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The Effect of Screen Hole Diameter and Hammer Tip Speed on the Subsequent Particle Size of Ground Corn Analyzed With and Without Sieving Agent

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Abstract

Reducing the particle size of grains increases the ratio of surface area to volume which provides digestive enzymes greater access to nutrients, therefore improving utilization of the feed. Hammermills are a very cost-effective method of reducing grains to very fine particle sizes for feeding. A variety of settings can be changed on hammermills to achieve a target particle size. Thus, the objective of this experiment was to determine the effects of screen hole diameter, hammer tip speed, and the inclusion of a sieving agent on the particle size of corn. Treatments were arranged in a 4 × 6 × 2 factorial with screen hole diameter (10/64, 12/64, 16/64, 24/64 in.), hammer tip speed (20,500, 18,450, 16,400, 14,350, 12,300, and 10,250 ft/min), and particle size analytical method (with and without sieving agent). All treatments were ground using a Bliss Hammermill (Model 22115) equipped with a variable frequency drive (VFD) and a 25 HP motor. The screen hole diameter and hammer tip speed were randomized to reduce the effects of grinding and sampling order. There were 3 replicates per treatment. Samples were analyzed for geometric mean diameter (d_{gw}) and standard deviation (S_{gw}) of the particle size. There was no evidence of a screen hole diameter × hammer tip speed × sieving agent interaction for all variables ($P > 0.327$). There was a linear screen hole diameter × linear hammer tip speed interaction ($P < 0.001$) for d_{gw}. When increasing tip speed from 10,250 to 20,500 ft/min, the rate of decrease in d_{gw} was greater as screen hole diameter increased from 10/64 to 24/64. There was a quadratic screen hole diameter × linear hammer tip speed interaction ($P < 0.035$) for S_{gw}. When increasing the screen size from 10/64 to 24/64, the rate of increase in S_{gw} was greater as tip speed increased from 10,250 to 16,400 ft/min and was similar from 16,400 to 20,500 ft/min. There was no evidence of a screen hole diameter × hammer tip speed interaction for percent fines ($P > 0.153$). There was no evidence of a screen hole diameter × sieving agent or hammer tip speed × sieving agent interaction for d_{gw} or S_{gw} ($P > 0.540$). There was a linear screen hole diameter × sieving agent interaction ($P < 0.001$) for percent fines. When increasing the screen size from 10/64 to 24/64, the rate of decrease in percent of fine particles was greater when sieving agent was used compared to when it wasn't used. The results of this trial indicate that the particle size range for a specified hammermill screen size can be altered by adjusting the hammer tip speed with a VFD. Additionally, particle size should be determined with the addition of sieving agent during analysis to more accurately characterize the particle size distribution, especially of finer particles that may influence flowability or animal intake.

Keywords

hammer tip speed, particle size, screen hole diameter, and sieving agent

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Summary

Reducing the particle size of grains increases the ratio of surface area to volume which provides digestive enzymes greater access to nutrients, therefore improving utilization of the feed. Hammermills are a very cost-effective method of reducing grains to very fine particle sizes for feeding. A variety of settings can be changed on hammermills to achieve a target particle size. Thus, the objective of this experiment was to determine the effects of screen hole diameter, hammer tip speed, and the inclusion of a sieving agent on the particle size of corn. Treatments were arranged in a 4 × 6 × 2 factorial with screen hole diameter (10/64, 12/64, 16/64, 24/64 in.), hammer tip speed (20,500, 18,450, 16,400, 14,350, 12,300, and 10,250 ft/min), and particle size analytical method (with and without sieving agent). All treatments were ground using a Bliss Hammermill (Model 22115) equipped with a variable frequency drive (VFD) and a 25 HP motor. The screen hole diameter and hammer tip speed were randomized to reduce the effects of grinding and sampling order. There were 3 replicates per treatment. Samples were analyzed for geometric mean diameter (d_{gw}) and standard deviation (S_{gw}) of the particle size. There was no evidence of a screen hole diameter × hammer tip speed × sieving agent interaction for all variables ($P > 0.327$). There was a linear screen hole diameter × linear hammer tip speed interaction ($P < 0.001$) for d_{gw}. When increasing tip speed from 10,250 to 20,500 ft/min, the rate of decrease in d_{gw} was greater as screen hole diameter increased from 10/64 to 24/64. There was a quadratic screen hole diameter × linear hammer tip speed interaction ($P < 0.035$) for S_{gw}. When increasing the screen size from 10/64 to 24/64, the rate of increase in S_{gw} was greater as tip speed increased from 10,250 to 16,400 ft/min and was similar from 16,400 to 20,500 ft/min. There was no evidence of a screen hole diameter × hammer tip speed interaction for percent fines ($P > 0.153$). There was no evidence of a screen hole diameter × sieving agent or hammer tip speed × sieving agent interaction for d_{gw} or S_{gw} ($P > 0.540$). There was a linear screen hole diameter × sieving agent interaction ($P < 0.001$) for percent fines. When increasing the screen size from 10/64 to 24/64, the rate of decrease in percent of fine particles was greater when sieving agent was used compared to when it wasn't used. The results of this trial indicate that the particle size range for a specified hammermill screen size can be altered by adjusting the hammer tip speed with a VFD. Additionally, particle size should be determined with the addition of sieving agent during analysis to

more accurately characterize the particle size distribution, especially of finer particles that may influence flowability or animal intake.

Introduction

The particle size of cereal grains in diets has a significant impact on animal performance. In general, decreasing particle size allows for greater surface area for digestive enzymes, which can increase the animal's access to nutrients. Smaller particles are not always better, however, as the optimal particle size can vary by species and growth phase. Additionally, fine particles can lead to issues with palatability and handling characteristics. Thus, determining the target particle size of cereal grains for diets can become a difficult task. The decision can further be complicated by the grinding limitations of the feed mill.

When grinding with hammermills, particle size flexibility can be increased with the installation of a variable frequency drive (VFD) on the motor. Once equipped with a VFD, the hammer tip speed can be easily adjusted through changes in rpm. This offers an alternative way to modify particle size targets without the idle time required to exchange screens for larger or smaller hole diameter. Thus, using a VFD to adjust hammer tip speed could potentially increase particle size flexibility with any available screen size in the facility.

Selection of a target particle size is complicated; the choice is influenced by the analytical method used to measure the size. A standard method was established by the American Society of Agricultural and Biological Engineers (ASABE); however, it allows for some variations in the methodology. One of the more typical variations includes the addition of a dispersing or flow agent prior to analysis. It is believed that the sieving agent helps facilitate particle movement through the sieve stack and prevent particle agglomeration due to factors such as static charge. By allowing particles to reach their smallest sieve location, the resulting calculated particle size should be more accurate. The increased accuracy in profiling the distribution of particles, especially fine particles, can help to better characterize the materials' handling characteristics and animal palatability. This distinction can be of greater importance when grinding with hammermills because they rely on impact force to shatter particles, typically resulting in a greater distribution of particle sizes. Therefore, the objective of this experiment was to determine the effects of screen hole diameter, hammer tip speed, and the inclusion of sieving agent during analysis on the geometric mean diameter (d_{gw}), geometric standard deviation (S_{gw}), and percent fines (< 212 µm) of corn.

Materials and Methods

Corn was ground and samples were collected at the Kansas State University O.H. Kruse Feed Technology Innovation 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 in. from the screen. The chamber diameter measured 22 in. with a width 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 4 × 6 × 2 factorial with four screen hole diameters (10/64, 12/64, 16/64, 24/64 in.), six hammer tip speeds (10,250, 12,300, 14,350, 16,400, 18,450, or 20,500 ft/min), and two analytical methods (with and without the sieving agent). Screen hole diameters were selected to represent the wide range potentially used in the industry. Specifically, screen hole diameters measuring 10/64, 12/64, 16/64, and 24/64 in. were used and referred to hereafter by their more common industry nomenclature of number 10, 12, 16, and 24 screens, respectively. For each screen size, whole corn was ground using six different motor speeds: 1,780, 2,136, 2,492, 2,848, 3,204, 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 (in.) and motor speed (rpm). This value was then divided by 12 to convert the hammer tip speed to ft/min. Based on this formula and the measured motor speeds, the resulting hammer tip speeds were 10,250, 12,300, 14,350, 16,400, 18,450, or 20,500 ft/min. Calculating tip speed allowed the results to be interpreted and extrapolated to other hammermills of varying dimensions.

Sample analysis
Samples of ground corn from each screen size and motor speed combination were analyzed for particle size. Particle size was determined according to the ASAE S319.2[1] standard method using a stainless-steel sieve stack (13 sieves), 15-minute sieve time, sieve agitators, and with and without sieving agent (0.5 g, Model SSA-58, Gilson Company, Inc., Lewis Center, OH). The sieve stack was washed between samples analyzed with and without sieving agent to reduce influence of residual sieving agent in the stack. Sieve sizes and agitators were arranged according to Kalivoda and others.[2] The d_{gw} and S_{gw} of the samples were calculated according to equations set forth in ASAE standard 319.2.[1] Fines were considered as any particle < 212 µm.

Statistical analysis
Data were analyzed using GLIMMIX procedure of SAS (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. Linear and quadratic contrast statements were used to evaluate increasing screen size and hammer tip speed as well as linear and quadratic interactions. Results were considered significant if $P \leq 0.050$.

Results and Discussion
There was no evidence of a screen hole diameter × hammer tip speed × sieving agent interaction for all variables ($P > 0.327$). There was a linear screen hole diameter × linear hammer tip speed interaction ($P < 0.001$) for d_{gw} (Table 1). When increasing tip speed from 10,250 to 20,500 ft/min, the rate of decrease in d_{gw} was greater as screen hole diameter increased from 10 to 24. Therefore, when tip speed was increased from 10,250 to 20,500 ft/min, d_{gw} was reduced by 369, 517, 548, and 571 µm for corn ground using the 10, 12, 16, and 24 screens, respectively. There was a quadratic screen hole diameter × linear hammer tip speed interaction ($P < 0.035$) for S_{gw}. When increasing the screen size from 10 to 24, the rate of increase in S_{gw} was greater as tip speed increased from 10,250 to 16,400 ft/min and was similar from 16,400 to 20,500 ft/min. There was no evidence of a screen hole diameter × hammer tip speed interaction for percent fines ($P > 0.153$).

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

[2] Kalivoda, J. R.; Jones, C. K.; and Stark, C. R. (2015) "Effects of Varying Methodologies on Grain Particle Size Analysis," *Kansas Agricultural Experiment Station Research Reports*: Vol. 1: Iss. 7. 2015 Swine Day. https://doi.org/10.4148/2378-5977.1125.

There was no evidence of a screen hole diameter × sieving agent or hammer tip speed × sieving agent interaction for d_{gw} or S_{gw} ($P > 0.540$). There was a linear screen hole diameter × sieving agent interaction ($P < 0.001$) for percent of fine particles (Table 2). When increasing the screen size from 10 to 24, the rate of decrease in percent fine particles was greater when sieving agent was used compared to when it was not used. Therefore, when screen size was increased from the 10 to 24 screen, percent fines were decreased by 5.1 and 1.9% for particle sizes analyzed using sieving agent and no sieving agent, respectively.

Main effects from this experiment indicated the screen hole diameter, tip speed, and sieving agent affected the d_{gw}, S_{gw}, and percent fines (Table 3, 4, and 5). Increasing screen hole diameter increased (linear, $P < 0.001$) d_{gw} and S_{gw} and decreased (linear, $P < 0.001$) percent fines. Increasing hammer tip speed from 10,250 to 18,450 ft/min decreased (quadratic, $P < 0.001$) d_{gw}, with no further decrease in d_{gw} using a faster hammer tip speed. Increasing hammer tip speed decreased (linear, $P < 0.001$) S_{gw}, and increased (linear, $P < 0.001$) percent fines. Particle size analysis conducted with a sieving agent had decreased ($P < 0.001$) d_{gw} and increased ($P < 0.001$) S_{gw} and percent fines compared to those measured without sieving agent.

Adjusting screen hole diameter or hammer tip speed both provide a practical method for particle size alteration; however, this experiment demonstrated the increased grinding flexibility when these strategies were used in combination. When the appropriate screen size is selected, the operator can alter particle size via a simple tip-speed change, as opposed to arduous physical screen changes. Consideration of screen hole diameter and operating tip speed can also expand the range of achievable particle sizes on a unit. Care should be taken, however, in selecting the screen size and tip speed as the S_{gw} may also be affected. Ensuring the precision of the chosen analytical method for particle size is equally important as the reduction strategies in the mill. The use of sieving agent during analysis provides a more accurate measurement of d_{gw} and S_{gw} by facilitating the movement of particles through the sieve stack. This can lead to better understanding of downstream effects such as flowability or even feed intake, particularly as it relates to analysis of particle fines.

Table 1. Interactive effect of screen hole diameter and hammermill motor speed on physical properties of corn[1]

	Tip speed,[2] ft/min							Probability,[3] $P <$			
	10,250	**12,300**	**14,350**	**16,400**	**18,450**	**20,500**	**SEM**	**1**	**2**	**3**	**4**
d_{gw},[4] µm											
Screen hole diameter, in.											
10/64	773	698	589	504	473	404	45.3	0.001	0.080	0.077	0.112
12/64	977	751	639	521	437	460					
16/64	1022	891	711	624	520	474					
24/64	1125	1073	936	738	641	554					
S_{gw},[5] µm											
Screen hole diameter, in.											
10/64	2.94	2.84	2.82	2.75	2.72	2.67	0.078	0.114	0.880	0.035	0.198
12/64	2.84	2.85	2.73	2.73	2.73	2.68					
16/64	2.83	2.99	2.98	2.98	2.96	2.93					
24/64	3.28	3.12	3.09	3.25	3.17	3.10					
Fine particles,[6] %											
Screen hole diameter, in.											
10/64	15.5	16.2	19.4	22.1	22.7	27.6	1.73	0.469	0.404	0.153	0.359
12/64	12.0	15.0	16.5	20.6	25.9	22.7					
16/64	11.4	14.6	17.0	19.5	23.3	25.3					
24/64	13.6	13.0	14.3	18.6	20.2	22.7					

[1] Whole corn was ground using a hammermill (Model 22115, Bliss Industries LLC., Ponca City, OK) furnished with 24 hammers, set 3/4 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 six different motor speeds: 1,780, 2,136, 2,492, 2,848, 3,204, and 3,560 rpm. Hammer tip speed was then calculated by multiplying π by the hammermill diameter (inches) and motor speed (rpm).

[3] Contrast statements were: 1) Screen hole diameter linear × tip speed linear; 2) screen hole diameter linear × tip speed quadratic; 3) screen hole diameter quadratic × tip speed linear; and 4) screen hole diameter quadratic × tip speed quadratic.

[4] Geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method. (ASABE Standards. (1995). S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.)

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

[6] Fine particles are considered as any particle < 212 µm.

Table 2. Interactive effect of screen hole diameter and flow agent on physical properties of corn[1]

	Screen hole diameter, in.					Probability, P <			
							Screen hole diameter		Flow
	10/64	12/64	16/64	24/64	SEM	Interaction	Linear	Quadratic	agent
d_{gw},[2] µm									
Sieving agent	509	564	648	775	44.1	0.715	0.001	0.298	0.001
No sieving agent	638	698	766	913					
S_{gw},[3] µm									
Sieving agent	3.16	3.12	3.29	3.54	0.065	0.540	0.001	0.562	0.001
No sieving agent	2.42	2.40	2.59	2.78					
Fines,[4] %									
Sieving agent	24.0	22.1	20.6	18.9	1.64	0.028	0.001	0.294	0.001
No sieving agent	17.1	15.4	16.3	15.2					

[1] Corn was ground in separate batches to create three replicates per treatment. Treatments were arranged in a 4 × 6 × 2 factorial with four screen hole diameters (10/64, 12/64, 16/64, or 24/64 in.), six hammer tip speeds (20,500, 18,450, 16,400, 14,350, 12,300, and 10250 ft/min), and two analytical methods (with and without the sieving agent). There was no evidence of sieving agent × screen hole × hammer tip speed interactions (P > 0.1).
[2] Geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method. (ASABE Standards. (1995). S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.)
[3] Standard deviation of the geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method.
[4] Fine particles are considered as any particle < 212 µm.

Table 3. Treatment main effect for screen hole diameter on physical properties of corn[1]

	Screen hole diameter, in.					Probability, P <	
Item	10/64	12/64	16/64	24/64	SEM	Linear	Quadratic
d_{gw},[2] µm	574	631	707	844	41.6	0.001	0.298
S_{gw}[3]	2.79	2.76	2.94	3.16	0.059	0.001	0.562
Fines,[4] %	20.6	18.8	18.4	17.0	1.54	0.001	0.294

[1] Treatments were arranged in a 4 × 6 × 2 factorial with four screen hole diameters (10/64, 12/64, 16/64, or 24/64 in.), six hammer tip speeds (20,500, 18,450, 16,400, 14,350, 12,300, and 10,250 ft/min), and two analytical methods (with and without the sieving agent). Corn was ground in separate batches to create three replicates per treatment.
[2] Geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method. (ASABE Standards. (1995). S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.)
[3] Standard deviation of the geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method.
[4] Fines are considered as any particle < 212 µm.

Table 4. Treatment main effect for screen hole diameter on physical properties of corn[1]

	Tip speed,[2] ft/min							Probability, P <	
Item	10,250	12,300	14,350	16,400	18,450	20,500	SEM	Linear	Quadratic
d_{gw},[3] µm	974	853	718	596	517	473	42.9	0.001	0.001
S_{gw}[4]	2.96	2.95	2.90	2.92	2.89	2.85	0.06	0.012	0.793
Fines,[5] %	13.0	14.6	16.8	20.2	23.1	24.6	1.59	0.001	0.698

[1] Whole corn was ground using a hammermill (Model 22115, Bliss Industries LLC., Ponca City, OK) furnished 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 six different motor speeds: 1,780, 2,136, 2,492, 2,848, 3,204, and 3,560 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 was determined using ASAE S319.2 standard particle size method. (ASABE Standards. (1995). S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.)
[4] Standard deviation of the geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method.
[5] Fine particles are considered as any particle < 212 µm.

Table 5. Main effects of sieving agent on ground corn particle size[1]

	Sieving agent			
Item	Yes	No	SEM	Probability, P <
d_{gw},[2] µm	618	749	13.9	0.001
S_{gw},[3] µm	3.29	2.55	0.02	0.001
Fines,[4] %	21.6	16.0	0.50	0.001

[1] Treatments were arranged in a 4 × 6 × 2 factorial with four screen hole diameters (10/64, 12/64, 16/64, or 24/64 in.), six hammer tip speeds (20,500, 18,450, 16,400, 14,350, 12,300, and 10,250 ft/min), and two analytical methods (with and without the sieving agent). Corn was ground in separate batches to create three replicates per treatment.
[2] Geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method. (ASABE Standards. (1995). S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.)
[3] Standard deviation of the geometric mean diameter of particles was determined using ASAE S319.2 standard particle size method.
[4] Fine particles are considered as any particle < 212 µm.