Influence of grinding method and grinding intensity of corn on mill energy consumption and pellet quality

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Abstract

In recent years there is an emerging trend of coarse grinding of cereals in production of poultry feed due to the positive influence of coarse particles on poultry digestive system. Influence of grinding method (hammer mill *vs.* roller mill) and grinding intensity of corn (coarseness of grinding) on mill specific energy consumption and pellet quality was investigated. By decreasing grinding intensity of corn (coarser grinding), specific energy consumption of both hammer mill and roller mill was significantly decreased ($p < 0.05$). When comparing similar grinding intensities on hammer mill and roller mill (similar geometric mean diameter or similar particle size distribution), specific energy consumption was higher for the hammer mill. Pellet quality decreased with coarser grinding on hammer mill but, however, this effect was not observed for the roller mill. Generally, pellet quality was better when roller mill was used. It can be concluded that significant energy savings could be achieved by coarser grinding of corn before pelleting and by using roller mill instead of hammer mill. From the aspect of pellet quality, if coarser grinding is applied it is better to use roller mill, concerning that more uniform particle size distribution of corn ground on roller mill probably results in more uniform particle size distribution in pellets and this provides better pellet quality.

Keywords: grinding, energy consumption, pellet quality, poultry, corn.

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Dominating principle in poultry breeding is to use complete mixtures (diets) in pelleted form [1] because it has been shown that pelleting (compared to using diets in mash form) increases feed intake [2], reduces feed wastage [3], prevents birds from selecting larger particles [4], prevents segregation of diet components [5], etc. The first step in production of pelleted poultry feed is grinding of diet ingredients. Grinding is most commonly done by hammer mills while roller mills are not widely used in animal feed production even though they grind with lower energy consumption [6], give less dust during grinding and are less noisy [7]. Hammer mills (HM) produce some large and many small particles, and roller mills (RM) produce more uniform particle size distribution (PSD) [6,8]. Higher cost for purchase and maintenance are the major disadvantage of roller mills [7].

Although fine grinding was considered as a key for achieving proper feed utilization in poultry digestive system [9], there is a lot of literature that emphasizes the importance of coarse particles in poultry diets [1]. Coarse particles stimulate development of gizzard, and well developed gizzard improves energy utilization and nutrient digestibility [10] and decreases pH value of digested material [11] lowering the risk of coccidiosis [12] and feed-borne pathogens [2]. Thus, coarser grinding of cereals, as the main component of poultry diets, should be applied. Additionally, coarser grinding will save energy and time in the grinding process.

On the other hand, it is well known that pelleting reduces size of micro-particles that constitute the pellets [4], but it is expected that coarser grinding before pelleting will increase the share of coarse particles in pellets to a certain extent which will enhance gizzard development. Problem with coarse grinding of cereals is the influence on pellet quality. Physical quality of pellets is important from the aspect of transport and handling, where certain resistance to abrasion is required, but also from the aspect of nutritional quality, *i.e.*, higher feed intake and, perhaps, improved nutritional value of good quality pellets [13–15]. Even though dominating belief is that pellet quality decreases with coarser grinding [16], Reece *et al*. [17] determined that coarseness of grinding has no effect on pellet quality. Thus, results about influence of grinding intensity on pellet quality are contradictory.

The aim of this research was to determine the influence of mill type (hammer mill vs. roller mill, *i.e.*, wide *vs.* narrow distribution of particle size) and

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coarseness of grinding on mill energy consumption and pellet quality.

MATERIAL AND METHODS

Experiments were conducted at pilot-plant facility of Institute of Food Technology (University of Novi Sad, Serbia). Dent corn obtained from local company (Agrobačka a.d., Bačka Topola, Serbia) was ground using hammer mill (ABC Engineering, Pančevo, Serbia) and roller mill (ROSKAMP TP650-9, California pellet mill, USA). Hammer mill had 16 hammers arranged in four rows and it was driven by 2.2 kW motor with rotational speed of hammers of 2880 rpm. By using hammer mill equipped with sieve openings diameter of 3, 6 and 9 mm, three different coarseness of corn were obtained: fine (treatment HM-F), medium (HM-M) and coarse (HM-C), respectively. Roller mill had three pairs of rollers with 1.8–5.5 corrugations per cm and differential speed of 1:1.5 for each pair of rollers. The upper pair was driven by a 5.5 kW motor and two lower pairs by an 11 kW motor. Gap between two higher pairs of rollers was fixed at 4.4 and 2.6 mm for all grinding treatments while gap between lower pair of rollers was set to 1.4, 2.0 and 2.6 mm for obtaining three different coarseness, i.e. medium (RM-M), coarse (RM-C) and very coarse (RM-VC), respectively.

Specific energy consumption (kWh/t) of hammer mill and roller mill was measured according to equation (1) described by Payne *et al*. [18]:

$$\text{Specific energy consumption} = \frac{\sqrt{3}\left(I - I_0\right)U\cos\varphi}{1000}\frac{1}{Q} \qquad (1)$$

In Eq. (1), I (A) and I_0 (A) are average hammer mill or roller mill motor amperage with and without material, respectively, U (V) is the voltage, $\cos\varphi$ is the power factor (ratio between the actual load power and the apparent load power drawn by an electrical load) and Q (kg/h) is the throughput of material.

Moisture content of ground corn was adjusted to 16% by the addition of water in the double shaft pedal mixer (SLHSJ0.2 Muyang, China) and corn was pelleted using flat pellet press (14-175, Amandus Kahl, Germany) with 6 mm diameter of die openings and 24 mm thickness, while throughput of material was 20 kg/h.

PSD of ground corn was determined according to ISO 1591-1 1988 (E) using sieve shaker (Endecotts, UK) with the following size of sieve openings: 5600, 4000, 3150, 2000, 1600, 1000, 630, 250 and 125 µm. Geometric mean diameter (*GMD*) and geometric standard deviation (*GSD*) were determined according to A.S.A.E. standard [19] using the Eqs. (2)–(4):

$$GMD = \log^{-1}\frac{\sum_{i=1}^{n} W_i \log d_i'}{\sum_{i=1}^{n} W_i} \qquad (2)$$

$$d_i' = \sqrt{d_i + d_{i+1}} \qquad (3)$$

$$GSD = \log^{-1}\frac{\sum_{i=1}^{n}(\log d_i' - \log GMD)}{\sum_{i=1}^{n} W_i} \qquad (4)$$

where d_i (µm) is the size of sieve openings of i^{th} sieve and W_i (g) is the mass on i^{th} sieve.

Pellet quality was measured using Holmen pellet tester (NHP 100, Norfolk, UK) and expressed as pellet durability index (*PDI*) which is calculated as the ratio of mass of pellets after the test and the mass of pellets before the analyses. Duration of treatment was 30 s and pellets were sieved before and after the treatment using a sieve with 4.8 mm size of sieve openings (sieve opening diameter = 0.8×pellet diameter).

One-way analysis of variance (ANOVA), applying Tukey HSD test, was used for comparison of sample means to analyze variations of the results (statistical software Statistica 12). Differences between the means with probability $p < 0.05$ were accepted as statistically significant.

RESULTS AND DISCUSSION

In production of pelleted poultry diets, cereals, as the main components, are usually finely ground using 3 to 4.5 mm hammer mill sieve openings diameter [9]. Thus, HM-F treatment represented grinding that is usually performed in practice. In other treatments of this study, coarseness of grinding was increased, with extreme coarseness for RM-VC treatment. Obtained *GMD*s and *GSD*s for different grinding treatments of corn are presented in Table 1. As it can be seen, wide range of GMDs was achieved, and *GSD*s were different for different mill type (hammer *vs*. roller mill), while for grinding treatments within the same mill, values were similar. According to A.S.A.E. [19], when *GSD* is equal to 1 all particles are exactly the same, and *GSD* around 3 or more indicates a lot of variation in particle size. This implies that for roller mill produced more uniform PSDs.

For RM-M and RM-C grinding treatments the distance between lower pair of rollers was selected in order to reflect 6 and 9 mm hammer mill grinding, *i.e.*, to obtain similar *GMD* between HM-M and RM-M, and between HM-C and RM-C (Table 1). These pairs of treatments were defined (according to *GMD*) to have similar grinding intensity. However, it can be seen that PSD of RM-M grinding treatment is more similar to PSD of HM-F treatment (Figure 1a) than to HM-M (Figure 1b). Likewise, PSD of RM-C was more similar to PSD of

HM-M treatment (Figure 1c) than to HM-C (Figure 1d), especially when looking at coarser fractions (> 2500 µm), while PSD of HM-C treatment was similar to RM-VC (Figure 1e).

Table 1. Geometric mean diameters (GMD) and geometric standard deviations (GSD) obtained with different mill type (hammer mill (HM) or roller mill (RM)) and different grinding intensity (fine (F), medium (M), coarse (C) and very coarse (VC))

Grinding treatment	*GMD* / µm	*GSD* / µm
HM-F	671	2.66
HM-M	1144	2.82
RM-M	1119	2.17
HM-C	1581	2.69
RM-C	1542	2.27
RM-VC	2108	2.09

Noticeably higher specific energy consumption for grinding was obtained for HM-F treatment comparing to other treatments (Figure 2). When comparing pairs of treatments with similar *GMD* obtained with hammer mill and roller mill (HM-M *vs*. RM-M and HM-C *vs*. RM-C), it can be seen that specific energy consumption was significantly higher ($p < 0.001$) when hammer mill was used. This suggests that significant energy savings in grinding process could be achieved by using roller mill instead of hammer mill in order to obtain similar *GMD*; specific energy consumption would be 39% lower with RM-M grinding treatment comparing to HM-M treatment and 46% lower if HM-C treatment is substituted by RM-C treatment. Possibilities for saving the energy with roller mill are even more pronounced if grinding with hammer mill is substituted by roller mill grinding that produce similar PSD. In this way if HM-F grinding treatment is substituted by RM-M, specific energy consumption would be 82% lower. If HM-M grinding treatment is substituted by RM-C specific energy consumption would be 66% lower, and by substituting HM-C with RM-VC, 54% of energy necessary for grinding would be saved.

Expected decrease of pellet quality (expressed as *PDI*) with coarser grinding was observed for corn ground using hammer mill (Figure 3). Surprisingly, this was not observed with roller mill where obtained *PDI* values for different grinding intensities were not significantly different between each other (even for very coarsely ground corn (RM-VC)). Generally, pellet quality was better (higher *PDI*) when roller mill was used compared to hammer mill. Only for the treatment HM-F, obtained pellet quality was not significantly different from RM treatments, yet it was slightly lower.

Possible reason for lower *PDI* values of pellets produced with corn ground on hammer mill could be wider distribution of particle size which results in more inhomogeneities in pellet structure, especially presence of higher quantity of coarse particles in pellet structure. Pellets are particularly sensitive near the points of inhomogeneities in their structure due to local stresses and strains are the highest near such imperfections [20].

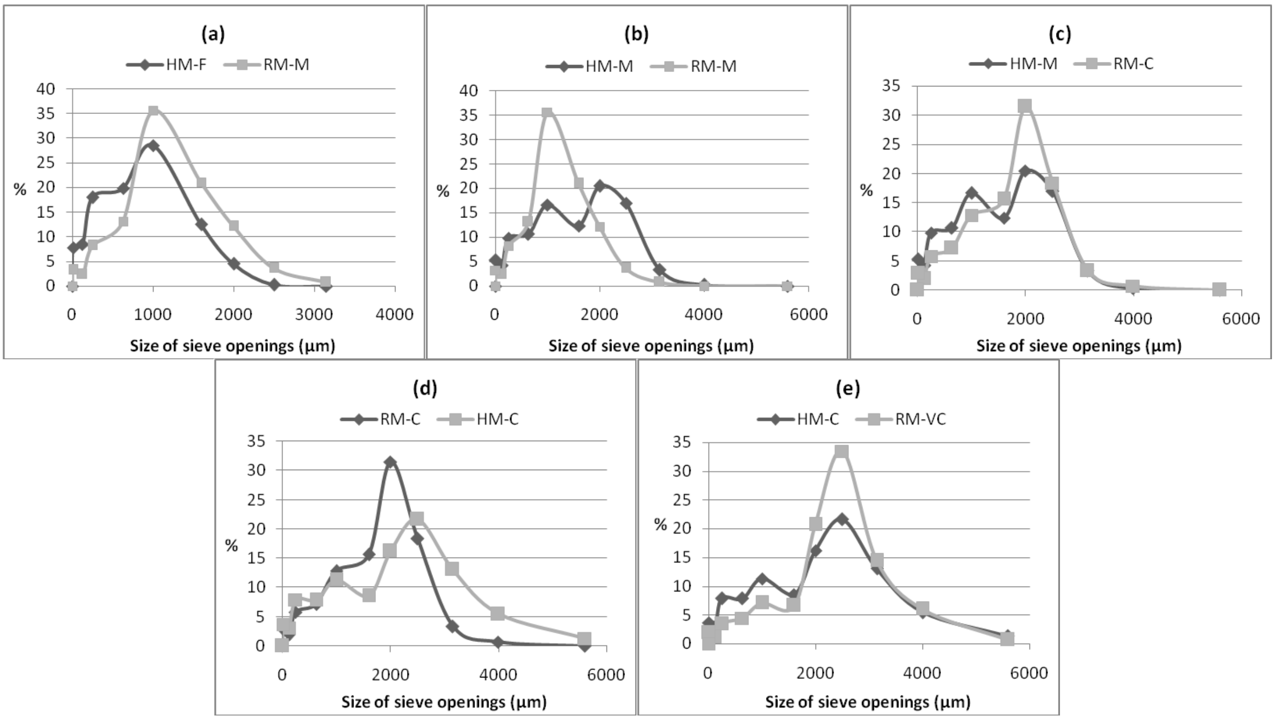

Figure 1. Comparison of particle size distributions for different grinding treatments (different mill type (hammer mill (HM) or roller mill (RM)) and different grinding intensity (fine (F), medium (M), coarse (C) and very coarse (VC)).

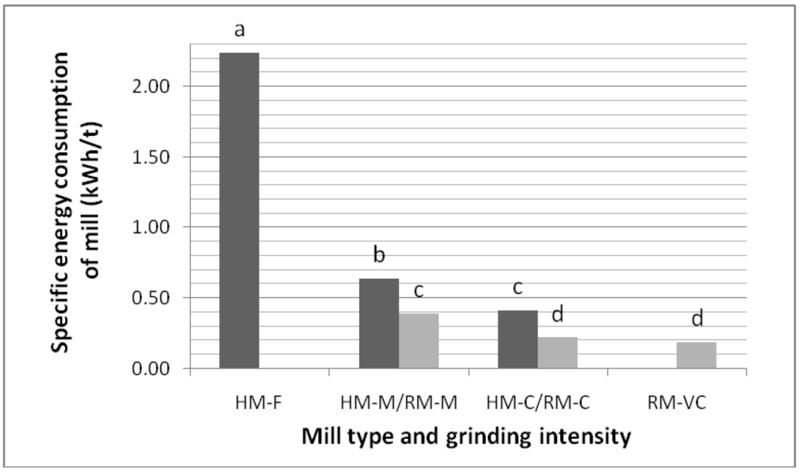

Figure 2. Influence of mill type (hammer mill (HM) or roller mill (RM)) and grinding intensity (fine (F), medium (M), coarse (C) and very coarse (VC)) on specific energy consumption of mill. Values with different letters are significantly different (p < 0.05).

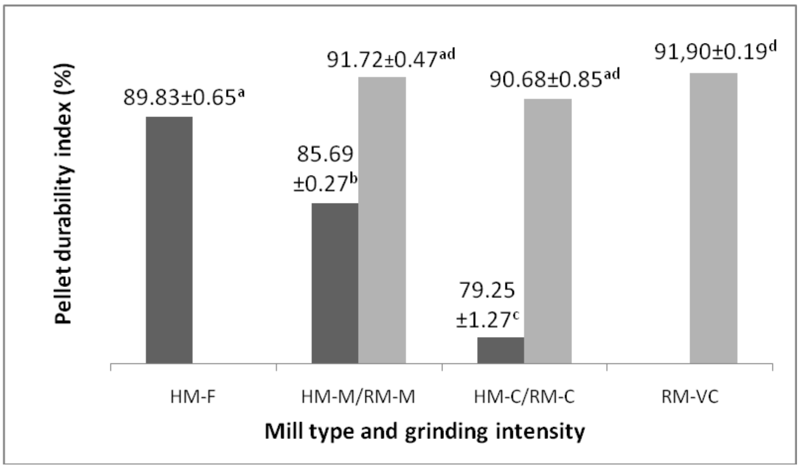

Figure 3. Influence of mill type (hammer mill (HM) or roller mill (RM)) and grinding intensity (fine (F), medium (M), coarse (C) and very coarse (VC)) on pellet durability index. Values with different letters are significantly different (p < 0.05).

Corn ground on roller mill had more uniform PSD and it can be assumed that this resulted in more uniform PSD in pellets, compared to pellets made of hammer milled corn. More uniform PSD of particles that made up the pellets contributed to better quality of pellets produced from material ground on roller mill.

CONCLUSIONS

From the obtained results it can be concluded that high energy savings could be achieved by coarser grinding of corn before pelleting. However, if coarser grinding is applied, it is better to use roller mill than hammer mill. Besides lower energy consumption for achieving the same *GMD* and especially for achieving similar PSD, quality of pellets will also be better when using roller mill instead of hammer mill. This is probably because more uniform PSD after roller mill results in more uniform PSD in pellets and this provides better pellet quality. In further research it is necessary to determine PSD in pelleted material and the amount of gelatinized starch in order to determine the reason for better quality of pellets produced with roller milled corn.

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IZVOD

UTICAJ NAČINA I INTENZITETA MLEVENJA KUKURUZA NA POTROŠNJU ENERGIJE MLINA I KVALITET DOBIJENIH PELETA

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Kod uzgoja živine se uglavnom primenjuje peletirana hrana, a prvi korak u proizvodnji peletirane hrane je mlevenje pojedinačnih sastojaka smeše. Za mlevenje su najviše u upotrebi mlinovi čekićari dok su mlinovi na valjke znatno manje zastupljeni. Iako je dugo smatrano da je sitno mlevenje ključno za proizvodnju kvalitetnih peleta i dobro iskorišćenje hrane u probavnom sistemu životinja, krupnije mlevenje žitarica, kao osnovnih komponenata hrane za živinu, postaje sve zastupljenije. Razlog za ovo je što mnoga istraživanja ukazuju da krupnije mlevenje ne dovodi do značajnijeg narušavanja kvaliteta proizvedenih peleta kao i da prisustvo krupnih čestica pozitivno deluje na probavni sistem živine. Cilj ovog istraživanja bio je da se ispita uticaj načina mlevenja (mlin čekićar ili mlin na valjke, tj. široka ili uska raspodela veličine čestica) i intenziteta usitnjavanja kukuruza na specifičnu potrošnju energije mlina i kvalitet dobijenih peleta. Sa smanjivanjem intenziteta usitnjavanja (krupnije mlevenje), došlo je do značajnog ($p < 0.05$) smanjenja specifične potrošnje energije kako mlina čekićara tako i mlina na valjke. Kada se porede slični intenziteti usitanjavanja na mlinu čekićaru i mlinu na valjke (sličan geometrijski srednji prečnik, a naročito slična raspodela veličine čestica), specifična potrošnja energije je bila veća na mlinu čekićaru. Kvalitet peleta se pogoršavao sa krupnijim mlevenjem na čekićaru, ali ne i kod mlina na valjke gde krupnoća mlevenja nije uticala na kvalitet peleta. Generalno, kvalitet peleta je bio bolji pri peletiranju kukuruza samlevenog na mlinu na valjke, bez obzira na krupnoću mlevenja. Može se zaključiti da se značajne uštede energije mogu postići krupnijim mlevenjem kukuruza pre peletiranja, a takođe i upotrebom mlina na valjke umesto mlina čekićara. Međutim, u pogledu kvaliteta peleta, ukoliko se primenjuje krupnije mlevenje, bolje je koristiti mlin na valjke s obzirom na to da ujednačenija veličina čestica koja se dobija nakon mlevenja najverovatnije dovodi i do ujednačenije veličine čestica u proizvedenim peletama što doprinosi boljem kvalitetu peleta.

Ključne reči: Mlevenje • Potrošnja energije • Kvalitet peleta • Živina • Kukuruz