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Evaluating Hammermill Tip Speed, Air Assist, and Screen Hole Diameter on Ground Corn Characteristics

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Evaluating Hammermill Tip Speed, Air Assist, and Screen Hole Diameter on Ground Corn Characteristics

Abstract

Whole yellow dent #2 corn was ground using two 43 mm Andritz hammermills (Model: 4330-6, Andritz Feed & Biofuel, Muncy, PA; JBS Live Pork LLC Feed Mill, Fremont, IA). Both mills discharged to a shared plenum where samples were collected via a sample port. Each mill was equipped with 72 hammers and 300 HP motors on a variable frequency drive (VFD). Corn was ground on 3 separate days to create replication and treatments were randomized within replication. Treatments were arranged in a 3 × 3 × 3 factorial design with 3 tip speeds (12,383, 16,323, and 20,263 ft/min); 3 screen hole diameters (6/64, 10/64, and 16/64 in.); and 3 air assist system fan RPM's (60, 80, and 100% of fan motor load). Samples of each treatment were collected and analyzed for moisture, particle size, and flowability characteristics. Particle size analysis was completed using a 13-sieve stack with the inclusion of sieve agitators and flow agent. Flowability characteristics were evaluated using a composite flow index (CFI), which includes percent compressibility, angle of repose (AoR), and critical orifice diameter (COD). Data were analyzed as a 3 × 3 × 3 factorial using the PROC GLIMMIX procedure of SAS with grinding run as the experimental unit and sample collection day as a blocking factor. There were no 3-way interactions for screen hole diameter × hammer tip speed × air flow for the geometric mean diameter (d_{gw}) or any flowability characteristics of ground corn. There was a 3-way interaction for particle size standard deviation (S_{gw}), (linear screen hole diameter × linear hammer tip speed × linear air flow, $P = 0.029$). There was a linear screen hole diameter × linear hammer tip speed interaction (P = 0.001) for d_{gw}. When tip speed increased from 12,383 to 20,263 ft/min, the rate of decrease in d_{gw} was greater as screen hole diameter increased from 6/64 to 16/64 in. An interaction of screen hole diameter and hammer tip speed (linear × linear, $P = 0.040$) was also observed for the CFI. The CFI results increased with increasing screen hole diameter when corn was ground using a hammer tip speed of 12,383 ft/min but no differences were observed as tip speed increased to 16,323 and 20,263 ft/min. An interaction of screen hole diameter and hammer tip speed (quadratic × quadratic, $P = 0.001$) was observed for mill motor load. Mill motor load decreased as screen hole diameter increased from 6/64 in. to 16/64 in., but increased as hammer tip speed was increased with the most significant reductions being observed as tip speed increased from 12,383 ft/min to 16,323 ft/min on the 6/64 in. screen. In conclusion, hammer tip speed and air flow rate are viable options for adjusting ground material characteristics when grinding using a hammermill, alongside the traditional screen variations. Along with the range of particle sizes capable of being produced, an increased level of accuracy can also be achieved with hammer tip speed and air flow adjustments with minimal down time necessary for screen changes.

Keywords

hammermill, hammer tip speed, air assist, screen hole diameter, particle size

Cover Page Footnote

The authors appreciate JBS Live Pork, LLC (Fremont, IA) for use of their facility and technical assistance for this study.

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Evaluating Hammermill Tip Speed, Air Assist, and Screen Hole Diameter on Ground Corn Characteristics[1]

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Summary

Whole yellow dent #2 corn was ground using two 43 mm Andritz hammermills (Model: 4330-6, Andritz Feed & Biofuel, Muncy, PA; JBS Live Pork LLC Feed Mill, Fremont, IA). Both mills discharged to a shared plenum where samples were collected via a sample port. Each mill was equipped with 72 hammers and 300 HP motors on a variable frequency drive (VFD). Corn was ground on 3 separate days to create replication and treatments were randomized within replication. Treatments were arranged in a 3 × 3 × 3 factorial design with 3 tip speeds (12,383, 16,323, and 20,263 ft/min); 3 screen hole diameters (6/64, 10/64, and 16/64 in.); and 3 air assist system fan RPM's (60, 80, and 100% of fan motor load). Samples of each treatment were collected and analyzed for moisture, particle size, and flowability characteristics. Particle size analysis was completed using a 13-sieve stack with the inclusion of sieve agitators and flow agent. Flowability characteristics were evaluated using a composite flow index (CFI), which includes percent compressibility, angle of repose (AoR), and critical orifice diameter (COD). Data were analyzed as a 3 × 3 × 3 factorial using the PROC GLIMMIX procedure of SAS with grinding run as the experimental unit and sample collection day as a blocking factor. There were no 3-way interactions for screen hole diameter × hammer tip speed × air flow for the geometric mean diameter (d_{gw}) or any flowability characteristics of ground corn. There was a 3-way interaction for particle size standard deviation (S_{gw}), (linear screen hole diameter × linear hammer tip speed × linear air flow, $P = 0.029$). There was a linear screen hole diameter × linear hammer tip speed interaction ($P = 0.001$) for d_{gw}. When tip speed increased from 12,383 to 20,263 ft/min, the rate of decrease in d_{gw} was greater as screen hole diameter increased from 6/64 to 16/64 in. An interaction of screen hole diameter and hammer tip speed (linear × linear, $P = 0.040$) was also observed for the CFI. The CFI results increased with increasing screen hole diameter when corn was ground using a hammer tip speed of 12,383 ft/min but no differences were observed as tip speed increased to 16,323 and 20,263 ft/min. An interaction of screen hole diameter and hammer tip speed (quadratic × quadratic, $P = 0.001$) was observed for mill motor load. Mill motor load decreased as screen hole diameter increased from 6/64 in. to 16/64 in., but increased as hammer tip speed was increased with the most significant reductions being observed as tip speed increased

[1] The authors appreciate JBS Live Pork, LLC (Fremont, IA) for use of their facility and technical assistance for this study.
[2] JBS Foods, Greeley, CO.

from 12,383 ft/min to 16,323 ft/min on the 6/64 in. screen. In conclusion, hammer tip speed and air flow rate are viable options for adjusting ground material characteristics when grinding using a hammermill, alongside the traditional screen variations. Along with the range of particle sizes capable of being produced, an increased level of accuracy can also be achieved with hammer tip speed and air flow adjustments with minimal down time necessary for screen changes.

Introduction

The influence of particle size on animal health and performance in combination with expanded capabilities of today's grinding machines has led to demands to target specific particle sizes for various species and growth stages. While this may seem to be a reasonable request of the feed mill, there are limitations to what can be achieved. Particle size reduction is achieved by utilizing a combination of impact, shear, and compression forces exerted by the hammers in the grinding chamber. Adjustments made to screen size, speed at which hammers strike particles, and air assist systems which remove sized particles via variable frequency drives (VFD) are all factors that can potentially affect the particle size, standard deviation, and flowability characteristics of the resulting ground material. Therefore, the objective of this study was to evaluate the effect of hammermill tip speed, assistive airflow rate, and screen hole diameter on hammermill throughput and characteristics of the ground material.

Materials and Methods

Whole yellow dent #2 corn was ground using two 1.7 in. Andritz hammermills (Model: 4330-6, Andritz Feed & Biofuel, Muncy, PA; JBS Live Pork LLC Feed Mill, Fremont, IA). Both mills discharged to a shared plenum where samples were collected via a sample port. Each mill was equipped with 72 hammers and 300 HP motors on a VFD. Corn was ground on 3 separate days to create replication and treatments were randomized within replication. Treatments were arranged in a 3 × 3 × 3 factorial design with 3 tip speeds (12,383, 16,323, and 20,263 ft/min); 3 screen hole diameters (6/64, 10/64 and 16/64 in.); and 3 air assist system fan RPMs (60, 80, and 100% of fan motor load). Motor load and outlet temperature was recorded for both mills at three separate time points during each grinding run via the operating system (Repete Corp., Sussex, WI). Air flow was measured using a hot wire anemometer (PerfectPrime Model WD9829) and taken between the baghouse and grinders. Samples of each treatment were collected and analyzed for moisture, particle size, and flowability characteristics. Ground corn samples were analyzed for moisture.[3]

Particle size analysis[4] was completed on a Ro-Tap machine (Model RX- 29, W. S. Tyler Industrial Group, Mentor, OH) using a 13-sieve stack with the inclusion of sieve agitators and flow agent, tapped for 10 min.[5] Sieves were weighed and the amount of material on each sieve was used to calculate the d_{gw} and S_{gw}.[4] Sieves were cleaned after each analysis with compressed air and a stiff bristle sieve cleaning brush.

[3] AOAC 930.15. 1990. Official methods of analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington VA.

[4] ASABE Standards. 2008. S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE.

[5] Kalivoda, J.R., C.K. Jones, and C.R. Stark. 2015. Effects of varying methodologies on grain particle size analysis. KSU Swine Day. KS State University: Manhattan, KS.

The flowability characteristics of ground corn samples were evaluated using the results of angle of repose (AoR), critical orifice diameter (COD), and percent compressibility which were then compiled into composite flow index (CFI) equations.[6] The AoR was determined by allowing a sample to flow from a vibratory conveyor above a free-standing platform until it reached maximum piling height.[7] The COD was determined using a powder flowability test instrument (Flodex Model WG-0110, Paul N. Gardner Company, Inc., Pompano Beach, FL) to represent ingredient flow characteristics in bins. Discs were used to determine the appropriate bin hole opening for material to flow freely. Three sequential positive results were used to determine the COD.[3] Compressibility was determined by measuring the initial and final tapped volume of a 0.2-lb sample in an 8.5 oz graduated cylinder.[3]

Statistical analysis

Data were analyzed as a 3 × 3 × 3 factorial using the PROC GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) with grinding run serving as the experimental unit and day of sample collection serving as the block. Contrast statements were used to separate treatment means with the comparison of the main effects screen (6/64 vs. 10/64 vs. 16/64), tip speed (12,383 vs. 16,323 vs. 20,263), and air flow rate (60 vs. 80 vs. 100). Linear and quadratic polynomials were used to test increasing parameters within each main effect. Results were considered significant if $P \leq 0.05$.

Results and Discussion

There were no 3-way interactions for screen hole diameter × hammer tip speed × air flow for the d_{gw} or any flowability characteristics of ground corn (Table 1). There was a 3-way interaction for S_{gw}, (linear screen hole diameter × linear hammer tip speed × linear air flow) ($P = 0.029$). When corn was ground using the 6/64 in. screen, increasing hammer tip speed decreased S_{gw} when the air assist setting was 60%. However, increasing tip speed did not influence S_{gw} when the air assist setting was 80 or 100%. There was no evidence of difference in the S_{gw} when air assist setting was increased and corn was ground using hammer tip speeds of 12,383, 16,323, or 20,263 ft/min. When grinding with the 10/64 in. screen, increasing hammer tip speed reduced S_{gw}. However, the rate of S_{gw} reduction was greater when the air flow setting was increased. In addition, increasing the air flow rate setting from 60 to 100% increased S_{gw} when corn was ground using a tip speed of 12,383 ft/min; however, there was no difference in air flow setting when a tip speed of 20,263 ft/min was used. When corn was ground using the 16/64 in. screen, there was no evidence of difference in S_{gw} when increasing hammer tip speed when the air assist motor was set at the 60%. Increasing hammer tip speed increased S_{gw} when the air assist motor was set at 80% and increasing hammer tip decreased S_{gw} when the air assist motor was set at 100%. Furthermore, increasing air flow at hammer tip speeds of 12,383 and 16,323 ft/min increased S_{gw} but no difference was observed at 20,263 ft/min.

There was a linear screen hole diameter × linear hammer tip speed interaction ($P = 0.001$) for d_{gw} (Table 2). When tip speed increased from 12,383 to 20,263 ft/min the rate of decrease in d_{gw} was greater as screen hole diameter increased from

[6] Horn, E. 2008. Development of a composite index for pharmaceutical powders. PhD dissertation. Potchefstroom, South Africa: North-west University, School for Pharmacy.
[7] Appel, W. B. 1994. Physical properties of feed ingredients. 4th ed. Feed Manufacturing Technology, (pp. 151). Arlington, VA: American Feed Industry Association, Inc.

6/64 to 16/64 in. Therefore, when tip speed was increased from 12,383 ft/min to 20,263 ft/min, d_{gw} was reduced by 67, 111, and 254 microns for corn ground using the 6/64, 10/64, and 16/64 in. screen hole diameter, respectively. There was a linear screen hole diameter × linear hammer tip speed interaction was also observed for critical orifice diameter ($P = 0.018$). When grinding using a hammer tip speed of 12,383 ft/min a decrease in COD was observed as screen hole diameter increased from 6/64 in. to 16/64 in. As tip speed increased to 16,323 and 20,263 ft/min no differences in COD were observed with increasing screen hole diameter. Additionally, an interaction of screen hole diameter and hammer tip speed was observed for percent compressibility (quadratic × linear, $P = 0.015$). Increasing screen hole diameter had a quadratic effect on percent compressibility and increasing hammer tip speed decreased percent compressibility when using the 6/64 in. screen but increased with the 10/64 in. and 16/64 in. screens. Furthermore, an interaction of screen hole diameter and hammer tip speed (linear × linear, P = 0.040) was also observed for the CFI. The CFI results increased with increasing screen hole diameter when corn was ground using a hammer tip speed of 12,383 ft/min, but no differences were observed as tip speed increased to 16,323 and 20,263 ft/min. An interaction of screen hole diameter and hammer tip speed was observed for mill motor load (quadratic × quadratic, $P = 0.001$). Mill motor load decreased as screen hole diameter increased from 6/64 in. to 16/64 in., but increased as hammer tip speed was increased with the most significant reductions being observed as tip speed was increased from 12,383 ft/min to 16,323 ft/min on the 6/64 in. screen.

A significant interaction of screen hole diameter and air flow was observed for the compressibility (quadratic × linear, $P < 0.046$) and CFI (linear × linear, $P < 0.026$) results (Table 3). Compressibility results increased as air flow rate was increased on the 6/64 in and 16/64 in. screens but decreased as air flow was increased on the 10/64 in. screen. Furthermore, screen hole diameter increased percent compressibility in a quadratic fashion with the highest measurements resulting from the 10/64 in. screen. The CFI increased as screen hole diameter was increased. The CFI also increased as air flow was increased on the 6/64 in. and the 10/64 in., but decreased with increasing air flow on the 16/64 in. screen. There were no hammer tip speed by air flow interactions.

In conclusion, hammer tip speed and air flow rate are viable options for adjusting ground material characteristics when grinding using a hammermill alongside the traditional screen variations. Along with the range of particle sizes capable of being produced, an increased level of accuracy can also be achieved with hammer tip speed and air flow adjustments with minimal down time necessary for screen changes. However, increasing the hammer tip speed with a VFD will increase the energy usage as motor load will be increased, especially on screens with smaller hole diameters. Furthermore, when grinding using a 10/64 or 16/64 in. screen hole diameter, increasing hammer tip speed decreased the flowability of ground corn, which was improved by increasing air assist rate.

Table 1. Influence of 3-way interaction of screen hole diameter × hammer tip speed × air flow on the particle size and standard deviation of hammermilled corn[1]

Screen hole diameter, in.[2]:	6/64			10/64			16/64				
Hammer tip speed, ft/min[3]:	**12,383**	**16,323**	**20,263**	**12,383**	**16,323**	**20,263**	**12,383**	**16,323**	**20,263**	**SEM**	**Probability, *P* <[6]**
Particle size, μm[5]											
Air flow[4]											
60	344	341	296	443	395	334	580	437	380		
80	361	314	273	477	390	336	652	437	357	25.26	0.227
100	408	330	342	433	389	349	620	452	351		
Standard deviation, S_{gw}[5]											
Air flow											
60	3.07	2.97	2.86	3.25	3.03	2.93	3.10	3.21	3.23		
80	2.97	2.82	2.89	3.05	2.91	2.87	2.89	3.07	3.24	0.086	0.029
100	3.13	2.97	2.97	3.47	3.13	2.97	3.54	3.46	3.27		

[1] Corn was ground using two 1.7 in. Andritz hammermills (Model 4330-6, Andritz Feed & Biofuel, Muncy, PA) equipped with 72 hammers and 300 HP motors on variable frequency drives (VFD). Treatments were arranged in a 3 × 3 × 3 factorial design with main effects of tip speed, screen hole diameter, and air flow rate. Each treatment was replicated 3 times.

[2] Corn was ground using screen hole diameters of 6/64, 10/64 or 16/64 in.

[3] Corn was ground using three motor speeds: 1100, 1450, or 1800 rpm. Hammer tip speed was then calculated by multiplying π by the hammermill diameter (mm) and motor speed (rpm).

[4] Corn was ground using three air flow settings of 60, 80, or 100% of motor load.

[5] Particle size and standard deviation (S_{gw}) are determined according to ASABE 319.2 methods (ASABE Standards. 2008. S319.2: Method of determining and expressing fineness of feed materials by sieving. St. Joseph, Mich.: ASABE).

[6] For the standard deviation result, a linear screen hole diameter × linear tip speed × linear air flow response was observed.

Table 2. Influence of 2-way interaction of screen hole diameter × hammer tip speed on the energy consumption, particle size, and flowability of hammermilled corn[1]

Screen hole diameter, in.[2]:	6/64			10/64			16/64				
Hammer tip speed, ft/min[3]:	**12,383**	**16,323**	**20,263**	**12,383**	**16,323**	**20,263**	**12,383**	**16,323**	**20,263**	**SEM**	**Probability, *P* <**
Physical analysis											
Particle size, microns	371[cd]	328[ef]	304[f]	451[b]	391[c]	340[def]	617[a]	442[b]	363[cde]	15.73	0.001*
Standard deviation, S_{gw}	3.05[b]	2.92[a]	2.90[c]	3.25[c]	3.02[bc]	2.92[c]	3.17[a]	3.24[a]	3.24[a]	0.064	0.002*†
Critical orifice diameter[5]	32.4[ab]	31.7[ab]	32.8[a]	31.1[b]	30.8[b]	31.7[ab]	29.1[c]	31.5[ab]	32.2[ab]	0.576	0.018*
Compressibility, %[6]	18.34[abc]	19.01[ab]	17.25[bc]	16.96[c]	19.75[a]	19.33[a]	18.96[ab]	18.52[abc]	19.49[a]	0.641	0.015†
Composite flow index[7]	46.14[c]	45.91[c]	45.75[c]	49.34[ab]	46.91[bc]	45.43[c]	51.53[a]	47.58[bc]	46.43[bc]	1.264	0.040*
Energy											
Motor load, %	66.85[a]	46.55[b]	45.18[b]	40.72[c]	40.44[c]	40.79[c]	34.55[d]	34.62[d]	35.55[d]	1.217	0.001‡

[1] Corn was ground using two 1.7 in. Andritz hammermills (Model 4330-6, Andritz Feed & Biofuel, Muncy, PA) equipped with 72 hammers and 300 HP motors on variable frequency drives (VFD). Treatments were arranged in a 3 × 3 × 3 factorial design with main effects of tip speed, screen hole diameter, and air flow rate. Each treatment was replicated 3 times.

[2] Corn was ground using screen hole diameters of 6/64, 10/64, or 16/64 in.

[3] Corn was ground using three motor speeds: 1100, 1450, or 1800 rpm. Hammer tip speed was then calculated by multiplying π by the hammermill diameter (mm) and motor speed (rpm).

[4] Angle of repose was determined by measuring the height and radius of the cone formed by the material and using the following equation: Tan θ = height of cone (mm)/ radius of cone (mm).

[5] Critical orifice diameter was determined using a Flodex device to determine product mass flow characteristics through varying discharge outlet sizes.

[6] Percent compressibility is calculated by using the Hausner ratio (PTapped/PBulk).

[7] The composite flow index is calculated by the following equation CFI = (-0.667(AoR Result) + 50) + (-0.667(%C Result) + 36.667) + (-1.778(COD Result) + 37.778).

* Denotes linear screen hole diameter × linear tip speed response.

† Denotes quadratic screen hole diameter × linear tip speed response.

‡ Denotes quadratic screen hole diameter × quadratic tip speed response.

Table 3. Influence of 2-way interaction of screen hole diameter × air flow on the compressibility and composite flow index of hammermilled corn[1]

Screen hole diameter, in.[2]:	6/64			10/64			16/64				Probability,
Air flow rate, %[3]:	60	80	100	60	80	100	60	80	100	SEM	*P* <
Physical characteristic											
Compressibility, %[4]	17.52[b]	18.37[b]	18.71[ab]	19.03[ab]	18.65[ab]	18.36[b]	18.15[b]	18.44[b]	20.39[a]	0.641	0.046[†]
Composite flow index[5]	45.48[cd]	44.62[d]	47.69[abc]	46.12[bcd]	46.51[bcd]	49.05[ab]	50.07[a]	47.72[abc]	47.76[abc]	1.264	0.026[*]

[1] Corn was ground using two 1.7 in. Andritz hammermills (Model 4330-6, Andritz Feed & Biofuel, Muncy, PA) equipped with 72 hammers and 300 HP motors on variable frequency drives (VFD). Treatments were arranged in a 3 × 3 × 3 factorial design with main effects of tip speed, screen hole diameter, and air flow rate. Each treatment was replicated 3 times.

[2] Corn was ground using screen hole diameters of 6/64, 10/64, or 16/64 in.

[3] Corn was ground using three air flow settings of 60, 80, or 100% of motor load.

[4] Percent compressibility is calculated by using the Hausner ratio (PTapped/PBulk).

[5] The composite flow index (CFI) is calculated by the following equation CFI = (-0.667(AoR Result) + 50) + (-0.667(%C Result) + 36.667) + (-1.778(COD Result) + 37.778).

* Denotes linear screen hole diameter × linear air flow response.

† Denotes quadratic screen hole diameter × linear air flow response.