IMPROVING EFFICIENCY OF GRAIN COMPONENT PREPARATION FOR CATTLE FEEDING

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Abstract. This article addresses the efficiency of preparing cattle feed mixtures, specifically the high-quality grinding of concentrated feeds with minimal dust. To this end, the grinding of grain components using hammer and roller mills was compared. We determined that when grinding grain components using a hammer mill, the amount of dust fraction increases by approximately 5-70% compared to a roller mill; in addition, the roller mill produces a more uniform composition of ground products - at a target grinding modulus of 2.0 mm, the amount of the 0.0-1.0 mm fraction is significantly lower than that of the 1.0-2.0 mm fraction. Grinding raw grain materials in hammer mills increases the mass of the flour-like fraction, and this can be reduced by adjusting the mill or increasing the grain moisture content. The study also showed that when grinding grain components at an ambient humidity of 94-96%, the ground material moisture content increased to 15.6%, compared with the raw material 15.2%. An experiment on mixing ground products with silage showed that the dust fraction adheres to the moist parts and practically does not participate in further mixing; however, the distribution uniformity reaches 85-90%. When mixed, the products ground by a roller mill have a more uniform distribution – 90-92%. Therefore, a roller mill is the preferred choice for grinding grain components used in cattle feed, as it delivers a higher-quality product and lower energy consumption (approximately 60% per ton).

Keywords: grinding, roller mill, hammer mill, fine fraction, feed preparation efficiency.

Introduction

The issue of feed mixture preparation efficiency for cattle remains relevant today, as grinding concentrated feeds to a specific particle size with minimal fine particles results in lower energy consumption and improved mixing uniformity. Therefore, the rational selection of a grain grinder is of great importance.

During the preparation of concentrated feeds (grains) for feeding, various grinding processes are used: flattening, grinding, and crushing. Each has its own advantages and disadvantages; however, the selection of equipment for this process must be based on criteria of quality and efficiency in producing the final product [1].

Hammer mills are versatile impact-type machines featuring high-speed working components that grind feed materials, including grain, mineral supplements, biomass, and processed industry waste. These machines operate on the principle of impact crushing and grinding, with some chipping. Significant particle grinding due to friction between the screen, deck, and side walls of the crushing chamber, as well as between particles themselves, leads to over-grinding and energy waste. The design advantages of hammer mills (versatility in grinding all types of feed, the ability to adjust the degree of grinding within relatively wide limits, the simplicity of drive from high-speed motors, etc.) have contributed to their widespread use across various industries. However, these grinders have significant drawbacks. The most significant of these is the high degree of particle-size distribution unevenness in the crushed products, which ultimately leads to excessive grain consumption. The particle sizes of the crushed products range from 0.001 to 5.0 mm [2-4].

Such a wide range (a high proportion of fine and coarse fractions) [5] creates problems during mixing and leads to irreversible losses of the powdery fraction of the ground particles. Hammer mills are generally more energy-intensive than other types of mills when achieving the same particle size [6]. This is also related to design features (hammer dimensions, rotor rotation speed, component wear) that significantly affect grinding efficiency [7]. Acar et al. [8] compared the yields of high-fiber fractions (HFF) obtained from two grinding methods of whole-grain Yalin barley. The HFF yield in the roller mill was 55.2 and 56.2 g per 100 g, while in the hammer mill it was 43.7 and 45.9 g per 100 g. The study [9] aimed to determine the effect of barley and wheat grinding methods on the total digestibility in the animal digestive tract, barley-soybean and wheat-soybean meal, nitrogen balance, and pig productivity. It was noted that coarse grinding increased the consumption of barley-based feed. The research [10] comparing the particle size characteristics of corn processed in a hammer mill with those processed in a roller mill found that the geometric mean particle size of corn processed in a roller mill ranged from 1.343 to 1.501 μm, while that of corn processed in a hammer mill ranged from 814 to 873 μm. These tests showed that the different particle size characteristics of feed processed on a hammer mill and a roller mill do not significantly affect the productivity of commercial laying hens, as measured by body weight, daily egg production rate, egg weight, average daily feed intake, eggshell strength, or mortality.

Roller mills are machines used for crushing grain and other dry, brittle materials. During operation, the grain is broken down primarily through shearing (cutting) combined with compression. A significant advantage of these machines is the high uniformity of the ground products. Due to the absence of a grinding factor in the process, the dust fraction output is minimized. Roller mills effectively process dry grain that does not exhibit high visco-plastic properties. In terms of design, roller mills differ in the number of roller pairs – single or double pairs, multi-roller (three or more rollers); there are also single-roller units in which a deck is installed instead of the second roller [4; 11].

These grinders are used where a uniform particle size distribution is required, particularly in feed and food production. Particle size control is achieved by precisely adjusting the gap between the rollers, allowing for variations from 0.1 mm for fine grinding [12] up to the specified maximum values.

Roller mills consistently produce more uniform particle sizes, with standard deviations 15-25% lower than those of impact-type machines. This advantage stems from the directed application of compressive forces, which minimizes the losses due to ventilation and turbulence characteristic of hammer mills.

Heat loss is another significant difference. Hammer mills increase product temperature by 30-50 °C, whereas roller mills are limited to 10-20 °C. Such heating can either degrade or improve the nutritional value of feed products depending on the type of feed [13; 14] and can affect the physical properties of heat-sensitive materials [15]. Furthermore, lower heat generation during grinding also means less moisture loss from the product and better preservation of feed quality.

Given the need to identify the most effective (rational) choice of the method and processing equipment for preparing grain components for cattle, the aim of our study is to carry out a comparative evaluation of the grinding efficiency of the most common grain feed components (wheat, barley, and corn) using hammer and roller mills. This evaluation is based on indicators such as particle size distribution, dust content, uniformity of distribution in the feed mixture, and specific electricity consumption under the conditions of a dairy-commercial farm.

To achieve the stated goal, the following objectives were formulated: to determine the particle size distributions and fineness moduli of wheat, barley, and corn after grinding with hammer and roller mills, using a target particle size of 2 mm; to determine the quantitative losses of the dust fraction during the operation of each type of grinder and to assess the effect of increased ambient humidity on the moisture content of the ground material; to evaluate the uniformity of the distribution of ground grain components in the feed mixture with silage depending on the type of grinder used; to measure the specific energy consumption required to grind a unit mass of grain raw material for each type of mill and each crop under study; and, based on the data obtained, to justify recommendations for selecting the most suitable type of grain mill for feeding cattle on a dairy farm.

Materials and methods

The study was conducted under production conditions on a dairy farm during the preparation of concentrated grain components (wheat, barley, and corn) and loose feed mixtures, which, in addition to grains, included hay, silage, and protein-mineral-vitamin supplements. To grind the grain components, an MKU-1 hammer mill and an Engi DV.350-22 roller mill were used, both set to an average particle size of 2 mm (in the hammer mill, this corresponds to a 4-mm-diameter screen, and in the roller mill, to a 2-mm gap between the rollers).

The degree of grinding of the processed grain components was assessed using a sieve classifier, which allows determining the grinding modulus of the fraction (by standard ASAE S319.2). To calculate the grinding modulus *M*, the method of determining the weighted average particle size of the ground grain was used according to the formula:

$$M = \frac{0.125P_0 + 0.325P_{0.25} + 0.95P_{0.4} + 1.75P_{1.5} + 2.5P_2 + 3.5P_3}{N}, \quad (1)$$

where 0.125, 0.325, 0.95, 1.75, 2.5, and 3.5 – coefficients characterizing the average fraction sizes at the bottom of the box and on the corresponding classifier screens, in mm; it is defined as the average of the sizes of the screen apertures above and below the corresponding product fraction.
P_0, $P_{0.25}$, $P_{0.4}$, $P_{1.5}$, P_2, P_3 – masses of residues at the bottom of the box and fractions on screens with apertures of 0, 0.25, 0.4, 1.5, 2, 3 mm, g.
N – total mass of the sample (weighing), g.

Joanlab JNB100001 laboratory electronic balances were used to determine the mass of residues and the sample weight. The moisture content of feed components before and after grinding was determined using Wile 78 and METRINCO M130G moisture meters, a household hygrometer-thermometer, and meteorological data from sinoptik.ua.

To determine the amount of dust-like over-ground material released from the machine during operation, a uniform clear floor area S was defined around the machine, from which all dust particles m were carefully collected after the grinder was stopped and the particles had settled on the floor. The percentage of losses, R, was then calculated based on the amount of processed material, G, and the total area, F, of the room where the grinding took place

$$R = \frac{m \cdot F}{s \cdot G} 100\% \cdot \tag{2}$$

During the preparation of feed mixtures according to the established ration, experiments were conducted involving the addition of components ground in a hammer mill and a roller mill, respectively, followed by an organoleptic (visual) assessment of the mixture's quality after mixing was complete. The particle distribution in the feed mixture was considered, and the uniformity of large particles (greater than 1 mm) was determined using standard methods [1; 16].

To determine the energy consumption for feed grinding, an experimental wattmeter and an energy consumption meter based on TAC7321C were used. The specific energy consumption Y for grinding a unit of feed was determined using the formula:

$$Y = \frac{E}{G}, \tag{3}$$

where E – amount of energy consumed, kWh;
G – amount of ground feed, kg.

All measurements were performed in triplicate ($n = 3$). The results are presented as the mean ± standard error of the mean ($M \pm SEM$). Given the applied nature of the study and the limited number of replicates, formal hypothesis testing was not performed; differences between the types of mills are discussed in terms of their practical significance under production conditions.

Results and discussion

During the studies, samples of grain components crushed in hammer and roller mills (Fig. 1) were selected, and their particle size distribution, grinding modulus M, standard deviation σ, and coefficient of variation ν were determined, as presented in Table 1.

Fig. 1. **Appearance of crushed wheat produced by roller and hammer mills**

An analysis of the data shows that the weighted-average particle size (grind size) of feed processed in a hammer mill is significantly smaller than the target value of 2 mm. This is due to the high proportion of fine particles produced by over-grinding (repeated impact), particularly in the case of corn. Fine particles in cattle feed are a negative factor, as they lead to intense digestion, digestive disorders, and, in some cases, deterioration of rumen health, resulting in a significant reduction in productivity. Adjusting the particle size distribution to reduce fine particle content is possible by changing settings such as the number and arrangement of hammers, the hammer rotor rotational speed, or the moisture content of the feedstock, but this requires further research.

Table 1

Grinding quality results for hammer and roller mills

Sieve aperture, mm	**Residue weight on sieve, g**								
	barley 15.3%			**wheat 15.2%**			**corn 15.5%**		
	hammer	**roll**	**SEM**	**hammer**	**roll**	**SEM**	**hammer**	**roll**	**SEM**
3.00	4.93	4.2	–	4.04	4.35	–	3.51	11.01	–
2.00	25.24	62.09	–	17.78	58.36	–	12.41	50.35	–
1.50	18.48	11.65	–	15.47	13.2	–	12.46	12.03	–
0.40	28.95	9.78	–	38.77	11.01	–	35.74	10.95	–
0.25	14.22	8.02	–	18.53	8.48	–	19	11.29	–
0.00	7.74	3.98	–	4.52	4.44	–	16.58	4.15	–
Total weight, g	99.56	99.72	–	99.11	99.84	–	99.70	99.78	–
M, mm	1.464	2.033	± 0.244	1.306	1.983	± 0.225	1.076	2.005	± 0.241
σ, mm	0.423	0.382	± 0.220	0.389	0.392	± 0.226	0.394	0.439	± 0.228
N	28.877	18.806	± 15.04	29.718	19.767	± 17.17	36.684	21.929	± 21.18
Mass of particulate matter, g	7.82	3.98	± 0.99	4.52	4.44	± 1.05	16.58	4.15	± 1.47

Roller mills yield better results – the weighted average particle size is close to the target value of 2 mm, but a significant proportion of particles are slightly larger than 2 mm, which is explained by the elastic properties of the raw material during crushing. At the same time, the content of the dust fraction in the material crushed by a roller mill is 5-70% lower than that of a hammer mill.

Given the intense airflow and the impact of the hammers on the material being processed, we observed the release of a dust-like fraction that is blown out of the machine by the airflow – material that the filter does not capture – as well as through gaps in the mill's housing and feed chute. To assess product losses, we determined the amount of residue that settled on the surface near the hammer mill; this ranged from 0.0015% to 0.015% of the processed product (the highest was from corn). Losses near the roller mill were negligible and fell below the measurement error margin of 0.0001%.

During the grinding of grain components in the hammer mill, which took place at ambient air humidity levels of 94-96%, it was found that the moisture content of the grain entering the processing increased from an initial 15.2% to 15.6% after grinding (Fig. 2). This is due to the specific operation of the hammer mill – since the grain actively interacts with the humid air, which transfers its moisture to the crushed components.

a) b) c)

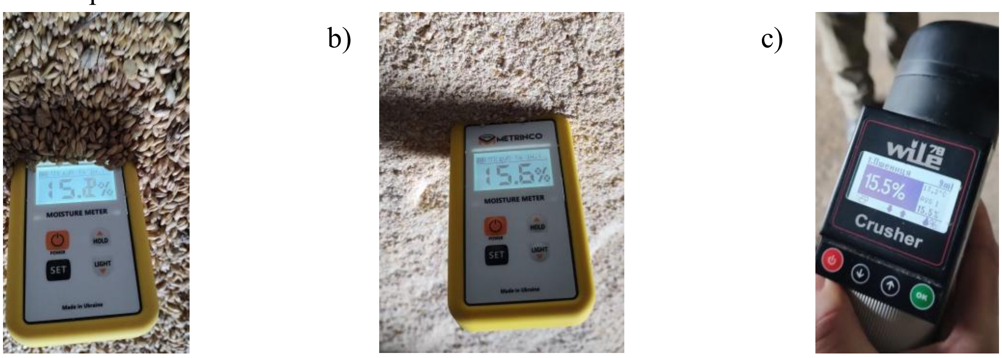

Fig. 2. **Measurement of wheat grain moisture content before (a) and after (b) grinding, and additional control (c)**

In the experiment mixing the crushed products with silage, it was found that the dust-like fraction adheres to the moist parts of the silage and practically does not participate in further mixing, while the larger particles are distributed throughout the feed volume (Fig. 3). For components ground by a hammer mill, the uniformity of distribution is 85-90%. Products ground by a roller mill have a more uniform distribution in the mixture, at 90-92%.

a)  b) 

Fig. 3. **Distribution of ground particles on silage sheets (a) and in the feed mixture (b)**

Electricity consumption for feed grinding is one of the key indicators [1; 2; 12; 19; 20] used to assess grinding efficiency. Therefore, we measured the power and amount of electricity consumed when grinding equal quantities of different feed components. Since the energy intensity of the process depends on many factors, such as grain type and moisture content, degree of grinding, mill loading mode, and others, we attempted to select the most similar (identical) values for these factors when measuring energy consumption. The processed data are presented in Table 2.

Table 2

Results of energy consumption during grinding in hammer and roller mills

Parameter	barley 15.3%			wheat 15.2%			corn 15.5%		
	hammer	Roll	SEM	hammer	roll	SEM	hammer	roll	SEM
Average power, kW	9.20	4.00	± 0.53	9.00	3.90	± 0.52	9.70	4.30	± 0.50
Specific energy consumption, $kJ \cdot kg^{-1}$	44.43	18.43	± 2.25	35.52	14.27	± 1.98	40.09	16.28	± 2.40

Barley and corn require slightly more energy than wheat due to their harder husks and the structural characteristics of the grain. A moisture content of about 15% is optimal for grinding: at higher moisture levels, the grain becomes pliable and harder to break down; at lower levels, it becomes brittle, but equipment wear increases. Given that grinding grain components for cattle feed requires coarse grinding with a minimal amount of dust, it is preferable to use a roller mill on cattle farms, as the output material has a higher grinding quality, is distributed more evenly in the mixture, and requires 60% less energy consumption per ton of product. In energy-saving technologies, roller mills are more efficient than hammer mills, a finding consistent with comparative studies by other researchers [3; 8; 20].

Conclusions

1. The Engi DV.350-22 roller mill produces a grind size close to the target value of 2 mm (1.98-2.03 mm), with a lower coefficient of variation in particle size distribution (18.8-21.9%), whereas the MKU-1 hammer mill systematically over-grinds the grain (1.08-1.46 mm, coefficient of variation 28.9-36.7%). The dust fraction content in hammer mill grinding exceeds that of roller mill grinding by 5-70%, and increased air humidity (94-96%) further raises the moisture content of the ground material from 15.2% to 15.6%.
2. The uniformity of grain component distribution in the feed mixture with silage when using a roller mill is 90-92% compared to 85-90% for a hammer mill, since the dust fraction of the latter adheres to the moist parts of the silage and does not participate in mixing. The specific energy consumption of the roller mill is ~60% lower for all crops studied (14.27-18.43 $kJ \cdot kg^{-1}$ versus 35.52-44.43 $kJ \cdot kg^{-1}$). Based on overall performance indicators for preparing grain feed for cattle, the use of a roller mill is recommended.

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