

2017

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Recommended Citation

Saensukjaroenphon, M.; Evans, C. E.; Sheldon, K. H.; Jones, C. K.; Paulk, C. B.; and Stark, C. R. (2017) "The Effect of Hammermill Screen Hole Diameter and Hammer Tip Speed on Particle Size and Flowability of Ground Corn," *Kansas Agricultural Experiment Station Research Reports: Vol. 3: Iss. 7*. <https://doi.org/10.4148/2378-5977.7505>

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Summary

A variable frequency drive can be installed on the motor of a hammermill to adjust motor speed and ultimately hammer tip speed. This enables particle size adjustments to be made externally without requiring screens to be changed, therefore reducing idle time. The objective of this study was to determine the effect of screen hole diameter and tip speed on geometric mean diameter (d_{gw}), geometric standard deviation (S_{gw}), and angle of repose (AoR). Treatments were arranged as a 3×3 factorial in a completely randomized design using three screen hole diameters and three hammer tip speeds. Each treatment replicate ($n = 3$) was manufactured as a separate grinding queue with individual queue samples as the experimental unit. Whole corn was ground using three common screen hole diameter (6/64, 10/64, and 16/64 in.) at varying hammer tip speeds (10,250, 15,375, and 20,500 ft/min). Results indicated a marginally significant linear interaction ($P < 0.077$) between screen hole diameter and tip speed for d_{gw} and S_{gw} . For d_{gw} , when tip speed increased from 10,250 to 20,500 ft/min the rate of decrease in d_{gw} was greater as screen hole diameter increased from 6/64 to 16/64 in. Therefore, when tip speed was increased from 10,250 to 20,500 ft/min, d_{gw} was reduced by 233, 258, and 305 μm for corn ground using the 6/64, 10/64, and 16/64 in. screen hole diameter, respectively. For S_{gw} , when tip speed increased from 10,250 to 20,500 ft/min the rate of decrease in S_{gw} was smaller as screen hole diameter increased. Therefore, when tip speed increased from 10,250 to 20,500 ft/min, S_{gw} was reduced by 0.31, 0.24, and 0.13 for corn ground using the 6/64, 10/64, and 16/64 in. screen hole diameter, respectively. There was no observed interaction between screen hole diameter and tip speed on AoR. Increasing hammer tip speed increased (linear, $P < 0.001$) AoR. Increasing screen hole diameter decreased (linear, $P < 0.001$) AoR. In summary, the particle size range for a specified hammermill screen size can be adjusted through manipulation of the hammer tip speed, which is made possible using motor variable frequency drives. This enables operators to quickly change the particle size output, while reducing idle time in the mill.

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Introduction

As particle size research has continued to evolve, so has the nutritionist's understanding of what is needed to optimize animal performance. There is a push to begin manufacturing diets of specific particle sizes to account for differences among species and growth phases. This may appear to be a relatively easy task for the feed mill; however, as the grinding limitations of the feed mill are exposed, it becomes more difficult to find a resolution between the nutritionist's demands and the capabilities of the milling equipment. Ultimately, the feed mill must find a way to use the same equipment to produce a wide range of particle sizes that will satisfy the nutritionist's requests.

The hammermill has become a very cost-effective method of reducing grains to very fine particle sizes for feeding. There are several facets which can affect the final particle size achieved using the hammermill. Traditionally, the most common method of changing the particle size is to exchange the size of screens for either a smaller or larger hole diameter. Screen changes lead to increased down time and loss of production within a facility. An alternative solution to reducing particle size is to adjust the hammer tip speed. This could potentially allow different particle sizes to be obtained from a single screen hole diameter, eliminating or reducing the need for screen changes. Because tip speed is a function of hammermill diameter and motor speed, it is necessary to have a variable frequency drive (VFD) on the hammermill motor to adjust tip speed. The VFD allows the operator to adjust hammer tip speed while requiring minimum idle time. It is hypothesized that lowering the tip speed of the hammers should result in a larger particle size when using the same screen hole diameter, thus allowing for more flexibility in particle size with any given screen size. Therefore, the objective of this experiment was to determine the effect of screen hole diameter and hammer tip speed on geometric mean diameter (d_{gw}), geometric standard deviation (S_{gw}), and angle of repose (AoR) of corn.

Procedures

Corn was ground and samples collected at the Kansas State University O.H. Kruse Feed Technology Center, Manhattan, KS. Whole corn was ground using a hammermill (Model 22115, Bliss Industries LLC., Ponca City, OK) equipped with 24 hammers set 3/4 inch from the screen. The chamber diameter measured 22 in. with a depth of 11.5 in. The hammermill was equipped with a 25 HP motor on a variable frequency drive (VFD), resulting in 3,560 rpm when operating at 100%. Corn was ground in separate batches to create three replicates per treatment. Treatments were arranged in a 3×3 factorial with main effects of screen hole diameter (6/64, 10/64, or 16/64 in.) and hammer tip speed (10,250, 15,375, or 20,500 ft/min). Screen hole diameters were selected to represent the wide range potentially used in the industry. For each screen size, whole corn was ground using three different motor speeds: 1,780, 2,670, and 3,560 rpm, achieved by adjusting the VFD. Using these values, hammer tip speed was then calculated by multiplying π by the hammermill diameter (inches) and motor speed (rpm). This value was then divided by 12 to convert the hammer tip speed to feet per minute. Based on this formula and the measured motor speeds, the resulting hammer tip speeds were 10,250, 15,375, and 20,500 ft/min. Calculating tip speed allowed the results to be interpreted and extrapolated to other hammermills of varying dimensions.

Samples of ground corn from each screen size and motor speed combination were analyzed for particle size and angle of repose (AoR). Particle size was determined according to the ASAE 319.2² standard method using a stainless-steel sieve stack (13 sieves), 15-minute sieve time, sieve agitators, and dispersing agent. The geometric mean diameter (d_{gw}) and geometric standard deviation (S_{gw}) of the samples were calculated. Additionally, AoR was measured as a predictor of the flowability of the ground product, with high values indicating a material that is less likely to flow.³ It was determined by weighing 200 ± 5 g of sample and allowing it to flow from an oscillating feeder 9.5 inches above a free-standing platform, 5.3 inches in diameter. The angle of repose was then calculated by taking the inverse tangent of the maximum pile height divided by the platform radius as described by Appel⁴ in 1994.

Data were analyzed using GLIMMIX procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC). Treatment was the fixed effect and the experimental unit was batch of corn ground each day. Day of grinding was included as a random effect. Results were considered significant if $P \leq 0.050$ and marginally significant if $P \leq 0.100$.

Results and Discussion

There was a marginally significant linear interaction ($P < 0.077$) between screen hole diameter and tip speed for d_{gw} and S_{gw} (Table 1). For d_{gw} , when tip speed increased from 10,250 to 20,500 ft/min, the rate of decrease in d_{gw} was greater as screen hole diameter increased from 6/64 to 16/64 in. (Figure 1). Therefore, when tip speed was increased from 10,250 to 20,500 ft/min d_{gw} was reduced by 233, 258, and 305 μm for corn ground using the 6/64, 10/64, and 16/64 in. screen hole diameter, respectively. For S_{gw} , when tip speed increased from 10,250 to 20,500 ft/min the rate of decrease in S_{gw} was smaller as screen hole diameter increased from 6/64 to 16/64 in. (Figure 2). Therefore, when tip speed increased from 10,250 to 20,500 ft/min S_{gw} was reduced by 0.31, 0.24, and 0.13 for corn ground using the 6/64, 10/64, and 16/64 in. screen hole diameter, respectively. There was no interaction between screen hole diameter and tip speed for AoR. Increasing hammer tip speed increased (linear, $P < 0.001$) AoR. Increasing screen hole diameter decreased (linear, $P < 0.001$) AoR.

The screen hole diameter determines the maximum particle size of the ground material passing through the hammermill, meaning those particles larger than the screen hole will remain in the chamber until small enough to pass through. As the particle's time in the chamber increases, it will continue to collide with the hammers which further decreases the size. Because the reduction in particle size can be considered a result of the frequency of hammer impact, then changing the speed of the hammers is also a viable method for reducing the particle size. In other words, the number of times the particle is impacted by the hammers can be a function of not only the screen hole diameter restricting throughput based on size, but also how fast the hammers are rotating in the chamber. Thus, reducing the screen hole diameter or increasing the hammer tip speed

² ASABE Standards. (1995). S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.

³ Horn, E. (2008). Development of a composite index for pharmaceutical powders. PhD dissertation. Potchefstroom, South Africa: North-west University, School for Pharmacy.

⁴ Appel, W. B. (1994). Physical properties of feed ingredients. In (4th ed.) Feed Manufacturing Technology, (pp. 551). Arlington, VA: American Feed Industry Association, Inc.

will increase the chance that particles will collide with the hammers multiple times prior to passing through the screen. The additional contact with the hammers is the result of both cases leading to a smaller particle size, as shown by the decrease in d_{gw} in this trial. The interaction between the screen size and hammer tip speed demonstrates how increasing tip speeds causes a larger reduction in particle size when grinding corn through a coarser screen hole diameter compared to a smaller screen hole. Furthermore, as the hammer is allowed additional contact with each particle, the particles become more uniform in size, resulting in less variation between particles. This is supported by the data in which the smaller screen hole diameter or faster tip speed yielded a smaller S_{gw} . Finally, the AoR was measured in this trial to characterize the flowability of the resultant ground corn to predict possible handling issues at the feed mill. The lower AoR degree was used as indicator of better flowability.³ The result indicated that the larger particle size had a lower degree of AoR than finer particle sizes; however, more importantly, the AoR of all treatments remained lower than the standard industry recommendation of 60 degrees for the vertical movement of a ground ingredient.

In summary, the particle size range for a specified hammermill screen size can be adjusted through manipulation of the hammer tip speed, which is made possible using motor variable frequency drives. This experiment showed that when using a 6/64, 10/64, and 16/64 in. screen hole diameter, increasing tip speed from 10, 250 to 20,500 ft/min reduced d_{gw} by 233, 258, and 305 microns, respectively. This not only expands the possible range of particle sizes that can accurately be produced, but also enables operators to quickly change the particle size output, while reducing idle time in the mill.

Table 1. Interactive effect of screen hole diameter and motor speed on physical properties of corn¹

Screen hole diameter, in.:	6/64			10/64			16/64			SEM	Probability, ³ <i>P</i> <			
	Tip speed, ² ft/min:	10,250	15,375	20,500	10,250	15,375	20,500	10,250	15,375		20,500	1	2	3
d_{gw} , ⁴ μm	499	346	266	627	442	369	727	584	422	52.3	0.077	0.174	0.908	0.263
S_{gw} ⁵	3.02	2.79	2.71	3.31	3.24	3.07	3.32	3.16	3.19	0.055	0.067	0.698	0.978	0.122
Angle of repose, ⁶ °	41.0	45.3	45.3	38.0	41.5	44.3	35.0	37.5	43.3	1.50	0.121	0.115	0.863	0.888

¹ Whole corn was ground using a hammermill (Model 22115, Bliss Industries LLC., Ponca City, OK) equipped with 24 hammers set 6/8 inch from the screen. The hammermill was equipped with a 25 HP motor on a variable frequency drive (VFD), resulting in 3,560 rpm when operating at 100%. Corn was ground in separate batches to create three replicates per treatment.

² Whole corn was ground using three different motor speeds: 1780, 2670, and 3560 rpm. Hammer tip speed was then calculated by multiplying π by the hammermill diameter (in.) and motor speed (rpm).

³ Contrast statements were: 1) Screen hole diameter linear $\times$ tip speed linear; 2) screen hole diameter linear $\times$ tip speed quadratic; 3) screen hole diameter quadratic $\times$ tip speed linear; and 4) screen hole diameter quadratic $\times$ tip speed quadratic.

⁴ Geometric mean diameter of particles determined using ASAE S319.2 standard particle size method.

⁵ Standard deviation of the geometric mean diameter of particles determined using ASAE S319.2 standard particle size method.

⁶ Angle of repose was calculated by taking the inverse tangent of the maximum pile height divided by the platform radius.

Table 2. Treatment main effect for screen hole diameter on physical properties of corn¹

Item	Screen hole diameter, inches			SEM	Probability, $P <$	
	6/64	10/64	16/64		Linear	Quadratic
$d_{gw}^2 \mu\text{m}$	370	479	577	12.7	0.001	0.1037
S_{gw}^3	2.84	3.21	3.23	0.030	0.001	0.0010
Angle of repose, ⁴ °	43.9	41.3	38.6	0.80	0.001	0.6087

¹ Whole corn was ground using a hammermill (Model 22115, Bliss Industries LLC., Ponca City, OK) equipped with 24 hammers set 6/8 inch from the screen. The hammermill was equipped with a 25 HP motor on a variable frequency drive (VFD), resulting in 3,560 rpm when operating at 100%. Corn was ground in separate batches to create three replicates per treatment.

² Geometric mean diameter of particles determined using ASAE S319.2 standard particle size method.

³ Standard deviation of the geometric mean diameter of particles determined using ASAE S319.2 standard particle size method.

⁴ Angle of repose was calculated by taking the inverse tangent of the maximum pile height divided by the platform radius.

Table 3. Treatment main effect for motor speed on physical properties of corn¹

Item	Tip speed, ² ft/min			SEM	Probability, $P <$	
	10,250	15,375	20,500		Linear	Quadratic
$d_{gw}^3 \mu\text{m}$	618	457	352	12.7	0.001	0.088
S_{gw}^4	3.22	3.06	2.99	0.030	0.001	0.275
Angle of repose, ⁵ °	38.0	41.4	44.3	0.80	0.001	0.775

¹ Whole corn was ground using a hammermill (Model 22115, Bliss Industries LLC., Ponca City, OK) equipped with 24 hammers set 6/8 inch from the screen. The hammermill was equipped with a 25 HP motor on a variable frequency drive (VFD), resulting in 3,560 rpm when operating at 100%. Corn was ground in separate batches to create three replicates per treatment.

² Whole corn was ground using three different motor speeds: 1780, 2670, and 3560 rpm. Hammer tip speed was then calculated by multiplying π by the hammermill diameter (inches) and motor speed (rpm).

³ Geometric mean diameter of particles determined using ASAE S319.2 standard particle size method.

⁴ Standard deviation of the geometric mean diameter of particles determined using ASAE S319.2 standard particle size method.

⁵ Angle of repose was calculated by taking the inverse tangent of the maximum pile height divided by the platform radius.

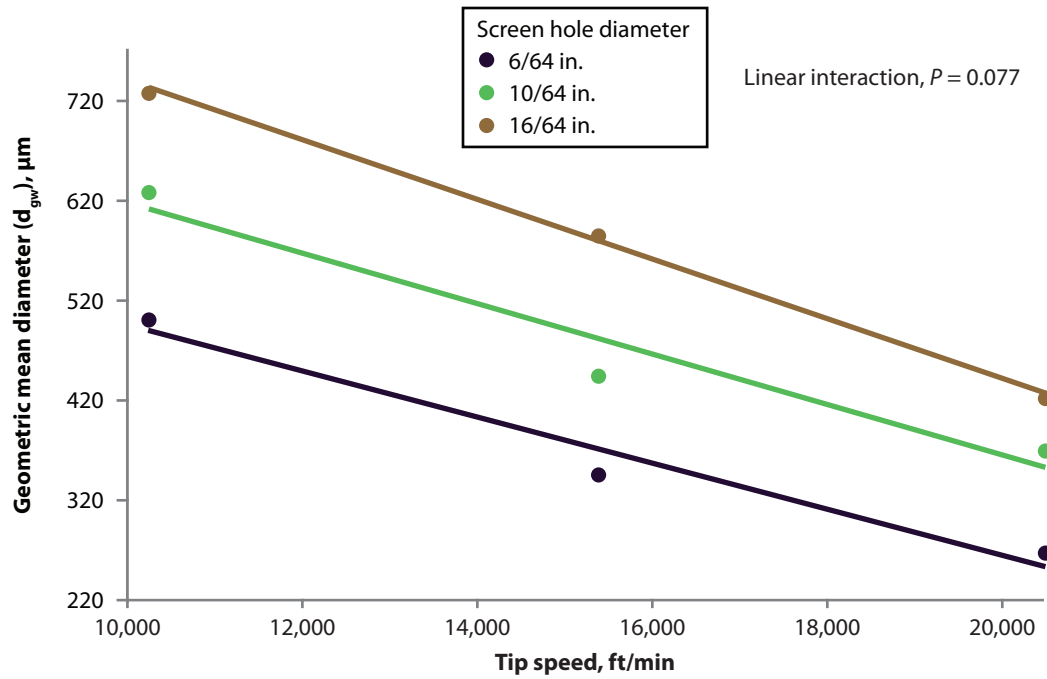


Figure 1. The effect of screen hole diameter on d_{gw} based on tip speed.

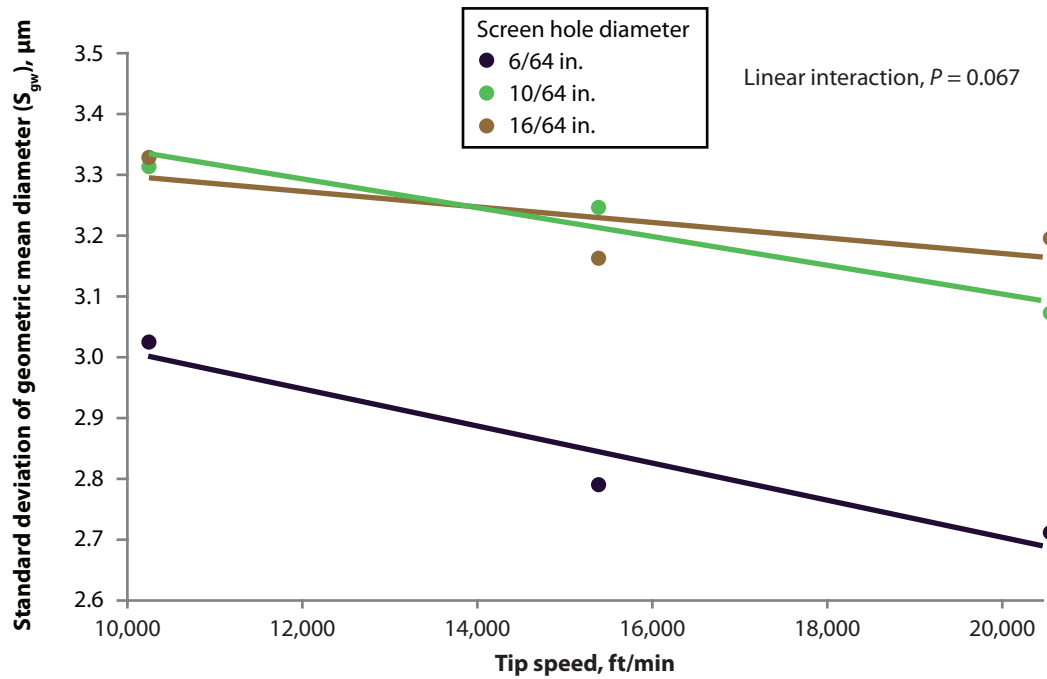


Figure 2. The effect of screen hole diameter on S_{gw} based on tip speed.