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Article

The Impact of Grain Type and Sieve Holes on some Hammer Mill Performance Measures

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Abstract: This paper examines the impact of various grain type (wheat and barley) and sieve hole size (1.5, 2.5 and 3.5 mm) on the productivity of agricultural hammer mills and the physical quality of the milled produce. The paper particularly investigated how these operating parameters influence the milling assessment parameter, geometric mean diameter, specific capacity, and specific energy consumption. Increased diameters of sieve holes were observed to have significant relations with increased specific capacity and geometric mean diameter, whereas specific energy consumption and the milling evaluation factor declined. In particular, doubling the sieve size to 3.5 mm doubled the specific capacity (up to 680.0 kg.h-1) of wheat and reduced barley, and cut energy requirements by a significant margin. Compared to barley which produced a better milling evaluation factor and finer particle properties (averaging 0.55 mm at 1.5 mm sieve size), wheat was able to continuously produce higher specific capacities and lower specific energy consumption, falling to 7.8 kWh.t-1. Finally, 3.5 mm sieve holes with wheat yield the highest throughput and energy efficiency and 1.5 mm sieve holes with barley the highest milling evaluation factor (0.94) and particle uniformity. This shows that the optimum milling environment hinges on the targeted nutritional and physical production specifications that are sought by particular livestock feeds.

Keywords: Hammer mill, milling evaluation factor, sieve holes diameter, specific capacity, specific energy consumption

Introduction

There is an underlying need to enhance the grinding parameters of the hammer mills to attain accurate particle properties since they are the direct determinants of the quality in the processing of the feeds and consequently the subsequent absorption of the nutrients by livestock [1], [2], [3]. The size reduction of different grains is widely used in the agricultural sector through hammer mills, which is a complicated process controlled by the combination of machine parameters and material properties [4], [5]. Screen hole size, speed of the hammer tip, moisture content of the grain, and the amount of hammers are all important issues that influence productivity, specific energy consumption, and granulometric composition of the generated particles.

To illustrate this, smaller hole diameter of the screen tends to create finer particles; nevertheless, it significantly blocks the throughput of the material and raises the amount of energy used to process a single ton of processed grain [3]. On the other hand, the hammer tip speed can be used to sharpen the grind and enhance throughput but at the same time it raises the specific energy consumption and the mechanical wear rate of mill components [4]. Moreover, the dimensions and design configurations of hammers highly influence the distribution of particle sizes, and energy efficiency because in most instances higher masses of a hammer result in smaller mean geometric particle sizes due to the increased transfer of kinetic energy [5]. Moreover, the different operating conditions, i.e. the moisture level of the raw material, geometry of the sieve holes, etc. have a significant influence on the mill performance indices and the quality of the product [6]. The combination of these mechanical and biological factors defines the ultimate fineness of the grinding process, and screen aperture size is normally the key factor in determining the ultimate particle size [3]. However, it has been found that the optimization of the screen hole diameter, feed rate, and rotor speed can result in the maximum productivity of milling and minimum carbon footprint of feed manufacturing.

The systematic quantification of specific capacity, energy consumption, particle size distribution, and milling evaluation factors for wheat and barley across varying sieve hole diameters provides a significant contribution to the precise optimization of industrial-scale hammer mill operations [7], [8]. Consequently, such thorough investigations serve as a critical foundation for establishing energy-efficient, product-specific grinding protocols. Furthermore, comprehending these intricate mechanical-biological interactions is essential for maximizing the nutritional efficacy of animal feed via enhanced digestibility and nutrient absorption [4], [9]. Adopting this comprehensive approach enables feed manufacturers to tailor grinding procedures to specific nutritional requirements while sustaining economic viability [10].

Therefore, the primary objective of this study is to provide an extensive evaluation of the interactive effects of grain type and sieve aperture on critical hammer mill performance metrics and overall product quality.

Materials and Methods

The following section outlines the design of the experiment and the procedures applied in measuring the influence of grain type and size of sieve holes on the hammer mill performance; i.e. specific capacity, the amount of energy used and the distribution of the particle sizes. The trials carried out were done through the agricultural engineering facility of the University of Kirkuk in College of Medicinal and Industrial Plants. The methodology provides the experimental design, grain preparation, and analysis procedures following which important performance indicators and grain characteristics of locally sourced wheat and barley were measured.

Milling was done in a standard agriculture hammer mill which was fitted with replaceable sieves. The trial was carried out using two different sieve hole diameters 1.5 mm and 3.5 mm, Specific Energy Consumption (SEC) was computed in the steady-state running of the mill when using the mathematical relationship as follows [11]:

$$\mathrm{SEC} = \frac{W}{Q}$$

Where W is the total electrical power consumption of the mill in kW, and Q is the specific capacity (throughput) in t. h^{-1}.

To determine the level of fineness and the granulometric structure of the ground samples, a laboratory sieve shaker was used to analyze the sample size following the protocols [3]. In order to calculate the geometric mean diameter, a stack of sieves with successively smaller openings was shaken during a specified period of time [12]. Mass left behind on each sieve was then measured with a lot of care to determine the standard deviation and the total milling assessment aspect [13].

Mathematical Modeling of Particle size

To determine the true characterization of the particle size distribution, Geometric Mean Diameter (dgw) and Geometric Standard Deviation (sgw) was calculated in each of the samples. The equations that were used in accordance with ASAE S319.4 standard (ANSI/ASAE, 2008), are the following:

$$dgw = \log^{-1}[\frac{\sum_{i=1}^{n}(Wi \log di^{-})}{\sum_{i=1}^{n} Wi}]$$

$$sgw = \log^{-1}[\sqrt{\frac{\sum_{i=1}^{n} Wi(\log di^{-} - \log dgw)^2}{\sum_{i=1}^{n} Wi}}]$$

Where:

Wi is mass of sample on sieve number *i* (g).

di is the geometric mean diameter of the adjacent sieves (mm).

n= the number of sieves and the pan.

The Milling Evaluation Factor (*MEF*) or the efficiency of the size reduction process in relation to the energy input was calculated with the relation between the specific capacity and the increase in the size of the particles area [5].:

$$MEF = \frac{Q \times \Delta A}{P}$$

Q is the productivity (kg. h^{-1}), ΔA the change in specific surface area (m ^{2}. Kg^{-1}) and P is the power consumption (kW).

Statistical Analysis

The experiment was a 2x3 factorial design of a Completely Randomized Design (CRD). These two were the type of grain (Wheat and Barley) and the diameter of the sieve holes (1.5, 2.5 and 3.5 mm). Mill experimentations were done three times to achieve reproducibility. The Analysis of Variance (ANOVA) was applied to data with the help of the SPSS (v. 26.0). To find out the effect of the interaction of the grain type and the sieve aperture, the separation was done using the Duncan Multiple Range Test which was conducted at the level of $P < 0.05$.

Raw Materials and Grains Properties.

The experimental trials were taken with the help of the local varieties of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) which were obtained in the Kirkuk region. The grains were also cleaned before the milling process to get rid of the foreign matter, broken kernels and dust. The physical properties that have a strong impact on the milling resistance and particle flow were measured and they are summarized in Table 1. [14].

Table 1. Physical Properties of Wheat and Barley Samples

Property	Wheat (Local Variety)	Barley (Local Variety)
Moisture Content (% w.b.)	11.4 ± 0.3	10.8 ± 0.5
Thousand-Kernel Weight (*g*)	42.15	38.40
Bulk Density (*kg*. m^{-3})	785.2	615.4
True Density (*kg*. m^{-3})	1340.5	1210.8

The amount of moisture was established through the method of oven-drying at 105 o C in 24 hours [15]. This was determined by Thousand-Kernel Weight (TKW) which was determined by counting and weighing 1,000 grains in five replicates with a high-precision digital balance (accuracy ±0.01 g).

Experimental Equipment

All grinding experiments were done in a multi-purpose agricultural hammer mill. A three-phase induction motor of 5.5 kW and a speed of 2850 rpm was used to drive the mill. The milling chamber had 12 hammers with high-carbon steel that were staggered so that there was total coverage of impact.

Three replaceable stainless steel sieves of diameter of circular holes of 1.5 mm, 2.5 mm and 3.5 mm were used. The overall effective screening area of every sieve was kept at 0.12 m^2 to make sure that the discharge capacity was a factor of the hole diameter and not overall screen surface.

Experimental Procedure

The constant feed rate of 500 kg.h^{-1} (nominal) was held by means of a gravity-fed hopper with a calibrated sliding gate to reduce the changes in motor load. In each of the runs, the mill was left to attain a steady-state velocity and then the grain was introduced.

1. **Energy Measurement:** To determine the motor's actual power consumption (P) in kW, a digital power analyser was connected to its leads.
2. **Sampling**: After the system was stable in each set of grain sieves, a 2 kg sample of the ground product was taken.
3. **Particle Distribution:** Over the course of ten minutes, the samples were analysed using a vibratory sieve shaker equipped with a stack of seven standard sieves (2.0 mm to 0.125 mm).

Data Calculation

The Specific Capacity (Sc) was determined by dividing the output obtained during a given time period within which the measurement was done [7], [8]:

$$\mathrm{Sc} = \frac{M}{t}$$

Where M is mass of the milled product (kg) and t is the time of collection (h). The Specific Energy Consumption (SEC) was calculated by dividing the average power demand and the specific capacity.

Results and Discussion

Table 2 shows that the effect of sieve aperture on mill performance and particle characteristics is progressive as shown by the increased data set.

Table 2. Influence of Grain Type and Sieve Hole Diameter on Performance

Grain Type	Sieve Hole Diameter (mm)	Specific Capacity (kg.h^{-1})	Specific Energy (kWh.t^{-1})	Geometric Mean Diameter (dgw) (mm)	Geometric Standard Deviation (sgw)	Milling Evaluation Factor*(MEF)*
Wheat	1.5	420.5	12.4	0.65	1.82	0.82
	2.5	565.2	9.6	0.92	1.95	0.74
	3.5	680.0	7.8	1.15	2.10	0.65
Barley	1.5	380.2	14.2	0.55	1.65	0.94
	2.5	495.8	11.4	0.81	1.78	0.86
	3.5	590.8	9.1	1.02	1.92	0.78

Effect of sieve hole diameter on specific capacity

Table 1 has shown that the diameter of sieve holes has remarkable effects on the throughput of the hammer mills. The bigger the apertures (3.5 mm) the greater the specific capacity is likely to be since it offers less resistance to particle escape out of the milling chamber. The correlation between increased productivity and the rate of material flow and reduction of the particle residence time in the grinding chamber is direct [16]. This is because bigger apertures make the material to be discharged faster and reduces the grinding resistance thus reducing the amount of energy per unit mass of processed grain [3]. Consequently, the particles which become sufficiently small to fit into the aperture of the sieve will be less likely to be carried out of the grinding chamber, which will decrease the amount of energy needed to ground a unit of ground material [17].

Specifically, it has been found in the previous studies that increasing the diameter of the screen hole significantly increases the throughput and reduces the specific energy consumption [4]. This tendency is also proven by our data, as a certain increase of the capacity by more than 60 % in the case of wheat and by 55 % in the case of barley was observed when the sieve hole was increased to 3.5 mm in height. In contrast, a smaller sieve hole diameter needs more intensive grinding that increases the required particle size and reduces the throughput [3], [4]. This makes the energy input per unit mass of individual masses to be higher due to the length of time taken in the grinding process and the number of repetitive impacts taken to allow particles to go through the smaller apertures.

Impact of type of grain on performance and energy consumption

The physical and structural variations between wheat and barley were a great determinant of the effectiveness of the milling process. The specific capacities and specific energy consumption of wheat were also more abundant in both sieve sizes and constant than those of barley [18], [19]. Nevertheless, barley always had a better milling evaluation factor and a smaller particle specificity. As in the case of the 1.5 mm sieve, barley had higher milling evaluation factor of 0.94 than that of wheat of 0.82 which highlights that although wheat maximizes the throughput, barley is more suited in maximizing the uniformity of the particles in case fine grinding is needed [18].

Interaction of Aperture and Type of Grains

The data shows that the specific capacity does not increase linearly with the increase in the sieve diameter. In the case of wheat, a 1.5 mm sieve was used, and the capacity ranged from 1.5 to 2.5 mm had a 34.4% gain as compared to the 2.5 to 3.5 mm increase of capacity [18], [20]. This indicates some threshold, which is known as diminishing returns, and where the internal feed rate or the speed of the hammer tip takes the place of the sieve discharge area as the main limiting case.

The Specific Energy Consumption (*SEC*) of barley was always high compared to wheat irrespective of the sieve size [21], [22], [23]. This is because the barley hull is fibrous, and thus it takes a high shear and impacts to achieve the discharge size. Nonetheless, the resistance generates a more consistent size distribution of particles since the Geometric Standard Deviation (*sgw*) values of barley (1.65 -1.92) are lower than wheat (1.82 -2.10) [18].

The Paradox of Milling Evaluation Factor (*MEF*)

Specific capacity had an inverse relationship with the MEF. The sieve with 3.5 mm maximized the throughput, but gave the lowest *MEF* values (0.65 of wheat). This shows that the mill is working with less intensity of milling per unit of energy and therefore the particles are coarser with lower specific surface area even though it is working with more material. On the other hand, the sieve that was used with barley and had 1.5 mm sieve had an *MEF* of 0.94, the highest in the experiment. This illustrates the fact that where the applications need a high-quality feed that has fine-grind to achieve better nutrient uptake, the energy penalty of smaller sieves is compensated by the high technical efficiency of the size reduction [18], [21].

After the statistical research, the dependence between the density of the grain and the sieve aperture became more evident. The lower specific capacity of barley than wheat is due to its lower bulk density (615.4 kg. m^{-3}) than that of wheat (785.2 kg. m^{-3}): when the mass-based feed rate is the same, the mill chamber will fill with barley more rapidly than with wheat [21].

What is more, the more fiber content habitually as a result of the barley pericarp resulted in a higher proportion of the oversize particles in the event of 3.5 mm sieve. This implies that 3.5 mm is effective in wheat, but might cause too much variation in the particle size in barley, and this might adversely affect the nutritional value of the product to younger livestock who need more consistent feed [19].

Practical Implications Discussion

The experimental findings provide a good guide to the optimization of the operations of hammer mills in accordance with certain production objectives. Facility managers could achieve a lot in terms of cutting down on the operational overhead by knowing the trade-offs between the sieve aperture and the type of grain.

Cost Reduction Strategy on Energy

One of the variable costs that are still high in feed production is energy consumption. The statistics show that about 37 % of the specific energy can be saved when the 1.5 mm of wheat sieve is changed to 3.5 mm (12.4 kWh .t^{-1} to 7.8 kWh .t^{-1}). This transition in the case of high-volume facilities which process 1,000 tons per month is a savings of 4,600 kWh. The managers are advised to give preference to larger sizes of the sieve of maintenance diets or older animals in which extremely fine particle sizes are not a biological need.

Optimality of Throughput of Wheat vs. Barley

Since the specific capacity (680.0 kg.h^{-1} at 3.5 mm) of wheat is much higher than that of barley (590.8 kg.h^{-1} at the same setting), the production schedules have to be changed in case of the grain switch [18], [20]. The tonnage of barley obtained takes about 15 % longer time to reach as compared to wheat. In order to sustain the constant flow of the factory it is suggested that a slight increase in the feed rate should be applied or sharper hammers should be used when handling barley in order to offset the hull resistance.

Nutritional Value and Quality Control

Although the 3.5 mm sieve has the highest economic efficiency, it gives a coarser end product (*dgw* of 1.15 mm in the case of wheat). In the case of poultry, where the fine particles are needed to ensure the best accessibility and digestion of enzymes, the sieves of 1.5 mm or 2.5 mm are more suitable [1], [2]. The barley Milling Evaluation Factor (*MEF*) of 0.94 at 1.5 mm confirms that the mill is performing at the maximum technical efficiency to reduce the size at this setup and is therefore the best to use in the preparation of the feed even though it uses more electricity.

Conclusion

The outcome of the experiment indicates that there are complicated interactions between grain type and sieve hole diameter and the specific energy consumption, specific capacity and the particle size distribution of the hammer mill. To deliver positive outcomes in order to enhance feed quality and milling activity, the given final section will combine the results concerning the dependence between mechanical parameters (sieve hole diameter and the speed of the hammer tip) and material properties [17]. With these parameters accurately adjusted to the specifics of the grain and target particle properties, the best milling conditions will be achieved, leading to the maximum nutritional value of the feed, as well as the maximum economic efficiency of feed production.

This broad understanding is critical to the development of advanced grinding processes that will meet the high-quality standards, as well as to assist in economic and sustainable agricultural practices [20], [24]. Specifically, the present research focuses on the relevance of variation in grain type and sieve hole diameter to significantly influence the outcome of the milling processes, which implies that different materials should be milled using different approaches. The results show that the use of 3.5 mm sieve holes and wheat would result in maximum specific capacity, and the use of 1.5 mm sieve holes and barley would result in maximum milling evaluation factor. Indeed, similar studies indicate that the control of machine parameters such as drum speed has a significant effect on increasing the particle size distribution of individual fraction with respect to a variety of concave hole diameters, such as the processing of different agricultural stalks [25]. Finally, the optimum milling conditions would all be determined by the required output properties of the particular livestock feed [1].

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