Impact of particle size reduction on feed cost and feed efficiency[1]

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Introduction

Processing of feed ingredients or diets may increase nutrient digestibility (Hancock and Behnke, 2001; NRC, 2012). One of the main purposes of grinding of feed ingredients is to reduce the particle size, which may increase nutrient digestibility (Fastinger and Mahan, 2003) and increase growth performance. Thus, grinding is used to increase the nutritional value of ingredients. It has been reported that pigs or sows fed corn ground to a fine particle had a greater energy, DM, and N digestibility than pigs or sows fed corn ground to a coarser particle size corn size (Healy et al., 1994; Wondra et al., 1995a-d). Reduction of particle size is accomplished with the use of different types of mills. The most common mills used in the industry are roller mills and hammer mills. Ingredients such as distillers dried grains with solubles (**DDGS**) and soybean meal (**SBM**) are often ground during the production process, and in most cases, no further grinding is needed for these ingredients before diets are mixed. In contrast, cereal grains and pulse crops are usually not ground prior to entering the feed mill, and these ingredients need to be ground.

Therefore, the objective of this manuscript is to summarize the results of 5 experiments on the concentration of ME, the standardized total tract digestibility of P, the apparent ileal digestibility of starch and GE, and the standardized ileal digestibility of AA and CP in corn ground to different particle sizes and their subsequent effect on pig growth performance and carcass characteristics.

Materials and methods

Five experiments were conducted. The same batch of corn (Pioneer P0528) was used in all diets in all experiments and the corn was grown in IA in 2011. The grain was milled at the Pioneer Hi-Bred Feed Mill in Johnston, IA, and stored at 15ºC until used (Table 1). The corn grain was first rolled using an automatic roller mill (Model CSU 500, 2 stage; Automatic Equipment Mfg. Co., Pender, NE). Four average final particle sizes of 865, 677, 485, and 339 μm were obtain after the rolled grain was divided into 4 batches that were ground using a hammer mill (Model #EL-9506-TF; Bliss Industries, Ponca City, OK) with 40, 24, 10, or 3 mm screens, respectively.

Exp. 1: Ileal Digestibility of CP, AA, Starch, and GE

Experiment 1 was designed to determine the SID of CP and AA and the AID of starch and GE in the 4 batches of corn ground to different particle sizes. Ten growing barrows (initial BW: 29.2 ± 1.35 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were allotted to a replicated 5 × 5 Latin square design with 5 diets and 5 periods in each square.

Exp. 2: Total Tract Digestibility of GE and P

Experiment 2 was designed to determine the concentration of ME, the ATTD of GE, and the STTD of P in the 4 batches of corn that were used in Exp. 1. Forty barrows (initial BW 22.8 ± 2.13 kg) were allotted to a randomized complete block design with 4 diets and 10 replicate pigs per diet and placed in metabolism cages, which allowed for the total, but separate, collection of urine and fecal materials from each pig.

Exp. 3: Effects of Corn Particle Size on Performance of Weanling Pigs

Experiment 3 was designed to test the hypothesis that the G:F is improved if diets fed to weanling pigs contain corn ground to a smaller rather than a greater particle size. A total of 128 weaned pigs with an average initial BW of 9.41 ± 1.54 kg were randomly allotted to 4 experimental treatment diets that were fed for 3 weeks. Diets were formulated using corn that was ground to the 4 different particle sizes (i.e., 865, 677, 485, 339 μm) and diets were formulated using values for ME, standardized total tract digestibility of P, and standardized ileal digestibility of CP and AA for each particle size that were calculated in Exp. 1 and 2. The 4 diets were based on corn, SBM, soybean oil, and fish meal, and all diets were formulated to meet or exceed current nutrient requirements (NRC, 2012).

The only difference between the 4 diets was that corn ground to a mean particle size of 865, 677, 485, or 339 μm were used in the 4 treatment diets. It was assumed that the ME in the 4 sources of corn was 3,311, 3,346, 3,371, and 3,432, respectively.

Exp. 4: Effects of Reducing Fat Addition in Diets Containing Corn Ground to a Finer Particle Size

Experiment 4 was designed to test the hypothesis that dietary concentrations of soybean oil may be reduced if corn is ground to a finer particle size without reducing pig performance. A total of 128 pigs that had been weaned for 14 d and had an average initial BW of 9.95 ± 1.95 kg were used. Pigs were allotted to 4 treatment diets in a randomized complete block design; experimental diets were provided on an ad libitum basis for 3 weeks. Diets were formulated using the values of energy and nutrient digestibility as explained for Exp. 3, but in contrast to the diets used in Exp. 3, diet ME values were adjusted by reducing the amount of soybean oil in the diets as the particle size of the corn used in the diets was reduced. The assumed ME for soybean oil was 8,400 kcal/kg (NRC, 1998). By adjusting the inclusion of soybean oil, all diets were formulated to contain 3,413 kcal ME/kg.

Exp. 5: Growth Performance of Growing Finishing Pigs

In experiment 5, a total of 36 gilts and 36 barrows with an average initial BW of 32.00 ± 1.58 kg were housed individually and used in a 3-phase growing–finishing experiment. Feed and water were provided on an ad libitum basis throughout the experiment. Diets were formulated as explained for Exp. 4 and within each phase, a constant ME was maintained by reducing the inclusion of soybean oil as the particle size was reduced..

Results and discussion

Exp. 1: Ileal Digestibility of CP, AA, Starch, and GE

The AID of starch and GE increased (linear, $P < 0.05$) as the particle size decreased from 865 to 339 μm (Table 2), The SID of CP and all indispensable and dispensable AA was not affected by the particle size of corn (data not shown). The average SID of indispensable and dispensable AA was also not different among diets. The fact that particle size of corn did not influence the SID of AA concurs with observations by Fastinger and Mahan (2003) who reported that a reduction in particle size of soybean meal from 949 to 185 μm has no effect on the SID of indispensable AA. In contrast, the SID of AA in lupins increases as particle size decreases (Kim et al., 2009).

Values for the AID of starch that were observed in this experiment for corn ground to 677 or 485 μm concur with values reported by Everts et al. (1996) and Cervantes-Pahm et al. (2014). Starch is the main form of energy storage in grains (Liu, 2012) and it is mainly digested in the small intestine. However, there is a portion of the starch that is not well digested, and this starch will be fermented in the large intestine (Champ, 2004). The concentration of starch in corn used in this experiment concurs with values reported by Li et al. (2006). The increase in the AID of GE and starch in corn that was observed as particle size decreased is likely a result of increased access to the starch granules for αamylase, which increases starch digestibility (Reece et al., 1985; Kim et al., 2002; Fastinger and Mahan, 2003). The reduced surface area of grain ground to the greater particle size may have contributed to the reduced access for enzymes (Al-Rabadi et al., 2009).

Exp. 2: Total Tract Digestibility of GE and P

The ME concentration, calculated on an as-fed or on a DM basis, increased from 3,311 to 3,432 kcal/kg and from 3,826 to 3,964 kcal/kg, respectively, when corn particle size decreased from 865 to 339 µm. Likewise, the STTD of P did not change as particle size of corn changed.

The concentration of ME in corn observed in this experiment concurs with reported values (Widmer et al., 2007; NRC, 2012; Rojas and Stein, 2013) and the ATTD of GE was also in good agreement with reported values (Pedersen et al., 2007; Baker and Stein, 2009). The ATTD of GE in DDGS and the concentration of ME also increased when pigs were fed DDGS ground to 308 µm compared with pigs fed DDGS ground to 818 µm (Liu et al., 2012). In contrast, if the particle size of lupins is decreased from 1304 to 567 µm, the ATTD of energy is not affected (Kim et al., 2009). It is not clear why there is this difference among feed ingredients. The observation that there is no difference in GE excreted in the urine amount treatments indicates that the entire improvement in ME of corn that was observed as particle size was reduced is due to the increase in energy digestibility.

The STTD of P in corn was not affected by the that was calculated in this experiment is in agreement with values reported by Li et al. (2013) and NRC (2012). The observation that particle size did not affect the STTD of P in corn also concurs with observations by Liu et al. (2012), who reported that reduction of particle size in distillers dried grains with solubles did not influence the ATTD of P. Thus, it appears that reduction in particle size or increases in surface area are not effective in improving P digestibility in pigs. The reason may be that to increase P digestibility in corn, the enzyme phytase is needed and pigs do not secrete phytase in the small intestine.

Exp. 3: Maintaining Ingredient Composition among Diets

In Exp. 3, there were no differences in the initial or the final BW among dietary treatments and ADG was also not different among treatments (Table 3). In contrast, ADFI increased and values for G:F were reduced, as the particle size of corn increased (linear, $P < 0.05$). This result is in agreement with previous data (Healy et al., 1994; Wondra et al., 1995b). The increased ADFI observed in pigs fed diets containing corn ground to a greater particle size represents an attempt by the pigs to compensate for the reduction in ME in diets containing the corn with greater particle size. This observation concurs with values reported by Healy et al. (1994) and Mavromichalis et al. (2000). The increased G:F that was observed as particle size of corn was reduced was expected because corn ground to a smaller particle size contains more ME than corn ground to a greater particle size as indicated in Exp. 2. A similar observation was reported by Wondra et al., 1995a.

Exp. 4: Maintaining Calculated ME among Diets

In Exp. 4, the initial and the final BW among dietary treatments were not different (Table 4). Likewise, no differences among treatments were observed for ADG and ADFI, but G:F was reduced (linear, $P < 0.05$) as corn particle size increased. This observation indicates that the increased addition of soybean oil to diets containing corn ground to a greater particle size was not effective in fully compensating for the reduction in ME of the corn ground to the coarser particle size. It is possible that the reason the added soybean oil did not fully compensate for the reduced ME in coarsely ground corn is that weaned pigs are limited in the utilization of fat (Tokach et al., 1995). Weanling pigs may have reduced digestibility of fat compared with older pigs because of reduced secretion of lipase (Cera et al., 1990) or because older pigs have a greater lipid deposition than younger pigs (de Lange et al., 2001). If that is the case then we may have overestimated the ME of fat in this experiment, which explains why we were not able to maintain a constant G:F among pigs fed the 4 experimental diets.

Exp. 5: Growth Performance of Growing Finishing Pigs

Growth Performance. The starting weight and the final weight were not different among dietary treatments (Table 5). Likewise, no differences among treatments were observed for overall ADG and ADFI. There was an increase ($P < 0.05$) in G:F for the overall experiment in gilts when corn particle size was increased, but this was not the case if corn particle size was increased in diets fed to barrows (interaction, $P < 0.05$). However, when G:F was calculated on the basis of HCW, no differences were observed as particle size decreased from 865 to 339 μm. The reason for the difference in G:F when calculated based on live weight, therefore, appears to be that the empty viscera weight was greater (linear, $P <$

0.05) for pigs fed corn ground to 865 μm compared with pigs fed corn ground to 339 μm.

Carcass Characteristics. There were no differences in live BW or HCW among dietary treatments. However, the dressing percentage was reduced (linear, P < 0.01) as corn particle size increased. The back fat was not different among dietary treatments. The weight of the empty viscera increased (linear, P < 0.01) as corn particle size increased and the reduction in dressing percentage that was observed as pigs were fed diets containing corn ground to a greater particle size is partly due to an increase in the intestinal weight. This observation is in agreement with data by Wondra et al. (1995a).

pH and Volatile Fatty Acid Concentration. The pH in the cecal and colon contents was reduced (linear, P < 0.01) as the particle size of corn increased. Likewise, the concentration of acetate, propionate, and butyrate in cecal contents increased (linear, P < 0.01) as corn particle size increased. In contrast, the concentration of isobutyrate and isovalerate was reduced (linear, P < 0.05) as the particle size increased from 339 to 865 μm, but the concentration of valerate was not different among diets.

The reduction in pH of cecal and colon contents that were observed as corn particle size was increased indicates that more VFA were produced as corn particle size increased. This observation concurs with data reported in lupins ground to different particle sizes (Kim et al., 2009). It is, therefore, likely that less fermentation took place in the hindgut of pigs fed the diets containing corn ground to the smaller particle sizes compared with corn ground to the greater particle sizes. These data are in agreement with results by Callan et al. (2007) and indicated that fermentation was increased as particle size increases. This is most likely a result of increased starch fermentation in the hindgut because the apparent ileal digestibility of starch is reduced as particle size increased, which in turn results in increased substrate for the microbes for fermentation in the hindgut. The increased microbial activity is also demonstrated by the reduction in cecal and colonic digesta pH. An increase in intestinal weight as a result of increased fermentation was also reported by Kass et al. (1980), and is likely a result of increased microbial activity in the hindgut of pigs fed diet containing corn ground to a greater particle size.

Ulcer and Paraketosis

There were no incidences of ulcers in the stomachs of pigs fed diets containing corn ground to different particle sizes (Table 6). However, some level of parakeratosis was observed in the pars oesophagae region in the stomach. For pigs fed a diet containing corn ground to a mean particle size of 865 μm, only 50% of the pigs developed, but the incidence of parakeratosis increased as particle size of corn decreased.

The observation that there were no differences in ADG among treatments confirms that the differences in ME among the 4 batches of corn can be used in diet formulations. By formulating diets to a constant ME, the amount of added fat could be reduced as particle size of corn was reduced. The observation that there were no differences among diets in animal growth performance despite the differences in inclusion of soybean oil in the diets, indicates that diet costs can be reduced if corn is ground to a finer particle size. However, if pigs are fed corn ground to 1,000 μm rather than 400 μm and energy is not balanced, there is a reduced ADFI and increased G:F in pig fed corn ground to 400 μm compared with pigs fed to 1,000 μm. This is likely a result of the greater energy value in corn ground to 400 μm compared with corn ground to 1,000 μm (Wondra et al., 1995a). Similar improvements in G:F was also observed when finishing pigs were fed wheat that was ground to 600 μm compared with pigs fed wheat ground to 1,300 μm. (Mavromichalis et al., 2000).

The pars oesophagea region is one of the 4 regions in the pig stomach (Yen, 2001) and the region that has the greatest risk of developing gastric ulcers if pigs are fed ingredients with a reduced particle size. The reason for this risk is that there is no synthesis of protective mucus in the pars oesophagea region (Mahan et al., 1966; Maxwell et al., 1970; Varum et al., 2010). Pigs fed corn ground to 1,200 μm have less ulcers and keratinization in the esophageal region compared with pigs fed corn ground to 400 μm (Wondra et al., 1995a). Likewise, data for sows indicate that ulcers and parakeratosis development increase as particle size of corn decreases from 1,200 to 400 μm (Wondra et al., 1995a). However, the increased incidence of parakeratosis in pigs fed diets containin g corn ground to a smaller particle size did not affect pig growth performance. This observation concurs with data indicating that G:F is not affected in pigs fed diets containing wheat ground to 600 μm even though those pigs had more parakeratosis in the pars oesophagea region compared with pigs fed diets containing wheat ground to 1,300 μm (Mavromichalis et al., 2000).

Conclusions

Reduction of particle size of corn from 865 to 339 µm linearly increased the AID of starch and GE and the concentration of ME in corn. However, there were no effects of corn particle size on the STTD of P or the SID of indispensable AA and CP. Therefore, the G:F of weanling pigs is improved if diets contain corn ground to a particle size of 399 um rather than a greater particle size, which indicates that the ME of finely ground corn is greater than the ME of more coarsely ground corn. As a consequence, the inclusion of dietary fat may be reduced if corn is ground to a finer particle size, but the amount of fat that may be removed from the diets without reducing pig growth performance remains to be determined. For growing-finishing pigs, the increased concentration of ME in finely ground corn makes it possible to reduce the inclusion of added lipids in diets containing finely ground corn, which will result in reduced diet costs and improved profits. Results of the growth performance experiment confirmed this hypothesis and also indicated that the dressing percentage is improved if diets contain corn ground to a reduced particle size. However, pigs fed diets containing corn ground to smaller particle size developed some level of parakeratosis, but this did not affect the G:F.

Tables

Table 1. Chemical and physical composition of corn with different particle sizes, as-fed basis

Item	Corn particle size				
	865 µm	677 µm	485 µm	339 µm	SBM
GE, kcal/kg	3,920	3,900	3,914	3,870	4,197
DM, %	86.54	86.40	86.71	86.30	91.60
CP, %	7.08	7.23	7.25	7.00	47.73
Ash, %	1.15	1.39	1.23	1.10	5.67
AEE[1], %	3.45	3.51	3.53	3.57	2.05
NDF, %	11.06	10.01	9.29	9.25	-
ADF, %	2.41	2.27	2.24	1.91	-
Starch, %	62.90	61.19	62.73	64.42	-
P, %	0.31	0.34	0.30	0.29	-
Ca, %	0.03	0.03	0.03	0.03	-
Indispensable, AA %					
Arg	0.35	0.37	0.35	0.35	3.39
His	0.20	0.21	0.20	0.20	1.22
Ile	0.24	0.26	0.25	0.24	2.20
Leu	0.85	0.84	0.83	0.83	3.78
Lys	0.25	0.26	0.25	0.25	3.02
Met	0.14	0.14	0.13	0.14	0.64
Phe	0.35	0.35	0.35	0.35	2.35
Thr	0.25	0.24	0.25	0.25	1.81
Trp	0.06	0.05	0.05	0.05	0.72
Val	0.35	0.38	0.36	0.35	2.45
Dispensable, AA %					
Ala	0.51	0.52	0.51	0.51	2.04

Asp	0.49	0.50	0.49	0.49	5.30
Cys	0.15	0.15	0.14	0.15	0.62
Glu	1.28	1.25	1.26	1.26	7.91
Gly	0.30	0.30	0.30	0.30	1.98
Pro	0.64	0.62	0.64	0.63	2.35
Ser	0.32	0.30	0.30	0.31	2.04
Tyr	0.20	0.22	0.20	0.21	1.67
Total AA	6.93	6.96	6.86	6.87	45.49
Physical characteristics					
Mean particle size, µm	865	677	485	339	785
SD of particle size	3.15	3.20	2.92	1.89	1.90
Angle of repose, º	46.8	50.7	54.9	57.4	73.18
Bulk density, g/L	650.6	631.5	601.4	564.5	705.6

[1]AEE = acid hydrolyzed ether extract.

Table 2. Apparent ileal digestibility (AID) of GE and starch, the apparent total tract digestibility (ATTD) of energy, the standardized total tract digestibility of P, and the concentration of digestible and metabolizable energy in corn that was ground to different particle sizes, as-fed basis[1,2], Exp. 1 and Exp. 2

Item	Corn particle size				Pooled SEM	*P*-value	
	865 µm	677 µm	485 µm	339 µm		Linear	Quadratic
AID of GE[1], %	66.1	69.2	71.6	74.3	4.77	0.03	0.96
AID of Starch[1], %	89.0	92.6	93.9	96.6	1.32	< 0.01	0.82
ATTD of GE, %	88.7	89.2	90.3	91.6	0.51	< 0.01	< 0.01
STTD of P, %	37.4	37.3	37.1	37.8	2.99	0.99	0.87
ME, kcal/kg	3,311	3,346	3,371	3,432	19.54	< 0.01	< 0.01
ME, kcal/kg DM	3,826	3,868	3,895	3,964	22.58	< 0.01	< 0.01

[1]Data are least squares means of 10 observations, except for the treatments with corn ground to 677 and 865 µm, which had only 9 observations. Data for the other variables are least squares means of 10 observations.

[2]The SID of CP and all indispensable and dispensable AA was not affected by the particle size of corn.

Table 3. Growth performance of pigs fed diets containing corn ground to different particle sizes and formulated to a different ME[1], Exp. 3

	Corn particle size					*P*-value	
Item	865 µm	677 µm	485 µm	339 µm	Pooled	Linea	Quadrati
Initial BW, kg	9.42	9.43	9.43	9.36	0.52	0.20	0.14
Final BW, kg	19.04	19.14	19.26	18.60	0.90	0.29	0.11
ADG, kg/d	0.46	0.46	0.47	0.44	0.02	0.37	0.16
ADFI, kg/d	0.71	0.71	0.67	0.64	0.03	0.02	0.34
G:F	0.65	0.66	0.70	0.69	0.01	<	0.86
Caloric efficiency							
ME/d	2,318	2,325	2,231	2,136	116.34	0.05	0.40
ME/kg gain	5,040	5,030	4,752	4,857	103.32	0.05	0.71
Kg gain/Mcal	0.199	0.199	0.211	0.206	0.004	0.05	0.71
Caloric	5,040	5,030	4,752	4,857	103.32	0.05	0.71

[1]Data are means of 8 observations per treatment.

Table 4. Growth performance of pigs fed diets containing corn ground to different particle sizes, but formulated to a constant ME[1], Exp. 4

	Corn particle size					*P*-value	
Item	865 µm	677 µm	485 µm	339 µm	Pooled	Linea	Quadrati
Initial BW, kg	9.95	9.97	9.94	9.94	0.66	0.51	0.45
Final BW, kg	18.9	19.62	19.56	19.47	1.14	0.22	0.20
ADG, kg/d	0.45	0.48	0.48	0.47	0.02	0.36	0.28
ADFI, kg/d	0.74	0.78	0.76	0.73	0.04	0.72	0.11
G:F	0.62	0.63	0.63	0.66	0.01	0.02	0.46
Caloric efficiency							
ME/d	2,514	2,647	2,594	2,485	150.27	0.73	0.11
ME/kg gain	5,532	5,470	5,408	5,209	99.72	0.03	0.44

Kg gain/Mcal	0.181	0.183	0.186	0.193	0.004	0.02	0.44
Caloric	5,532	5,471	5,409	5,209	99.72	0.03	0.44

[1]Data are means of 8 observations per treatment.

Table 5. Growth performance, carcass characteristics, and concentration of VFA in cecal contents from growing-finishing pigs fed diets containing corn ground to different particle sizes[1], Exp. 5

Item	Corn particle size, µm				Treatment			Sex			
	865	677	485	339	Pooled SEM	Linear	Quadratic *P*-	Barrows	Gilts	Pooled	*P*-val
Growth performance											
BW, kg											
Day 0	31.97	31.93	32.19	32.00	0.44	0.47	0.64	32.57	31.49	0.27	0.01
Day 93	129.97	128.58	130.25	129.81	2.90	0.88	0.75	136.24	122.98	1.41	< 0.01
ADG, kg/d											
Day 0 – 93	1.03	1.02	1.03	1.03	0.03	0.97	0.76	1.09	0.96	0.01	< 0.01
ADFI, kg/d											
Day 0 – 93	2.81	2.85	2.90	2.94	0.10	0.09	0.98	3.12	2.63	0.04	< 0.01
G:F											
Day 0 - 93[2]											
Gilts	0.38	0.37	0.37	0.35	0.01	< 0.01	0.45	-	-	-	-
Barrows	0.36	0.34	0.35	0.36	0.01	0.82	0.06	-	-	-	-
Day 0 – 93[3]	0.26	0.26	0.25	0.25	0.01	0.17	0.84	0.25	0.26	0.01	0.23
Carcass characteristics											
Dressing[4], % percentage, %	79.30	79.78	79.82	80.29	0.31	< 0.01	0.97	80.27	79.32	0.17	< 0.0
Hot carcass wt, kg	101.10	101.30	101.67	102.31	2.44	0.57	0.87	107.35	95.76	1.15	< 0.0
Back fat, cm	2.23	2.22	2.48	2.25	0.19	0.53	0.51	2.69	1.88	0.09	< 0.0
pH											
Cecum	6.04	6.2	6.54	6.64	0.09	< 0.01	0.94	6.36	6.36	0.06	0.98
Colon	5.85	5.94	6.2	6.25	0.08	< 0.01	0.94	6.10	6.01	0.05	0.15
Short-chained fatty acids, ug/ml in cecal contents											
Acetate	2537	2286	1973	1846	136	< 0.01	0.79	2206	2113	85	0.44
Propionate	872	794	690	617	48	< 0.01	0.85	768	720	29	0.24

Butyrate	702	611	391	226	57	< 0.01	0.20	518	447	34	0.14
Branched-chained fatty acids, ug/ml in cecal contents											
Isobutyrate	62	59	67	76	6	0.02	0.16	70	62	3	0.09
Isovalerate	94	92	105	115	8	0.01	0.28	105	97	5	0.23
Valerate	105	88	91	87	8	0.10	0.39	101	85	5	0.02
Organ wt, kg											
Empty viscera	3.01	2.65	2.72	2.52	0.11	< 0.01	0.34	2.80	2.64	0.06	0.0

[1]Data are means of 18 observations per treatment, except for the treatment with corn particle size of 677 µm, which had only 17 observations.

[2]Particle size × sex interaction (P < 0.05).

[3]G:F calculated based on HCW.

[4]Dressing, % = HCW / live wt × 100.

Table 6. Stomach morphology from finishing pigs fed diets containing corn ground to different particle sizes[1], Exp. 5

Item, %	Corn particle size, µm 865	677	485	339	Pooled SEM	*P*-value
Normal	50.00	29.41	5.56	0.00	-	< 0.01
Minor parakeratosis	33.33	64.71	61.11	44.44	-	0.21
Medium parakeratosis	16.67	0.00	22.22	22.22	-	0.22
Major parakeratosis	0.00	5.88	11.11	33.33	-	0.02
Average stomach score[2]	50.00	29.41	5.56	0.00	0.22	< 0.01

[1]Data are means of 18 observations per treatment, except for the treatment with corn particle size of 677 µm, which had only 17 observations. Data are expresses as a frequency of incidence of parakeratosis in the pars oesophagae region in the stomach of the pig.

[2]Score system ranged from 0 to 10. (0= no evidence of ulcers or parakeratosis and 10= severe damage in tissue.

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