Pelleting and Starch Characteristics of Diets Containing High Amylase Corn

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Summary

This experiment was designed to evaluate the effects of die thickness and conditioning temperature on pelleting and starch characteristics in diets containing either conventional yellow dent or high amylase corn (Enogen®, Syngenta Seeds, LLC). Treatments were arranged as a 2 × 2 × 3 factorial of corn type (conventional and high amylase), die thickness (L:D 5.6 and 8.0), and conditioning temperature (165, 175, and 185°F). For the high amylase corn treatments, ground high amylase corn replaced conventional ground corn on a lb:lb basis. Diets were pelleted via steam conditioning (10 in × 55 in Wenger twin staff pre-conditioner, Model 150) and using a pellet mill (CPM Model 1012-2) with a 5/32 in × 7/8 in (L:D 5.6) or 5/32 in × 1 1/4 in (L:D 8.0) pellet die. Conditioner retention time was set at 30 sec and production rate was set at 33 lb/min. All treatments were replicated on 3 separate days. Pellets were composited and analyzed for starch and pellet durability index (PDI). Conditioning temperature, hot pellet temperature (HPT), production rate, and pellet mill energy consumption were recorded throughout each processing run. Data were analyzed using the GLIMMIX procedure in SAS (v. 9.4, SAS Institute Inc., Cary, NC), with pelleting run as the experimental unit and day as the blocking factor. The 3-way interaction was not significant ($P > 0.15$) for any of the pelleting or starch responses analyzed in this study. There was no evidence ($P > 0.14$) for a corn type × conditioning temperature interaction for HPT, PDI, or energy consumption. There was a tendency ($P = 0.08$) for a corn type × die thickness interaction for PDI. The PDI for the high amylase and conventional corn treatments were similar when diets were pelleted using the L:D 8.0 die. However, PDI for conventional corn diets was greater than high amylase corn diets when pelleted using the L:D 5.6 die. Pelleting diets with the L:D 8.0 die had improved ($P < 0.01$) PDI compared to the L:D 5.6. Additionally, PDI increased (linear, $P = 0.03$) with increasing conditioning temperature. Pellet mill energy consumption was greater for the thicker pellet die ($P = 0.02$), and tended to decrease (quadratic, $P = 0.07$) with increasing conditioning temperature. There was a corn type × conditioning temperature interaction ($P = 0.01$) for gelatinized starch in conditioned mash. High amylase corn diets steam conditioned at 185°F had greater gelatinized starch than all other corn type × conditioning temperature treatments. Cooked starch of conditioned mash was greater for diets containing high amylase corn compared to conventional corn and increased

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(linear, $P < 0.01$) with increasing conditioning temperature. There was a corn type × die thickness interaction ($P < 0.01$) for total starch in pellets. Total starch was greater for high amylase corn diets pelleted using the L:D 8.0 compared to the L:D 5.6 die, but not different from the conventional corn diets pelleted using either the L:D 5.6 or 8.0 die. Starch gelatinization was greatest ($P < 0.01$) for the high amylase diets and increased (linear, $P = 0.05$) with increasing conditioning temperature. Lastly, pelleted high amylase corn diets had a greater percentage ($P < 0.01$) of cooked starch compared to conventional corn diets, and there was a tendency ($P = 0.06$) for cooked starch to increase with increasing conditioning temperature. In conclusion, increasing die L:D and conditioning temperature improved pellet quality. Starch gelatinization was increased when diets were pelleted at the highest conditioning temperature of 185°F, and high amylase corn diets resulted in greater gelatinized starch than conventional corn diets.

Introduction

Enogen® feed corn (Syngenta Seeds, LLC) is a high amylase corn originally developed for use in the ethanol industry.[3] Increased amylase activity of Enogen® corn is designed to assist in the rapid degradation of starch to sugars, thereby providing more available energy for growth. It is currently unknown how a corn variety with high amylase may react in the pelleting process. Pelleting requires addition of heat and moisture in the form of steam. Pressure is then applied to the steamed feed mixture as it is pressed through the pellet die. The combination of moisture and frictional heat increases starch gelatinization, which is an irreversible process. The amylase activity in Enogen® corn would be expected to further increase the degree of gelatinization in pelleted feed. Furthermore, improvements in throughput have been noted when Enogen® corn is steam flaked. Therefore, this experiment was designed to evaluate the effects of corn type, die thickness, and conditioning temperature on pelleting and starch characteristics of a finishing swine diet.

Procedures

Treatments were arranged as a 2 × 2 × 3 factorial of corn type (conventional and high amylase), die thickness (L:D 5.6 and 8.0), and conditioning temperature (165, 175, and 185°F). Conventional and high amylase corn was ground to approximately 600 microns using a 3-high roller mill (RMS, Model 924). For the high amylase corn treatments, ground high amylase corn replaced conventional ground corn on a lb:lb basis (Table 1). Diets were mixed in a 1-ton horizontal counterpoise mixer (Hayes & Stolz, Fort Worth, TX), steam conditioned (10 in × 55 in twin staff pre-conditioner, Model 150, Wenger, Sabetha, KS) for 30 sec at 165, 175, or 185°F, and subsequently pelleted using a 30-horsepower pellet mill (1012-2 HD Master Model, California Pellet Mill, Crawfordsville, IN) equipped with a 5/32 in × 7/8 in (L:D 5.6) or 5/32 in × 1 1/4 in (L:D 8.0) pellet die. Conditioner retention time was calculated by adjusting the conditioner screw speed and dividing the amount of feed in the conditioner by the production rate. Production rate was set at 33 lb/min, approximately 100% of the rated throughput for the pellet mill, and steam pressure was 24 psi. All treatments were replicated on 3 separate days, thus achieving 3 replications per treatment. Die thickness was randomized across day and corn type was randomized within die to minimize

[3] Syngenta Crop Protection, LLC. 2019. Minnetonka, MN. http://www.syngenta-us.com/corn/enogen.

the effects of pelleting order. A conventional corn-soybean meal flush diet was used to warm the mill up to 165°F before each day of pelleting. Six hundred lb of the first corn type diet was pelleted on the first die, according to randomization, at all 3 conditioning temperatures in ascending order. The pellet mill was flushed with a diet not containing high amylase corn and the second corn type diet was pelleted in the same manner. Once completed, the pellet mill was shut down and the die was changed. A conventional corn-soybean meal flush was again used to warm the mill up to 165°F before pelleting on the second die, and pelleting procedures followed the pattern previously mentioned. Conditioning temperature, hot pellet temperature (HPT), production rate, and pellet mill energy consumption were recorded at 3 time points during each run (Table 2).

For each treatment, 3 conditioned mash samples were collected and immediately frozen. Frozen conditioned mash samples were composited into a single sample for starch analysis. Three pellet samples per treatment were collected as feed exited the pellet die, cooled for 15 min, and composited into 2 samples. Composite pellet samples were analyzed for total starch, gelatinized starch, cooked starch, and pellet durability index (PDI). Samples for starch analysis were sent to the Wenger Technical Center Laboratory (Sabetha, KS) and were analyzed by methods outlined by Mason et al.[4] Briefly, one 0.5-g subsample was hydrolyzed in distilled water at room temperature while a second 0.5-g subsample was boiled with distilled water. Samples were incubated with glucoamylase, and free D-glucose was measured. The quantity of free glucose analyzed in the room temperature sample represents the percentage of starch that was gelatinized during processing, and the quantity of free glucose in the boiled sample represents the percentage of total starch in the sample. Cooked starch was then calculated as the percentage of gelatinized starch divided by the percentage of total starch multiplied by 100.

For analysis of PDI, fines were sifted off from cooled pellets using a U.S. No. 5 (4 mm) sieve. One hundred g of the sifted pellets were placed into a Holmen 100 pellet tester and agitated with air for 60 sec. Following agitation, the sample was again sifted through a No. 5 sieve and the remaining pellets were weighed. Pellet durability index was calculated as the percentage of the initial pellet sample remaining after agitation with air.

Data were analyzed using the GLIMMIX procedure in SAS (v. 9.4, SAS Institute Inc., Cary, NC), with pelleting run as the experimental unit and day as the blocking factor. Hot pellet temperature, PDI, energy consumption, and starch characteristics of pellets were analyzed with main effects of corn type, die thickness, and conditioning temperature. Conditioned mash starch data were analyzed with main effects of corn type and conditioning temperature. For all data, linear and quadratic contrasts were used to evaluate the effect of conditioning temperature. Results were considered significant if $P \leq 0.05$ and were considered marginally significant between $P > 0.05$ and $P \leq 0.10$.

[4] Mason, M., B. Gleason, and G. Rokey. 1982. A new method for determining degree of cook. Proceedings of the American Association of Cereal Chemists 67th Annual Meeting. p. 123-124. San Antonio, TX, USA.

Results and Discussion

Production rate and conditioning temperature were as expected for each treatment. There was no evidence ($P > 0.21$) for a corn type × die thickness × conditioning temperature interaction for any of the pelleting or starch responses analyzed in this study (Table 2). Additionally, there was no evidence ($P > 0.14$) for a corn type × conditioning temperature interaction for HPT, PDI, or pellet mill energy consumption.

There was no evidence for a corn type × die thickness or die thickness × conditioning temperature interaction for HPT. Inclusion of high amylase corn ($P < 0.01$), a thicker pellet die ($P < 0.01$), and increasing conditioning temperature from 165 to 185°F (linear, $P < 0.01$) resulted in increased HPT.

There was a tendency ($P = 0.08$) for a corn type × die thickness interaction for PDI. Pellet durability index for high amylase and conventional corn treatments were similar when diets were pelleted using the L:D 8.0 die. However, PDI for conventional corn diets was greater than high amylase corn diets when pelleted using the L:D 5.6 die. Pelleting diets with the L:D 8.0 die improved ($P < 0.01$) PDI compared to the L:D 5.6 die. Additionally, PDI increased (linear, $P = 0.03$) with increasing conditioning temperature.

Pellet mill energy consumption was greater for the thicker pellet die ($P = 0.02$), and tended to decrease (quadratic, $P = 0.07$) with increasing conditioning temperature. There was no evidence of difference ($P = 0.12$) in energy consumption due to corn type.

There was no evidence for a corn type × conditioning temperature interaction ($P > 0.12$) for average moisture, total starch, or cooked starch in conditioned mash (Table 3). Corn type had no effect on average moisture in conditioned mash ($P > 0.82$), however, there was an increase (linear, $P < 0.01$) in moisture of conditioned mash with increasing conditioning temperature. Additionally, there was no evidence of difference ($P > 0.42$) in total starch due to corn type or conditioning temperature. There was a corn type × conditioning temperature interaction ($P = 0.01$) for gelatinized starch in conditioned mash. High amylase corn diets steam conditioned at 185°F had greater gelatinized starch than all other corn type × conditioning temperature treatments. Cooked starch of conditioned mash was greater for diets containing high amylase corn compared to conventional corn and increased (linear, $P < 0.01$) with increasing conditioning temperature.

There were no significant interactions ($P > 0.15$) for average moisture, gelatinized starch, or cooked starch in pelleted diets (Table 4). There was no evidence of difference ($P > 0.40$) in pellet moisture due to corn type, die thickness, or conditioning temperature. There was a corn type × die thickness interaction ($P < 0.01$) for total starch in pellets. Total starch was greater for high amylase corn diets pelleted using the L:D 8.0 compared to the L:D 5.6 die, but not different from the conventional corn diets pelleted using either the L:D 5.6 or 8.0 die. Pelleted high amylase corn diets had greater ($P < 0.01$) gelatinized starch than conventional corn diets, and gelatinized starch increased (linear, $P = 0.05$) with increasing conditioning temperature. Similarly, cooked starch was greatest ($P < 0.01$) for the high amylase diets and tended to increase (linear, $P = 0.06$) with increasing conditioning temperature.

Results of this experiment demonstrated that increasing die L:D from 5.6 to 8.0 improved pellet quality but increased pellet mill energy consumption. However, increasing conditioning temperature from 165 to 185°F linearly improved PDI without increasing energy consumption. Diets containing high amylase corn had poorer PDI compared to conventional corn when feed was pelleted using the 5.6 L:D die, but PDI was similar when pelleted using the 8.0 L:D, with corn type not affecting pellet mill energy consumption. Starch gelatinization was increased when diets were pelleted at the highest conditioning temperature of 185°F, and high amylase corn diets resulted in greater gelatinized starch than conventional corn diets. On average, diets containing high amylase corn had a 3% increase in cooked starch compared to diets containing conventional corn. In conclusion, starch gelatinization was maximized in high amylase corn diets steam conditioned at 185°F.

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Table 1. Diet composition[1]

Ingredient	%, as-is
Ground corn[2]	75.88
Soybean meal, 47% crude protein	20.07
Soybean oil	1.50
Monocalcium phosphate	0.50
Limestone	1.10
Salt	0.35
L-Lysine HCl	0.26
DL-Methionine	0.02
L-Threonine	0.05
Trace mineral premix	0.13
Vitamin premix	0.13
HiPhos 2700	0.03

[1]Diets were mixed in a 1-ton Hayes & Stolz horizontal counterpoise mixer with a 60-sec dry mix time and 120-sec wet mix time.
[2]In high amylase corn diets, high amylase ground corn (Enogen®, Syngenta Seeds, LLC) replaced conventional yellow dent ground corn on a lb:lb basis.

Table 2. Pelleting characteristics of swine diets containing either conventional or high amylase corn[1]

Die L:D:	5.6			8.0				Probability,[2] <					
Conditioning temp, °F:	165	175	185	165	175	185	SEM[3]	Corn	Die	Linear[4]	Quadratic[4]	Corn × die	Die × temp
Production rate, lb/min													
Conventional[5]	33.8	34.0	34.0	33.8	33.8	34.0	0.17	-	-	-	-	-	-
High amylase[6]	33.8	34.2	33.7	33.9	33.7	34.1							
Condition temp, °F													
Conventional	165.5	175.3	185.2	165.3	175.4	184.4	0.28	-	-	-	-	-	-
High amylase	164.8	175.3	185.2	165.4	175.6	184.3							
Hot pellet temp, °F													
Conventional	174.7	181.4	189.2	177.4	183.6	189.7	1.02	0.01	0.01	0.01	0.16	0.83	0.73
High amylase	178.5	182.1	189.2	179.8	184.6	191.4							
Pellet durability index, %													
Conventional	81.2	83.7	87.9	87.9	89.0	92.0	2.42	0.11	0.01	0.03	0.39	0.08	0.91
High amylase	78.8	78.1	81.4	89.1	88.9	91.4							
Energy consumption, kWh/ton													
Conventional	13.4	12.9	13.1	14.1	13.7	13.7	0.45	0.12	0.02	0.38	0.07	0.36	0.70
High amylase	14.0	13.1	14.0	14.2	13.8	14.0							

[1]Diets were steam conditioned (10 in × 55 in Wenger twin staff pre-conditioner, Model 150) for 30 sec at 165, 175, or 185°F and pelleted (CPM, 1012-2 HD Master Model) using a 5/32 in × 7/8 in (L:D 5.6) or 5/32 in × 1 1/4 in (L:D 8.0) pellet die.

[2]There was no evidence for a corn type × die thickness × conditioning temperature interaction ($P > 0.46$) or corn type × conditioning temperature interaction ($P > 0.14$) for hot pellet temperature, pellet durability index, or energy consumption.

[3]Pooled standard error of least squares means ($n = 3$).

[4]Linear and quadratic contrasts were used to evaluate the effect of conditioning temperature.

[5]Yellow dent corn.

[6]High amylase corn (Enogen®, Syngenta Seeds, LLC).

Table 3. Starch characteristics of steam conditioned swine diets containing either conventional or high amylase corn[1]

	Conditioning temperature, °F				Probability, <			
Item	165	175	185	SEM[2]	Corn	Linear[3]	Quadratic[3]	Corn × temp
Moisture, %								
Conventional[4]	17.3	17.7	18.0	0.26	0.93	<0.01	0.96	0.42
High amylase[5]	17.3	17.8	17.7					
Total starch,[6] %								
Conventional	59.2	59.2	58.0	1.86	0.42	0.98	0.58	0.35
High amylase	59.1	58.7	61.6					
Gelatinized starch,[7] %								
Conventional	3.9	4.4	4.0	0.22	<0.01	<0.01	0.93	0.01
High amylase	4.4	4.4	5.6					
Cook,[8] %								
Conventional	6.4	7.3	6.9	0.41	<0.01	<0.01	0.64	0.12
High amylase	7.3	7.4	9.1					

[1]Diets were steam conditioned (10 in × 55 in Wenger twin staff pre-conditioner, Model 150) for 30 sec at 165, 175, or 185°F.
[2]Pooled standard error of least squares means (n = 3).
[3]Linear and quadratic contrasts were used to evaluate the effect of conditioning temperature.
[4]Yellow dent corn.
[5]High amylase corn (Enogen®, Syngenta Seeds, LLC).
[6]Total starch was calculated as the percentage of free D-glucose in a 0.5-g subsample after hydrolysis in distilled water at room temperature and incubation with glucoamylase.
[7]Gelatinized starch was calculated as the percentage of free D-glucose in a 0.5-g subsample after boiling with distilled water and incubation with glucoamylase.
[8]Cooked starch was calculated as the percentage of gelatinized starch divided by the percentage of total starch multiplied by 100.

Table 4. Starch characteristics of pelleted swine diets containing either conventional or high amylase corn[1]

Die L:D:	5.6			8.0				Probability,[2] <				
Conditioning temp, °F:	165	175	185	165	175	185	SEM[3]	Corn	Die	Linear[4]	Quadratic[4]	Corn × die
Moisture, %												
Conventional[5]	12.0	12.5	12.8	12.2	12.7	12.9	0.67	0.41	0.60	0.40	0.81	0.88
High amylase[6]	12.1	12.2	12.0	12.4	12.3	12.4						
Total starch,[7] %												
Conventional	59.4	58.2	58.1	57.3	57.3	57.4	1.44	0.34	0.19	0.18	0.94	<0.01
High amylase	53.2	55.6	57.4	57.5	58.9	60.2						
Gelatinized starch,[8] %												
Conventional	10.7	11.2	12.0	11.8	11.7	12.6	0.99	<0.01	0.14	0.05	0.37	0.85
High amylase	12.2	12.2	14.1	13.1	13.5	15.0						
Cook,[9] %												
Conventional	18.0	19.2	20.7	20.6	20.4	22.0	1.36	<0.01	0.18	0.06	0.27	0.41
High amylase	23.0	21.9	24.4	22.8	22.9	24.9						

[1]Diets were steam conditioned (10 in × 55 in Wenger twin staff pre-conditioner, Model 150) for 30 sec at 165, 175, or 185°F and pelleted (CPM, 1012-2 HD Master Model) using a 5/32 in × 7/8 in (L:D 5.6) or 5/32 in × 1 1/4 in (L:D 8.0) pellet die.
[2]There was no evidence for a corn type × die thickness × conditioning temperature interaction, a corn type × conditioning temperature interaction, or a die thickness × conditioning temperature interaction ($P > 0.15$) for starch responses of pelleted diets analyzed in this study.
[3]Pooled standard error of least squares means ($n = 3$).
[4]Linear and quadratic contrasts were used to evaluate the effect of conditioning temperature.
[5]Yellow dent corn.
[6]High amylase corn (Enogen®, Syngenta Seeds, LLC).
[7]Total starch was calculated as the percentage of free D-glucose in a 0.5-g subsample after hydrolysis in distilled water at room temperature and incubation with glucoamylase.
[8]Gelatinized starch was calculated as the percentage of free D-glucose in a 0.5-g subsample after boiling with distilled water and incubation with glucoamylase.
[9]Cooked starch was calculated as the percentage of gelatinized starch divided by the percentage of total starch multiplied by 100.