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EVALUATING THE PERFORMANCE OF A HAMMER MILL THROUGH USING DIFFERENT TYPES OF LOCALLY MANUFACTURED HAMMERS

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ABSTRACT

The study has investigated the effects of three factors, which were feeding rate, the rotational speed, and the type of used hammers on the some important indicators that could reflecting the performance of the hammer mill. These indicators were: grinding fineness (%), productivity (Kg hr^{-1}), and consumed energy (KW). The experiment parameters were organized using a Randomized Complete Design (CRD) with three replications. The results showed that by increasing the feeding rate from 2 cm up to 4 cm, the fineness of grinding, productivity and energy consumed for both crops increased. The results also indicated that by increasing the rotational speed, the productivity and energy consumption increased, while the speed of 2154 rpm achieved the fineness grinding of barley and corn. The results also indicated that the use of conventional hammer led to the highest value concerning the fineness of grinding, and to the highest energy consumptions for both crops, barley, and corn. As for productivity, the manufactured hammer led to the highest values for both crops. However, considering the triple interaction between the studied factors (grinding fineness, productivity, and consumed energy), the manufactured hammer led to the highest value in productivity.

INTRODUCTION

In recent decades, interest in livestock has increased greatly, as it is the main sector responsible for providing animal protein, which is one of the most important nutrients in human and animal nutrition. Therefore, improving feed consumption comes as a result of increasing the surface area of the forage components and thus improving the rate of digestion (Nasir, 2005). The process of grinding the grain leads to making the forage more palatable and attractive. Therefore, the grain processed by the grinding process facilitates the digestion of the feed material by the animal, and makes the forage better tasting and be easier to digest (Baker and Herrman, 2002). The process of producing any animal feed (forage) depends on several things, including the type of mill used, type and number of hammers used in the grain crushing process, engine power and rotational speed. Field crops constitute the main source of energy in animal feed, and this is not related to the quality of the crop or its nutritional composition, but rather to how it is manufactured (Goodband *et al*,2002). Reducing the size of the particles increases the surface area of the grain and thus allows for greater interaction with the digestive enzymes. Therefore, one of the performance advantages of the volumetric reduction process for feed materials is concentrated in the homogeneity of the product in relation to the volume and reducing the capacity spent on the crushing process.

The mechanical reduction of the size, from the physical point of view, is breaking the grain. Therefore, the effort spent on chewing will decrease and the benefit of the food will increase, knowing that the mechanical reduction has certain limits, because the exaggeration of the mechanical miniaturization can lead to opposite result (Rundnitski, 1990). Therefore, the production of such feed necessitates the use of appropriate machines and tools to reach the maximum benefit, and among these machines is the hammer mill, which is one of the most widespread and used machines in feed manufacturing plants (Al-Saeedi, 1983).

Therefore, the process of evaluating the performance of the grinder is done on the basis of productivity requirements, energy per unit of miniaturization, and the size of the crushed particles. The hammer mills are one of the most widely used grinders in the process of volumetric reduction of grain. They improve forage quality, and quantity, ensure grain size reduction, reduce grain losses and energy consumption, which in turn lead to an increase in productivity. This depends on the type of hammers used in the crushing process (Adekomaya and Samuel, 2014). Therefore, the process of crushing and grinding the grains starts during the process of feeding the grain to the hammer mill. The mill strikes the grains with the hammers, and this initiates the grinding process because of the repeated effects of hammers colliding with the grains. Therefore, the fineness of the crushed material depends on the structure of the hammer in addition to the rotational speed. The hammer mill can be defined as the machine or tool that is designed and manufactured to reduce large materials into smaller pieces, which can be considered primary, secondary, or granules according to the percentage of reduction size (Khurmi and Gupta, 2005). In order to obtain a good design and performance from the mill, some basic factors must be considered, such as: a wise selection of the hammer material and its shape, the optimum number of hammers, the rotational speed and the characteristics of the material used in the grinding process in order to increase productivity and reduce the energy consumed. In addition, the design of the hammers is determined by operating parameters such as rotational speed and engine power, in addition to the sieve used .The optimum hammer design will provide maximum contact with the feed component, which increases the chance of collision between the hammer and the material and thus reduce its particles size. The problem is that there are few designs of hammers that are compatible with different types and sizes of grain which prompted us to design hammers of different shapes, Therefore The research aims to find the best suitable combination of the studied factors, and to show the effect of manufactured hammers on the degree of fineness of grain milling an different crops, in addition to reducing the time required for the crushing process in order to reduce the energy consumed and increase productivity.

MATERIALS AND METHODS

The experimental location.

The experiment was conducted in the Agricultural Machinery Department of the College of Agriculture and Forestry at the University of Mosul in 2021, and a hammer mill was used (Fig. 1). This device was containing 24 hammers, the distance between each hammer was 41 mm, the clearance between the hammers and the sieve was 6 mm, the diameter of the sieve used was 4.8 mm, the number of blades of the air fan is 6, the size of the feeding hopper is 72 cm x 41 cm x 35,5 cm, the size of the hammer is 87 mm x 44.5 mm (Fig. 2). The hammer weighs 146.76 g and have 6 mm thickness. The mill is operated by an electric motor that generate 5.5-6.4 hp.

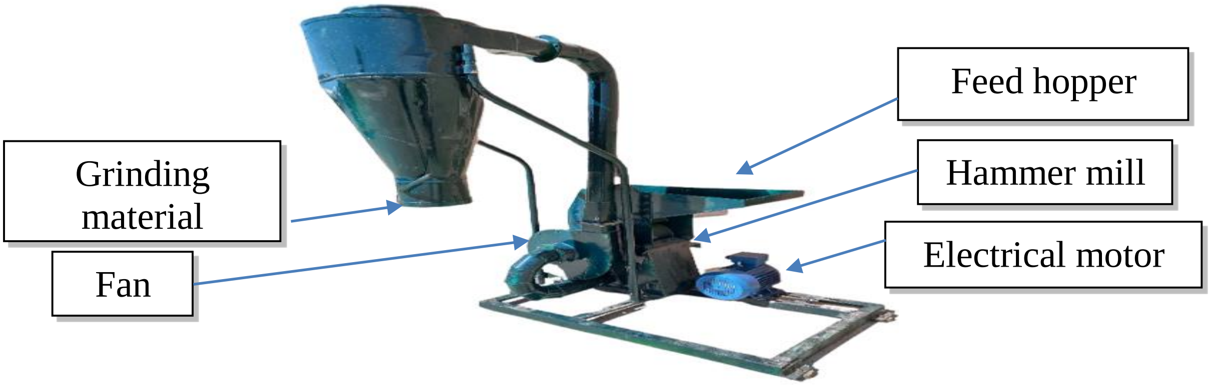

Figure 1. The main parts of the investigated hammer mill

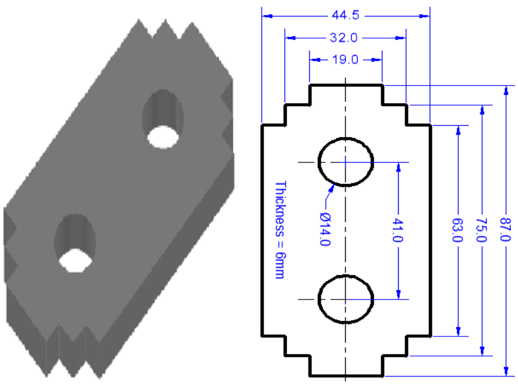

Figure 2 – (a) The size of the conventional hammer – (b) The conventional hammer

Two crops of grains (barley and corn) were used, and the moisture percentage (6.3% in barley, and 11.8% in corn, respectively), was measured using a Seedburo 1200 Measur device produced in USA. The specific weight of the grains (hectoliters) was measured using Specific weight measuring device of German origin, and the readings were recorded 64.6 kg/hectoliter and 69.4 kg/hectoliter, respectively. The experiment was carried out in two stages:

Methodology Outline

First stage – Pulleys and Hammers Manufacturing.

At this stage, the required shape of design was determined through the sizes and measurements of the pulleys, based on the design blueprint of them (Fig. 3, and Fig. 4). and the hammers were also drawn based on the blueprint design (Fig. 5).

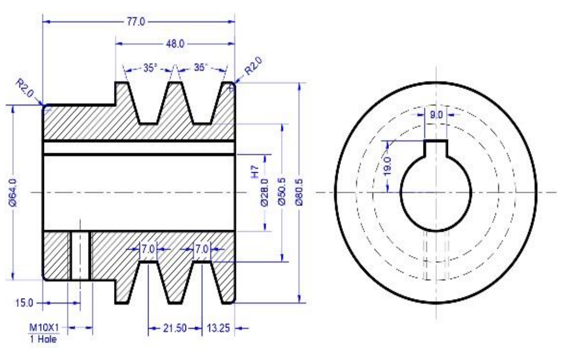

Figure 3. The sizes of 8 mm pulley

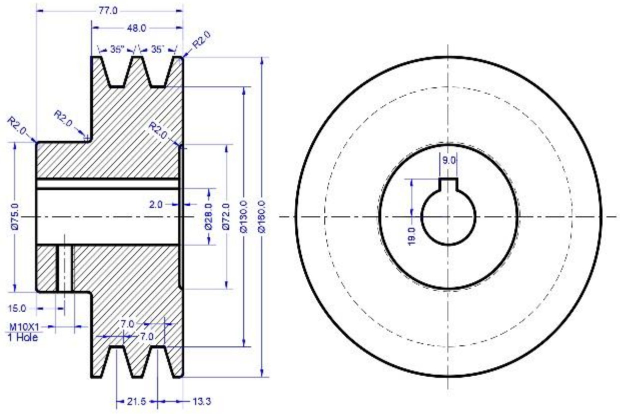

Figure 4. The sizes of 16 mm pulley

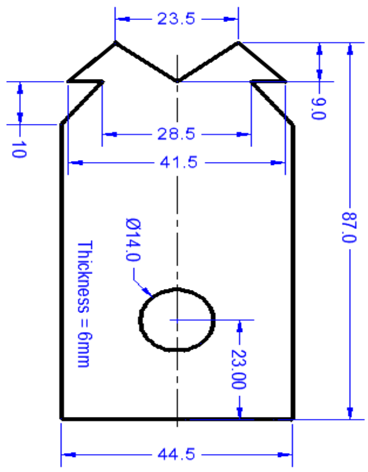

Figure 5. The sizes of the designed hammer

Selection and testing the metal for manufacturing the designed pulleys and hammers.

This stage was considered very important, as it consists in the selection of the metal required in the process of manufacturing of the pulley, and hammer, considering the set of specifications available for the chosen material. When selecting a metal, one must consider: the resistance of the metal and its tolerance to the stresses that will be subject to the high temperatures resulting from friction and their effects on hammer's erosion, the exposure of hammer, during its movement to sudden shocks such as interaction with stones and other materials. Hammers have good properties such as toughness and hardness, ductility and resistance against breakage during impacts. Then, the necessary tests were conducted on the metal that was selected for the pulley and hammers, including examining its chemical composition and mechanical properties (Tables 1, and 2).

Table (1): The chemical composition of conventional hammers, manufactured hammers, and pulleys.

	Chemical composition - classification according to ASTM					
Silicon SI %	Iron Fe %	Sulfur S%	Phosphorous P%	Manganese Mn%	Carbon C %	ITEM
——	Rem.	0.055	0.043	0.80	0.67	ASTM 1065 Conventional hammer
——	Rem.	0.052	0.041	0.85	0.72	ASTM 1070 Manufactured hammer
1.9	——	0.12	0.1	0.6	2.3	Pulleys/ Grey Castiron 30

Table (2): The mechanical properties of conventional hammers, manufactured hammers, and pulleys.

ASTM Mechanical Properties, classification according to				
Elongation (%)	Hardness (HRC)	Yield Strength (Mpa)	Tensile Strength (Mpa)	ITEM
11	27.2	390	680	ASTM 1065 conventional hammer
9	32.3	435	755	ASTM 1070 Manufactured hammer
——	172	——	——	Pulleys/ Grey Castiron 30

After adopting the appropriate metal, a model was drawn for the hammers and pulleys to be manufactured, based on the dimensions and measurements determined by the researcher and shown in Figures (6), (7) and (8), respectively.

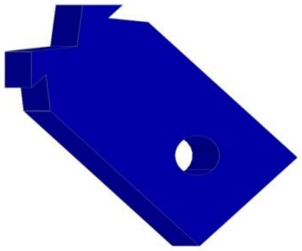

Figure 6. Manufactured hammer model

Figure 7. 16 mm pulley mode

Figure 8. 8 mm pulley model

Second stage – the Implementation of the experiment in practice.
The experiment was carried out using a Randomized Complete Design (CRD) where three factors were studied: feeding rate with two levels, 2 cm and 4 cm, rotational speed with two levels, 2154 rpm and 4339 rpm, and types of hammer (conventional and manufactured). The impact of the hammer type on the studied indicators (crushing smoothness, productivity, consumed energy) was also studied, by grinding two crops of cereals (barley and corn grains) in three replications. Then the data were analyzed for each experiment separately, using the SAS. The variance analysis was performed according to the Duncan test, were implemented. The significance of the differences between the means of the transactions was tested at the level of 0.05%, and 0.01%. The experiment was also implemented in two stages.

The first stage:

Random samples were taken from both crops (barley, corn). The samples were weighed by an electric balance and the grains were placed in the feed hopper to be crushed. During the beginning of the crushing process, the voltage difference consumed by the electric motor was measured to calculate the consumed capacity, and time necessary to conduct the crushing process was calculated for each experimental unit. In the end of grain crushing process, the output was collected for each experimental unit, for both experimental cereal species, placed in numbered bags and weighed in order to calculate the productivity of each species.

The second Stage.

A random sample of the crushed grains was taken from each experimental unit at a rate of 200 g, and the sifting process was carried out using multi-diameter sieves (3.35 mm, 2.36 mm, 2.00 mm, 1.18 mm, 0.85 mm, 0.30 mm, 0.15 mm, 0.075 mm). Where the sieves were arranged from the large openings placed at the top and in descending manner to the last sieve with small holes, which ends with a bowl in which collects what comes down from the last sieve. Then the sieves were shaken for five minutes, and after the sifting process was completed, each sieve was emptied separately, the samples were weighed by a sensitive electronic balance, the readings were recorded for each sieve (hand sieves), and then the studied indicators were calculated as follows:

Fineness of Grinding (%).

It was calculated after weighing the samples with a digital balance. The samples were placed in a group of sieves arranged in descending order from the large holes to the smaller holes down to a container in which the remains of the last sieve falls (Istvan, 1980).

$Fm = 1F1 + 2F2 + 3F3 + \ldots + 7F7 + \ldots$ (1)

where:

FM - Fineness of Grinding.

F1 - the % weight for the last entry.

F2 - the % weight for the penultimate entry.

1, 2, 3 - constants.

Productivity (Kg hr^{-1}). It was measured using an electric balance weighing up to 40 kg (Chinese origin,System Electronic Scale, Model NO.ACS-A).For both crops (barley and corn) and a stopwatch to fix the time. After placing the sample in the machine and starting grinding, the time is calculated until the grinding process is completed using the following equation (Payne,1997).

Productivity = $\frac{\text{outcome weight (kg)}}{\text{time (hr)}}$ ……………………….. (2)

Power consumption (kw). It was measured using a digital amperemeter (Clamp Meter, Chinese origin) with measurement domain 20-600 amperes, device number DT-9250 A and during the period of grinding and collecting the outcome, the electricity consumed for the motor is measured in order to calculate the consumed power, according to the following equation proposed by (Payne,1997).

$P = \mathrm{I}\frac{\mathrm{V.\ 1{,}73\ .\ PF}}{1000}$ ……………………… (3)

Where :

P - consumed power (kW).

I - current intensity (kA).

V - voltage (kV).

PF - Power Factor = 0.93

RESULTS AND DISCUSSIONS

First: The barley crop.

1-Fineness of Grinding (%). Table 3 shows the effects of the studied factors on the Fineness of Grinding. The feeding rate had a significant effect on the grinding fineness. By increasing the feeding rate from 2 cm to 4 cm, the softness percentage increased. The 4 cm feeding rate achieved the highest value of 11.44 %, while the 2cm feeding rate achieved the lowest percentage of the Fineness of Grinding, which was 10.569%. The reason is that the amount of grain entering at a feeding rate of 4 cm requires a longer period of time to be crushed, and therefore it will be exposed to the shocks of hammers for a longer period, which will result in an increase in the number of grain particles and thus increase the fineness of the grain.

The rotational speed factor also had a significant effect, as the rotational speed of 2154 rpm achieved the highest value in the fineness of the grind, which amounted to 13.103% while the lowest value was at the rotational speed of 4339 rpm, which was 8.906%. The reason for this is that increasing the rotational speed will reduce the average diameter of the minutes, and consequently, the smoothness of the crushing will decrease, meaning that the relationship between the speed and the smoothness of the crush is an inverse relationship.

It was also found that the type of Hammer had a significant effect, as the Conventional hammer achieved the highest value, amounting to 11,096%, while the manufactured weapon achieved the lowest value, which was 10,940%. It leads to a decrease in the fineness of the grinding due to the decrease in the rate of granules diameter. As for the interaction of feeding rate and rotational speed, there were significant differences, as the feeding rate 4 cm achieved the highest value amounted to 13.414% at a rotational speed of 2154 rpm, while the feeding rate of 2cm at a rotational speed of 4339 rpm achieved the lowest percentage, which amounted to 8,345%. The reason is with higher feeding rate and slower rotational speed, the grinding time will be longer, and therefore it will take much more hitting from hammers to crash the grains to smaller pieces to come out of the sieve, thus increasing the fineness of the crushing. Regarding the interaction between the feeding rate and the type of hammer used in the crushing process and its effect on the fineness of grinding , it was noted that there were no significant differences at the feeding rate of 2 cm for both hammers (conventional and manufactured). While significant differences were observed at the feeding rate of 4 cm, where the conventional hammer achieved the highest value and was 11.616%, while the manufactured hammer achieved the lowest value and was 11.264%.

This is due to the different design and geometry of the hammer used in terms of serrations and angles, which affect the degree of fragmentation of the grain into small parts. As for the interaction between the rotational speed and the type of hammer used, it was noted that there were no significant differences at the speed 4339 rpm, while there was a significant effect at the speed 2154 rpm, the Conventional hammer achieved the highest value, which amounted to 13,280% While the manufactured hammer achieved the lowest percentage of grinding fineness, which amounted to 12.947%. The reason may also be attributed to the overlap between the rotational speed, the type of hammer and the sifter used, as with an increase in the rotational speed in addition to the geometrical shape of the hammer, the paths oriented to the grain will increase. Thus, the sifter will work to seize the grains for the longest possible period of time until the particles of the crushed grains become less than the sieve opening, and this was indicated (Richey and Hall 1961) where the fineness standards are the indication numbers, the lower the number the finer the granules and vice versa. The triple interaction of the studied factors showed that there were no significant differences in the characteristic of the fineness of the grind.

Table (3): The effects of the studied factors on the characteristics of the Fineness of rending (%) *.

Feeding Rate Cm	Rotational speed rpm	Type of Hammers		Interference between feed rate and rotational speed	Feeding rate cm	Rotational speed rpm
		Conventional	Manufactured			
2 cm	2154	12.843	12.743	12.793 b		
	4339	8.199	8.491	8.345 d		
4 cm	2154	13.677	13.151	13.414 a		
	4339	9.556	9.378	9.467 c		
Interference between feeding rate and hammer types	2cm	10.521 c	10.617 c		10.569 b	
	4cm	11.616 a	11.264 b		11.440 a	
Interference between rotational speed and hammer types	2154	13.280 a	12.947 b			13.103 a
	4339	8.878 c	8.934 c			8.906 b
Type of Hammers		11.096 a	10.940 b			

***** The presence of significant differences**.**

2-Productivity (Kg hr^{-1}).

It is noted from Table (4) the effect of the studied factors on the characteristic of productivity, where the table indicates the presence of significant differences, as it is noted that the effect of the characteristic of productivity is significant with the factor of the rate of feeding, whereby the increase of the feeding rate from 2 cm to 4 cm, the productivity increased significantly from 249,475 Kg hr-1 to 329,198 Kg hr^{-}

^{1}, and the reason may be attributed to the fact that "the higher feeding rates, the greater the quantity of crushed grains" and this in turn increases the productivity of the mills. It was also shown that the productivity was significantly affected by the rotational speed factor, as the productivity increased from 198,147 Kg hr^{-1} at a rotational speed of 2154 rpm to 380,526 Kg hr^{-1} at a rotational speed of 4339 rpm. The reason is that by increasing the speed, the time required for crushing will decrease, and this leads to an increase in productivity, as the speed of the crusher is what determines the efficiency of the crushing process in term of increasing productivity, and this is consistent with what was indicated by (Khader, 2001).

It was also found that there are significant differences in the type of hammer used and its impact on productivity, where the conventional hammer gave the lowest value, which amounted to 258,878 Kg hr^{-1}, while the manufactured hammer outperformed in giving it the highest value, which was 319,795 Kg hr^{-1}, where the design of the hammer had the greatest impact on increasing productivity. In terms of increasing the rate of crushed grains. As for the interaction between feeding rate and rotational speed, it was found that there were significant differences, as the highest value reached was 442,269 Kg hr^{-1} at a feeding rate of 4 cm and a rotational speed of 4339 rpm, while the lowest value was 180,168 Kg hr^{-1} at a feeding rate of 2 cm and a rotational speed of 2154 rpm. Where it was found that there is a direct relationship between the feeding rate and the rotation speed, as the feeding rate and the rotation speed increase, the grain crushing rate increases, and this is reflected in the productivity, which increases because the time taken for the crushing process is decreased. As for the interaction between the feeding rate and the type of hammer used, significant effects were observed, as the feeding rate of 2 cm for the

Conventional Hammer achieved the lowest value and was 232,597 Kg hr^{-1}, while manufactured hammers at the same feeding rate gave the highest value, which amounted to 266,354 Kg hr^{-1}. Also, it was noted that when the feeding rate was increased from 2 cm to 4 cm, it was accompanied by an increase in productivity, as the highest value was obtained with the manufactured hammers, which amounted to 373,236 Kg hr^{-1}.The interaction between the rotational speed and the type of hammer used indicated that there are significant differences, as it is noted that with an increase in the rotational speed, productivity increased, as the manufactured hammer recorded its superiority by recording the highest value and amounted to 432,007 Kg hr^{-1}, while the Conventional hammer recorded the lowest value and was 188,712 Kg hr^{-1}. The reason for this is that the higher the rotational speed, the greater the amount of crushed grains, and thus the productivity increased, in addition to the geometrical design of the hammer and its angles, which increased the degree of crushing the grains and consequently exiting the sieve openings. The table shows that there are significant differences at the triple interaction of the studied factors. The feeding rate of 2 cm and a rotational speed of 2154 rpm achieved the lowest value, which amounted to 170.19 Kg hr^{-1} using the Conventional hammer, while the feeding rate of 4 cm and a rotational speed of 4339 rpm achieved the highest value using the manufactured hammer at 521.45 Kg hr^{-1}. The reason is that the productivity increases with the increase in the feeding rate and the rotational speed (Salama *et al*, 2002), in addition to the design shape of the manufactured hammer in the upper working part increased the crushing efficiency.

Table (4): Effects of the studied factors on the productivity characteristic (Kg hr^{-1}) *.

Feeding Rate Cm	Rotational speed rpm	Type of Hammers		Interference between feed rate and rotational speed	Feeding rate cm	Rotational speed rpm
		Conventional	Manufactured			
2 cm	2154	170.19 F	190.14 F	180.168 d		
	4339	295.00 C	342.56 B	318.782 b		
4 cm	2154	207.23 D	225.02 D	216.236 c		
	4339	363.09 B	521.45 A	442.269 a		
Interference between feeding rate and hammer types	2cm	232.597 c	266.354 b		249.475 b	
	4cm	285.160 b	373.236 a		329.198 a	
Interference between rotational speed and hammer types	2154	188.712 c	207.583 c			198.147 b
	4339	329.044 b	432.007 a			380.526 a
Type of Hammers		258.878 b	319.795 a			

* The presence of significant differences.

3-Power Consumption. (KW)

Table (5) shows the effect of the studied factors on the characteristic of the consumed power (KW), where the table indicates the presence of significant differences, as the results showed the effect of the characteristic of the consumed power on the feeding rate significantly, as it was noted that with an increase in the feeding rate from 2 cm to 4 cm, the consumed power increased with it from 1,563 KW to 1,786 KW. As the increase in the amount of grain, the capacity required for grinding will increase, and this is consistent with what was indicated by (Bulgakov *et al*, 2018) that with the increase in feeding rates, the energy requirements for the grinding process increase. The results also indicated that there were significant differences for the rotational speed factor, as it was found that by increasing the rotational speed from 2154 rpm to 4339 rpm, the power consumed with it increased from 1,389 KW to 1,960 KW. The reason for this is that with an increase in the rotational speed, the effort imposed by the hammers on the grain will increase as a result of increase knocking until the process complete of the grinding process, and in turn the capacity and energy required for the grinding process will increase. The factor of the type of hammer used recorded significant differences, as it reached the highest value for the conventional hammer, which was 1,726 KW, while the manufactured hammer recorded its superiority in recording the lowest value, which amounted to 1,623 KW. The reason for this is due to the geometrically designed hammer shape and the way it hits the grain, which led to a decrease in the capacity and energy spent on crushing. Significant differences were found during the interaction between feeding rate and rotational speed, as the feeding rate of 4 cm and a rotational speed of 4339 rpm achieved the highest value and was 2,125 KW, while the lowest value was recorded at a feeding rate of 2 cm and a rotational speed of 2154 rpm and it amounted to 1,331 KW. As we increase the amount of grain, the amount of power will increase, and the reason for this is that the increase in the amount of grain, will need a greater speed to crush, this means greater strikes by the hammers on the grain. where decreasing the rotational speed, the force of the hammer blow to the grain will decrease, and thus the consumed power will decrease, and this is consistent with what was mentioned (Svihus *et al*, 2004). It was also found that there was no significant effect of the interaction between the feeding rate and the type of hammer used in the power consumed. The interaction between the rotational speed and the type of hammer used, the results showed that there were no significant differences between the Conventional hammer and the manufactured hammer at a rotational speed of 2154 rpm. While it was found that there were significant differences at the rotational speed of 4339 rpm, it reached the highest value for the conventional hammer and was 2,039 KW, compering to the manufactured hammer, where it recorded the lowest value, which was 1,881 KW, where the design shape of the manufactured hammer had a clear effect in reducing the power consumed in crushing grain. The results indicated that there were no significant differences for the triple interaction between the studied factors regarding power consumption.

Table (5): the effect of the studied factors on power consumption (kW)*.

Feeding Rate Cm	Rotational speed rpm	Type of Hammers		Interference between feed rate and rotational speed	Feeding rate cm	Rotational speed rpm
		Conventional	Manufactured			
2 cm	2154	1.363	1.300	1.331 d		
	4339	1.862	1.730	1.796 b		
4 cm	2154	1.463	1.431	1.447 c		
	4339	2.216	2.033	2.125 a		
Interference between feeding rate and hammer types	2cm	1.612	1.515		1.563 b	
	4cm	1.840	1.732		1.786 a	
Interference between rotational speed and hammer types	2154	1.413 c	1.369 c			1.389 b
	4339	2.039 a	1.881 b			1.960 a
Type of Hammers		1.726 a	1.623 b			

* The presence of significant differences.

Second: corn crop.

1-Fineness of Grinding (%).

Table (6) shows the effect of the studied factors on the fineness of the grind (%). Where it is clear that there is no significant effect of the feeding rate factor and at the feeding rates of 2 cm and 4 cm. It is noted from the table that there is a significant effect of the rotational speed on the smoothness of the crunches. The rotational speed of 2154 rpm achieved the highest value, which amounted to 10.213%, while the lowest value was at the rotational speed of 4339 rpm, which was 7.195%. This is due to the nature of crystal corn, which is fragmented to smaller parts easier. And faster, so the speed of rotational increases, the softness of the crunches decreases. The reason for this is due to the nature of the crystalline atom, which is easier and faster to break into smaller parts. Therefore, the higher the rotational speed, the lower the fineness of the crunches. It was also found that the type of weapon had a significant effect, as the Conventional Hammer achieved the highest value, reaching 8,848%, while the manufactured weapon achieved the lowest value, which amounted to 8,560%. The diameter of the minutes, and thus the smoothness of the crush is greater. This is consistent with what was indicated by (Istvan, 1980), that the smaller the average of granules diameter, the higher the fineness of the grinding. As for the interaction of feeding rate and rotational speed, there were significant differences, as the feeding rate of 2 cm achieved the highest value of 10.337% at a rotational speed of 2154 rpm, while the lowest value and at a rotational speed of 4339 rpm reached 7.029%. The reason may be due to the fact that by lowering the feeding rate and speeding rotational speed, the time of crushing the grains will reduce, as the force applied by the hammers on the grains will be greater, in addition to the flow of corn at a feeding rate of 2 cm will be greater than if it was at a feeding rate of 4 cm, so the stress on the hammer will decrease by grains. Thus, the grains splits and comes out of the sieve, leading to an increasing the fineness of the crushing, as the physical and mechanical properties of the material determine the ease or difficulty in reducing it to a particle size smaller than others (Sule and Odugbose, 2014). As for the interaction between the feeding rate and the type of hammer used in the grinding process, it was found that there were significant differences at the feeding rate of 2 cm for both hammers (conventional and manufactured), where the highest value was recorded for the conventional hammer and reached 8.939%, while the manufactured hammer upon achieved the lowest value and was 8.427%. This is due to the different design and geometry of the hammers used in terms of the serrations and angles to them, which affect the degree of fragmentation of the grain into small parts, where the reduction of grain size is affected by several parameters such as hardness, moisture content and feeding rate (Mani *et al*., 2004) and (Tumuluru *et al.*, 2014). While there were no significant differences in the feeding rate of 4 cm for both weapons in the characteristic of the fineness of the grind. As for the interaction between the rotation speed and the type of hammer used, it was found that there is a significant effect of the fineness of the grind, where the Conventional hammer recorded the highest value and was 10.453% at a rotational speed 2154 rpm while the manufactured hammer achieved the lowest value and reached 7.147% at a rotational speed 4339 rpm. The reason may be attributed to the fact that the crushing process is affected by the type of hammer used in terms of its shape and engineering design, in addition to that the high rotational speed increases the rate of measuring the diameter of the grain particles and thus decreases the fineness of the grind as the fineness standers indicates that the lower the number, the more fineness (Hanif *et al*.,2014). The three-factor interaction of the studied factors shows that there were no significant differences in the characteristic of the fineness of the grind %.

Table (6) The effect of the studied factors on the characteristic of the Fineness of Grinding (%)*.

Feeding rate cm	Rotational speed rpm	Type of Hammers		Interference between feed rate and rotational speed	Feeding rate cm	Rotational Speed rpm
		Conventional	Manufactured			
2cm	2154	10.714	9.960	10.337 a		
	4339	7.165	6.894	7.029 d		
4cm	2154	10.193	9.988	10.090 b		
	4339	7.321	7.399	7.360 c		
Interference between feeding rate and hammer types	2cm	8.939 a	8.427 c		8.683	
	4cm	8.757 b	8.694 b		8.725	
Interference between rotational speed and hammer types	2154	10.453 a	9.974 b			10.213 a
	4339	7.243 c	7.147 c			7.195 b
Type of Hammers		8.848 a	8.560 b			

* The presence of significant differences.

2- Productivity (Kg hr^{-1})

It is noted from Table (7) the effect of the studied factors on the characteristic of productivity, where the table indicates the presence of significant differences, as it is noted that the characteristic of productivity is significantly affected by the factor of feeding rate, as the increase of the feeding rate from 2 cm to 4 cm, productivity increased significantly from 220,223 Kg hr^{-1} to 310,645 Kg hr^{-1}, The reason may be attributed to the fact that the higher the feeding rates, the greater the amount of crushed grain, which in turn increases the productivity of the mill. It was also shown that productivity was significantly affected by the rotational speed factor, as the productivity increased from 196,479 Kg hr^{-1} at a rotational speed 2154 rpm to 334,389 Kg hr^{-1} at a rotation speed 4339 rpm. The reason is that by increasing the speed, the time required for crushing will decrease, hence leading to an increase in productivity. (Ahmed, 2017). In addition, the angle of stability of the grain is less, and the value of this angle reflects the amount of internal friction of the grain during its transfer. It was also found that there are significant differences for the type of hammer used, where the Conventional hammer gave the lowest value, which amounted to 238,891 Kg hr^{-1}, while the manufactured weapon outperformed in giving it the highest value, which was 291,977 Kg hr^{-1}, where the design of the weapon had the greatest impact on increasing productivity from Where the rate of crushed grain increased. As for the interaction between the feeding rate and rotational speed, it was found that there were significant differences, as the highest value reached 382,639 Kg hr-1, at a feeding rate of 4 cm and a rotational speed 4339 rpm, while the lowest value was 154,307 Kg hr-1 at a feeding rate of 2 cm and a rotational speed 2154 rpm

The reason is attributed to the fact that the increase in feeding rates and the increase in the rotational speed will lead to a reduction in the jams that occur on the sieve, as the high rotational speed makes the hammers collide with corn grains more.

As the relationship between the feeding rate and the rotational speed is direct, by increasing in the feeding rate and the rotational speed, the grain grinding rate increases, and this is reflected in the productivity and increases because the time taken for the grinding process is less. As for the interaction between the feeding rate and the type of hammer used, significant effects were observed. By using feeding rate of 2 cm with the conventional hammer achieved the lowest value and was 198,496 Kg hr^{-1}, while the manufactured hammer at a feeding rate of 4 cm gave the highest value, which amounted to 342,004 Kg hr^{-1}. The reason is that the design of the moving part of the manufactured hammer and the presence of serrations in the upper part of it led to the disintegration of the corn kernels, hence exiting the sieve slots completely, and thus increased productivity. The interaction between the rotation speed and the type of hammer used indicated that there were significant differences, as it was noted that by increasing the rotational speed from 2154 rpm to 4339 rpm, the productivity increased as the manufactured hammer recorded its superiority by recording the highest value of 375,256 Kg hr^{-1}, while the conventional hammer recorded the lowest value amounted to 293,522 Kg hr^{-1}. The reason for this is that the high rotational speed works to break up the grains by increasing the times the hammers hits the grains. The table shows that there are significant differences at the triple interaction of the studied factors, as the feeding rate of 2 cm and a rotational speed of 2154 rpm achieved the lowest value, which amounted to 141,676 Kg hr^{-1} using the Conventional weapon, while the feeding rate of 4 cm and a rotational speed 4339 rpm achieved the highest value Using the manufactured weapon, it was 433,551 Kg hr^{-1}. The reason may be attributed to the fact that the increase in feeding rates and rotational speed and taking into account the design shape of the serrations and angles of the manufactured hammers led to an increase in productivity as the crushing process is affected by the mechanical properties of the grain (Ahmed *et al.*, 2015).

Table (7):The effect of the studied factors on the productivity characteristic ($Kghr^{-1}$)*

Feeding rate cm	Rotational speed Rpm	Type of Hammers		Interference between feed rate and rotational speed	Feeding rate Cm	Rotational Speed rpm
		Conventional	Manufactured			
2cm	2154	141.676 g	166.939 f	154.307 d		
	4339	255.316 d	316.961 c	286.139 b		
4cm	2154	226.844 e	250.457 d	238.650 c		
	4339	331.727 b	433.551 a	382.639 a		
Interference between feeding rate and hammer types	2cm	198.496 d	241.950 c		220.223 b	
	4cm	279.285 b	342.004 a		310.645 a	
Interference between rotational speed and hammer types	2154	184.260 d	208.698 c			196.479 b
	4339	293.522 b	375.256 a			334.389 a
Type of hammers		238.891 b	291.977 a			

* The presence of significant differences.

3-Power Consumption (kw)

Table (8) shows the effect of the studied factors on the characteristic of the consumed power (KW), where the table indicates the presence of significant differences, as the results showed the effect of the consumed power on the feeding rate significantly, as it was noted that by increasing the feeding rate from 2 cm to 4 cm, the consumed power increased with it from 1,683 KW to 1,887 kW. As the increase in the amount of grain, the capacity required for crushing will increase, and this is consistent with what was indicated by (Bulgakov et al, 2018) that with the increase in feeding rates, the energy requirements for the crushing process increase. The results also showed that there were significant differences for the rotational speed factor, as it was found that by increasing the rotational speed from 2154 rpm to 4339 rpm, the power consumed increased from 1,511 KW to 2,059 KW. The reason for this is that with an increase in the rotational speed, the effort exerted by the hammers on the grain will increase due to the increase in the times the hammers hits on the grain. In addition, the shear forces affecting the grain by the hammer, which lead to a reduction in the grain size, will increase (Berk, 2018), until the crushing process is completed, and in turn, the power and energy required for the crushing process will increase. The type of Hammer Factor used has recorded significant differences in term of power consumption, as it reached the highest value using the conventional Hammer, which was 1,887 KW, while the manufactured Hammer recorded its superiority in recording the lowest value, which amounted to 1,682 KW. The reason for this is due to the geometrically design and hammer shape and the way it hits the grain, which led to a decrease in the capacity and energy spent on crushing process. As for the interaction between feeding rate and rotational speed, there were no significant differences in the power consumption. It was found that there was no significant effect of the interaction between the feeding rate and the type of hammer used in term of Power consumption. The table also shows that there is no significant effect of the interaction between rotational speed and type of hammer in terms of power consumption. The results also indicated that there were no significant differences for the triple interaction between the studied factors in term of power consumption.

Table (8): The effect of the studied factors on power consumption (kW)*.

Feeding rate cm	Rotational speed rpm	Type of Hammers		Interference between feed rate and rotational speed	Feeding rate cm	Rotational Speed rpm
		Conventional	Manufactured			
2cm	2154	1.546	1.264	1.405		
	4339	2.057	1.863	1.960		
4cm	2154	1.696	1.536	1.616		
	4339	2.250	2.064	2.157		
Interference between feeding rate and hammer types	2cm	1.802	1.564		1.683 b	
	4cm	1.973	1.800		1.887 a	
Interference between rotational speed and hammer types	2154	1.621	1.400			1.511 b
	4339	2.154	1.964			2.059 a
Type of hammers		1.887 a	1.682 b			

* The presence of significant differences.

CONCLUSIONS

At the end of the evaluation of the Hammer Mill it is concluded that the manufactured Hammer achieved the highest values for (productivity) for both crops. The manufactured hammer achieved the lowest values for each of the characteristics (Fineness of Grinding , Consumed Power) for both crops, while the Conventional Hammer gave the highest values, Feeding rate (4) cm achieved the highest values for the characteristics (Fineness of Grinding) at the barley crop, and The highest values of (productivity, Consumed Power) for both crops, The rotational speed of (2154) rpm achieved the highest values for (Fineness of Grinding) for both crops, while the speed of (4339) rpm achieved the highest values for each of the characteristics (productivity, Consumed Power). The manufactured hammer achieved the shortest time in the grinding process compared to the Conventional hammer, and this led to a reduction in energy consumed and an increase in productivity.

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CONFLICT OF INTEREST

None of the authors has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

تقييم أداء المجرشة المطرقية باستخدام أنواعاً مختلفة من المطارق المصنعة محليا

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الخلاصة

اشتمل البحث على دراسة ثلاثة عوامل وهي معدل التغذية وسرعة الدوران ونوع المطارق المستعملة وتأثيرها على بعض مؤشرات أداء المجرشة المطرقية وكانت المؤشرات الفنية المدروسة هي: نعومة الجرش (٪) و الإنتاجية (كغم / ساعة) والقدرة المستهلكة (كيلوواط). تم تنظيم معاملات التجربة باستخدام تصميم القطاعات العشوائية الكاملة (CRD) بثلاثة مكررات ، وأظهرت النتائج أنه بزيادة معدل التغذية من 2 سم إلى 4 سم زادت نعومة الجرش والإنتاجية والقدرة المستهلكة لكلا المحصولين. كما أشارت النتائج إلى أن زيادة سرعة الدوران أدت الى زيادة الإنتاجية والقدرة المستهلكة. بينما حققت السرعة 2154 دورة / دقيقة أعلى نعومة جرش للشعير والذرة الصفراء. كما أشارت النتائج إلى أن استخدام المطرقة التقليدية أدى إلى تحقيق أعلى قيمة فيما يتعلق بنعومة الجرش وأعلى قدرة مستهلكة لكل من محصولي الشعير والذرة الصفراء. أما بالنسبة للإنتاجية ، فقد أدت المطرقة المصنعة إلى الحصول على أعلى القيم لكلا المحصولين . ومع الأخذ بنظر الاعتبار التداخل الثلاثي بين العوامل المدروسة وتأثيرها في كل من (نعومة الجرش ، الإنتاجية ، والقدرة المستهلكة) إذ أدت المطرقة المصنعة إلى الحصول على أعلى القيم في صفة الإنتاجية.

الكلمات الدالة: المجرشة المطرقية, تصميم, جرش, سرعة دوران, إنتاجية

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