GRINDING CORN COBS

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ABSTRACT

The grinding operations of corn cobs using two different local manufactured hammer mills namely: Aamagro (mill A), and El-Gohary (mill E) were evaluated and compared to be used as an ingredient in feedstuffs for animal and poultry farms. The field experiments were carried out at Sakha Agricultural Research Station, Kafrelsheikh Governorate, Egypt during the year of 2015. These experiments were deduced to evaluate and compare the performance of the investigated hammer mills under the effects of three feeding rate levels (0.2, 0.4 and 0.6ton/h), four rotor speed levels (1200, 1500, 1800 and 2100rpm), and two screen hole diameter levels (9 and 14mm) using corn cobs. The performances of both machines were evaluated in terms of: fineness degree (particle size distribution), machine productivity, power requirements, specific energy consumption, and machinery unit cost.

The results revealed that, the optimum operating conditions for both A and E mills were obtained at rotor speed of 2100rpm, cobs feed rate of 0.2 ton/h and 9mm screen hole diameter. Whereas, under these conditions the maximum percentages of fine milled cobs (1.7-≤1.18mm) of were 63.71 and 53.16% for A and E mills, respectively. Also, mill productivity of 0.185 and 0.146ton/h, power requirements of 2.245 and 3.076kW and specific energy consumption of 12.134 and 21.065kW.h/ton were determined under the optimal operating conditions for A and E mills, respectively. Moreover, the estimated machinery unit cost for mill E was about 1.124 times that of mill A.

INTRODUCTION

Hammer mills are machines used in agriculture graded to obtain concentrated fodder mix and food industry for grinding vegetable raw materials necessary for obtaining various types of flours. The hammer mills grinding materials is produced upon impact of the hammer material and crushing plate located inside the grinding chamber. Depending on the hammers rotor assembly mode, the following types of mills can be used: hammer mills articulated and fixed hammer mills (*Muntean, et al., 2013*). There are several potential advantages of a hammer mill: produce a wide range of particle sizes; work with any friable material and fiber; less initial purchase cost compared to roller mill; offer minimal expense for maintenance; generally feature uncomplicated operation and greater capacity per unit horsepower than roller mill (*Dey et al., 2013*). Fineness of grinding depends on factors as a type of grain, moisture content, screen size and flow rate. The size of the screen hole size has the greatest influence on the particle size of the product. The screen prevents the ground feed from leaving the grinding chamber until it reaches an appropriate size. In split screen designs, screens with smaller holes are placed the "down" side while screens with larger holes are on the "up" side (*Heiman, 2005*). *Yousef (2005)* reported that the power requirement of grinding operation increased as the feeding rates increased, while it decreased with increasing the screen opening size. The best results of power consumption obtained at 2200rpm hammer speed, 550kg/h feeding rate and screen opening sizes of 6 and 9mm for soybean and maize crops respectively. *Hegazy (2006)* adapted a fixed beaters-type hammer mill, for grain crusher to be suitable for date pits crushing. The crusher was modified by adding hammers with edge angles of 22.5degree on the longitudinal axis. The experimental results show that the optimum operating conditions of modified crusher were found at hammers speed of 44.21m/s, hammer edge angle of 22.5degree and sieve size of 7.94mm that gave the best results of productivity rate, power and energy consumption. *Elshal et al. (2010)* reported that the proper conditions for operating the hammer mill to produce pelleting feed were 33.56m/s drum speed, 10% moisture content, 5mm concave clearance and 5mm hammer thickness. At these levels, a higher fineness degree was obtained. Cereal grains and crop residues/by-product typically are processed before they are mixed into diets for both ruminants and monogastric animals. This processing very often involves grinding through a hammer mill to break the intact kernel and reduce particle size. This reduction in size is important to increase the surface area for improving the rate of fermentation and digestion, decrease segregation and mixing problems, and to facilitate further processes such as pelleting (*Svihus et al., 2005 and Amerah et al., 2007*). Cereals and crop residues are important components of animal feeds. Every animal has its own needs, which means that the degree of processing for various diets must also vary. Cattle and sheep have rather long, complex digestive tracts and so require a less processed feed material. Pigs have a fairly short, simple digestive system (similar to humans) and therefore benefit from a more highly processed feed. Poultry have a short but rather complicated digestive system, and depending on the make up of the diet, can efficiently utilise feedstuffs less highly processed than pigs. The size and age of the animals also affect the dietary requirements concerning particle size. In general younger animals benefit more from a finer, more highly processed feed than older livestock that have a fully developed digestive tract (*Nasir, 2005*). Corn cob is an important by-product of corn production: for every 100kg of corn grain, approximately 18kg of corn cobs are produced. A large quantity of corn cobs remains used as animal feed (*Chiellini et al., 2009*). *According to the Egyptian standard specification for prepared animal feeds and feedstuffs, in Arabic, 1987,* compressed feeds are sized into four categories as follows: a) sizes <2mm in diameter ranked: powder or mash, which was used for all types of poultry and birds. b) sizes 2-6mm in diameter, which was used for rabbits, goats and fishes. c) sizes 5-10mm in diameter for small animals (<6months). And d) sizes 10-22mm in diameter for large animals (>6months). Therefore, the objective of this study was to compare the performance between two different types of local manufactured hammer mills to grind corn cobs.

MATERIALS AND METHODS

In the present investigation, two local manufactured hammer mills (Models: Aamagro and El-Gohary) were deduced to grind corn cobs.

Aamagro mill (mill A):

Aamagro mill consists principally of a frame, feeding hopper, rotor assembly, flywheel, electric motor, and pulley-belt drives. The rotor assembly was made from six rotor plates mounted to a main shaft and enclosed in a screened grinding chamber. Forty five hammers (30 smooth and 15 serrated edges) were attached to the rotor assembly and were distributed equally on three shafts. Each hammer has 100mm long, 50mm wide and 2.5mm thick. A vertical slide gate controlled the feed rates from the feed hopper. Hammers clearance with screen (concave clearance) was 12.5mm. The tested Aamagro mill (mill A) is shown schematically and photographically in Figs. 1 and 3 respectively.

El-Gohary mill (mill E):

El-Gohary mill consists of a frame, feeding hopper, rotor assembly, electric motor, and pulley-belt drives. Its rotor was fabricated from ten rotor plates, which are equipped to a main shaft and enclosed in a screened grinding chamber. Thirty six swinging type hammers (with smooth edges) were mounted to the rotor assembly and were distributed equally on four shafts. Each Hammer has 140mm long, 40mm wide and 8mm thick. A horizontal slide gate controlled the feed rates from the feed hopper. The clearance between hammers and screen was adapted at 13mm. El-Gohary mill (mill E) is shown schematically and photographically in Figs. 2 and 3. The technical specifications of both A and E mills are listed in Table 1.

Studied operational factors:

The performance of A and E mills were evaluated and compared under the following operational factors:

- Three corn cobs feeding rates of 0.2, 0.4 and 0.6ton/h:
- Four rotor speeds of 1200, 1500, 1800 and 2100rpm, and,
- Two screen hole diameters of 9 and 14mm.

For all previous treatments, average moisture content of corn cobs was measured, and found to be 12.63±0.241%(w.b.).

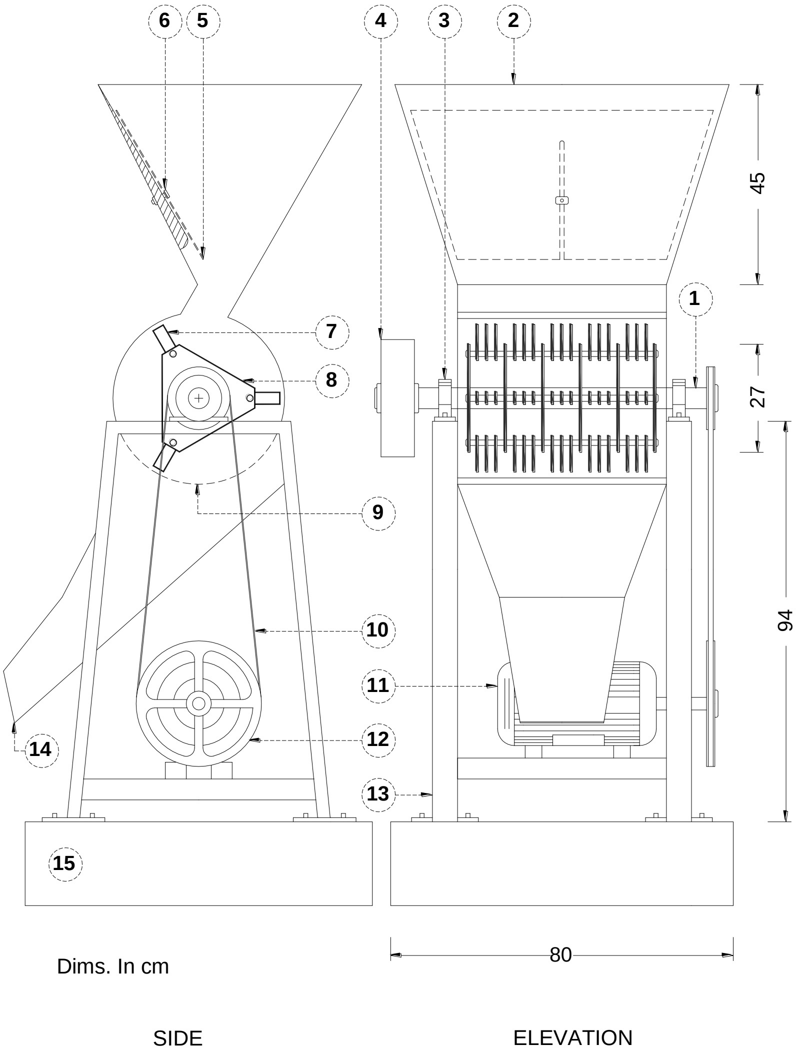
Measurements:

Rotor speed:

For A and E mills, the output rotation of the electric motors were controlled using the electrical digital inverter, while the rotor speeds (rpm) controlled by the pulley–belt drives, and were measured for each treatment using a digital tachometer that was engaged into the rotor shaft.

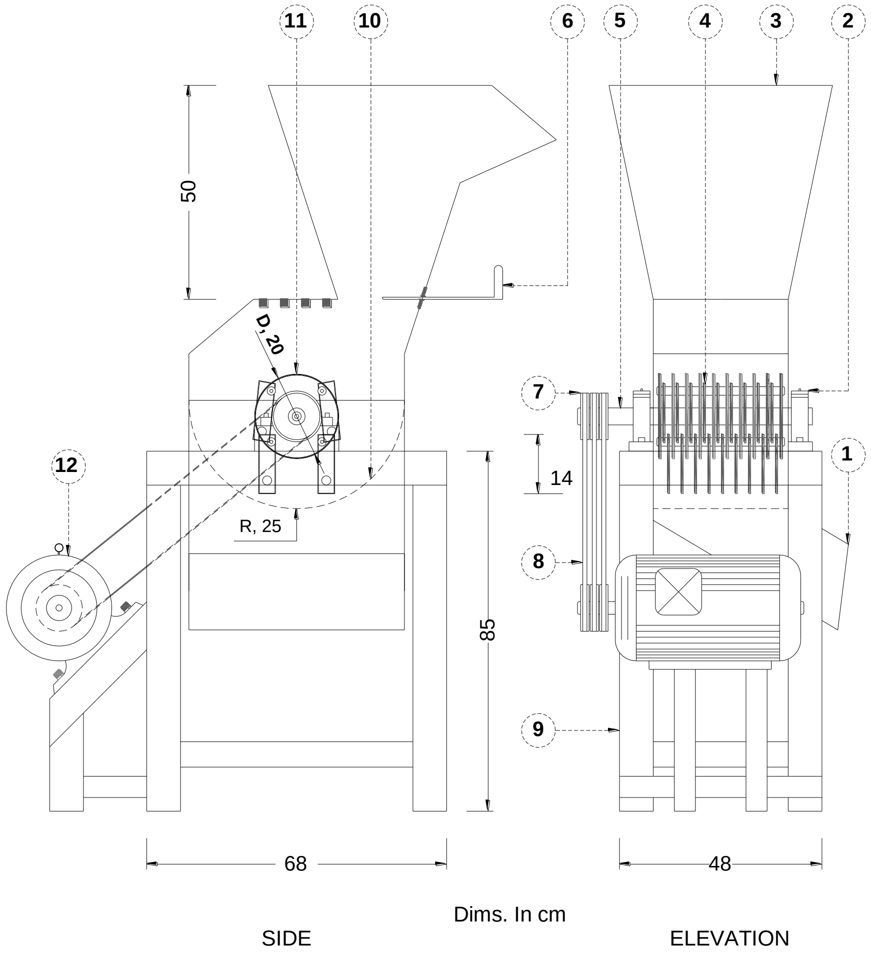
Table 1: The technical specifications of tested mills (A and E).

Item	Type of tested Hammer mill	
	Aamagro mill (mill A)	**El-Gohary mill (mill E)**
Manufacture	Locally	Locally
Overall dimensions:		
Height, cm	196	172
Length, cm	88.5	130
Width, cm	80	52
Flywheel	With Flywheel	Without Flywheel
Electric motor, hp (kW)	10 (7.46)	20 (14.91)
Rotor assembly:		
Plates No.	6	10
Plate shape	Triangle	Circular
Plate diameter, mm	270	200
No. of hammers	45	36
Hammer edge shape	(30 smooth + 15 serrated)	36 smooth
Hammer edge angle, deg.	50	90
Hammer type	Swinging	Swinging
Hammer size (L, W, T), mm	(100, 50, 2.5)	(140, 40, 8)
Screen hole diameter, mm	14	14.5
Clearance between hammers and screen, mm	12.5	13



1- Main shaft
2- Feed hopper
3- Bearing
4- Flywheel
5- Feed gate
6- Adjusting gate
7- Hammer
8- Rotor
9- Screen
10- Belt
11- Electric motor
12- Pulley
13- Frame
14- Opening outlet
15- Concrete base

Fig. 1: Schematic diagram of mill A (Aamagro).



1- Opening outlet
2- Bearing
3- Feed hopper
4- Hammer

5- Main shaft
6- Feed gate
7- Pulley
8- Belt

9- Frame
10- Screen
11- Rotor
12- Electric motor

Fig. 2: Schematic diagram of mill E (El-Gohary).

Mill A (Aamagro) **Mill E (El-Gohary)**

Fig. 3: Photographs view of A and E mills.

Fineness degree (particle size distribution):

The cobs granulation and sieve analyses were determined using a laboratory sieve shaker (Japanese type, model: SNF-7, TERAOKA-OSAKA) according to *ASAE Standards, 1998*, as follows: After milling process, samples were analyzed for particle size by sieving triplicate samples of 100g of milled material that was placed on the top of sieves and the shaker was run for 10min, using a sieve series of 4.75, 3.35, 2.36, 1.7 and 1.18mm round holes respectively. The cobs samples were classified into three main categories. The first one is coarse milled cobs (≥4.75mm), the second is medium milled cobs (3.35-≤2.36mm), the third is fine milled cobs (1.7-≤1.18mm).

Mills productivity:

Before milling process, the hopper was filled with corn cobs, then the feed opening gates were calibrated to give the appropriate feeding rate per time. During cobs milling, the consumed time from the moment of full dropping until the end time was calculated. And then, mill productivity was determined the milled cobs mass per time.

Power requirements and energy consumption:

Ammeter and voltmeter devices were used for measuring the current intensity and potential difference respectively. Readings of Amperes and Volts were taken before and during each treatment. The power requirement was calculated for each treatment by using the following formula (*Lockwood and Dunstan, 1971*):

$$Power\,consumption = \sqrt{3}\ \left(I.V.\cos\theta.\eta\right)/1000\,,kW \ \ldots..1$$

Where:

I	current intensity, Amperes;
V	potential difference, Volts;
$\cos\theta$	electrical power factor, decimal (being equal to 0.71), and
η	mechanical efficiency of motor assumed to be 80%.

The energy consumption for each treatment was calculated by using the following equation:

$$Energy\,consumption = \frac{Power\ requriments}{productivity}\,,kW.h/ton \cdots 2$$

Cost Estimations (fixed + variable):

For estimating the machinery fixed cost, declining balance method was used to determine the depreciation. In this method the depreciation value is different for every year of the machines life. The interest on investment, shelter, taxes and insurance were estimated as 17.5% of the remaining value. While, variable costs include the cost of repairs and maintenance, electricity, lubricant and labor. For machinery, repairs and maintenance is about 5.77% as a percent of purchase price *(Hunt, 1983)*.

Estimating the machinery unit cost:

The operating cost was calculated by using the following formula:

$$Cost\,unit = \frac{Total\,cost}{Productivity}\,,LE/ton \quad \ldots\ldots\ldots\ldots 3$$

RESULTS AND DISCUSSION

Fineness degree (particle size distribution):

Figs. 4 and 5 illustrate the effect of rotor speeds, cobs feed rates and screen hole diameters on fineness degree for both A and E mills. It was cleared that the increase of rotor speed was followed with an increase in fine milled cobs while medium and coarse milled cobs decrease. Also, the cobs fineness degree decreased by increasing the feed rates and increasing screen hole diameters. Concerning mill A, the results obtained show that increasing the rotor speed from 1200 to 2100rpm increased the particle size distribution of fine milled cobs (1.7-≤1.18mm) from 57.65 to 63.71, from 55.31 to 61.37 and from 52.52 to 58.57% at feed rates of 0.2, 0.4 and 0.6ton/h, respectively and screen hole diameter of 9mm. Also, the same increase in rotor speeds increased the particle size distribution of fine milled cobs (1.7-≤1.18mm) from 52.95 to 58.31, from 49.94 to 56.15 and from 46.19 to 52.15% at feed rates of 0.2, 0.4 and 0.6ton/h, respectively and 14mm screen hole diameter. The lowest values of medium milled cobs (3.35-≤2.36mm) and coarse milled cobs (≥4.75mm) were found to be 28.65 and 7.65%, respectively at rotor speed of 2100rpm, feed rate of 0.2ton/h and 9mm screen hole diameter. Relating to mill E, the results obtained show that increasing the rotor speed from 1200 to 2100rpm increased the particle size distribution of fine milled cobs (1.7-≤1.18mm) from 47.34 to 53.16, from 44.63 to 50.84 and from 41.86 to 48.45% at feed rates of 0.2, 0.4 and 0.6ton/h, respectively and screen hole diameter of 9mm. Also, the same increase in rotor speeds increased the particle size distribution of fine milled cobs (1.7-≤1.18mm) from 43.56 to 48.49, from 40.26 to 46.27 and from 37.19 to 44.38% at feed rates of 0.2, 0.4 and 0.6ton/h, respectively and 14mm screen hole diameter. The lowest values of medium milled cobs (3.35-≤2.36mm) and coarse milled cobs (≥4.75mm) were found to be 33.56 and 13.28%, respectively at rotor speed of 2100rpm, feed rate of 0.2ton/h and 9mm screen hole diameter. From the previous mentioned results, it can be stated that, mill A (Aamagro) was able to offer the best fineness degree of milled cobs suitable for use as an ingredient in feedstuffs in the animal and poultry industries.

Mills productivity:

Data in Fig. 6 shows the effect of rotor speeds, cobs feed rates and screen hole diameters on mill productivity for both A and E mills. In connection with A and E mills, the data revealed that at any feeding rate from 0.2 to 0.6ton/h, the productivity rate of the mill increased gradually as the rotor speeds and screen hole diameters increased. On the other words, at 0.6ton/h feed rate of mill A, the results indicated that increasing rotor speed from 1200 to 2100rpm cause a corresponding increase in the mill productivity from 0.563 to 0.585 and from 0.587 to 0.599ton/h at screen hole diameters of 9 and 14mm, respectively. Also, at 0.6ton/h feed rate of mill E, the results indicated that increasing rotor speed from 1200 to 2100rpm cause a corresponding increase in the mill productivity from 0.531 to 0.553 and from 0.549 to 0.569ton/h at screen hole diameters of 9 and 14mm, respectively. In general, data presented in the same figure showed that, the productivity values of A mill were higher than that of mill E under all operating conditions. For instance, the productivity increases by 5.79% in case of using mill A in comparison with mill E at rotor speed of 2100rpm, feed rate of 0.6ton/h and 9mm screen hole diameter. Meanwhile, it was increases by 5.27% at screen hole diameter of 14mm and under the above mentioned conditions.

Power and energy:

The obtained results in Figs. 7 and 8 illustrate the effect of rotor speeds, cobs feed rates and screen hole diameters on power consumed and energy requirement for both A and E mills. It can be stated that, the increase of rotor speed from 1200 to 2100rpm tends to increase the power consumed from 2.098 to 2.245 and 2.91 to 3.076kW for A and E mills, respectively at cobs feed rate of 0.2ton/h and 9mm screen hole diameter. However, the same increase in rotor speed decreases the energy requirement from 12.489 to 12.134 and 21.715 to 21.065kW.h/ton at the same above mentioned conditions for both two tested mills, respectively. The same results were obtained with other cobs feed rates and screen hole diameter. This trend may be due to increase of rotor speed was occurred a decrease in energy requirement that is can be attributed to increasing of mills productivity rate is higher than increasing in power consumed rate.

In the same manner, the increase of cobs feed rate from 0.2 to 0.6ton/h leads to increase the power consumed from 2.098 to 6.058 and 2.91 to 10.542kW for A and E mills, respectively at rotor speed of 1200rpm and 9mm screen hole diameter. However, there were a reduction in energy requirement from 12.489 to 10.761 and 21.715 to 19.853kW.h/ton for A and E mills, respectively at the same above mentioned operation conditions. The same tendency was obtained with the other rotor speeds and screen hole diameter. This trend may be due to the increase in mills productivity.

On the other hand, the increase of screen hole diameters from 9 to 14mm tends to decrease both power consumed and energy requirement for the two proposed mills. However, the power consumed decreases from 2.098 to 1.857 and 2.91 to 2.733kW at rotor speed of 1200rpm, cobs feed rate of 0.2ton/h. The same increase in screen hole diameters decreases the energy requirement from 12.489 to 9.983 and 21.715 to 17.979kW.h/ton for A and E mills, respectively. The same trend was noticeable with the other cobs feed rates and rotor speeds.

The obtained results showed that, the minimum values of power consumed were 1.857 and 2.733kW at rotor speed of 1200rpm, cobs feed rate of 0.2ton/h and 14mm screen hole diameter for A and E mills, respectively. However, the minimum values of energy requirement were 7.848 and 15.493kW.h/ton at rotor speed of 2100rpm, cobs feed rate of 0.6ton/h and 14mm screen hole diameter for the above mentioned two mills.

Operating cost:

Estimation of the annual global cost for A and E mills were listed in the Table 2. From the Table 2, it can be revealed that, the machinery unit cost of A an E mills were 16675.71 and 18751.35LE/year respectively. While the hourly cost of A and E mills were estimated as 11.117 and 12.501LE respectively. From Table 3, it is noticed that, operating cost is decreased with increasing both rotor speed, cobs feed rate and screen hole diameter. Where for A and E mills, the lowest values of operating cost were found to be 18.559 and 21.970LE/ton respectively, at rotor speed of 2100rpm, cobs feed rate of 0.6ton/h, and 14mm screen hole diameter. On the other hand, the highest values of operating cost of A and E mills were reached 66.173 and 93.291LE/ton respectively, at cobs feed rate of 0.2ton/h, rotor speed of 1200rpm and 9mm screen hole diameter.

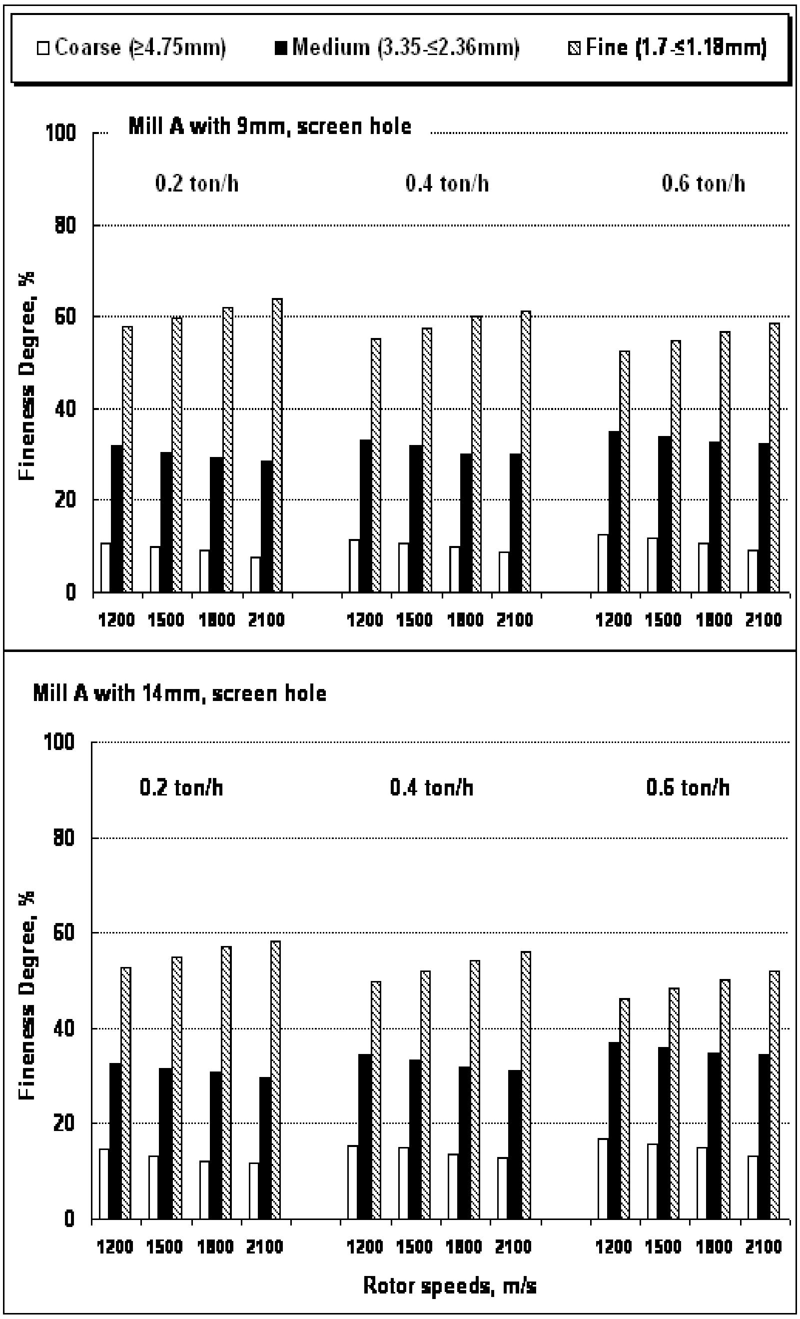


Fig. 4: Effect of rotor speed, cobs feed rate and screen hole diameter on fineness degree for mill A.

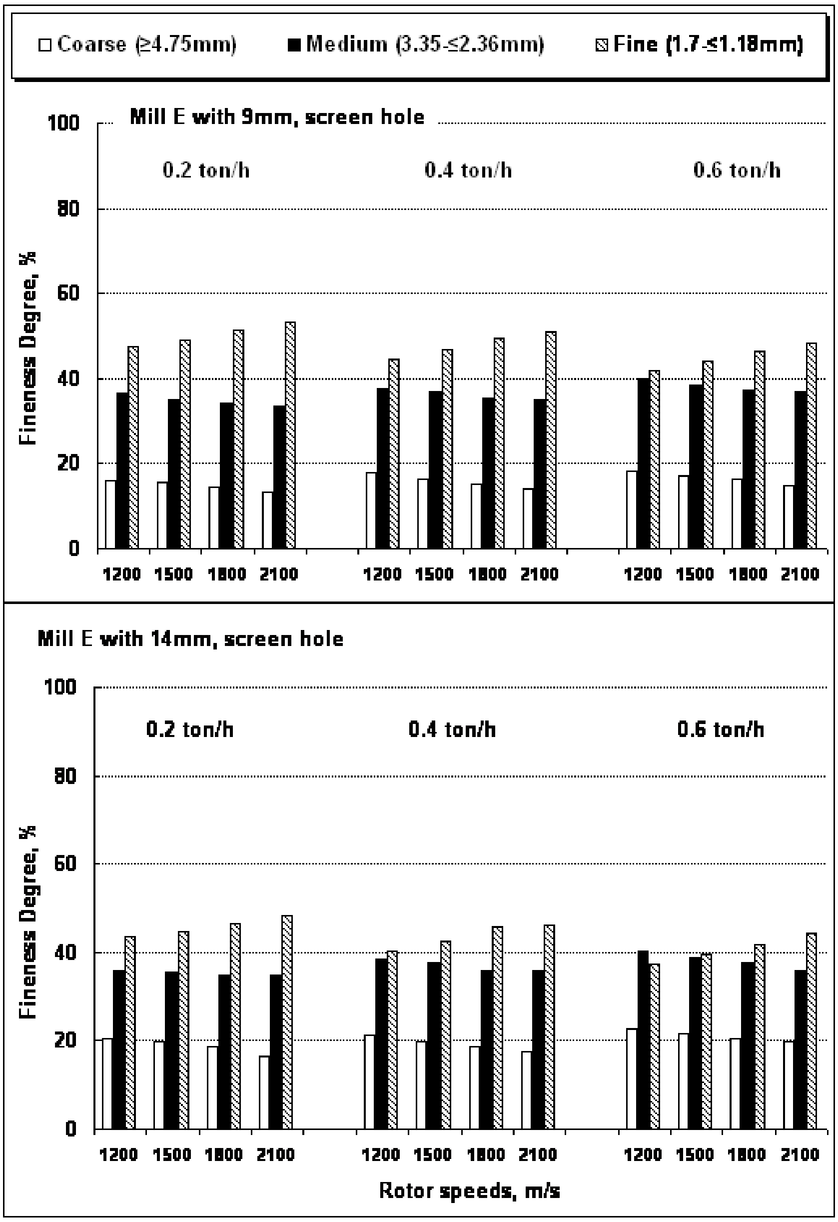


Fig. 5: Effect of rotor speed, cobs feed rate and screen hole diameter on fineness degree for mill E.

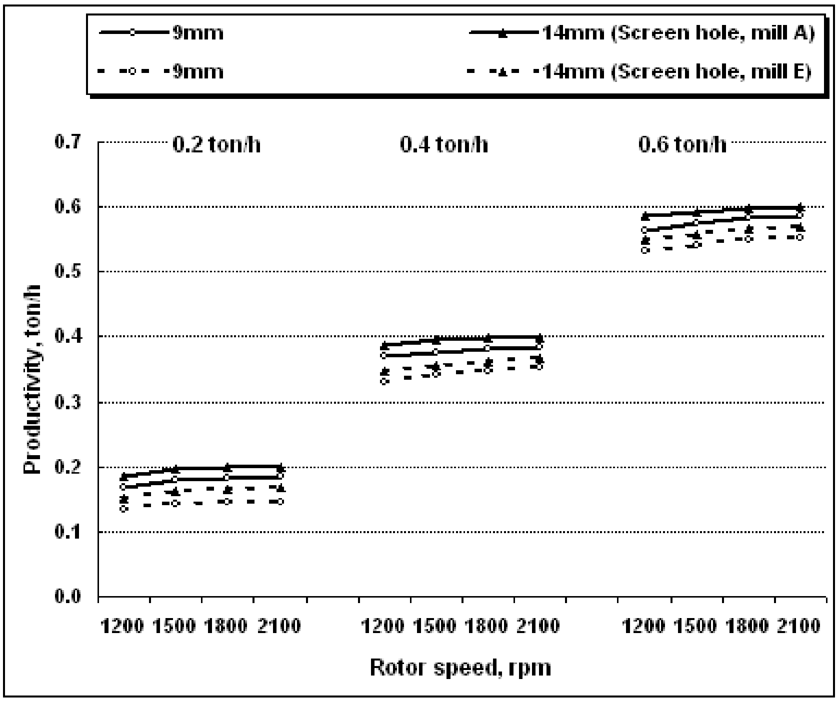


Fig. 6: Effect of rotor speed, cobs feed rate and screen hole diameter on productivity for A and E mills.

Table 2: Cost estimation for hammer mills.

Hammer mills	**mill A**	**mill E**
Assumptions:		
Price of hammer mill, LE	13500	20850
Life span, Yr	10	10
Operation hours, h/Yr	1500	1500
Total fixed cost, LE/Yr	3428.16	5294.60
Depreciation cost, LE/Yr	1721.25	2658.38
Interest, taxes, insurance and shelter cost, LE/Yr	1706.91	2636.22
Total Variable cost, LE/Yr	13247.55	13456.75
Repair and maintenance cost, LE/Yr	77.895	120.30
Electricity cost, LE/Yr	1129.65	1293.45
Lubricant cost, LE/Yr	40	43
Labor cost, LE/Yr	12000	12000
Machinery unit cost:		
LE/Yr	16675.71	18751.35
LE/h	11.117	12.501

Table 3: Values of the operating cost for all parameters.

Feed rate, ton/h	**Rotor speed, rpm**	**Operating cost, LE/ton**			
		mill A		**mill E**	
		9mm	***14mm***	***9mm***	***14mm***
0.2	***1200***	66.173	59.769	93.291	82.243
	1500	62.106	57.010	88.660	77.646
	1800	60.749	56.146	86.813	75.307
	2100	60.092	55.864	85.623	73.970
0.4	***1200***	30.127	28.652	37.997	35.922
	1500	29.645	28.073	36.660	35.115
	1800	29.178	28.003	36.026	34.629
	2100	28.875	27.862	35.414	33.970
0.6	***1200***	19.746	18.939	23.542	22.770
	1500	19.334	18.747	23.107	22.403
	1800	19.101	18.590	22.770	22.087
	2100	19.003	18.559	22.606	21.970

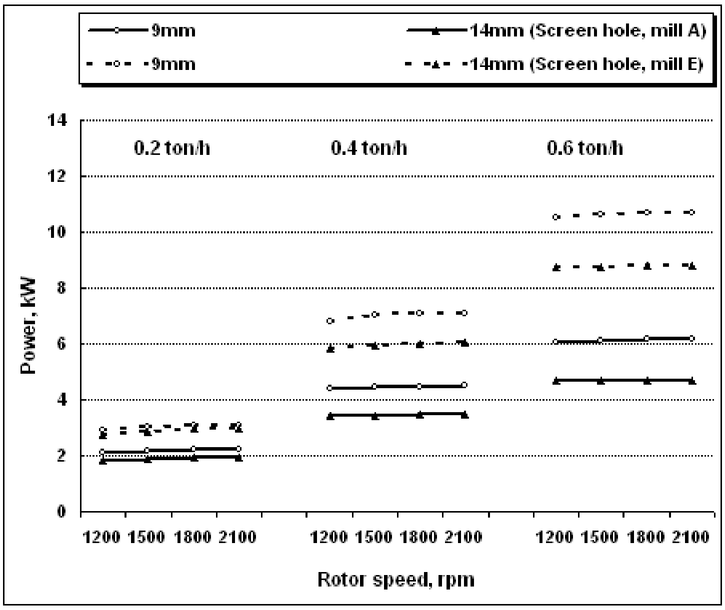


Fig. 7: Effect of rotor speed, cobs feed rate and screen hole diameter on power for A and E mills.

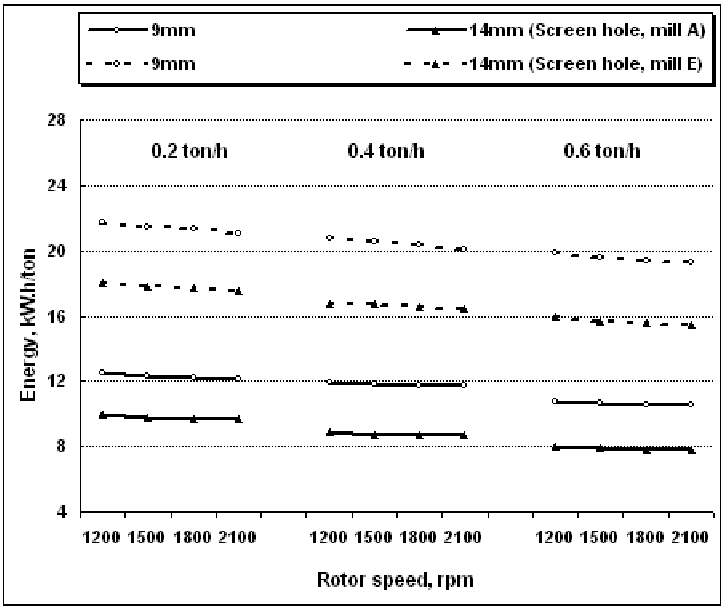


Fig. 8: Effect of rotor speed, cobs feed rate and screen hole diameter on energy for A and E mills.

CONCLUSION

For A and E mills, the optimum operating conditions to produce pelleting feed were at rotor speed of 2100rpm, cobs feed rate of 0.2ton/h and 9mm screen hole diameter by increasing percentage of fine milled cobs and decreasing medium and coarse milled cobs. Also, mill productivity of 0.185 and 0.146ton/h, power consumed of 2.245 and 3.076kW and energy requirements of 12.134 and 21.065kW.h/ton were occurred under the same previous conditions for A and E mills, respectively. Moreover, the machinery unit cost estimations indicated that, mill E costs about 1.124 times mill A.

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الهيئة المصرية العامة للتوحيد القياسي (1987). المواصفات القياسية المصرية 987/3 ، الأعلاف المصنعة ومواد العلف الخام.

تقييم أداء آلتين مختلفتين لجرش قوالح الذرة

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أجرى هذا البحث بغرض اختيار وتحديد آلة ملائمة لجرش قوالح الذرة الصفراء لاستخدامها كعنصر ضمن مكونات مواد العلف التي تدخل في صناعة تربية الثروة الحيوانية والداجنة فى مصر. حيث تم تقييم ومقارنة اداء آلتين مختلفتين في التصميم ومن النوع المطرقى لجرش قوالح الذرة. والآلتان المختبرتان محليتان الصنع هما (ايماجرو ، والجوهري). وقد تم تقييم ومقارنة أداء تلك الآلتين في عملية جرش القوالح عند تشغيلهما على عدة مستويات لأهم عوامل التشغيل المؤثرة على الجرش الآلي والتي تضمنت:

- معدل تلقيم قوالح الذرة (0.2 ، 0.4 ، 0.8طن/ساعة).
- سرعة الدوار (1200 ، 1500 ، 1800 ، 2100لفة/ د).
- قطر فتحات الغربال (9 ، 14مم).

وقد تم دراسة وتحليل مدى تأثير تلك المعاملات على درجة نعومة المجروش (توزيع حجم الحبيبات) والإنتاجية والقدرة المطلوبة والطاقة المستهلكة وتكلفة التشغيل لكل من الآلتين المختبرتين.

وقد أوضحت النتائج أن مستويات عوامل التشغيل المثلى للآلتين المختبرتين (ايماجرو ، والجوهري) هى 2100لفة/د كسرعة للدوار و0.2طن/ساعة كمعدل تلقيم للقوالح و9مم كقطر لفتحات الغربال. حيث تحققت أعلى نسب مئوية لدرجة جرش القوالح الناعم (من 1.7 إلى اقل من أو يساوى 1.18مم) هي 63.71 و53.16% لكل من المجرشتين ايماجرو ، والجوهري على التوالي. وبينت النتائج أيضا أنة عند نفس مستويات عوامل التشغيل المذكورة سابقا كانت الإنتاجية 0.185 و0.146طن/ساعة وان متطلبات القدرة هي 2.245 و3.076كيلووات وان معدلات الطاقة المستهلكة هي 12.134 و21.065كيلووات.ساعة/طن وان تكلفة إنتاج واحد طن من جرش القوالح الناعم هي 60.749 و85.623جنيها مصريا لكل من المجرشتين ايماجرو ، والجوهري على التوالي.